Machinery Protection Systems

API STANDARD 670
FIFTH EDITION, NOVEMBER 2014

AMERICAN PETROLEUM INSTITUTE

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Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the specification.

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Machinery Protection Systems

1 Scope

1.1 General

This standard covers the minimum requirements for a machinery protection system (MPS) measuring radial shaft vibration, casing vibration, shaft axial position, shaft rotational speed, piston rod drop, phase reference, overspeed, surge detection, and critical machinery temperatures (such as bearing metal and motor windings). It covers requirements for hardware (transducer and monitor systems), installation, documentation, and testing.

NOTE A bullet (●) at the beginning of a subsection or paragraph indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on the datasheets (see Annex A); otherwise, it should be stated in the quotation request or in the order.

1.2 Alternative Designs

The MPS vendor may offer alternative designs. Equivalent metric dimensions and fasteners may be substituted as mutually agreed upon by the purchaser and the vendor.

1.3 Conflicting Requirements

In case of conflict between this standard and the inquiry or order, the information included in the order shall govern.

2 Normative References

2.1 The editions of the following standards, codes, and specifications that are in effect at the time of publication of this standard shall, to the extent specified herein, form a part of this standard. The applicability of changes in standards, codes, and specifications that occur after the inquiry shall be mutually agreed upon by the purchaser and the MPS vendor.

API Recommended Practice 552, *Transmission Systems*

API Standard 610, *Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries*

API Standard 611, *General Purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Systems*

API Standard 612, *Petroleum Petrochemical and Natural Gas Industries—Steam Turbines—Special-Purpose Applications*

ANSI MC96.1 [1], *Temperature Measurement Thermocouples*

ASME Y14.2M [2], *Line Conventions and Lettering*

EN 61000-6-2:2005 [3], *Electromagnetic Compatibility Generic Immunity Standard; Part 2: Industrial Environment*

ICEA S-61-402 [4], *Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy*

IEC 60079 [5], (all parts) *Explosive atmospheres*

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1 American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.
2 ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.
3 European Committee for Standardization, Rue de Stassart 36, B-1050 Brussels, Belgium, www.cenorm.be.
4 Insulated Cable Engineers Association, P.O. Box 1568, Carrollton, Georgia 30112, www.icea.net.

IEC 61508, *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61511, *Functional safety—Safety instrumented systems for the process industry sector*

IEC 62061, *Safety of machinery—Functional safety of safety-related electrical, electronic and programmable electronic control systems*

ISA S12.1 [6], *Definitions and Information Pertaining to Electrical Instruments in Hazardous (Classified) Locations*

ISA S12.4, *Instrument Purging for Reduction of Hazardous Area Classification*

ISA S84.00.01, *Application of Safety Instrumented Systems for the Process Industries*

ISO 13849, (all parts) *Safety of machinery—Safety-related parts of control systems*

ISO 21789, *Gas turbine applications—Safety*

Military Specification MIL-C-39012-C [7], *Connectors, Coaxial, Radio Frequency, General Specification for*

Military Specification MIL-C-39012/5F, *Connectors, Plug, Electrical, Coaxial, Radio Frequency [Series N (Cabled) Right Angle, Pin Contact, Class 2]*

NEMA 250 [8], *Enclosures for Electrical Equipment (1000 Volts Maximum)*

NEMA WC 5, *Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy*

NFPA 70 [9], *National Electrical Code*

NFPA 496, *Purged and Pressurized Enclosures for Electrical Equipment*

Schneider Electric PI-MBUS-300*,13 Modbus® Protocol Reference Guide*

2.2 The standards, codes, and specifications of the American Iron and Steel Institute (AISI) [10] also form part of this standard.

2.3 The purchaser and the MPS vendor shall mutually determine the measures that shall be taken to comply with any governmental codes, regulations, ordinances, or rules that are applicable to the equipment.

5 International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.
6 International Society of Automation, 67 T.W. Alexander Drive, Research Triangle Park, North Carolina, 22709, www.isa.org.
7 U.S. Department of Defense, Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, Pennsylvania 19111-5094, https://assist.daps.dla.mil.
8 National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209, www.nema.org.
9 National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.
10 American Iron and Steel Institute, 1540 Connecticut Avenue, NW, Suite 705, Washington, DC 20036, www.steel.org.

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
1X
The machine running speed in cpm.

3.1.2
1X amplitude
The vibration amplitude at running speed. (See also **harmonics**.)

3.1.3
1X vectors
The vector of vibration amplitude and phase, at the machine running speed.

3.1.4
2X
Twice the machine running speed.

3.1.5
2X amplitude

The vibration amplitude at twice the running speed. (See also **harmonics**.)

3.1.6
2X vectors
The vector of vibration, amplitude, and phase, at twice the machine running speed.

3.1.7
acceleration
The time rate of change of velocity. The unit for vibration acceleration is G; 1 G = acceleration of Earth's gravity = 386.1 in./s^2 = 32.17 ft/s^2 = 9.81 m/s^2.

3.1.8
accelerometer
A sensor with an output proportional to acceleration.

3.1.9
accelerometer cable
An assembly consisting of a specified length of cable and mating connectors. Both the cable and the connectors shall be compatible with the particular accelerometer and (when used) intermediate termination.

3.1.10
acceptance region
The area around the 1X or 2X vibration vector wherein the amplitude and phase are considered normal.

3.1.11
accuracy
The degree of conformity of an indicated value to a recognized accepted standard value or ideal value.

3.1.12
active magnetic speed sensor
A magnetic speed sensor that requires external power and provides a conditioned (i.e. square wave) output. Typical excitation is between +5 Vdc to +30 Vdc.

3.1.13
active (normal) thrust direction
The direction of a rotor axial thrust load expected by the machinery vendor when the machinery is operating under normal running conditions.

3.1.14
A/D
Analog to digital conversion.

3.1.15
air interface
The technology used for a radio transmission between base station and mobile units in a wireless network.

3.1.16
alarm (alert) setpoint
A preset value of a parameter at which an alarm is activated to warn of a condition that requires corrective action.

3.1.17
alarm levels
API 670 provides for alert and danger levels, where the danger level is often associated with an automatic shutdown of the monitored equipment.

NOTE 1 May be called severity levels within condition monitoring and provide for additional levels of notification.

NOTE 2 By adding additional software alarm levels at amplitudes lower than alert, maintenance personnel can be notified when levels increase even though there may not be cause for immediate concern or action by operators.

3.1.18
alarm/shutdown/integrity logic
Violations of these setpoints or circuit fault criteria result in alarm or shutdown status conditions in the monitor system.

NOTE 1 The function of a monitor system whereby the outputs of the signal processing circuitry are compared against alarm or shutdown setpoints and circuit fault criteria.

NOTE 2 These status conditions may be subjected to preset time delays or logical voting with other status conditions and are then used to drive the system output relays and status indicators and outputs.

3.1.19
aliasing
In measurements, false indication of frequency components caused by sampling a dynamic signal at too low of a sampling frequency.

3.1.20
amplitude
The magnitude of vibration. Displacement is measured in peak-to-peak. Velocity and acceleration are measured in zero-to-peak or root mean square (rms).

3.1.21
analog
A signal using frequency or amplitude modulation.

3.1.22
asynchronous sampling
The sampling of a vibration signal at time intervals not related to shaft rotation.

3.1.23
axial position
The average position, or change in position, of a rotor in the axial direction with respect to some fixed reference (see 3.1.13).

3.1.24
balance
(See **unbalance**.)

3.1.25
balance resonance speed
A shaft rotational speed (or speed range) that is equal to a lateral natural frequency of the rotor system. [See also **critical speed(s)**.]

3.1.26
base station
The central radio transmitter/receiver within a given range.

3.1.27
baseline data
The reference data set acquired when a machine is in acceptable condition after installation or most recent overhaul that establishes a basis to which subsequent data may be compared.

3.1.28
bearing instability
A self-excited vibration caused by interaction between the fluid in the bearing and the rotor.

3.1.29
bench test
A test performed on system components within the testing range.

3.1.30
best fit straight line
The line drawn through the actual calibration curve where the maximum plus or minus deviations are minimized and made equal.

3.1.31
blind monitor system
A monitor that does not contain an integral display. The blind monitor provides certain minimal integral status indication independently of any nonintegral displays (see 7.1.6).

3.1.32
Bluetooth
A communications protocol using the 2.4 GHz spectrum band.

3.1.33
Bode plot
A pair of graphs in Cartesian format displaying any vibration vector (phase lag angle and amplitude) as a function of shaft rotational speed. The y-axis of the top graph represents phase lag angle, while the y-axis of the bottom graph represents amplitude. The common x-axis represents shaft rotational speed. Sometimes called an unbalance response plot.

3.1.34
broadband
Bandwidth capacity sufficient to carry multiple voice, video, or data channels simultaneously. Per FCC: "200 kbps upstream and downstream transmission speeds."

3.1.35
buffered output
An unaltered, analog replica of the transducer input signal that preserves amplitude, phase, frequency content, and signal polarity. It is designed to prevent a short circuit of this output to monitor system ground from affecting the operation of the MPS. The purpose of this output is to allow connection of vibration analyzers, oscilloscopes, and other test instrumentation to the transducer signals.

3.1.36
cascade plot
A series of spectrum plots taken over a speed range, plotted against speed. The difference between a cascade plot and a waterfall plot is that the spectra within a cascade (the z-axis) are selected based upon differential speed, while a waterfall plot selects its spectra based upon differential time.

3.1.37
casing vibration
The absolute vibration of machine housing or structure, usually measured on the bearing housing.

3.1.38
catastrophic failure
The sudden unexpected failure of a machine or component resulting in considerable damage.

3.1.39
channel
The monitor system components associated with a single transducer. The number of channels in a monitor system refers to the number of transducer systems it can accept as inputs.

3.1.40
channel pair
Two associated measurement locations (such as the X and Y proximity probes at a particular radial bearing or the two axial proximity probes at a particular thrust bearing).

3.1.41
circle plot
The data from a single waveform that is normalized to the turning speed of the shaft and then wrapped around a circle in polar format. Points outside the circle correspond to positive waveform amplitudes, while points inside the circle correspond to negative waveform amplitudes. This representation makes it possible to easily visualize events, which occur at a specific point in the shaft rotation.

3.1.42
circuit fault
A MPS circuit failure that adversely affects the function of the system.

3.1.43
circuit switched data
An exclusively reserved connection.

3.1.44
code division multiple access
CDMA
A technology used to transmit wireless calls by assigning them codes.

3.1.45
colocation
Placement of multiple antennas at a common site.

3.1.46
commercial mobile radio service provider
FCC designation for carrier connected to public switched telephone network and/or operated for profit.

3.1.47
condition based maintenance
(See **machinery condition based maintenance**.)

3.1.48
condition monitoring system
CMS
(See **machinery condition monitoring system**.)

3.1.49
construction agency
The contractor that installs the machinery train or its associated MPS.

3.1.50
contiguous
Mechanically connected and included in the same housing or rack containing the signal processing and alarm/shutdown/integrity logic functions of the monitor system.

NOTE Installation of all monitor system components in the same panel or cabinet is not the same as contiguous.

3.1.51
continuous display
Simultaneous, uninterrupted indication of all status conditions and measured variables in the MPS as required by this standard. It also continuously updates this indication at a rate meeting or exceeding the requirements of this standard.

3.1.52
controlled access
A security feature of a MPS that restricts alteration of a parameter to authorized individuals. Access may be restricted by means such as the use of a key or coded password or other procedures requiring specialized knowledge.

3.1.53
critical speed(s)
A shaft rotational speed at which the rotor-bearing-support system is in a state of resonance.

3.1.54
dBm
Decibels relative to 1 milliwatt.

3.1.55
dedicated display
A display that indicates only those parameters from its associated MPS(s) and is not shared with or used to indicate information from other systems such as process controllers, logic controllers, turbine controllers, and so forth.

3.1.56
defect
An anomaly or imperfection in a machine or component.

3.1.57
diagnostics
The examination of symptoms and syndromes to determine the nature of faults or failures (kind, situation, extent).

3.1.58
diagnostics
The methods used to identify sources of faults from data gathered using monitoring and analytical equipment.

3.1.59
digital
A binary communications protocol.

3.1.60
displacement
A vibration measurement that quantifies the amplitude in engineering units of mils (1 mil = 0.001 in.) or micrometers.

3.1.61
display
An analog meter movement, cathode ray tube, liquid crystal device, or other means for visually indicating the measured variables and status conditions from the MPS. A display may be further classified as integral or nonintegral, dedicated or shared, or continuous or noncontinuous.

3.1.62
dual path
A configuration of the monitor system such that the same transducer system is used as an input to two separate channels in the monitor system and different signal processing (such as filtering or integration) is applied to each channel.

NOTE An example of this is a single casing vibration accelerometer that is simultaneously processed in the monitor system to both acceleration and velocity for separate filtering, display, and alarming.

3.1.63
dual-path monitor
A device that performs more than one type of signal conditioning from a single transducer or signal interface.

3.1.64
dual voting logic
A monitor feature whereby the signals on two channels shall both be in violation of their respective setpoints to initiate a change in status (two-out-of-two logic).

3.1.65
dynamic data
That aspect of a signal that cannot be fully characterized by a single static or vector quantity but is instead characterized by an array of data points. Examples include orbit plots from orthogonal vibration sensors, spectrum plots, and timebase plots. Most trend plots are composed of static data values versus time and are therefore

considered static data trends. In contrast, a trend plot of dynamic data, such as a spectrum waterfall showing the entire spectrum at various intervals in time, would be considered a dynamic data trend.

3.1.66
dynamic range
The usable range of amplitude of a signal, usually expressed in decibels.

3.1.67
electrical runout
A source of error on the output signal from a noncontacting probe system resulting from nonuniform electrical conductivity properties of the observed material or from the presence of a local magnetic field at a point on the shaft surface.

3.1.68
electrically isolated accelerometer
An accelerometer in which all signal connections are electrically insulated from the accelerometer case or base.

3.1.69
emergency shutdown system
ESD
A safety instrumented system (SIS) as defined by IEC 61508/ISA S84 and IEC 61511, dedicated to stopping the machine under abnormal conditions.

NOTE 1 The ESD is separate and distinct from the machinery control system.

NOTE 2 The ESD may or may not include overspeed detection and/or surge detection.

NOTE 3 The ESD may be simple (e.g. set of relay contacts in series) or complex [e.g. programmable logic controller (PLC) type] based on the type of machine train and application (e.g. steam and gas turbines, electric drives, expanders, pumps, and compressors).

3.1.70
exception-based reporting
A monitoring strategy where the system reports back data on exception rather than adhering strictly to a specific reporting interval.

3.1.71
extension cable
The interconnection between the proximity probe's integral cable and its associated oscillator-demodulator.

3.1.72
failure
The termination of the ability of an item to perform a required function.

NOTE 1 After the failure, the item has a fault.

NOTE 2 "Failure" is an event, as distinguished from a "fault," which is a state.

NOTE 3 This concept as defined does not apply to items consisting of software only.

3.1.73
fast Fourier transform
FFT
An algorithm for transforming data from the time domain to the frequency domain. The FFT process is used to create a spectrum plot from a digitized sample of time waveform data.

3.1.74
fault
The state of an item characterized by inability to perform a required function, excluding such inability during preventative maintenance or other planned actions or due to lack of external resources.

3.1.75
field changeable
Refers to a design feature of a MPS that permits alteration of a function after the system has been installed.

3.1.76
filter
An electrical device that attenuates signals outside the frequency range of interest.

3.1.77
final shutdown element
The device(s) that accepts relay contacts and actuates the mechanism to initiate a forced shutdown.

3.1.78
flow sensor
A device used for sensing the rate of fluid flow.

3.1.79
frequency
The repetition rate of a periodic vibration per unit of time. Vibration frequency is typically expressed in units of cycles per second (Hertz), cycles per minute, or orders of shaft rotational speed.

3.1.80
frequency component
The amplitude, frequency, and phase characteristics of a dynamic signal filtered to a single frequency.

3.1.81
frequency division multiplexing
Numerous signals combined for transmission on a single communications channel.

3.1.82
g
A unit of acceleration equal to 9.81 m/s^2 (386.4 in./s^2).

3.1.83
gap voltage
A direct current (DC) voltage from a proximity transducer that quantifies the distance from the tip of the transducer to the observed shaft surface.

3.1.84
gauss level
The magnetic field level of a component. It is best measured with a Hall effect probe.

3.1.85
general packet radio service
Packet technology approach enables high-speed wireless Internet and other GSM-based data communications.

3.1.86
Hanning window
Windows are weighting functions used in the FFT process. The FFT algorithm requires the input data to be periodic in the sampled time record. Therefore, the sampled time waveform is multiplied by a window function to force the amplitude of the input data to zero at the beginning and end of the sample. Many different window functions exist, and each type reduces the frequency resolution and introduces some amplitude error into the resulting spectrum. A Hanning window provides the best compromise between amplitude accuracy and frequency resolution for general-purpose measurements for rotating equipment.

3.1.87
harmonics
The vibration content of a spectrum consisting of exact frequency integer multiples or submultiples of a fundamental frequency.

3.1.88
Hertz
Hz
The unit of frequency measurement in cycles per second.

3.1.89
high-speed circuit switched data
A permanent connection is established between the called and calling parties for the exchange of data.

3.1.90
inactive (counter) thrust direction
The direction opposite the active thrust direction.

3.1.91
inches per second
ips
A unit of velocity equal to 25.4 mm/s (1 in./s).

3.1.92
integral display
A display that is contiguous with the other components comprising the monitor system.

3.1.93
integrated digital enhanced network
Technology that combines two-way radio, telephone, text messaging, and data transmission into one digital network.

3.1.94
interconnection
Connecting one wireless network to another.

3.1.95
interoperability
Coordination and communication with other networks, such as two systems based on different protocols or technologies.

3.1.96
latency
In a network, latency is an expression of how much time it takes for a packet of data to get from one designated point to another.

3.1.97
linear frequency response range
The portion of the transducer's voltage output versus frequency curve, between lower and upper frequency limits, where the response is linear within a specified tolerance.

3.1.98
linear range
The portion of a transducer's output where the output versus input relationship is linear within a specified tolerance.

3.1.99
local
Refers to a device's location when mounted on or near the equipment or console.

3.1.100
machine case
A driver (e.g. electric motor, turbine, or engine) or any one of its driven pieces of equipment (e.g. pump, compressor, gearbox, generator, fan). An individual component of a machinery train.

3.1.101
machine characteristics
Distinguishing attributes, qualities, and properties of a machine and its subsystems that, by their presence and magnitudes, define the configuration, performance, behavior, and capabilities of the machine or process.

3.1.102
machinery condition based maintenance
Maintenance performed based on the condition of the machine as indicated by a condition monitoring system or program.

3.1.103
machinery condition monitoring system
machinery CMS
A system that measures and trends specified machine and process parameters. Provides alarming, presentation, and analysis tools for the detection and identification of developing faults. Allows for the continued monitoring of a detected fault to determine its propagation and severity. May also be used to manage the operating conditions of the machine to reduce stress from a developing fault. Can, in some cases, reduce the rate at which a fault propagates to minimize additional damage thus extending the time before necessary repairs. The goal of a CMS is to maximize availability while reducing operating and maintenance costs.

3.1.104
machinery protection system
MPS
The system that senses, measures, monitors, and displays machine parameters indicative of its operating condition. When a parameter exceeds predefined limits, indicating an abnormal condition, the system will communicate the event to operators and/or a shutdown system. The goal of the system is to mitigate damage to the machine. The system consists of the transducer system, signal cables, the monitor system, all necessary housings and mounting fixtures, and documentation (see Figure 1).

3.1.105
machinery protection system vendor
MPS vendor
The agency that designs, fabricates, configures/programs, and tests components of the MPS.

3.1.106
machinery train
The driver(s) and all of its associated driven pieces of equipment.

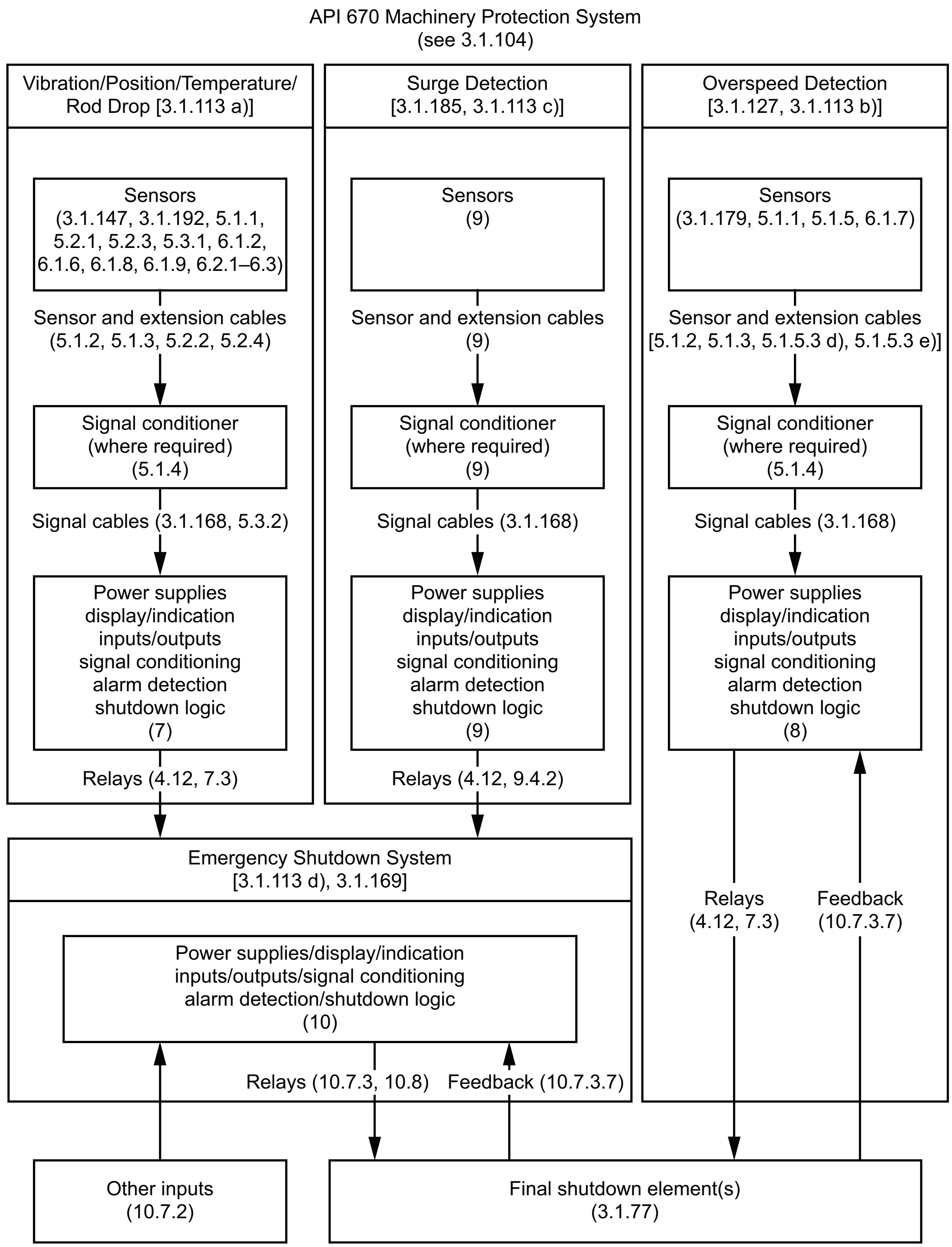


Figure 1—Machinery Protection System

3.1.107
machinery vendor
The agency that designs, fabricates, and tests machines. The machinery vendor may purchase the monitor system or transducer system, or both, and may install the transducers or the sensors on machines.

3.1.108
magnetic speed sensor
Responds to changes in magnetic field reluctance as the gap between the sensor and its observed ferrous target (speed sensing surface) changes. By choosing a proper speed sensing surface, the magnetic speed sensor's output will be proportional to the rotational speed of the observed surface. Magnetic speed sensors may be either passive (self-powered) or active (require external power).

3.1.109
mechanical runout
A source of error in the output signal of a proximity probe system resulting from surface irregularities, out-of-round shafts, and such.

3.1.110
megaHertz
MHz
Unit of frequency equal to one million Hertz or cycles per second.

3.1.111
misalignment
The degree to which the axes of machine components are noncollinear, either in offset or angularity.

3.1.112
mode shape
The deflection shape of a machine and support structure due to an applied dynamic force at a natural frequency; also used for the deflection shape of a forced response.

3.1.113
monitor system
Consists of signal processing, alarm/shutdown/integrity logic processing, power supply(ies), display/indication, inputs/outputs, and protective relays (see Figure 1 and Figure 2). Monitor systems defined in this document are:

a) vibration monitoring system (see Section 7),

b) electronic overspeed detection system (ODS) (see Section 8),

c) surge detection system (see Section 9),

d) ESD (see Section 10).

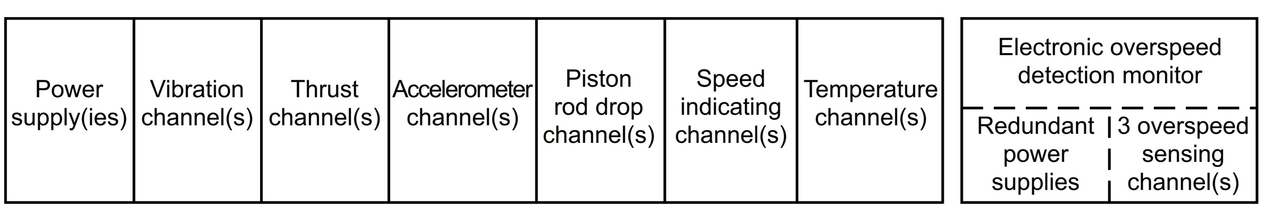


Figure 2—Standard Monitor System Nomenclature

3.1.114
natural frequency
The frequency of free vibration of a mechanical system at which a specific natural mode shape of the system elements assumes its maximum amplitude.

3.1.115
negative averaging
A technique that isolates specific vibration components by subtracting two measured signals from each other.

3.1.116
nonintegral display
A display that is not contiguous with the other components comprising the monitor system.

3.1.117
nonsynchronous
Any component of a vibration signal that has a frequency not equal to an integer multiple of shaft rotational speed (1X).

3.1.118
Np
The number of electrical poles in a motor.

3.1.119
***n*X amplitude**
The vibration amplitude at n times running speed, where n is an integer. (See also **harmonics**.)

3.1.120
observed
The purchaser shall be notified of the timing of the inspection or test; however, the inspection or test shall be performed as scheduled, and if the purchaser or his/her representative is not present, the MPS vendor shall proceed to the next step. (The purchaser should expect to be in the factory longer than for a witnessed test.)

3.1.121
oil whirl
(See **bearing instability**.)

3.1.122
OPC
Standard that specifies communication of real-time plant data between control devices from different manufacturers (formerly an acronym).

3.1.123
orbit
The path of the shaft centerline motion at the probe location during rotation.

3.1.124
orthogonal frequency division multiplexing
System for transmission of digital message elements spread over multiple channels within a frequency band.

3.1.125
oscillator-demodulator
A signal conditioning device that sends a radio frequency signal to a proximity probe, demodulates the probe output, and provides an output signal suitable for input to the monitor system.

3.1.126
overall
A value representing the magnitude of vibration over a frequency range determined by the design of the instrument or as specified. Expressed as rms, zero-peak (0-P), or peak-to-peak (P-P).

3.1.127
overspeed detection system
ODS
A system that consists of speed sensors, power supplies, output relays, signal processing, and alarm/shutdown/ integrity logic. Its function is to continuously measure shaft rotational speed and activate its output relays when an overspeed condition is detected.

3.1.128
overspeed protection system
An electronic ODS and all other components necessary to shut down the machine in the event of an overspeed condition. It may include (but is not limited to) items such as shutdown valves, solenoids, and interposing relays.

NOTE Only electronic ODS's are addressed in this standard. Mechanical ODS's are intentionally not addressed.

3.1.129
owner
The final recipient of the equipment who will operate the machinery and its associated MPS and may delegate another agent as the purchaser of the equipment.

3.1.130
packet data
Information reduced to digital pieces or "packets" so it can travel more efficiently across networks, including radio airwaves and wireless networks.

3.1.131
packet switched data
Efficient technology used for data communication across the Internet.

3.1.132
passive magnetic speed sensor
A magnetic speed sensor that does not require external power to provide an output.

3.1.133
path loss
range loss
Attenuation (in dB) of a wireless signal as it travels between antennas.

3.1.134
peak-to-peak value
pp
The difference between positive and negative extreme values of an electronic signal or dynamic motion.

3.1.135
personal communications services
Broad family of wireless services including two-way digital voice, messaging, and data services.

3.1.136
personal digital assistant
Portable computing device capable of transmitting data.

3.1.137
phase angle
The timing relationship, in degrees, between two signals, such as a once-per-revolution reference probe and a vibration signal.

3.1.138
phase reference transducer
A gap-to-voltage device that consists of a proximity probe, an extension cable, and an oscillator-demodulator and is used to sense a once-per-revolution mark.

3.1.139
piston rod drop
A measurement of the position of the piston rod relative to the proximity probe mounting location(s) (typically oriented vertically at the pressure packing box on horizontal cylinders).

NOTE Piston rod drop is an indirect measurement of the piston rider band wear on reciprocating machinery (typically addressed by API 618).

3.1.140
point of presence
The interconnectivity points between networks or population of transceivers.

3.1.141
polar plot
A graphical format used to display vectors (amplitude and phase) on a polar coordinate system.

3.1.142
positive indication
An active (i.e. requires power for annunciation and changes state upon loss of power) display under the annunciated condition. Examples include an LED that is lighted under the annunciated condition or an LCD that is darkened or colored under the annunciated condition.

3.1.143
predictive maintenance
Maintenance performed based on the detection of faults and/or the prediction of failure.

3.1.144
preload
A unidirectional, axial, or radial static load due to external or internal mechanisms. Also applied to the installation configuration of certain bearing types such as tilting pad bearings.

3.1.145
pressure sensor
A device that measures the force per unit area of liquids or gasses.

3.1.146
preventive maintenance
Maintenance performed according to a fixed schedule or according to a prescribed criterion that is intended to allow for the detection of faults, typically by inspection, and the replacement of wearable parts before faults develop or before a fault can propagate to failure.

3.1.147
primary probes
Those proximity probes installed at preferred locations and used as the default inputs to the monitor system.

3.1.148
probe area
The area observed by the proximity probe during measurement.

3.1.149
probe gap
The physical distance between the face of a proximity probe tip and the observed surface. The distance can be expressed in terms of displacement (mils, micrometers) or in terms of voltage (Vdc).

3.1.150
protocol
Standard definitions governing formatting of communications across networks and between devices.

3.1.151
proximity probe
A noncontacting sensor that consists of a tip, a probe body, an integral coaxial or triaxial cable, and a connector and is used to translate distance (gap) to voltage when used in conjunction with an oscillator-demodulator.

3.1.152
purchaser
The agency that issues the order and specification to the vendor.

3.1.153
radial shaft vibration
The vibratory motion of the machine shaft in a direction perpendicular to the shaft longitudinal axis.

3.1.154
radio
The transceiving device-part of all radio frequency systems.

3.1.155
remote
Refers to the location of a device when located away from the equipment or console, typically in a control room.

3.1.156
repeater
Devices that receive, amplify, and retransmit radio signals to extend range of wireless networks.

3.1.157
resistance temperature detector
RTD
A temperature sensor that changes its resistance to electrical current as its temperature changes.

3.1.158
resolution
The smallest increment of measure. In analog to digital conversion (A/D) systems, resolution is calculated as the full-scale value divided by $2n$ where "n" is the number of bits of the analog to digital converter. In a spectra plot, resolution refers to the frequency change from one bin to the next, calculated as F_{max}/number of FFT lines.

3.1.159
root mean square
rms
The square root of the mean of the sum of the squares of the sample values.

3.1.160
router
A switching device in a network that directs and controls the flow of data through the network.

3.1.161
rub
Potentially severe machine fault consisting of contact between the rotating and stationary parts of a machine.

3.1.162
self-organizing network
A technology that dynamically manages configuration and communications, automatically making changes as needed to ensure messages reach their destinations efficiently and reliably.

3.1.163
sensor
A device (such as a proximity probe or an accelerometer) that detects the value of a physical quantity and converts the measurement into a useful input for another device.

3.1.164
shaft bow
A condition of deformation of a shaft that results in a curved shaft centerline.

3.1.165
shaft vibration or position transducer
A gap-to-voltage device that consists of a proximity probe, an extension cable, and an oscillator-demodulator.

3.1.166
short messaging service
A protocol that enables “text messaging.”

3.1.167
shutdown (danger) setpoint
A preset value of a parameter at which automatic or manual shutdown of the machine is required.

3.1.168
signal cable
The field wiring interconnection between the transducer system and the monitor system.

NOTE Signal cable is typically supplied by the construction agency.

3.1.169
signal processing
Transformation of the output signal from the transducer system into the desired parameter(s) for indication and alarming. Signal processing for vibration transducers may include, for example, peak-to-peak, zero-to-peak, or rms amplitude detection; pulse counting; DC bias voltage detection; and filtering and integration. The output(s) from the signal processing circuitry are used as inputs to the display/indication and alarm/shutdown/integrity logic circuitry of a monitor system.

3.1.170
signal-to-noise ratio
The ratio of the power of the signal conveying information to the power of the signal not conveying information.

3.1.171
slow roll
A machine state in which the shaft is rotating but too slowly for any consequential vibratory (dynamic) forces to develop.

3.1.172
spare probes
Probes installed at alternate locations to take the place of primary probes (without requiring machine disassembly) in the event of primary probe failure.

3.1.173
spectrum allocation
The federal government's designation of frequencies.

3.1.174
spectrum assignment
The federal government's authorization for use of specific frequencies within a given spectrum allocation, usually in a specific geographic location.

3.1.175
spectrum averaging
The averaging of multiple spectra to reduce random nonrecurring frequency components.

3.1.176
spectrum plot
An x-y plot in which the x-axis represents vibration frequency and the y-axis represents amplitudes of vibration components. A full spectrum plot is an enhanced spectrum plot produced by using the timebase waveforms from XY transducers to calculate the amplitudes of the forward and reverse (backward) frequency components. A half spectrum plot displays forward or positive frequency components only.

3.1.177
speed
The frequency at which a shaft is rotating at a given moment, usually expressed in units of revolutions per minute (rpm) or revolutions per second (rps).

3.1.178
speed sensing surface
A gear, toothed-wheel, or other surface with uniformly-spaced discontinuities that causes a change in gap between the speed sensing surface and its associated speed sensor(s) as the shaft rotates.

3.1.179
speed sensor
A proximity probe or magnetic speed sensor used to observe a speed sensing surface. It provides an electrical output proportional to the rotational speed of the observed surface.

3.1.180
spread spectrum
Transmitting radio signals by using a wide range of frequencies

3.1.181
standard option
A generally available alternative configuration that may be specified in lieu of the default configuration specified herein.

3.1.182
static data
That aspect of a signal that can be fully characterized by a single static or vector quantity.

NOTE Examples include waveform DC bias (e.g. probe gap voltage), waveform amplitude, waveform period, or the amplitude/phase of a discrete vibration frequency such as 1X. Static data is so named because although changes in static values occur over time, the changes constitute a trend rather than a repeating waveform and are typically measured in seconds, minutes, hours, or days rather than in milliseconds.

3.1.183
steady state data
Data acquired from a machine at constant shaft rotational speed and process conditions.

3.1.184
subsynchronous
The component of a vibration signal that has a frequency less than 1X shaft rotational speed.

3.1.185
surge
At a given head, the minimum volumetric flow for a specific set of gas conditions below which a centrifugal or axial compressor becomes aerodynamically unstable.

3.1.186
surge cycle
Consists of a flow reversal accompanied by fluctuations in the compressor pressure and temperature followed by flow recovery.

3.1.187
surge detection system
Consists of surge sensors (typically temperature, pressure, or flow), power supplies, output relays, signal processing, and alarm/shutdown/integrity logic. Its function is to continuously measure and count surge cycles.

3.1.188
surge limit line
The line formed by theoretical or tested surge points across the head range of the compressor.

3.1.189
surge point
(See **surge** in 3.1.185.)

3.1.190
synchronous
The component of a vibration signal that has a frequency equal to an integer multiple of the shaft rotational speed (1X). (See also **time synchronous averaging**.)

3.1.191
synchronous sampling
The sampling of a vibration waveform initiated by a shaft phase-reference transducer.

3.1.192
tachometer
A device for indicating shaft rotational speed.

3.1.193
temperature sensor
A thermocouple or RTD and its integral sensor lead.

3.1.194
thermocouple
A temperature sensor consisting of two dissimilar metals so joined to produce different voltages when their junction is at different temperatures.

3.1.195
third generation
Technologies that offer increased capacity and capabilities delivered over digital wireless networks.

3.1.196
time division multiple access
Convention for transmission of information by dividing into time slots so a single channel can carry many calls at once.

3.1.197
time synchronous averaging
The averaging of multiple synchronously sampled waveforms to reduce the nonrotational-related frequency components.

3.1.198
topology
Arrangement of network components. Describes both physical layout of devices, routers, and gateways and the paths that data follows between them. Three common wireless topologies for in-plant wireless field network applications are star, mesh (self-organizing), and cluster tree.

3.1.199
transducer system (centrifugal machinery)
A proximity probe, accelerometer, or sensor, an extension or accelerometer cable, and oscillator-demodulator (when required). The transducer system generates a signal that is proportional to the measured variable (see Figure 3).

3.1.200
transducer system (reciprocating compressor and surge detection)
In reciprocating compressor and surge detection applications, other measured variables may be required. Variables include pressure, differential pressure, flow, liquid level, temperature, etc. In these applications, the system consists of a sensor, a transmitter, and associated electrical cable.

NOTE Pressure and flow transducer nomenclature can be found in API 554.

3.1.201
transient data
The data acquired from a machine at variable shaft rotational speed and process conditions.

3.1.202
transmission control protocol/internet protocol
Protocol permitting communications over and between networks, the basis for Internet communications.

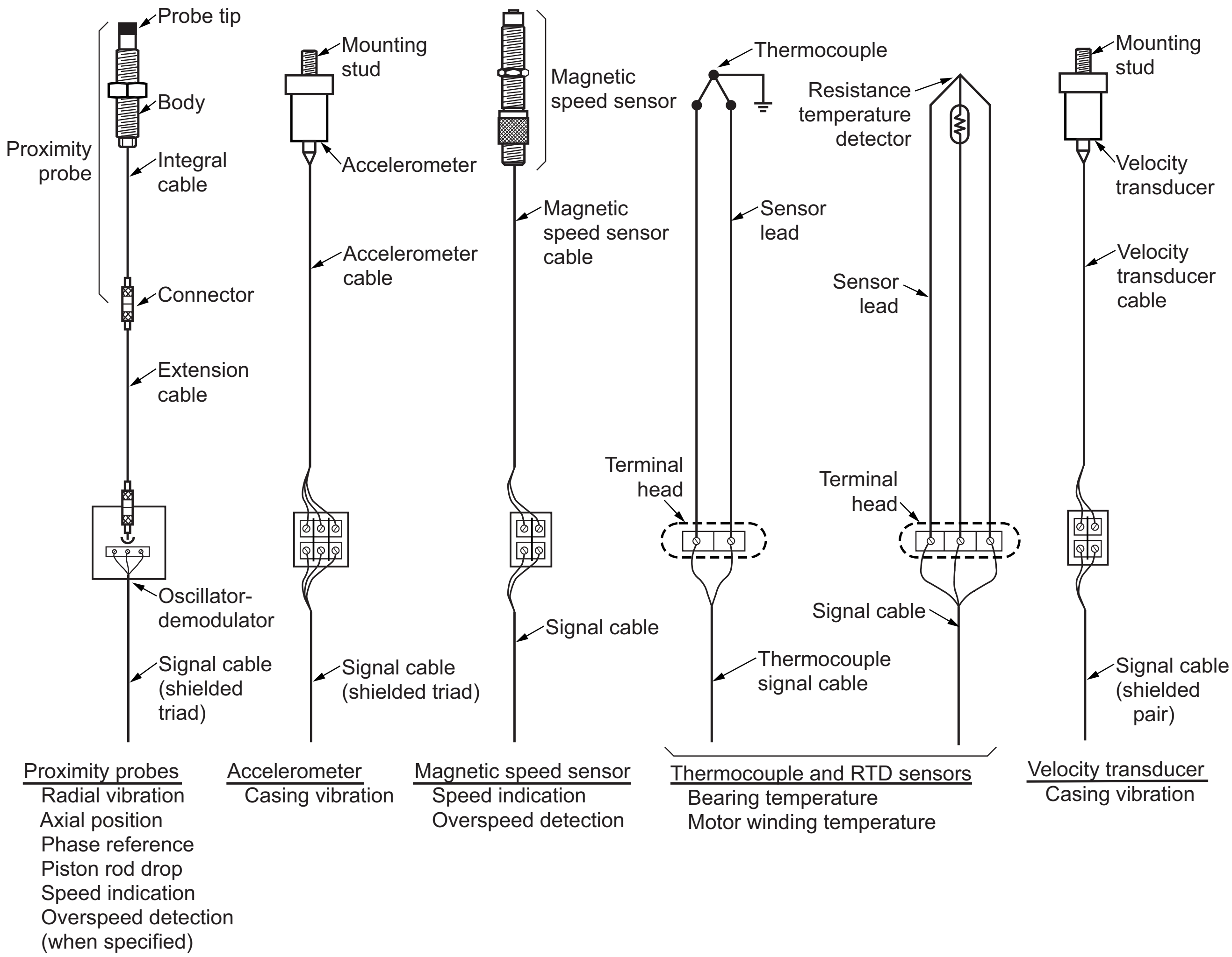


Figure 3—Transducer System Nomenclature

3.1.203
transmitter (reciprocating compressor and surge detection)
A device that consists of a sensor and a signal conditioner, usually combined into one assembly. The electrical output is proportional to the magnitude of the sensed condition and bounded by a range (lower and upper limits) (i.e. 4 mA to 20 mA). Transmitters are not used or included in the class of transducer systems defined in 3.1.199.

3.1.204
transverse sensitivity
An accelerometer's response to dynamic loads applied in a direction perpendicular to the principal axis. It is also sometimes called cross-axis sensitivity.

3.1.205
trend
Any parameter whose magnitude is displayed as a function of time.

3.1.206
trend parameter
A characteristic extracted from a vibration spectrum or waveform. This analysis technique is often referred to as frequency band monitoring. Typical examples include the vibration within a fixed or variable frequency band or peak and phase values for a specific harmonic of shaft speed.

NOTE Any parameter associated with machinery can be displayed as a function of time.

3.1.207
tri-band handset
Multiple frequency phones, typically in the 1900 MHz, 800 MHz, and 900 MHz frequencies used in the United States and elsewhere.

3.1.208
tri-mode handset
Phones that operate in different modes such as the CDMA, time division multiple access, and analog standards.

3.1.209
unbalance
A rotor condition where the mass centerline (principal axis of inertia) does not coincide with the geometric centerline, expressed in units of gram-inches, gram-centimeters, or ounce-inches.

3.1.210
unfiltered
Data that is not filtered and represents the original transducer output signal.

3.1.211
unit responsibility
Refers to the responsibility for coordinating the delivery and technical aspects of the equipment and all auxiliary systems included in the scope of the order. The technical aspects to be considered include, but are not limited to, such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, material test reports, instrumentation (such as the MPS), piping, conformance to specifications, and testing of components.

3.1.212
universal mobile telecommunications systems
Third-generation technology based on wideband code division multiple access with speed between 384 kbps and up to about 2 Mbps.

3.1.213
vector
A quantity that has both magnitude and angular orientation. For a vibration vector, magnitude is expressed as amplitude (displacement, velocity, or acceleration) and direction as phase angle (degrees).

3.1.214
velocity
The time rate of change of displacement. Units for velocity are inches per second or millimeters per second.

3.1.215
velocity sensor—piezoelectric
An accelerometer with integral amplification and signal integration such that its output is proportional to its vibratory velocity (5.2.3).

3.1.216
velocity sensor—moving coil
An electromechanical type of transducer that contains a moving coil as a seismic mass suspended in a permanent magnetic field and outputs an analog signal proportional to the instantaneous velocity of the machine case (5.2.3).

3.1.217
voice recognition
Capability for wireless phones, computers, and other devices to be activated and controlled by voice commands.

3.1.218
voted channel
A channel requiring confirmation from one or more additional channels as a precondition for alarm (alert) and shutdown (danger) relay actuation.

3.1.219
waterfall plot
A plot similar to cascade plot, except that the z-axis is usually time or another time-related function, such as load, instead of shaft rotational speed (rpm or rps).

3.1.220
waveform plot
A presentation of the waveform of a signal as a function of time. A vibration time waveform can be observed on an oscilloscope in the time domain.

3.1.221
wideband code division multiple access
One of two third-generation standards that makes use of wider spectrum than CDMA to transmit and receive information faster and more efficiently.

3.1.222
wi-max
Technology based on IEEE 802.16 standard providing metropolitan area network connectivity for fixed wireless access at broadband speeds.

3.1.223
wireless application protocol
Standards that enable wireless devices to browse content from specially-coded web pages.

3.1.224
wireless fidelity
WiFi
Wireless connectivity over unlicensed spectrum (using the IEEE 802.11a or IEEE 802.11b standards), generally in the 2.4 GHz and 5 GHz radio bands. WiFi offers local area connectivity to WiFi-enabled computers.

3.1.225
wireless internet
A general term for using wireless services to access the Internet, email, and/or the World Wide Web.

3.1.226
wireless private branch exchange
Allows wireless communication within a building or limited area in place of traditional landlines.

3.1.227
witnessed
A hold shall be applied to the production schedule and the inspection or test shall be carried out with the purchaser or his/her representative in attendance. For factory acceptance testing of the MPS, this requires written notification of a successful preliminary test.

3.1.228
wireless local area network
Using radio frequency technology to transmit and receive data wirelessly in a certain area.

3.1.229
wireless local loop
System connecting wireless users to public switched telephone network. Wireless systems can often be installed faster and cheaper than traditional wired systems.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

AWG	American Wire Gage
CDMA	code division multiple access
CMS	condition monitoring system
cpm	cycles per minute
DC	direct current
E/E/PES	electrical/electronic/programmable electronic system
ESD	emergency shutdown system
FFT	fast Fourier transform
HFT	hardware fault tolerance
HSE	health, safety, and environment
Hz	Hertz
ips	inches per second
kHz	kiloHertz
LAN	local area network
mA	milliamp
MHz	megaHertz
MPS	machinery protection system
MTTF	mean time to failure
$MTTF_d$	mean time to fail to dangerous condition
MTTR	mean time to repair
mV	millivolt
N	Newton
ODS	overspeed detection system
OEM	original equipment manufacturer
PCB	printed circuit board
PES	programmable electronic system

PFD	probability of failure on low demand
PFD_{avg}	probability of failure on low demand, average
PFH	probability of failure on high demand (1/h)
PL	performance level
PLC	programmable logic controller
pp	peak-to-peak value
RBD	reliability block diagram
RFQ	request for quotation
rpm	revolutions per minute
rps	revolutions per second
rms	root mean square
RRF	risk reduction factor
RTD	resistance temperature detector
SFF	safe failure fraction
SIF	safety instrumented function
SIL	safety integrity level
SIS	safety instrumented system
SRS	safety requirement specification
SOV	solenoid operated valve
TI	proof test interval
USC	U.S. customary
Vac	volt AC
Vdc	volt DC
VFD	variable frequency drive
WiFi	wireless fidelity

4 General Design Specifications

4.1 Component Temperature Ranges

4.1.1 MPS components have two temperature ranges, testing range and operating range, over which accuracy shall be measured and in which the system components shall operate, as summarized in Table 1.

NOTE The testing range is a range of temperatures in which normal bench testing occurs. It allows verification of the accuracy and operation of transducer and monitor system components without the need for special temperature- or humidity-controlled environments. The operating range represents temperatures over which the transducer and monitor system components are expected to operate in actual service conditions.

4.1.2 For temperature ratings on other monitor system components (such as power supplies, relay, communication cards, displays), see Table 1.

4.2 Humidity

4.2.1 For transducer systems, the accuracy requirements of Table 1 shall apply at levels of relative humidity up to 100 % condensing, nonsubmerged, with protection of connectors.

4.2.2 For monitor system components, the accuracy requirements of Table 1 shall apply at levels of relative humidity up to 95 % noncondensing.

4.3 Shock

Accelerometers shall be capable of surviving a mechanical shock of 5000 g, peak, without affecting the accuracy requirements specified in Table 1.

4.4 Chemical Resistance

4.4.1 Probes, probe extension cables, and oscillator-demodulators shall be constructed of corrosion-resistant materials suitable for environments containing trace levels of chemicals such as hydrogen sulfide or ammonia.

NOTE 1 The intent of this subsection is to ensure that the standard probe system is compatible with commonly encountered bearing lube oil environments.

NOTE 2 Rod position probes may often be used in environments (such as sour gas compressors) containing elevated levels of hydrogen sulfide for which a standard probe system may not be suitable.

NOTE 3 Ammonia plants may contain atmospheres in which elevated levels of ammonia are present and for which a standard probe system may not be suitable.

• **4.4.2** If specified, probes, probe extension cables, and oscillator-demodulators shall be compatible with an environment containing other chemicals or concentrations (4.4.1).

• **4.4.3** The purchaser shall specify the list of required chemicals and concentrations.

4.5 Accuracy

4.5.1 Accuracy of the transducer system and monitor system in the testing and operating temperature ranges shall be as summarized in Table 1.

4.5.2 If monitor system components or transducer system components will be used in applications exceeding the requirements of Table 1, the MPS vendor shall supply documentation showing how the accuracy is affected or suggest alternative transducer and monitor components suitable for the intended application.

NOTE 1 Some applications may require piston rod drop and axial position measurements with measuring ranges greater than 2 mm (80 mil). Special transducer systems, such as those with 3.94 mV/μm (100 mV/mil) scale factors, are required for these applications and are not covered by this standard.

NOTE 2 Gas turbines may require special high-temperature seismic sensors that exceed the operating range specified in Table 1 and monitor systems with special filtering based on original equipment manufacturer (OEM) recommendations. Consult the MPS vendor.

NOTE 3 Radial vibration or position measurements using proximity probe transducers on shaft diameters as small as 76 mm (3 in.) do not introduce appreciable error compared to measurements made on a flat target area. Shaft diameters smaller than this can be accommodated but generally result in a change in transducer scale factor. Consult the MPS vendor.

NOTE 4 Proximity probe measurements on shaft diameters smaller than 50 mm (2 in.) may require close spacing of radial vibration or axial position transducers with the potential for their electromagnetic emitted fields to interact with one another (cross talk) resulting in erroneous readings. Care should be taken to maintain minimum separation of transducer tips, generally at least 40 mm (1.6 in.) for axial position measurements and 74 mm (2.9 in.) for radial vibration measurements.

4.5.3 The proximity probe transducer system accuracy shall be verified on the actual probe target area or on a target with the same electrical characteristics as those of the actual probe target area (see Figure 4).

4.5.4 When verifying the accuracy of any individual component of the proximity probe transducer system in the operating range, the components not under test shall be maintained within the testing range.

Table 1—Machinery Protection System Accuracy Requirements

Components	Temperature: Testing Range	Temperature: Operating/ Storage Range	Accuracy Requirements as a Function of Temperature: Within Testing Range	Accuracy Requirements as a Function of Temperature: Outside Testing Range but Within Operating Range
Proximity probes	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 120 °C (–30 °F to 250 °F)	Incremental scale factor [a]: ±5 % of 7.87 mV/µm (200 mV/mil) Deviation from straight line [b]: within ±25.4 µm (±1 mil) of the best fit straight line at a slope of 7.87 mV/µm (200 mV/mil) Minimum linear range: 2 mm (80 mil)	Incremental scale factor [a]: an additional ±5 % of the testing range accuracy Deviation from straight line [b]: within ±76 µm (±3 mil) of the best fit straight line at a slope of 7.87 mV/µm (200 mV/mil) Minimum linear range: same as for testing range
Extension cables	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 65 °C (–30 °F to 150 °F)		
Oscillator-demodulators	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 65 °C (–30 °F to 150 °F)		
Accelerometers and accelerometer extension cables [c]	20 °C to 30 °C (68 °F to 86 °F)	–55 °C to 120 °C (–65 °F to 250 °F)	Principal axis sensitivity [f]: 100 mV/g ± 5 % Amplitude linearity: 1 % from 0.1 g peak to 50 g peak [d] Frequency response [e]: ±3 dB from 10 Hz to 10 kHz, referenced to the actual measured principal axis sensitivity [f]	Principal axis sensitivity [f]: 100 mV/g ± 20 %
Temperature sensors and leads	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 175 °C (–30 °F to 350 °F)	±2 °C (±4 °F) over a measurement range from –20 °C to 150 °C (0 °F to 300 °F)	±3.7 °C (±7 °F) over a measurement range from –20 °C to 150 °C (0 °F to 300 °F)
Monitor system components for measuring:				
radial vibration, axial position, piston rod drop, and casing vibration	0 °C to 45 °C (32 °F to 110 °F)	–20 °C to 65 °C (0 °F to 150 °F)	±1 % of full-scale range for the channel	Same as for testing range
temperature			±1 °C (±2 °F)	Same as for testing range
speed			±1 % of alarm setpoint	Same as for testing range
overspeed			±0.1 % of shutdown setpoint or ±1 rpm, whichever is less	Same as for testing range
Other monitor system components (such as: power supplies, relay, communication cards, displays)		–20 °C to 65 °C (0 °F to 150 °F)		

[a] The incremental scale factor (ISF) error is the maximum amount the scale factor varies from 7.87 mV/µm (200 mV/mil) when measured at specified increments throughout the linear range. Measurements are usually taken at 250 µm (10 mil) increments. ISF error is associated with errors in radial vibration and axial position readings.

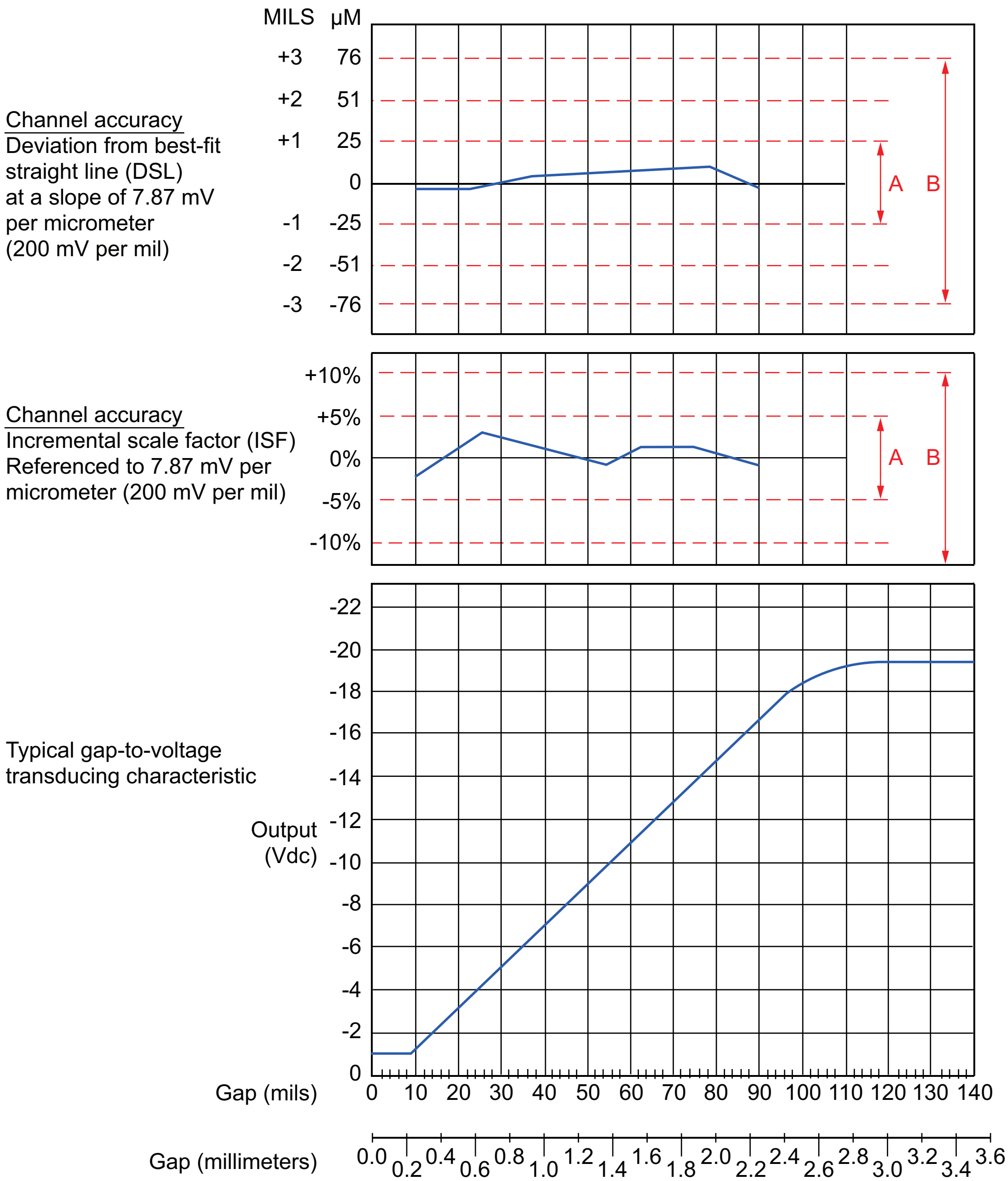
[b] The deviation from straight line (DSL) error is the maximum error (in mils) in the probe gap reading at a given voltage compared to a 7.87 mV/µm (200 mV/mil) best fit straight line. DSL errors are associated with errors in axial position or probe gap readings.

[c] During the testing of the accelerometers, the parameter under test is the only parameter that is varied. All other parameters shall remain constant.

[d] Conditions of test: at any one temperature within the testing range, at any single frequency that is not specified but is within the specified frequency range of the transducer.

[e] Frequency response testing conditions: at any one temperature within the testing range, at an excitation amplitude that is not specified but is within the specified amplitude range of the transducer.

[f] Principal axis sensitivity testing conditions: (testing range) at any one temperature within the testing range, at 100 Hz, at an excitation amplitude that is not specified but is within the specified amplitude range of the transducer. Operating range: at any one temperature within the operating range, at 100 Hz, at an excitation amplitude that is not specified but is within the specified amplitude range of the transducer.



A Maximum error during bench test within testing temperature range of 0 °C to 45 °C (30 °F to 110 °F).

B Maximum error over operating temperature range.

Figure 4—Typical Curves Showing Accuracy of Proximity Transducer System

4.6 Interchangeability

4.6.1 All components covered by this standard shall be physically and electrically interchangeable within the accuracy specified in Table 1. This does not imply that interchangeability of components from different MPS vendors is required or that oscillator-demodulators calibrated for different shaft materials are electrically interchangeable.

4.6.2 Unless otherwise specified, probes, cables, and oscillator-demodulators shall be supplied calibrated to the MPS vendor's standard reference target of AISI Standard Type 4140 steel.

NOTE Consult the MPS vendor for a precision factory target when verifying the accuracy of the transducer system to this standard. The MPS vendor should be consulted for applications using target materials other than AISI Standard Type 4140 steel as they may require factory recalibration of the transducer system.

4.7 Scope of Supply and Responsibility

4.7.1 For each train, the purchaser shall specify the agency or agencies responsible for each function of the design, scope of supply, installation, and performance of the monitoring system (see Annex B).

4.7.2 The details of systems or components outside the scope of this standard shall be mutually agreed upon by the purchaser and MPS vendor.

4.8 Segregation

4.8.1 The MPS shall be separate from and diverse of all other control or protective systems such that its ability to detect an alarm within the required response time on any monitored parameter and activate its system output relays (4.12) does not depend in any way upon the operation of these other systems.

NOTE The intent of this subsection is to prevent the MPS hardware from being combined with hardware from other control and automation systems, thereby eliminating common-cause failure modes and protecting the machine in the event of failure of its associated machinery control system or failure of the process control system. It is not intended to prohibit the inclusion of condition monitoring functionality within the MPS, provided failure of those functions does not impact the protective functions. See also Annex N.

4.8.2 Wireless technologies shall not be used for protective functions (see Table 2).

NOTE Annex N contains a discussion of permissible wireless condition monitoring applications, and Annex Q provides a basic tutorial on wireless technology.

4.9 System Enclosures and Environmental Requirements

4.9.1 Field-installed MPS installations shall be suitable for the area classification (zone or class, group, and division) specified by the purchaser and shall meet the requirements of the applicable sections of IEC 60079/NFPA 70 (Articles 500, 501, 502, 504, and 505) as well as any local codes specified and furnished on request by the purchaser. If instruments are located outdoors or are subject to fire sprinklers, their housings shall be watertight (IP 65/NEMA Type 4 stainless steel), as specified in IEC 60079/NEMA 250, in addition to any other enclosure requirements necessary for the area classification in which the instrument is installed. Nonincendive or intrinsically safe instruments are preferred (see Note). When air purging is specified to meet the area classification, it shall be in accordance with ISA S12.4 or with NFPA 496, Type X, Y, or Z, as required.

NOTE Explosion-proof or intrinsically safe instrumentation is acceptable for Class I, Division 1 and Division 2 hazardous (classified) locations; nonincendive instrumentation is acceptable for Class I, Division 2 hazardous (classified) locations when installed in accordance with Article 501, NFPA 70.

• **4.9.2** If specified, air purging shall be used to avoid moisture or corrosion problems, even when weatherproof or watertight housings are used (see 4.9.1). Purge air shall be clean and dry.

NOTE Circuit board and backplane connectors may require additional corrosion resistance in extreme environments (i.e. gold-plating, gas tight connector design, and so forth). Consult the MPS vendor for availability.

Table 2—Summary of Allowable Usage of Wireless Technology for Machinery Protection Systems

Input or Output	Type	Description	670 Subsection/ Paragraph	Integral Part of Machinery Protection Loop?	Wireless Media Permitted?	Notes
Input/ output	Interconnection	All interconnections between the monitor system components depicted in Figure 1, with exception of a nonintegral display	Figure 1	Y	N	If the components separated by dotted lines in Figure 1 are composed of physically separate systems interconnected by hardwiring as opposed to a contiguous system design that interconnects functions via circuit board traces or a common backplane (i.e. a traditional “rack-based” system), then such interconnections may not use wireless transmission media.
Output	Display	Circuit fault indicators	4.11.4 b)	Y	N	To annunciate circuit faults within the protection system, independent of other display functionality, such as bar graphs.
		Channel alert indicator	4.11.7 e)	Y	N	
		Channel danger indicator	4.11.7 d)	Y	N	
		Channel danger bypass indication	4.11.7 f)	Y	N	
		Integral display indication	7.1.9	Y	N	An integral display is the default option and when used, employs a hardwired connection. When an optional nonintegral display is specified in lieu of an integral display, it may use a wireless connection. However, the requirements of 4.11.7 still apply.
		“Blind monitor” indication	7.1.10	Y	N	Loss of a nonintegral display should not render the underlying protection system completely blind. As such, the nonintegral display may be wireless, but the minimal display requirements described in this paragraph may not be wireless.
		System danger bypass indication	4.11.5 f)	Y	N	A relay contact that allows external annunciation that the monitoring system is bypassed and machinery protection functionality is disabled. For example, to turn on an indicator in an annunciation panel in a control room or a large red warning light on the machine control cabinet.
		Setpoint multiplier indication	7.4.1.6 a); 7.4.4.4	Y	N	The annunciation of this condition is absolutely critical so that if falsely activated, it can be rectified. It is unacceptable for the monitor to be in this condition and the operator not to know about it because a wireless transmission link has failed or updates too infrequently.
	Alarm	Signal from alert detection circuitry to alert relay	4.11.5 b)	Y	N	
		Signal from danger detection circuitry to danger relay	4.11.5 c)	Y	N	
		System output relays	4.12	Y	N	These are the primary intended output mechanisms for providing machinery protection because of the integrity of relays, the speed with which they act, and the various facilities within the monitoring system to properly suppress the relays under circuit fault conditions or deliberate bypass conditions.

Table 2—Summary of Allowable Usage of Wireless Technology for Machinery Protection Systems (Continued)

Input or Output	Type	Description	670 Subsection/ Paragraph	Integral Part of Machinery Protection Loop?	Wireless Media Permitted?	Notes
Input	Tranducers and Wiring	Proximity probes, extension cables, oscillator-demodulators, and field wiring from oscillator-demodulators to monitor modules	5.1.1; 5.1.2; 5.1.3; 5.1.4	Y	N	
		Magnetic speed sensors, cables, and field wiring from sensor to monitor	5.1.5	Y	N	
		Accelerometers, cables, and field wiring from accelerometers to monitors	5.2	Y	N	
		Temperature sensor wiring	5.3.2	Y	N	
	Configuration	Monitor configuration ports/switches	7.1.3 c)	Y	N	
		Gain adjustment	7.1.4 a)	Y	N	
	Switch	System danger bypass activation	4.11.7	Y	N	Typically a keylock or other controlled mechanism to bypass the monitoring system while it is being maintained. It could conceivably be activated via a wireless link, but the annunciation/indication that the monitor is in a shutdown bypass condition is too critical to entrust to a wireless link. It is unacceptable for the monitor to be in this condition and the operator to not know about it because a wireless transmission has failed or updates too infrequently.
		Setpoint multiplier activation	7.4.1.6 a); 7.4.4.4	Y	N	The purpose of this input is discussed in length in Annex I.
Output	Condition monitoring	Digital interface for connection to condition monitoring system/software	new	N	Y	Typically incorporates a proprietary protocol for use between a vendor's 670 protection system and that vendor's corresponding condition monitoring software.
		Buffered outputs	4.11.4 d)	N	Y	Intended for connection to portable instruments such as route-based data collectors, oscilloscopes, data acquisition instruments, and test/calibration equipment such as multimeters.
	Control system	Digital comm port for process control interface	4.11.4 f)	N	Y	Primarily intended for sending pertinent monitor information to a DCS, PLC, machine control system, of human machine interface, emulating status indicators and current values that are provided by the monitor's integral (or nonintegral) display.
		4 mA to 20 mA proportional analog outputs	4.11.4 e)	N	Y	Connection to strip chart recorders, or analog interfacing to process control systems to emulate display of variables measured by machinery protection system.
	Display	Link between "monitor system" and nonintegral display	Figure 1; 3.1.116	N	Y	A "blind monitor system" (3.1.31) still provides minimal integral display functionality (7.1.10), and this minimal integral display functionality may not incorporate wireless transmission media.
Input	Switch	Rear-panel remote alarm reset/ acknowledgment	4.11.5 h)	N	Y	This does not relax the requirement for a front-panel manual switch discussed in this paragraph.

4.9.3 The satisfactory operation of electronic instrumentation in the presence of radio frequency interference requires that both the level and the form of the interference, as well as the required degree of immunity to it, be clearly defined by the owner (one company may not allow the use of radios in a control room whereas another may allow their use behind instrument panels in the control room while the enclosures are open). Once the requirement for immunity to radio frequency interference is defined, the details of electronic design and hardware installation can be established (see Note). Unless otherwise specified, MPS's shall comply with the electromagnetic radiation immunity requirements of EN 61000-6-2 and shall use metallic conduit or armored cable.

NOTE In addition to sound practices in the areas of instrument design, grounding, and shielding, the use of metallic conduit or armored cable and radio frequency interference (conductive) gasketing is critical to a successful installation. To ensure a trouble-free installation, the detailed requirements of a particular system should be discussed during the procurement phase by the MPS vendor, the construction agency, and the owner. The MPS vendor does not usually have control over all aspects of the system installation.

• **4.9.4** If specified, printed circuit boards (PCBs) shall have conformal coating to provide protection from moisture, fungus, and corrosion.

NOTE It may not be possible or desirable to conformal coat PCBs in all monitor applications. Examples include complex circuit boards containing heat sinks, DIP switches, or complex interconnections. In general, field-mounted systems in humid or corrosive environments justify conformal coating. Contact MPS vendor for specific details and capabilities.

4.10 Power Supplies

4.10.1 All machinery protection monitor systems shall be capable of meeting the accuracy requirements specified in Table 1 with input voltage to the power supply of 90 Vac rms to 132 Vac rms or 180 Vac rms to 264 Vac rms, switch selectable, with a line frequency of 48 Hz to 62 Hz.

4.10.2 If specified, the following power supply options may be used:

• a) 19 Vdc to 32 Vdc,

• b) 14 Vdc to 70 Vdc,

• c) 90 Vdc to 140 Vdc.

4.10.3 All machinery protection monitor system power supply(ies) shall be capable of supplying power to its components as defined in 3.1.113.

NOTE Nonintegral displays are exempted from this requirement and may be powered by external supplies.

4.10.4 All power supplies shall be capable of sustaining a short circuit of indefinite duration across their outputs without damage. Output voltages shall return to normal when an overload or short circuit is removed.

4.10.5 All transducer power sources shall be designed to prevent a fault condition in one transducer circuit from affecting any other channel.

4.10.6 All power supplies shall be immune to an instantaneous transient line input voltage equal to twice the normal rated peak input voltage for a period of 5 µs.

4.10.7 Transient voltage shall not damage the power supplies or affect normal operation of the monitor system.

4.10.8 All power supplies shall continue to provide sufficient power to allow normal operation of the monitor system through the loss of AC power for a minimum duration of 50 ms.

4.10.9 As a minimum, the input power supply transformer for all instruments shall have separate windings with grounded laminations or shall be shielded to eliminate the possibility of coupling high voltage to the transformer secondary. In case of an insulation fault, the input voltage shall be shorted to ground.

• **4.10.10** If specified, the machinery protection monitor system shall be fitted with a redundant power supply. Each power supply shall:

a) accept the same input voltages or different input voltages as the other power supply (for input voltage options, see 4.10.1 and 4.10.2);

b) independently supply power for the entire machinery protection monitor system such that a failure in one supply and its associated power distribution busses shall not affect the other;

c) allow removal or insertion with power applied without affecting the operation or integrity of the protection system;

d) provide automatic switchover from one power supply to the other without affecting the operation or the integrity of the protection system.

4.10.11 The power supplies of all machinery protection monitor systems shall be energized by the purchaser's independent and uninterruptible instrument branch power circuits.

4.11 Machinery Protection System Features/Functions

• **4.11.1** If specified, the requirements of SIS's shall apply to some or all of the MPS, and the MPS supplier(s) shall provide the reliability/performance documentation to allow the SIS supplier to determine the safety integrity level (SIL) for the SIS. SIS requirements are specified by IEC 61508. The purchaser shall be responsible for the following.

a) Identify and ensure compliance with any applicable law that mandate the use of functional safety methods.

NOTE 1 The use of the methods of functional safety is mandatory for personnel and environmental risks.

NOTE 2 When an instrumented system is used to reduce health and safety risks to personnel or the environment, several countries now have legislation mandating the use of functional safety methods as described in IEC 61508, IEC 61511, ANSI/ISA 84.00.01, IEC 62061, or ISO 13849. The end user has to perform the risk assessment for the entire plant. Local laws may require equipment vendors to perform their own risk assessment and SIL classification additionally.

NOTE 3 See Annex L for a discussion of functional safety methodologies and typical calculations as they apply to MPS's.

b) Perform the risk assessment for the entire process.

NOTE 1 The purchaser has the overall responsibility for the safety of the process.

NOTE 2 If the vendor has performed his/her own risk assessment with different requirements, the highest requirement governs.

c) Determine the particular SIL required for each measurement within the MPS. A list with all safety instrumented functions (SIFs) and corresponding SIL shall be provided to the machine and MPS vendor along with the request for quotation (RFQ). Additional information such as minimum proof test interval (TI), required mean time to repair (MTTR), etc., may need to be provided with the RFQ.

NOTE 1 In some instances, different SILs will pertain to different measurements within the MPS. For example, a single MPS may have SIL 3 requirements for the overspeed detection, but SIL 1 requirements for other measurements.

NOTE 2 When determining a SIL for a particular measurement, protection of health and environment has priority over equipment protection and avoidance of economic losses.

d) Identify with the RFQ the data and/or certification(s) that the MPS vendor shall supply to demonstrate compliance with the appropriate SIL.

e) Identify whether the methods of functional safety apply to risks beyond health, safety, and environment (HSE), such as equipment damage, production loss, reputation loss.

NOTE 1 The use of the methods of functional safety is mandatory for personnel and environmental risks.

NOTE 2 See Annex M for a discussion of methods to reduce economic losses.

4.11.2 It is the responsibility of the vendor(s) to support the activity of 4.11.1 with the appropriate data.

4.11.3 At minimum, each machinery protection monitor system shall be provided with the following features and functions:

a) a method of energizing all indicators for test purposes;

b) an internal timeclock with provisions for remotely setting the time and date through the digital communication port of 4.13.1;

NOTE The internal clock time setting or synchronization should be made with the master remote clock and the monitor system internal clock for effective time correlation of events.

c) all modules capable of removal and insertion while the system is under power without affecting the operation of, or causing damage to, other unrelated modules.

NOTE It is not the intent of this paragraph to permit module removal/replacement in hazardous areas without appropriate precautions taken by the end user, such as in purged panels, explosion-proof housings, etc.

4.11.4 A MPS shall include the following signal processing functions and outputs.

a) Isolation to prevent a failure in one transducer from affecting any other channel.

b) A means of indicating internal circuit faults, including transducer system failure, with externally visible circuit fault indication for each individual channel. A no-fault condition shall be positively indicated (e.g. lighted). A common circuit fault relay shall be provided for each monitor system.

• c) A circuit fault shall not initiate a shutdown or affect the shutdown logic in any way except as noted in 7.4.1.5 and 7.4.2.5.

• d) Individual unfiltered buffered output connections for all system transducers (except temperature) via front-panel bayonet nut connector (BNC) connectors and rear panel connections. If specified, the monitor system may employ connectors other than BNC or locations other than the front panel.

• e) If specified, a 4 mA to 20 mA DC analog output shall be provided for each measured variable used for machine protection in addition to the digital output of 4.13.1.

NOTE This output is designed and intended for transmitting MPS measurements to strip chart recorders and other control/automation equipment as part of their operator display and trending environments. It is not designed or intended to replace the relays of 4.12 for machinery protection purposes. Relays are the only acceptable method of interconnecting the MPS to other devices used for carrying out a shutdown command (4.12.1).

• f) If specified, a digital communications port shall be supplied for transmitting data between the MPS and compatible condition monitoring software. The protocol used shall be mutually agreed upon between vendor and purchaser.

NOTE See Annex N for additional details on the purpose of this digital interface and the types of data typically transmitted.

4.11.5 A machinery protection monitor system shall include the following alarm/shutdown functions.

a) For each channel, alarm (alert) and shutdown (danger) setpoints that are individually adjustable over the entire monitored range. Alarm (alert) setpoints do not apply to overspeed and surge detection.

b) An alarm (alert) output from each channel or voted channels to the corresponding alarm (alert) relay. Nonvoting (OR) logic is required.

c) A shutdown (danger) output from each channel or voted channels to the corresponding shutdown (danger) relay, as discussed in 7.4.1.4, 7.4.2.4, 7.4.3.6, and 7.4.5.4.

d) With exception of electronic overspeed detection (see Note), the time required to detect and initiate an alarm (alert) or a shutdown (danger) shall not exceed 100 ms. Relay actuation and the monitor system's annunciation of the condition shall be fixed by the time delay specified in 7.1.5 a).

NOTE 1 The 100 ms response time requirement applies after the system has executed any signal processing algorithms and/or filtering for disturbance rejection.

NOTE 2 Electronic ODS response is specified in 8.4.4.1.

• e) Shutdown (danger) indication for each channel that indicates channel alarm status independent of voting logic. Shutdown (danger) indication shall be positive indication (e.g. illuminated when channel violates its shutdown setpoint). If specified, shutdown (danger) indication shall conform to operation of the voting logic.

• f) If specified, a tamperproof means for disarming the shutdown (danger) function and a visible indicator (positive indication, for example, lighted when disarmed) shall be provided for each channel. Any disarmed condition shall activate a common relay located in the rack or power supply. This relay shall be in accordance with 4.12 and may be used for remote annunciation.

NOTE This requirement is intended for use to remove a failing or intermittent channel from service.

g) Local and remote access for resetting latched alarm (alert) and shutdown (danger) conditions. For rack-based systems, front-panel switch and rear-panel connections shall be supplied.

h) A means to identify the first-out alarm (alert) and the first-out shutdown (danger).

4.11.6 If specified, selected channels (or all channels) of the monitor system shall be available in two additional configurations utilizing redundancy or other means.

• a) A single circuit failure (power source and monitor system power supply excepted) shall only affect the offending channel and shall not affect the state of alarm relays.

• b) A single circuit failure (power source and monitor system power supply included) shall only affect the offending channel and shall not affect the state of alarm relays. This requirement is mandatory for all electronic ODS channels (8.4.2).

4.11.7 A monitoring system shall have the following indications:

a) power status,

b) digital communications link status,

c) system circuit fault,

d) system shutdown (danger),

e) system alarm (alert),

f) system shutdown (danger) function bypassed.

4.11.8 ODS's shall have Items a) through d) in 4.11.7.

4.12 System Output Relays

4.12.1 The output relays described in this section shall be used for interconnecting the MPS to all other devices used as part of the auto-shutdown loop.

4.12.2 The optional digital interfaces of 4.11.4 f) and 4.13 and the analog outputs of 4.11.4 d) and 4.11.4 e) shall not be used as part of the auto-shutdown loop.

4.12.3 Unless otherwise specified, output relays shall be the epoxy-sealed electromechanical type.

4.12.4 If specified, either of the following relay types may be provided in lieu of epoxy-sealed relays.

- a) hermetically-sealed electromechanical type;

- b) solid state type. If a solid state relay interface between systems is proposed, the vendor with unit responsibility shall provide a complete review of the relay capabilities and requirements to ensure reliable operation.

4.12.5 The relay control circuit shall be field changeable to be either normally de-energized or normally energized. The factory default shall be de-energize to alarm and energize to shutdown except for overspeed channels and/or functional safety requirements that preclude the use of energize-to-shutdown relays.

4.12.6 All relays shall be double-throw type with electrically isolated contacts and all contacts available for wiring.

4.12.7 Shutdown (danger), alarm (alert), and circuit-fault relays shall be field changeable to latching (manual reset) or nonlatching (automatic reset). Latching shall be standard.

4.12.8 The circuit fault relay shall be normally energized. A failure in the transducer system, monitor system, primary power supply power, or redundant power supply shall de-energize the circuit fault relay.

- **4.12.9** Contacts shall be rated at a resistive load of 2 amperes at 120 Vac, or 1 ampere at 240 Vac, or 2 amperes at 28 Vdc for a minimum of 10,000 operations. When inductive loads are connected, arc suppression shall be supplied at the load. If specified, contacts rated at a resistive load of 5 amperes at 120 Vac shall be provided.

NOTE Final element solenoid(s) power requirements may necessitate a higher power interposing relay(s). Machinery vendor should provide final element solenoid power requirements to allow proper specification of interposing relays if required.

4.12.10 For normally de-energized shutdown (danger) output relays, an interruption of power [line power or direct current (DC) output power] shall not transfer the shutdown (danger) relay contacts regardless of the mode or duration of the interruption.

4.12.11 Each monitor subsystem in the MPS (overspeed exempted) shall be provided with a means to disarm the subsystem's shutdown capability, conforming to the following.

a) It may be internal or external to the monitor subsystem.

b) It shall be tamperproof.

c) A disarmed condition shall be locally annunciated at the monitor subsystem via positive indication (e.g. lighted when disarmed).

d) Operation or maintenance of the monitor subsystem in the disarmed mode, including power supply replacements, shall not shut down the machine (see Note). Refer to IEC 61508 for governing requirements.

NOTE This feature is intended to be used during monitor system maintenance only.

e) A disarmed condition shall be available for remote annunciation via the digital communications link of 4.13.

• f) If specified, two sets of isolated external annunciator contacts shall be provided.

4.13 Digital Communication Links

4.13.1 A digital output representative of each measured variable shall be provided at a communications port. A short circuit of this output shall not affect the MPS, and the output shall follow the measured variable and remain at full scale as long as the measured variable is at or above full scale. Unless otherwise specified, the protocol utilized for this standard digital output shall be Modbus.

NOTE This output is intended for transmitting MPS status, proportional values, and other data to process control and automation systems as part of their operator display and trending environments. It is not designed or intended to replace the relays of 4.12 for machinery protection purposes. Relays are the only acceptable method of interconnecting the MPS to other devices used for carrying out a shutdown command (4.12.1). See also Annex N.

4.13.2 If specified, any one or more of the following shall also be available from the digital communications link of 4.13.1:

• a) channel status of alarm or no alarm;

• b) armed/disarmed (maintenance bypass) shutdown status for the monitor system (see 4.12.11);

• c) alarm storage for storing the time, date, and value for a minimum of 64 alarms;

• d) channel value ±2 % full-scale range resolution;

• e) measured value as a percent of alarm (alert) and shutdown (danger) values to 1 % resolution;

• f) channel status: armed/disarmed [see 4.11.5 f)];

• g) transducer OK limits;

• h) hardware and software diagnostics;

• i) communication link status;

• j) alarm setpoints;

• k) gap voltage, when applicable;

• l) current system time, time stamp, and date of event for all transmitted data;

• m) system entry log to include date, time, individual access code, and record of changes;

• n) setpoint multiplier invoked (see 7.4.1.6 and 7.4.4.4).

4.14 System Wiring and Conduits

4.14.1 General

Installation shall be in accordance with the following.

a) Wiring and conduits shall comply with the electrical practices specified in NFPA 70 (see Figure 5, Figure 6, Figure 7, Figure C.1, Figure C.2, and Figure C.3).

b) All conduit, signal and power cable, and monitor system components shall be located in well-ventilated areas away from hot spots such as piping, machinery components, and vessels.

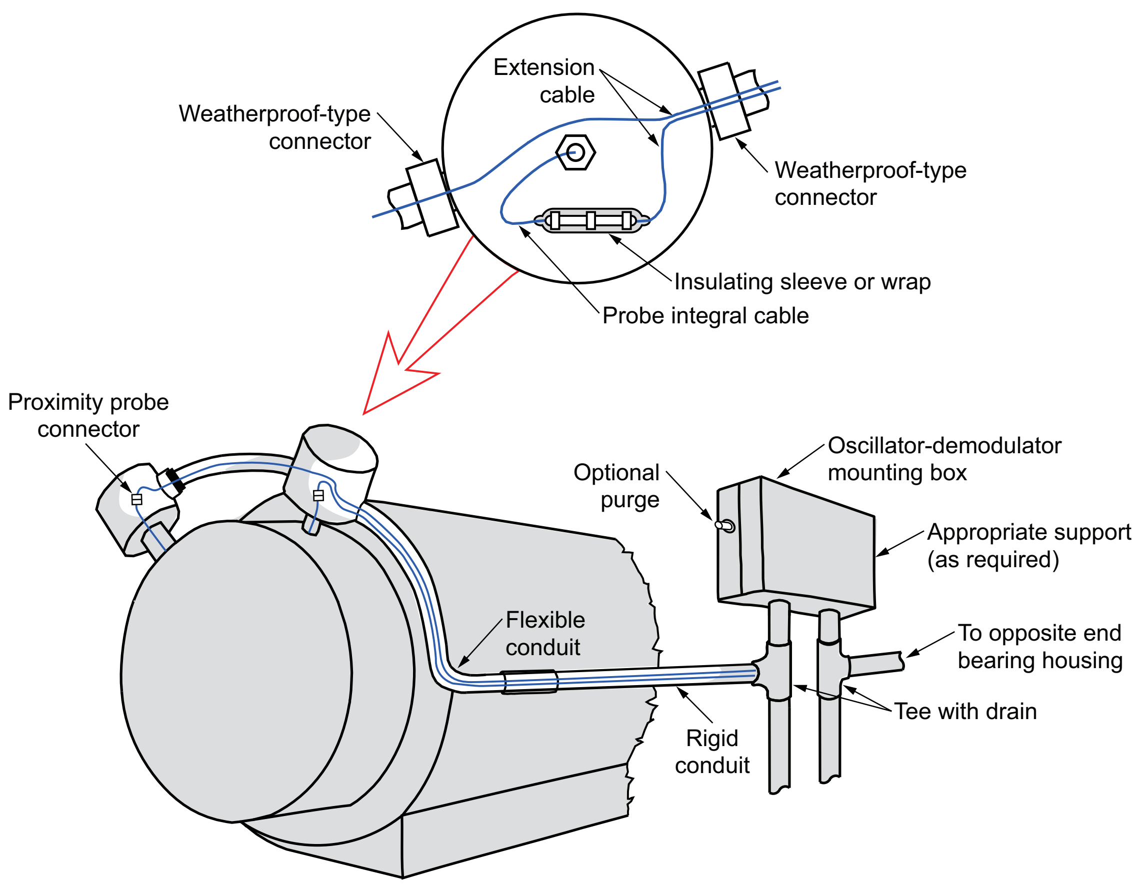
c) MPS components shall not be covered by insulation or obstructed by items such as machinery covers, conduits, and piping.

d) All conduits, armored cable, and similar components shall be located to permit disassembly and repair of equipment without causing damage to the electrical installation.

e) Signal and power wiring shall be segregated according to good instrument installation practices (see 4.14.2.4).

f) Signal wiring shall not be run in conduits or trays containing circuits of more than 30 V of either alternating or direct current.

g) Signal wiring shall be shielded, twisted pair, or shielded triad to minimize susceptibility to electromagnetic or radio frequency interference.



NOTE Proximity probe extension cable connectors insulated from the ground (see 5.1.3.3).

Figure 5—Typical Conduit Cable Arrangement

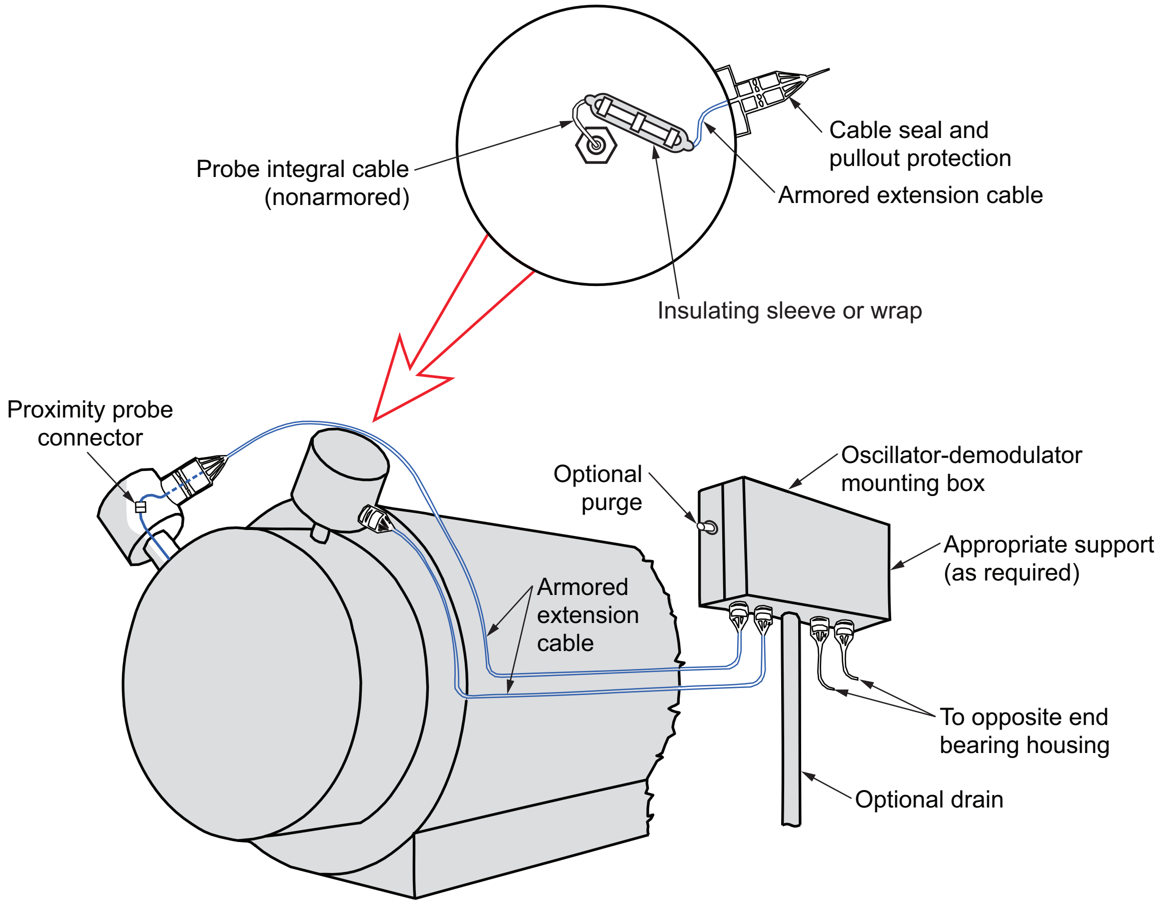


Figure 6—Typical Armored Cable Arrangement

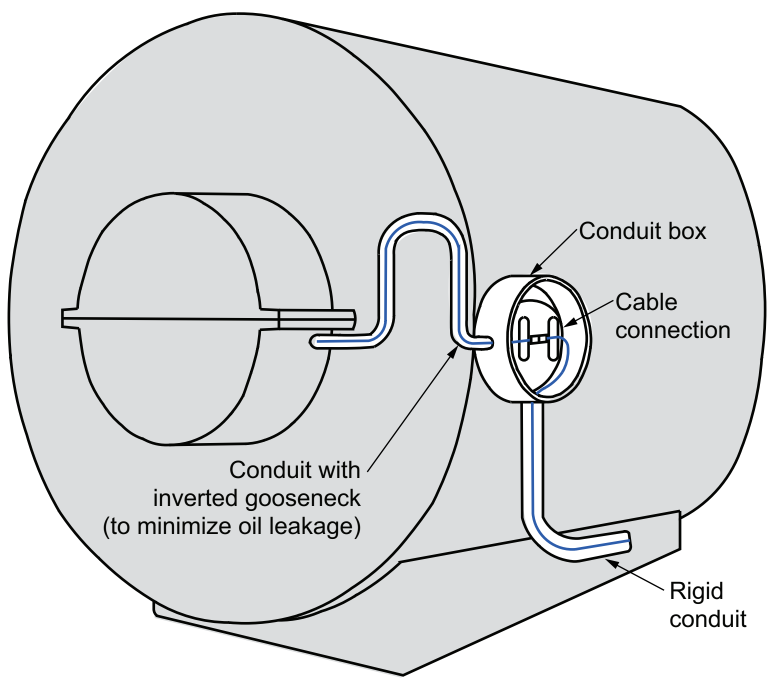


Figure 7—Inverted Gooseneck Trap Conduit Arrangement

4.14.2 Conduit Runs to Panels

4.14.2.1 Conduits shall be:

a) weatherproof and of suitable size to meet NFPA 70 requirements for the size and number of signal cables to be installed,

b) supplied with a drain installed at each conduit low point.

4.14.2.2 Signal cable installed in underground conduit shall be suitable for continuous operation in a submerged environment.

NOTE Underground conduit will accumulate moisture over long periods of time regardless of the sealing methods employed.

4.14.2.3 Signal cables shall:

a) be supplied in accordance with the provisions of Annex D;

b) not exceed a physical length of 150 m (500 ft). The use of longer cable runs shall be reviewed and approved in writing by the MPS vendor;

c) use continuous runs only. The use of noncontinuous runs shall be approved by the owner and, if employed, the shield shall be carried across any junction.

4.14.2.4 The minimum separation between installed signal and power cables shall be as specified in Table 3.

NOTE More detailed information on signal transmission systems is available in API 552.

Table 3—Minimum Separation Between Installed Signal and Power Cables

Voltage AC	Minimum Separation	
	mm	in.
120	300	12
240	450	18
480	600	24

4.15 Grounding of the Machinery Protection System

The responsible party as identified in Annex B shall ensure that:

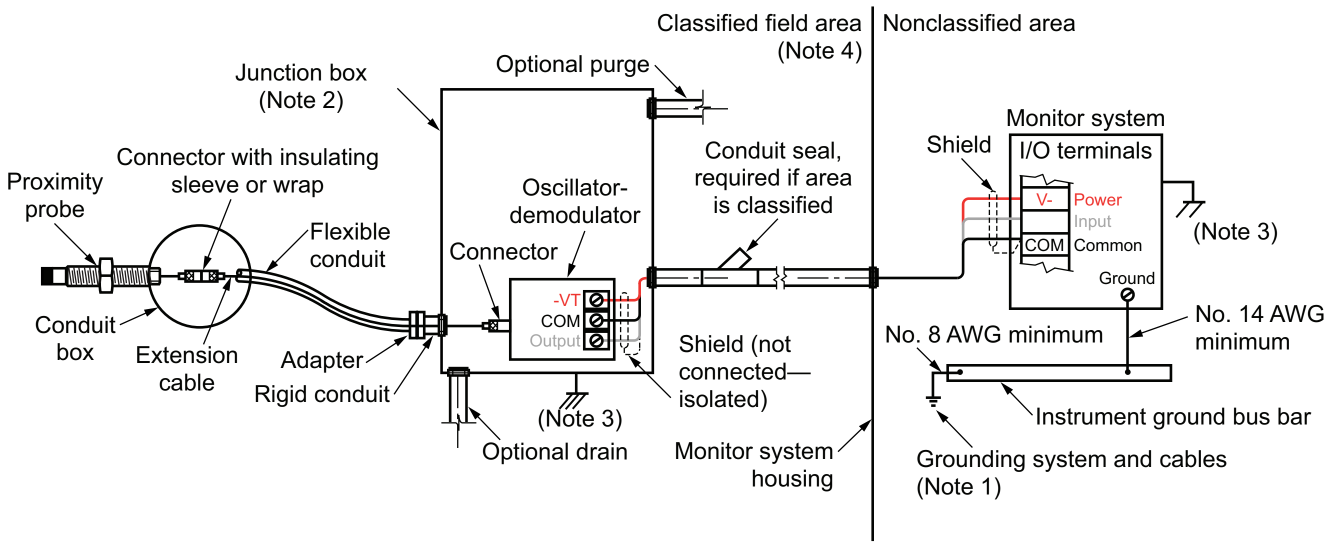
a) the system is grounded in accordance with Article 250 of NFPA 70 and all metal components (i.e. conduit, field junction boxes, and equipment enclosures) are electrically bonded (see Figure 8);

b) all metal enclosure components are connected to an electrical grounding bus and that this electrical grounding bus is connected to the electrical grounding grid with a multistrand AWG 4 or larger, dedicated copper ground wire;

c) mutual agreement is obtained from the purchaser and the MPS vendor with respect to grounding, hazardous area approvals required, instrument performance, and elimination of ground loops;

d) the transducer signal and common is isolated from the machine ground;

e) the MPS instrument common is designed to be isolated (not less than 500 Kohms) from electrical ground and installed with single-point connection to the instrument grounding system;



NOTE 1 Meet NFPA 70, Article 250 (common and probe circuit isolated from ground).

NOTE 2 NEMA 4, IP 65 or IP 66.

NOTE 3 Metal housing bonded to safety ground.

NOTE 4 The figure represents an explosion-proof or purged installation. Intrinsic safety barriers may be used in lieu of these methods.

Figure 8—Typical Instrument Grounding

f) the signal cable shield is only grounded at the monitor system;

g) the shield is not used as the common return line;

h) shields are carried through any field junctions.

4.16 System Security, Safeguards, Self-tests, and Diagnostics

4.16.1 Controlled access for monitor system adjustments shall be in the form of a programming access key located at the front of the monitor system rack or via software (i.e. password protection).

4.16.2 Configuration shall be stored in nonvolatile memory so it is not lost in the event of a total power loss to the monitor system.

NOTE When configuring a system over the network, password protection only may not prevent accidental downloading of a new configuration (resulting in possible machine shutdown condition). If this is a concern, both an access key and password protection should be considered.

4.16.3 The machinery protection monitor system modules shall have the capability of onboard self-test.

4.16.4 The machinery protection monitor system shall maintain an event list to log module/system alarms and diagnostic tests results. This event list shall be:

a) stored in the system's nonvolatile memory;

b) maintained in the event of a total loss of power or loss of communications.

4.17 Reliability

4.17.1 Vendor shall advise in the proposal any component designed for a finite life.

NOTE 1 Finite life means that the components are designed to fail under normal operating conditions or date of planned obsolescence is known.

NOTE 2 It is realized that there are some services where this objective is easily attainable and others where it is difficult.

● **4.17.2** The purchaser shall specify the period of uninterrupted continuous operation. Shutting down the equipment to perform maintenance or inspection during the uninterrupted operation is not acceptable.

NOTE 1 The period of uninterrupted continuous operation for a MPS will normally meet or exceed the interval for planned machinery maintenance outages. For example, a machine train with a five-year maintenance turnaround schedule will normally require a MPS with a mean time between failure of five years or more.

NOTE 2 Auxiliary system design and design of the process in which the equipment is installed are very important in meeting this objective.

NOTE 3 Section 12.2.3 j) requires the vendor to identify any component or maintenance requirement that would result in the need to shut down the equipment within the uninterrupted operational period.

5 Sensors and Transducers

5.1 Radial Shaft Vibration, Axial Position, Phase Reference, Speed Sensing, Flow, and Piston Rod Drop Transducers

5.1.1 Proximity Probes

5.1.1.1 A proximity probe consists of a tip, a probe body, an integral coaxial cable or triaxial cable, and a connector as specified in 5.1.3 and shall be chemically resistant as specified in 4.4. This assembly is illustrated in Figure 9.

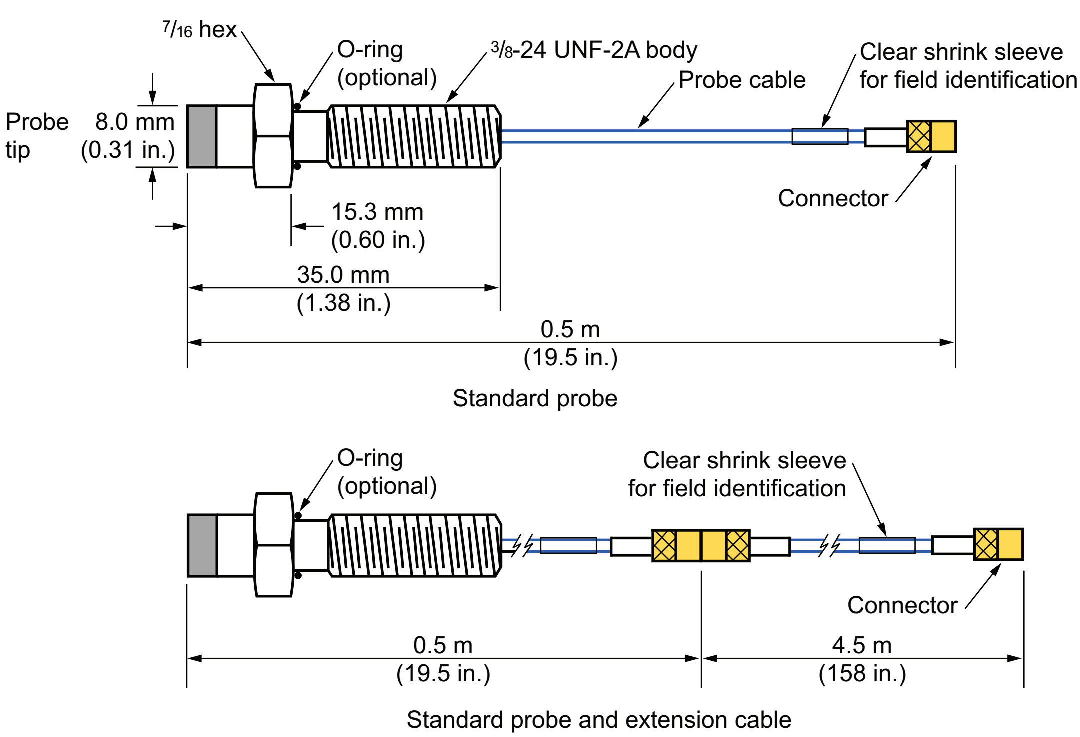


Figure 9—Standard Proximity Probe and Extension Cable

5.1.1.2 Unless otherwise specified, the standard probe shall have a tip diameter of 7.6 mm to 8.3 mm (0.300 in. to 0.327 in.), with a reverse mount, integral hex nut probe body approximately 25 mm (1 in.) in length and 3/8-24-UNF-2A threads.

NOTE 1 Reverse mount probes are intended for use with probe holders allowing external access to the probe and its integral cable. The use of a reverse mount probe as the standard probe allows a single probe configuration and thread length to be used throughout the entire machine train. The length of the probe holder stem will typically vary from one probe mounting location to the next, but this can be trimmed in the field without the need to employ different probes.

NOTE 2 Piston rod drop applications do not generally enable reverse mount probes to be used. A standard option forward mount probe should be selected instead. See P.4.2.1.

• **5.1.1.3** If specified, the standard options may consist of one or more of the following forward mount probe configurations (see Figure 10):

a) a tip diameter of 7.6 mm to 8.3 mm (0.300 in. to 0.327 in.) and 3/8-24-UNF-2A U.S. customary (USC) threads;

b) a tip diameter of 4.8 mm to 5.3 mm (0.190 in. to 0.208 in.) and 1/4-28-UNF-2A USC threads;

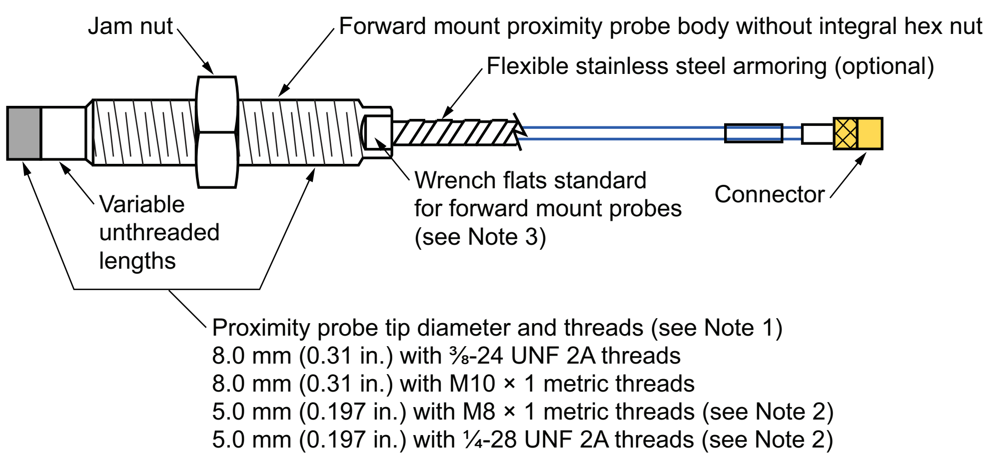
c) a tip diameter of 7.6 mm to 8.3 mm (0.300 in. to 0.327 in.) and M10 × 1 metric threads;

d) a tip diameter of 4.8 mm to 5.33 mm (0.190 in. to 0.208 in.) and M8 × 1 metric threads;

e) lengths other than approximately 25 mm (1 in.);

f) flexible stainless steel armoring attached to the probe body and extending to within 125 mm (5 in.) of the connector;

g) the design shall allow sufficient room for tagging and connector protection while maximizing the protected length of the cable.



NOTE 1 The standard option proximity probe may consist of one or more of the options discussed in 5.1.1.3.

NOTE 2 Forward-mount probes are generally only available in case lengths longer than 20.3 mm (0.8 in.). A ¼-28 (or M8 × 1) body more than 51 mm (2 in.) in length is undesireable from the standpoint of mechanical strength and availability.

NOTE 3 Wrench flats to be compatible with standard wrench sizes. The dimension of the flats will vary with the diameter chosen for the pobe body.

Figure 10—Standard Options for Proximity Probes

5.1.1.4 The overall physical length of the probe and integral cable assembly shall be approximately 0.5 m (20 in.) measured from the probe tip to the end of the connector. The minimum overall physical length shall be 0.5 m (20 in.); the maximum overall physical length shall be 1 m (40 in.).

• **5.1.1.5** If specified, the overall physical length of the probe and integral cable assembly may be approximately 1 m (40 in.), measured from the probe tip to the end of the connector. The minimum overall physical length may be 0.8 m (31 in.); the maximum overall physical length may be 1.3 m (51 in.). When probes with longer integral cables are provided, take care to ensure that terminations occur within a junction box. Cable lengths will need to be recalculated to meet the requirements of the probe and integral cable length.

5.1.1.6 A piece of clear heat-shrink tubing (not to be shrunk at the factory) not less than 40 mm (1.5 in.) long shall be installed over the coaxial or triaxial cable before the connector is installed to assist the owner in tagging. If connector protectors are used, the portion that rests on the insulated cable shall not overlap the heat shrink to ensure proper seal.

5.1.1.7 The probe tip shall be molded, or otherwise bonded into the probe body, in a secure fashion. Probes shall support a differential pressure of 6 bars (100 psid) between probe tip and probe body without leakage.

5.1.1.8 The integral probe lead cable shall be securely attached to the probe tip to withstand a pull test (without damage) of a minimum tensile load of 225 N (50 lb).

• **5.1.2 Probe Extension Cables**

Probe extension cables shall be coaxial or triaxial, with connectors as specified in 5.1.3. The nominal physical length shall be 4.5 m (177 in.) and shall be a minimum of 4.1 m (161 in.) (see Figure 9). Shrink tubing shall be provided at each end in accordance with 5.1.1.6.

• If specified, probe extension cables may have a nominal physical length of 4 m (158 in.) and may be a minimum of 3.6 m (140 in.). Shrink tubing shall be provided at each end in accordance with 5.1.1.6.

5.1.3 Connectors

5.1.3.1 The attached connectors shall meet or exceed the mechanical, electrical, and environmental requirements specified in Section 4 and in MIL-C-39012-C and MIL-C-39012/5F.

5.1.3.2 The cable and connector assembly shall be designed to withstand a minimum tensile load of 225 N (50 lb).

5.1.3.3 Proximity probe extension cable connectors shall be insulated from ground.

5.1.4 Oscillator-demodulators

5.1.4.1 The standard oscillator-demodulator shall be designed to operate with the probes defined in 5.1.1.2 and 5.1.1.3 and the probe extension cable as defined in 5.1.2.

5.1.4.2 The oscillator-demodulator output shall be 7.87 mV/µm (200 mV/mil) with a standard supply voltage of –24 Vdc.

5.1.4.3 The oscillator-demodulator shall be calibrated for the standard length of the probe assembly and extension cable.

5.1.4.4 The output, common, and power-supply connections shall be heavy-duty, corrosion-resistant terminations suitable for at least 18 AWG wire (1 mm^2 cross section).

5.1.4.5 The oscillator-demodulator shall be electrically interchangeable in accordance with 4.6.1 for the same probe tip diameter.

5.1.4.6 The interference or noise of the installed system (including oscillator-demodulator radio frequency output noise, line-frequency interference, and multiples thereof) on any channel shall not exceed 20 mV pp, measured at the monitor inputs and outputs, regardless of the condition of the probe or the gap. The transducer system manufacturer's recommended tip-to-tip spacing for probe cross talk shall be maintained.

5.1.4.7 The oscillator-demodulator common shall be isolated from ground.

5.1.4.8 Oscillator-demodulators shall be mechanically interchangeable.

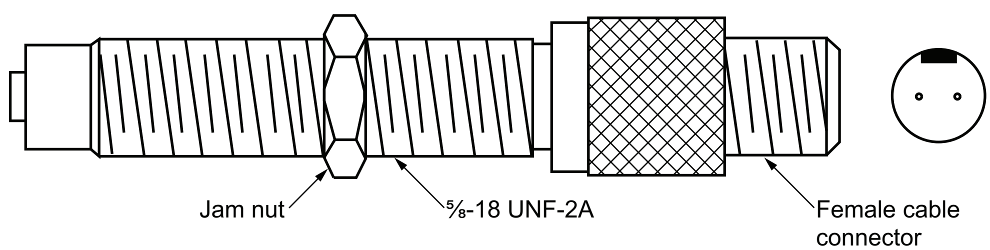
NOTE The intent of this subsection is that interchangeability requirements apply only to components supplied by the same vendor.

- **5.1.4.9** If specified, oscillator-demodulators shall be supplied with a DIN rail mounting option.

5.1.5 Magnetic Speed Sensors

5.1.5.1 A magnetic speed sensor consists of the encapsulated sensor (pole piece and magnet), threaded body, and cable.

5.1.5.2 The standard magnetic speed sensor shall be a passive (i.e. self-powered) type with a cylindrical pole piece. The standard body shall have 5/8-18-UNF-2A threads. The maximum diameter of the pole piece shall be 4.75 mm (0.187 in.) (see Figure 11).



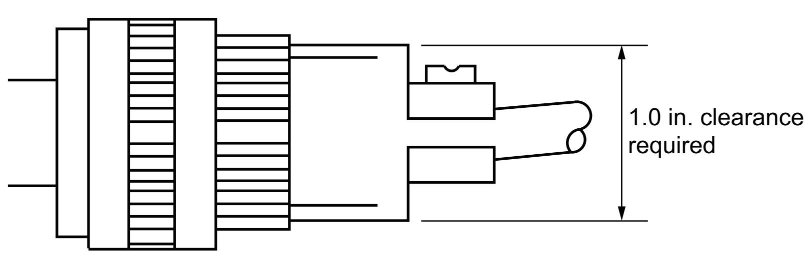


Figure 11—Standard Magnetic Speed Sensor with Removable (Nonintegral) Cable and Connector

5.1.5.3 If specified, the standard options may consist of one or more of the following:

- a) conical or chisel pole pieces,
- b) 3/4-20-UNEF-2A threads,
- c) M16 × 1.5 metric threads,
- d) explosion-proof design with integral cable and conduit threads at integral cable exit,

- e) removable (i.e. nonintegral) cable and connector,
- f) an active (i.e. externally-powered) magnetic speed sensor.

NOTE Active magnetic speed sensors or proximity probes are often used on machines where rotational speeds below 250 rpm need to be reliably sensed. Passive magnetic speed sensors do not typically generate a suitable signal amplitude at slow shaft rotational speeds. To sense shaft rotation speeds down to 1 rpm, active magnetic speed sensors or proximity probes are required.

5.1.5.4 The sensor body and any protective housings for the sensor shall be constructed of nonmagnetic stainless steel such as AISI Standard Type 303 or 304.

NOTE Magnetic stainless steel, such as AISI Standard Type 416, tends to alter the flux path and reduce the sensor's output voltage. Aluminum housings can decrease the sensor's output voltage and introduce phase shift as speed changes.

5.1.5.5 The sensor and its associated multitoothed speed sensing surface shall be compatible (see Annex J).

5.2 Seismic Transducers

5.2.1 Accelerometer Sensors

5.2.1.1 The standard accelerometer system shall be an electrically isolated transducer consisting of a case, a piezoelectric crystal, an integral amplifier, and a connector.

5.2.1.2 The accelerometer case shall be constructed from AISI Standard Type 316 or other corrosion-resistant stainless steel.

5.2.1.3 The accelerometer case shall be electrically isolated from the piezoelectric crystal and all internal circuitry.

5.2.1.4 The accelerometer case shall be hermetically sealed.

5.2.1.5 The accelerometer case shall have a maximum outside diameter of 25 mm (1 in.). The overall case height shall not exceed 65 mm (2.5 in.), not including the connector.

5.2.1.6 The accelerometer case shall be fitted with standard wrench flats.

5.2.1.7 Unless otherwise specified, the mounting surface of the accelerometer case shall be finished to a maximum roughness of 0.8 μm (32 μin.) Ra (arithmetic average roughness). The center of this mounting surface shall be drilled and tapped (perpendicular to the mounting surface ±5 minutes of an arc) with a $^{1}/_{4}$-28-UNF-2A threaded hole of 6 mm ($^{1}/_{4}$ in.) minimum depth.

5.2.1.8 The vendor shall supply with each accelerometer a standard mounting option consisting of a double-ended, flanged, $^{1}/_{4}$-28-UNF-2A threaded, AISI Standard Type 300 stainless steel mounting stud. The stud shall not prevent the base of the accelerometer from making flush contact with its mounting (see Annex C).

5.2.1.9 The standard accelerometer shall have a top connector with body material of AISI Standard Type 300 stainless steel and meeting the mechanical, electrical, and environmental requirements of the accelerometer. When attached to the accelerometer cable (or when using an integral cable), the combined assembly shall withstand a minimum tensile load of 225 N (50 lb).

5.2.1.10 If specified, accelerometer standard options may consist of one or more of the following (see Annex C):

- a) integral stud for flush mounting;
- b) integral stud for nonflush mounting (see Annex C);

NOTE Accelerometers mounted using integral studs are known to be more accurate; however, damaging a stud will cause the disposal of the entire sensor.

- c) mounting stud: USC threads other than 1/4-28-UNF;
- d) mounting stud: metric threads;
- e) integral accelerometer cable.

5.2.1.11 The accelerometer transverse sensitivity shall not exceed 5 % of the principal axis sensitivity over the ranges specified in Table 1.

5.2.1.12 The accelerometer transducer shall have a noise floor no higher than 0.004 g rms over the frequency range specified in Table 1.

5.2.2 Accelerometer Cables

5.2.2.1 Accelerometer cables shall be supplied by the MPS vendor. They shall meet the mechanical, electrical, and environmental requirements of the accelerometer system.

5.2.2.2 Unless otherwise specified, the nominal physical length of the accelerometer cable shall be 5 m (200 in.).

5.2.2.3 A piece of clear heat-shrink tubing (not to be shrunk at the factory) 40 mm (1.5 in.) long shall be installed over the accelerometer cable at each end to assist the owner in tagging.

5.2.2.4 Connectors on accelerometer cables shall meet the mechanical, electrical, and environmental requirements of the accelerometer. The body material shall be AISI Standard Type 300 stainless steel and shall be designed to withstand a minimum tensile load of 225 N (50 lb).

5.2.3 Velocity Sensors

5.2.3.1 The standard velocity sensor shall be an electrically isolated, internally integrating accelerometer consisting of a case, a piezoelectric crystal, an integral amplifier and integrator, and a connector.

• **5.2.3.2** If specified, a velocity sensor utilizing a moving coil (electromechanical design) may be used instead of an internally integrating accelerometer, with performance specifications as mutually agreed by vendor and purchaser.

NOTE The standard velocity sensor is inherently an accelerometer, but provides an output in velocity units because of the sensor's integral electronic integration stage. It is a solid state device and therefore has no moving parts (such as springs and coils) to wear out, is generally less sensitive to cross-axis vibration (depending on construction), and can be mounted in any orientation. These attributes, combined with the sensor's ability to make high-quality velocity measurements on most machines, make it a good choice for the majority of casing vibration measurements. However, there are notable exceptions where a moving-coil (electromechanical) velocity sensor is a better choice. These include, but are not limited to:

a) low-speed machinery (i.e. machines operating below 600 rpm) where acceleration levels are extremely small relative to velocity levels; this is especially true if the velocity signal will be integrated to a displacement readout in the monitor;

b) applications in which the sensor shall be self-powered;

c) applications where impacts or impulsive forces may excite the transducer and generate an output that is not truly indicative of casing velocity.

5.2.3.3 The velocity sensor case shall be constructed from AISI Standard Type 316 or other corrosion-resistant stainless steel

5.2.3.4 The velocity sensor case shall be electrically isolated from the piezoelectric crystal and all internal circuitry.

5.2.3.5 The velocity sensor case shall be hermetically sealed.

5.2.3.6 The velocity sensor case shall have a maximum outside diameter of 30 mm (1.2 in.). The overall case height shall not exceed 70 mm (2.75 in.), not including the connector.

5.2.3.7 The velocity sensor case shall be fitted with standard wrench flats.

5.2.3.8 The mounting surface of the velocity sensor case shall be finished to a maximum roughness of 0.8 μm (32 μin.) Ra (arithmetic average roughness). The center of this mounting surface shall be drilled and tapped (perpendicular to the mounting surface ±5 minutes of an arc) with a $^{1}/_{4}$-28-UNF-2A threaded hole of 6 mm ($^{1}/_{4}$ in.) minimum depth.

5.2.3.9 The vendor shall supply with each velocity sensor a standard mounting option consisting of a double-ended, flanged, $^{1}/_{4}$-28-UNF-2A threaded, AISI Standard Type 300 stainless steel mounting stud. The stud shall not prevent the base of the velocity sensor from making flush contact with its mounting.

5.2.3.10 The standard velocity sensor shall have a top connector with body material of AISI Standard Type 300 stainless steel and meeting the mechanical, electrical, and environmental requirements of the velocity sensor. When attached to the velocity sensor cable (or when using an integral cable), the combined assembly shall withstand a minimum tensile load of 225 N (50 lb).

5.2.3.11 If specified, velocity sensor standard options may consist of one or more of the following:

- ● a) $^{1}/_{4}$-18 NPT integral stud for nonflush mounting;
- ● b) flush-mount stud: USC threads other than $^{1}/_{4}$-28-UNF;
- ● c) flush-mount stud: metric threads;
- ● d) integral velocity sensor cable.

5.2.3.12 The velocity sensor transverse sensitivity shall not exceed 5 % of the principal axis sensitivity over the ranges specified in Table 1.

5.2.3.13 The velocity sensor shall have a noise floor no higher than 0.004 mm/s rms over the frequency range specified in Table 1.

5.2.4 Velocity Sensor Cables

5.2.4.1 Velocity sensor cables shall be supplied by the MPS vendor and shall meet the temperature requirements of the velocity sensor.

5.2.4.2 Unless otherwise specified, the nominal physical length of the velocity sensor cable shall be 5 m (200 in.).

5.2.4.3 A piece of clear heat-shrink tubing (not to be shrunk by the manufacturer of the cable) 40 mm (1.5 in.) long shall be installed over the velocity sensor cable at each end to assist the owner in tagging.

5.2.4.4 Connectors on the velocity sensor cables shall meet the mechanical, electrical, and environmental requirements of the velocity sensor. The body material shall be AISI Standard Type 300 stainless steel and shall be designed to withstand a minimum tensile load of 225 N (50 lb).

5.3 Temperature Sensors

5.3.1 Sensors

5.3.1.1 The standard temperature sensor shall be a 100-ohm, platinum, three-lead resistance temperature detector (RTD).

5.3.1.2 Unless otherwise specified, the standard RTD shall have a temperature coefficient of 0.00385 ohm/ohm/°C.

• **5.3.1.3** If specified, Type J, Type K, or Type N thermocouples shall be supplied in accordance with ANSI MC96.1 (IEC 584-1).

NOTE Type N thermocouples would be typically used for higher temperature applications.

5.3.1.4 Temperature sensors for electrically insulated bearings shall maintain the integrity of the bearing insulation (see 6.2.4.5 Note).

• **5.3.1.5** Sensor leads shall be coated, both individually and overall, with insulation. If specified, flexible stainless steel overbraiding (see Note) shall cover the leads and shall extend from within 25 mm (1 in.) of the tip to within 100 mm (4 in.) of the first connection.

NOTE Stainless steel overbraiding may be difficult to seal in some installations.

5.3.1.6 A 40-mm (1.5-in.) piece of clear heat-shrink tubing (not to be shrunk by the manufacturer of the cable) shall be installed at the connection end to assist in the tagging of the sensor.

5.3.2 Wiring

Wiring from the temperature sensor to the monitor shall be as follows.

a) For RTDs, use three-conductor shielded wire in accordance with Annex D.

b) For thermocouples, use thermocouple extension wire of the same material as the thermocouple and in accordance with Annex D.

5.3.3 Connectors

The standard installation shall employ a single compression-type, like-metal-to-like-metal connection technique between the sensor and the monitor. Unless otherwise specified, this connection shall be at a termination block external to the machine. Plug-and-jack, barrier-terminal-strip, or lug connectors shall not be used.

NOTE It is a recommended practice to have a separate junction box for each class of sensor. The junction box(s) should be located for ease of access and on the same side of the machinery train as the oscillator-demodulator junction box(s). The junction box(s) should not be mounted on the machine but in a vibration-free environment.

5.3.4 Surge Sensors and Transducers

See Section 9 for specific requirements.

6 Sensor and Transducer Arrangements

6.1 Locations and Orientation

6.1.1 General

See Annex H for typical system arrangement plans showing quantities and types of transducers for various machines.

6.1.2 Radial Shaft Vibration Probes

6.1.2.1 For monitored radial bearings, two radially oriented probes shall be provided. These two probes shall be:

a) coplanar, 90° (±5°) apart and perpendicular to the shaft axis (±5°);

b) located 45° (±5°) from each side of the vertical center;

c) referenced such that when viewed from the driver end of the machine train, the Y (vertical) probe is on the left side of the vertical center, and the X (horizontal) probe is on the right side of the vertical center regardless of the direction of shaft rotation;

d) located within 75 mm (3 in.) of the bearing;

e) located the same with respect to the predicted nodal points as determined by a rotordynamic analysis of the shaft's lateral motion (e.g. both sets of probes shall be either inside or outside the nodal points) (refer to API 684, *API Standard Paragraphs Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals, and Rotor Balancing*);

f) located such that they do not coincide with a predicted nodal point.

6.1.2.2 The surface areas to be observed by the probes (probe areas):

a) shall be concentric with the bearing journals and free from stencil and scribe marks or any other mechanical discontinuity, such as an oil hole or a keyway;

b) shall not be metallized or plated;

c) shall have a final surface finish that does not exceed (be rougher than) 1 µm (32 µin.) rms, preferably obtained by diamond burnishing;

d) shall be properly demagnetized or otherwise treated so that the combined total electrical and mechanical runout does not exceed 25 % of the maximum allowed peak-to-peak vibration amplitude or 6 µm (0.25 mil), whichever is greater.

NOTE 1 Diamond burnishing with a tool-post-held, spring-mounted diamond is common. In addition to use in reducing mechanical runout, it has also proven to be effective for electric runout reduction.

NOTE 2 Final finishing or light surface-removal finishing by grinding will normally require follow-up demagnetization.

NOTE 3 The gauss level of the proximity probe area should not exceed 2 gauss. The variation of gauss level around the circumference of the proximity probe area should not exceed 1 gauss.

6.1.2.3 For all conditions of rotor axial float and thermal expansion, a minimum side clearance of one-half the diameter of the probe tip is required. The probe shall not be affected by any metal other than that of the probe's observed area.

6.1.2.4 Unless otherwise specified, the probe gap shall be set at –10 Vdc (±0.2 Vdc).

6.1.3 Axial Position Probes

6.1.3.1 Two axially oriented probes shall be supplied for the thrust bearing end of each casing. Both probes shall sense the shaft itself or an integral axial surface installed within an axial distance of 300 mm (12 in.) from the thrust bearing or bearings (see Figure 12).

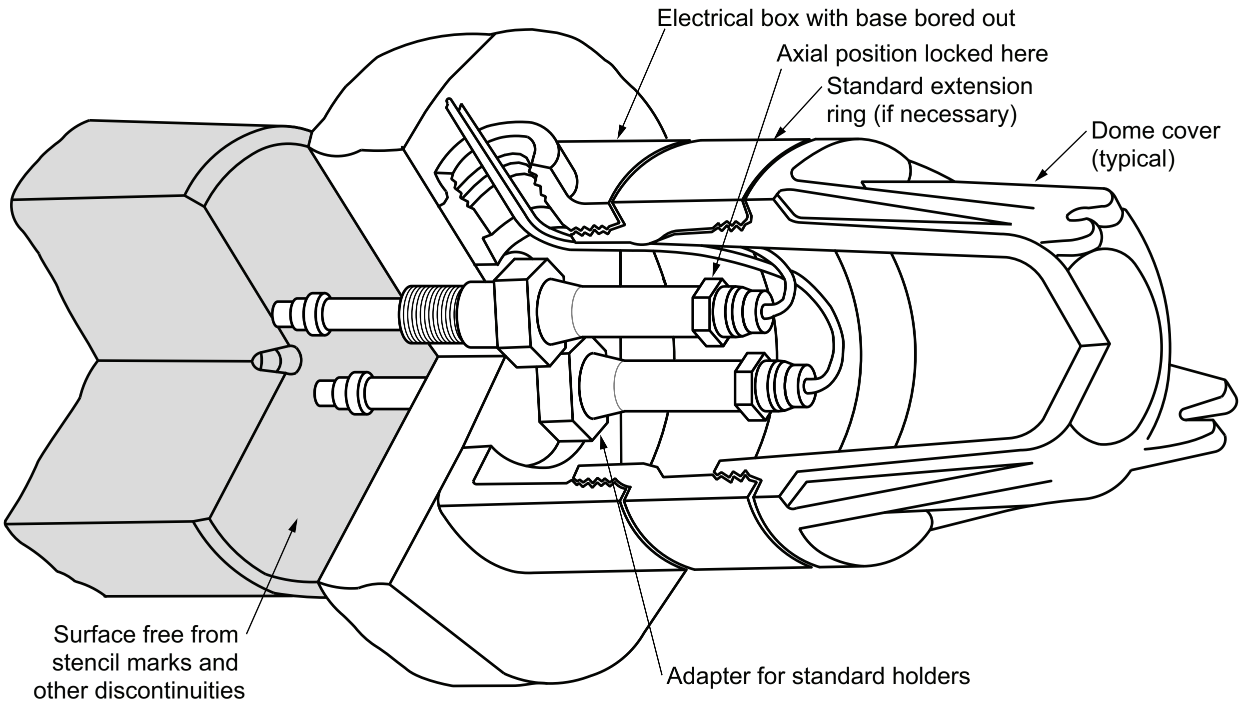


Figure 12—Standard Axial Position Probe Arrangement

• **6.1.3.2** If specified, the standard optional arrangement shall be one probe sensing the shaft end and one probe sensing an integral thrust collar.

NOTE When choosing the locations for all probes used in direct shaft measurements, it is always more desirable to measure the shaft directly rather than a component attached to the shaft. When choosing a location that measures a component attached to the shaft, the component may shift or loosen causing a loss of measurement and possible machine damage.

6.1.3.3 It shall be possible to adjust the probe gap using commercially available wrenches. No special bent or split socket wrenches shall be required.

6.1.3.4 The electrical box shall protect the axial probe assembly so that external loads (e.g. those resulting from personnel stepping on the box) do not impose stress on the assembly and result in false shaft-position indication (see Figure 12).

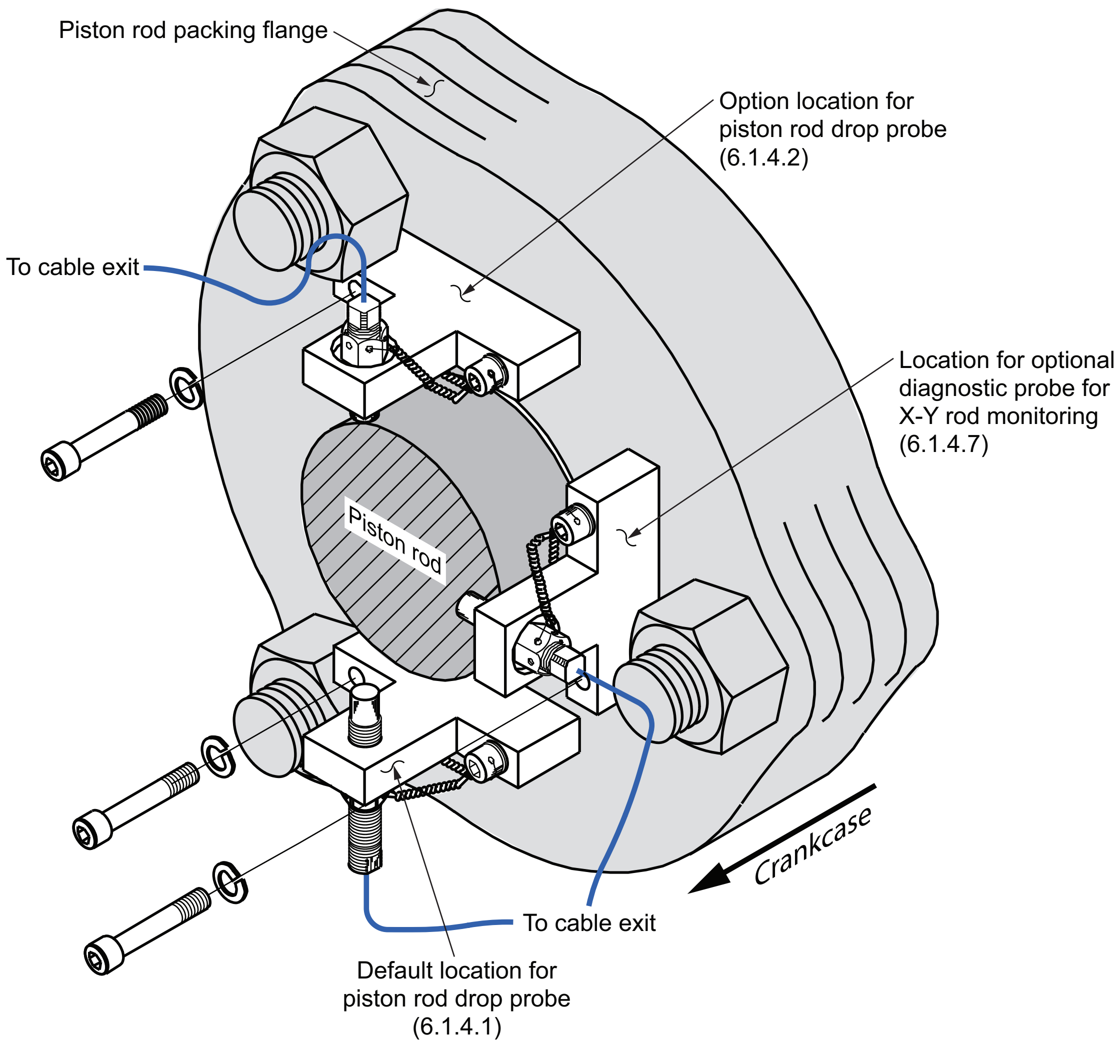
6.1.3.5 Externally removable probes shall include provisions to indicate that the gap adjustment has not been changed from the original setting. This may be accomplished by either tie wires or external markings.

6.1.3.6 Shaft and collar areas sensed by axial probes shall have a combined total electrical and mechanical runout of not more than 13 μm (0.5 mil) pp. The provisions of 6.1.2.2 regarding surface finish and the requirement of 6.1.2.3 regarding minimum side clearance shall be observed.

6.1.3.7 The axial probe gap shall be set so that when the rotor is in the center of its thrust float, the transducer's output voltage is –10 Vdc (±0.2 Vdc).

6.1.4 Piston Rod Drop Probes

6.1.4.1 Piston rod drop probes shall be mounted internally in the distance piece with a mounting block attached to the face of the pressure packing box. The mounting bracket length shall not exceed 75 mm (3 in.). The probe area is the piston rod. Unless otherwise specified, the piston rod drop probe shall be mounted directly below the piston rod (see Figure 13).



NOTE Piston rod position measurements do not generally enable the use of reverse mount probes. A standard option forward mount probe should be selected instead.

Figure 13—Typical Piston Rod Position Probe Arrangement

• **6.1.4.2** If specified, the piston rod drop probe may be mounted directly over the piston rod rather than below the piston rod.

NOTE This location may also be used when a redundant or spare probe is needed.

6.1.4.3 It shall be possible to adjust the probe gap using commercially available wrenches. No special bent or split socket wrenches shall be required.

6.1.4.4 When the piston rod is coated, the proximity transducer system calibration curve shall use the actual observed surface of the piston rod.

NOTE The intent of this subsection is to preclude the use of a representative target with similar metallurgy, rather than the actual piston rod surface. Coated probe areas will affect the system calibration. Coated probe areas require special calibration of the probe system and depend not only on coating metallurgy but also coating thickness and roughness of parent material.

6.1.4.5 When the piston rod is coated, the results of the calibration curve obtained in 6.1.4.4 shall be used in programming the monitor system to compensate for any coated areas on the probe target area.

6.1.4.6 Unless otherwise specified, the piston rod drop probe shall be gapped as follows:

a) –15 Vdc (± 0.2 Vdc) for bottom-mounted probes;

b) –10 Vdc (± 0.2 Vdc) for top-mounted probes.

NOTE 1 Piston rod drop probes need more linear range available in the piston rod drop direction than in the piston rod rise direction. Therefore, these probes should not be gapped at center range. Proper gap for these probes depends on the rider band size, the amount of piston rod rise expected because of thermal growth, and whether the probe is mounted above or below the piston rod. The position of the piston rod for bottom-mounted probes [6.1.4.6 a)] is with the piston rod at its maximum height. The position of the piston rod for top-mounted probes [6.1.4.6 b)] is with the piston rod at its minimum height.

NOTE 2 The initial piston rod drop probe gap should allow the probe sufficient range to view the piston rod under the following two conditions:

a) with new rider bands installed after allowing for thermal expansion of the piston,

b) with the rider bands completely worn and the piston riding directly on the cylinder liner.

• **6.1.4.7** If specified, an additional probe shall be mounted in the horizontal plane to assist in diagnostics in accordance with 7.4.3.3 (see Figure 13).

NOTE The convention for X and Y probes when making piston rod drop measurements is to view the probes from the crankshaft looking towards the cylinder. The probe referred to as “Y” is always located 90° counterclockwise from the probe referred to as “X,” regardless of what vertical or horizontal orientation they may have.

6.1.4.8 For all conditions of machine operation and thermal expansion, a minimum side clearance of one-half the diameter of the probe tip is required. The probe shall not be affected by any metal other than that of the probe’s observed area.

6.1.5 Phase Reference Transducers

6.1.5.1 A one-event-per-revolution mark and a corresponding phase reference transducer shall be provided on the driver for each machinery train (see Figure H.4 for an example), on the output shaft(s) of all gearboxes (see Figure H.2) and on reciprocating compressors when piston rod drop measurements are made (see Figure H.6).

NOTE When used for protection on reciprocating compressors, redundant phase reference transducers should be used.

• **6.1.5.2** If specified, a spare phase reference transducer shall be installed per 6.2.1.1 c). The radial location of a spare phase reference transducer, relative to the primary phase reference transducer, shall be documented.

NOTE Loss of a phase reference transducer, when used as an input to a tachometer, results in loss of speed indication. Also, loss of a phase reference transducer results in the loss of diagnostic capabilities for all other radial and axial transducers referenced to that shaft.

6.1.5.3 Phase reference probe mounting requirements and electrical conduit protection shall be identical to that of a radial shaft vibration probe (see 6.2.1.1).

6.1.5.4 The phase reference probe and its angular position shall be permanently marked with a metal tag on the outside of the machine casing. The angular position of the one-event-per-revolution mark on the rotor shall be marked on an accessible portion of the shaft.

6.1.5.5 A change in the transducer's output voltage of at least 7 V shall be provided for triggering external analysis equipment and digital tachometers.

6.1.5.6 The one-event-per-revolution marking groove for phase reference transducers shall comply with the following:

a) minimum width shall be one and one-half times the diameter of the probe tip;

b) minimum length shall be one and one-half times the diameter of the probe tip;

c) minimum depth shall be 1.5 mm (0.06 in.);

d) all edges shall be radiused to a minimum of 0.8 mm (0.03 in.);

e) shall be long enough to allow for shaft thermal expansion and rotor float.

6.1.5.7 Phase reference probes shall be radially mounted to sense a one-event-per-revolution mark. The mark shall not be placed in the path of the normal radial vibration probes.

6.1.6 Standard Tachometer Transducers

• The phase reference transducer in 6.1.5 shall be used as the input to the tachometer. Mounting requirements and electrical conduit protection shall be identical to that of a radial shaft vibration probe (see 6.2.1.1). If specified, options include the following:

a) the standard probe of 5.1.1.2 observing a multitooth speed sensing surface;

b) the magnetic speed sensor of 5.1.5 observing a multitooth speed sensing surface.

NOTE 1 To achieve the required tachometer accuracy and response time, a multitooth speed sensing surface may be required, particularly for applications involving low shaft speeds (below 250 rpm) such as slow-roll or zero speed. See Annex J for application considerations pertaining to multitooth speed sensing surfaces.

NOTE 2 See Notes following 6.1.7.2 for application considerations pertaining to speed sensor selection.

6.1.7 Electronic Overspeed Detection System Speed Sensors

6.1.7.1 Three separate speed sensors that are not shared with any other system shall be provided for the electronic ODS.

6.1.7.2 Unless otherwise specified, speed sensors used as inputs to the electronic ODS shall be passive magnetic speed sensors (see 5.1.5).

NOTE 1 While passive magnetic speed sensors are often employed for speed sensing, they may not allow low shaft speeds (typically below 250 rpm) to be measured, even when a multitoothed wheel is employed. Externally-powered sensors (both active magnetic speed sensors and proximity probes) are capable of providing a signal down to shaft speeds of 1 rpm or lower and represent a better choice for these applications.

NOTE 2 For applications involving overspeed sensing, powered sensors have inherent advantages over passive magnetic speed sensors and should be considered because they allow the electronic ODS to more completely assess the integrity of its inputs. They enable self-checking and circuit fault diagnostic capabilities (such as sensor gap within acceptable range or sensor and field wiring deterioration).

NOTE 3 Proximity probes can be gapped further from the speed sensing surface than active or passive magnetic speed sensors and are therefore less likely to rub and fail during abnormal rotor vibration conditions (such as encroaching on a second critical speed during an overspeed condition) when radial vibration amplitudes at the speed sensing surface location may be large.

6.1.7.3 Mounting requirements and electrical conduit protection for speed sensors shall be identical to that required for radial shaft vibration probes (see 6.2.1.1).

6.1.7.4 A multitoothed surface for speed sensing shall be provided integral with, or positively attached to, or locked to the driver shaft. This surface may be shared by other speed sensors but shall not be used as a gear for driving other mechanical components. See Annex J for typical details of this multitoothed surface.

6.1.8 Accelerometers and Velocity Sensors

6.1.8.1 Accelerometers intended to monitor radial casing vibration shall be located on the radial bearing housing. Location and number of accelerometers shall be jointly developed by the machinery vendor and the owner. In some applications, field determination of the optimum mounting location may be required.

6.1.8.2 Accelerometers intended to monitor axial casing vibration shall be oriented axially located on or as near as possible to the thrust bearing housing.

6.1.9 Bearing Temperature Sensors

6.1.9.1 Radial Bearing Sensors

6.1.9.1.1 The intent of this section is to locate the temperature sensor as close to the load position as possible.

6.1.9.1.2 Unless otherwise specified, temperature sensors for sleeve journal bearings shall be arranged as follows.

a) Bearings whose length-to-diameter ratio is greater than 0.5 shall be provided with two axially collinear temperature sensors located in the lower half of the bearing, 30° (±10°) from the vertical centerline in the normal direction of rotation.

b) Bearings whose length-to-diameter ratio is less than or equal to 0.5 shall be provided with a single sensor axially located in the center of the bearing, 30° (±10°) from the vertical centerline in the normal direction of rotation.

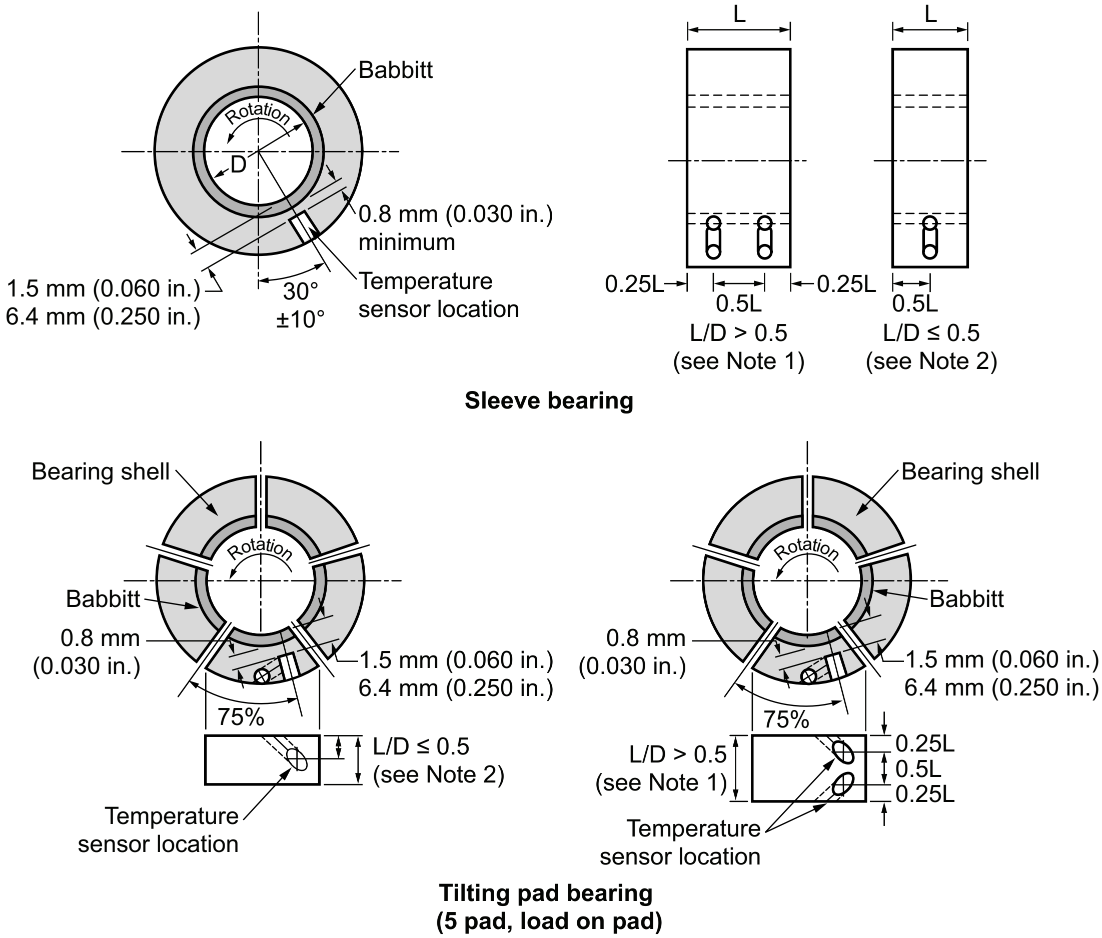
6.1.9.1.3 Unless otherwise specified, temperature sensors for tilting-pad journal bearings shall be arranged as follows.

a) Bearings whose length-to-diameter ratio is greater than 0.5 shall be provided with two axially collinear embedded temperature sensors located at the three-quarter arc length (75 % of the pad length from the leading edge). For pads with self-aligning pivots, installation in accordance with 6.1.9.1.2 b) is acceptable.

b) Bearings whose length-to-diameter ratio is less than or equal to 0.5 shall be provided with a single sensor axially located in the center of the pad at the three-quarter arc length (75 % of the pad length from the leading edge).

c) For bearings with load-on-pad designs, the sensor or sensors shall be located in the loaded pad (see Figure 14).

d) For bearings with load-between-pad designs, the sensor or sensors shall be located in the pad trailing the load (see Figure 15).



NOTE 1 If the length-to-diameter (L/D) is greater than 0.5, two sensors are installed, each located at a distance of 0.25L from the end of the bearing's running face [see 6.1.9.1.3 a)].

NOTE 2 If the L/D ratio is less than or equal to 0.5, a single sensor is axially located in the center of the bearing [see 6.1.9.1.3 b)].

Figure 14—Typical Installations of Radial Bearing Temperature Sensors

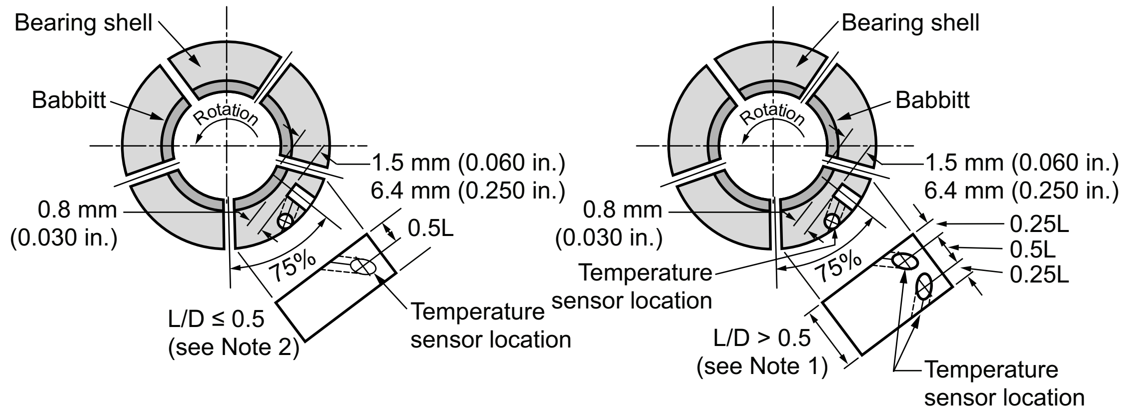
6.1.9.1.4 The machinery vendor shall notify the owner when the point of minimum lubrication film thickness does not coincide with the sensor locations specified in 6.1.9.1.2 and 6.1.9.1.3. The location of the temperature sensors shall then be mutually agreed upon by the owner and the machinery vendor.

6.1.9.1.5 For machines such as gearboxes, the shaft operating attitude shall be considered in determining the exact location of the temperature sensors. Sensors should be placed as close to the high load region as possible.

NOTE The gearbox manufacturer should be consulted to define the normal shaft-to-bearing load points when selecting the exact location of temperature sensors, because the position of the journal in the bearing depends on such considerations as transmitted power and direction of gear mesh.

6.1.9.2 Thrust Bearing Sensors

6.1.9.2.1 A temperature sensor shall be located in each of two shoes in the normally active thrust bearing. These sensors shall be at least 120° apart. For maintenance purposes, and to identify the maximum pad temperature, the sensors preferably shall be located in the lower half of the thrust bearing assembly (see Figure 16).



Tilting pad bearing
(5 pad, load between pad)

NOTE 1 If the length-to-diameter (L/D) is greater than 0.5, two sensors are installed, each located at a distance of 0.25L from the end of the bearing's running face [see 6.1.9.1.3 a)].

NOTE 2 If the L/D ratio is less than or equal to 0.5, a single sensor is axially located in the center of the bearing [see 6.1.9.1.3 b)].

Figure 15—Standard Installation of Radial Bearing Temperature Sensors

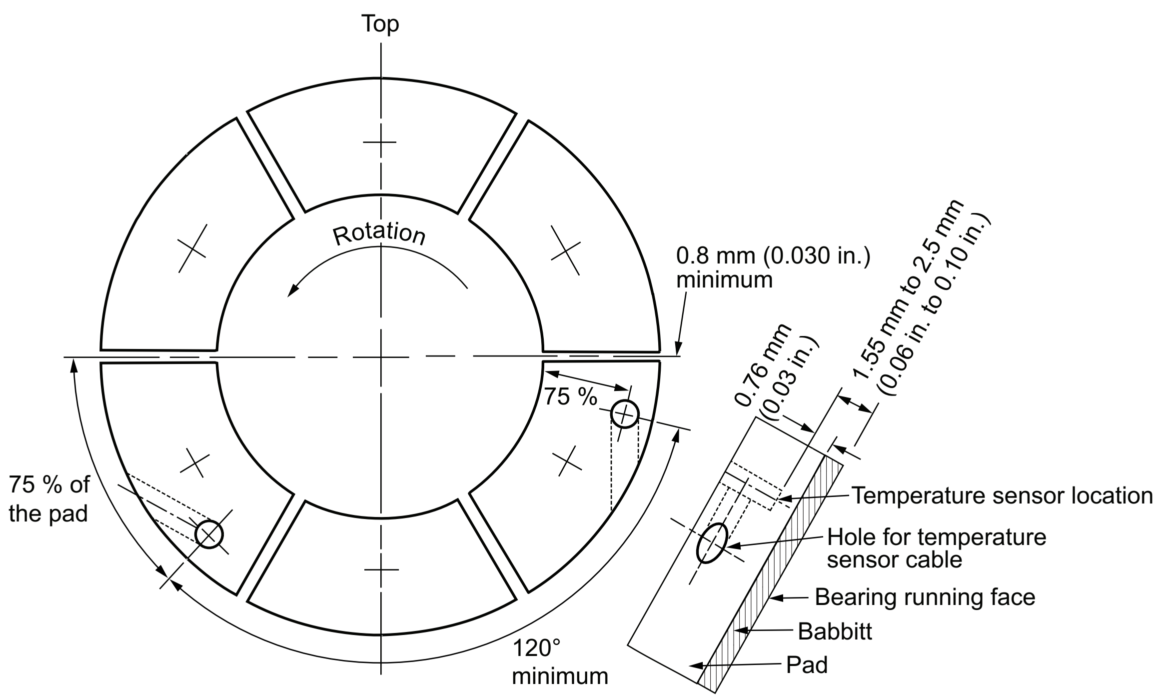


Figure 16—Typical Installation of Thrust Bearing Temperature Sensors

6.1.9.2.2 Thrust bearing temperature sensors shall be placed at 75 % of the pad width radially out from the inside bearing bore and at 75 % of the pad length from the leading edge (see Figure 16).

6.1.9.2.3 Unless otherwise specified, at least two additional temperature sensors shall be provided in the normally inactive thrust bearing, arranged as specified in 6.1.9.2.1 and 6.1.9.2.2.

6.1.9.2.4 The temperature sensor shall be located 1.5 to 2.5 mm (0.060 to 0.100 in.) from the bearing running face and not less than 7.6 mm (0.030 in.) from the (white metal) babbitt/pad interface. The holes shall be finished with a bottoming drill, and all corners shall be broken.

6.1.9.2.5 The sensor lead shall be routed from the bearing to the outside of the machine through a penetration fitting. The sensor lead shall be properly secured, with no internal connections, to prevent damage as a result of whipping, chafing, windage, and oil. The sensor lead shall not restrain pivoting thrust shoes.

6.2 Mounting

6.2.1 Probes

6.2.1.1 All probes (except piston rod drop probes) shall be mounted in holders that permit adjustment and are retractable or removable while the machine is running. Internal mounting of probes is acceptable only when approved by the owner or when externally mounted probes do not allow true measurement of the rotor-to-bearing relative motion but internally mounted probes do. When internal probes are used, all probe components not externally accessible shall be spared and the location of these redundant components shall be approved by the owner and provided in the MPS documentation. The preferred location for the installed redundant probes is as follows.

a) *Radial Probes*—180° radially from that of the installed primary probes. If this mounting location is inaccessible, spare probes shall be mounted where space permits but shall always be mounted 90° apart from one another per 6.1.2.1.

b) *Axial Probes*—Spare axial probes shall be mounted to observe the same axial surface(s) as that of the installed primary probes. Their radial orientation relative to one another can vary depending on machine design.

c) *Phase Reference Probes*—Spare phase reference probes will ideally be at the same radial orientation as the installed primary phase reference probes. When this is not possible, they shall be located 180° radially opposite the installed primary phase reference probes.

NOTE 1 Depending on the installation, internally mounted probes may be preferable because they can often be mounted on the bearing itself and provide true relative displacement between the bearing and the rotor. Externally mounted probes may not provide this bearing-to-rotor measurement and instead may simply provide a casing-to-rotor relative motion that is a less direct measurement of true machine behavior.

NOTE 2 When constrained mounting areas do not allow spares to be installed, externally mounted probes should be used instead, or, with the owner's agreement, a single spare probe can be installed for each radial and axial bearing location.

NOTE 3 When choosing the locations for all probes used in direct shaft measurements, it is always more desirable to measure the shaft directly rather than a component attached to the shaft. When choosing a location that measures a component attached to the shaft, the component may shift or loosen causing a loss of measurement and possible machine damage.

Caution—It is not a recommended or safe practice to access probes while a machine is operating.

6.2.1.2 Probe holders shall be free from natural frequencies that could be excited by machine-generated frequencies. The free cantilevered length of a probe holder sleeve shall not exceed 200 mm (8 in.). Longer lengths require the use of a probe holder sleeve support guide.

6.2.1.3 When a probe is internally mounted, the probe holder shall be at least 10 mm ($^3/_8$ in.) thick. The probe lead shall be securely tied down to prevent cable whipping or chafing resulting from windage or oil. No cable connections shall be made inside the machine. To facilitate maintenance while the machine is running, all cable connections shall be made in conduit boxes located outside the machine.

6.2.1.4 In the standard configuration, all extension cables shall be protected in conduit as shown in Figure 5.

6.2.1.5 Extension cable connectors shall be electrically isolated from conduit using an insulating sleeve or wrap located in an externally accessible junction box.

• **6.2.1.6** If specified, armored extension cable as shown in Figure 6 shall be provided.

6.2.2 Oscillator-demodulators

The number, location, and installation of mounting boxes for oscillator-demodulators shall be approved by the owner. Unless otherwise specified, the following requirements shall be met.

a) There shall be at least one mounting box per machinery casing.

b) All mounting boxes for oscillator-demodulators shall be located for ease of access and on the same side of the equipment train.

c) These boxes shall not be mounted on the machine. The mounting location shall be selected so that minimal vibration is imparted to the oscillator-demodulator. The mounting location shall also be selected so that the oscillator-demodulators are not subjected to ambient temperatures exceeding their operating range (see Table 1).

6.2.3 Accelerometers and Velocity Sensors

6.2.3.1 The machinery vendor shall provide machined and finished accelerometer mounting points as shown in Annex C. The boss or surface shall be part of the machine casing.

6.2.3.2 Unless otherwise specified, the machinery vendor shall provide the standard accelerometer and velocity sensor mounting configuration as shown in Annex C for each accelerometer.

6.2.3.3 All cables shall be enclosed in conduit. The conduit shall be attached to an enclosure, not to the accelerometer (see Annex C for typical mounting and enclosure arrangements).

• **6.2.3.4** If specified, the accelerometer cable shall be protected by a weatherproof, flexible armor (see Annex C for additional details).

NOTE 1 Armored cable permits mounting the accelerometer with mechanical protection without using conduit.

NOTE 2 It is not the intent of this subsection to relax local regulatory requirements for conduit or cable-tray wire routing and support systems (e.g. European/Cenelec regulations).

6.2.4 Bearing Temperature Sensors

6.2.4.1 Embedded temperature sensors shall be provided. They shall not contact the babbitt (white metal) but shall be located in the bearing backing metal (see Figure 14, Figure 15, and Figure 16). Through-drilling and puddling of the babbitt is not permitted.

6.2.4.2 The heat-sensing surface of the temperature sensor shall be in positive contact with the bearing backing metal and not less than 0.75 mm (30 mil) from the babbitt bond line. The recommended distances from the babbitt running face are as follows (see Figure 14, Figure 15, and Figure 16):

a) for tilting-pad bearings, from 1.5 mm to 2.5 mm (60 mil to 100 mil);

b) for sleeve bearings, from 1.5 mm to 6.4 mm (60 mil to 250 mil).

• **6.2.4.3** If specified, spring-loaded (bayonet type) temperature sensors that contact the outer shell of the bearing metal are permitted without bonding or embedment.

6.2.4.4 The leads from all temperature sensors shall:

a) be oriented to minimize bending or movement during operation and maintenance;

b) be secured to prevent cable whipping and chafing resulting from windage or oil without restricting pad movement;

c) unless otherwise specified, be free from connections inside the machine;

d) utilize a terminal head outside the machine for all cable connections;

NOTE This requirement facilitates maintenance of sensor leads while the machine is running.

e) be free from splices (see Figure 3).

NOTE The default configuration does not permit connectors on temperature sensor leads inside the machine because connectors are an intermittent source of potential problems. Requiring all connections outside the machine ensures connector problems can be addressed without machine shutdown and disassembly. However, the subsection does allow the user to specify internal connectors when required for ease of mechanical maintenance.

• **6.2.4.5** If specified, the temperature sensor tip shall be electrically insulated from the bearing.

NOTE Many machines, notably electric motors and generators, require electrically insulated bearings to prevent circulating shaft currents. (see 4.15 and 5.3.1.4).

6.2.4.6 The temperature sensor signal cables shall not permit liquid or gas to leak out of the point where they penetrate the bearing housing.

Acceptable arrangements include the following:

a) potted, encased sleeves that are sealed with compression seals;

b) molded signal leads within an elastomeric material that is sealed with a tapered compression fitting;

c) hermetic seals;

d) inverted gooseneck trap arrangement in conduit (see Figure 7).

6.3 Identification of Sensor Systems

Each sensor, extension cable, and oscillator-demodulator (when applicable) lead shall be plainly marked to indicate the location and service of its associated probe or sensor. This tagging shall be visible without disassembly of machine or removal from machine.

7 Vibration Monitor Systems

7.1 General

7.1.1 The manufacturer of the monitoring system shall provide documentation affirming the system's compliance with and/or exceptions to all aspects of this standard except those that are configuration- and/or installation-related.

The entity(ies) responsible for installation and configuration of the system shall provide documentation affirming the system's compliance with and/or exceptions to all aspects of this standard that are configuration- and/or installation-related.

NOTE Certain aspects of the system are hardware dependent, such as performance and most aspects of reliability. In these cases, the manufacturer of the system is expected to verify the system satisfies the requirements of the standard. However, many aspects of the standard are installation dependent, such as number and placement of sensors and the configurable capabilities of a system (e.g. alarm and relay configuration).

• **7.1.2** Unless otherwise specified, signal processing/alarm/integrity comparison, display/indication, and all other features and functions specified in Section 4 shall be contained in one contiguous enclosure (rack) (see Figure 1).

With purchaser approval, a system not enclosed in one contiguous enclosure (rack) and meeting all other requirements and functionality of a default system may be supplied.

7.1.3 At minimum, each monitor system shall be provided with the following features and functions.

a) An installation design ensuring that a single circuit failure (power source and monitor system power supply excepted) shall not affect more than two channels (regardless of channels available on the monitor module) of radial shaft vibration, axial position, casing vibration, speed indicating tachometer, or six channels of temperature or rod drop on a single machine case.

   NOTE The intent of this requirement is to ensure an installation design that will not lose all monitoring on a machine case in the event of a single circuit fault.

b) All radial shaft vibration, axial position, rod drop, and casing vibration channels, associated outputs, and displays shall have a minimum resolution of 2 % of full scale. Temperature channels, associated outputs, and displays shall have 1° resolution independent of engineering units. Tachometer and electronic ODS channels, associated outputs, and displays shall have a resolution of 1 rpm.

c) Electrical or mechanical adjustments for zeroes, gains, and alarm (alert) and shutdown (danger) setpoints that are field changeable and protected through controlled access. The means for adjustment, including connection(s) for a portable configuration device, shall be accessible from the front of the monitor system. The monitor system alarm and shutdown functions shall be manually or automatically bypassed in accordance with 4.12.11 during adjustment.

d) It is permissible to install the modules to monitor more than one machine train in the same monitor system rack (chassis). However, each machine train shall have dedicated monitor modules. When multiple machine trains are monitored using a single rack, the monitoring system shall support the capability of accommodating multiple phase reference transducer inputs from each of these machine trains/cases.

e) The monitor system shall include digital and/or analog interfaces capable of serving an external host computer for implementing a CMS. (Reference Annex N for recommendation on condition monitoring.)

7.1.4 A monitor system shall include the following signal processing functions and outputs:

a) gain adjustment for each radial shaft vibration and axial position channel,

b) default gain adjustment shall be factory preset to 7.87 mV/μm (200 mV/mil).

7.1.5 A monitor system shall include the following alarm and integrity comparison functions.

a) Fixed time delays for shutdown (danger) relay activation that are field changeable (via controlled access) to require from 1 to 3 seconds sustained violation. A delay of 1 second shall be standard.

b) Alarm (alert) indication for each channel or axial position channel pair.

7.1.6 A monitor system shall include an integral, dedicated display capable of indicating the following:

a) all measured variables used in the protection function;

b) alarm (alert) and shutdown (danger) setpoints;

c) DC gap voltages (for radial shaft vibration, axial position, piston rod drop, speed indicating tachometer, and electronic overspeed detection channels used with noncontact displacement transducers).

7.1.7 The monitor system display shall be updated at a minimum rate of once per second.

• **7.1.8** The display may be an analog, digital, graphic, or other indication as specified by the purchaser.

7.1.9 Unless otherwise specified, the monitor system shall indicate:

a) the higher radial shaft vibration at each bearing,

b) all axial position measurements,

c) the highest temperature for each machine case,

d) the highest casing vibration for each machine case,

e) all standard speed indication and overspeed detection channels,

f) the highest rod drop channel for each machine case.

NOTE These requirements are in addition to the indications required in 4.11.7.

• **7.1.10** If a blind monitor system is specified, a nonintegral display may be used provided it fulfills all the same measurement and status indication criteria required of the integral version.

7.2 Power Supplies

The output voltage to all oscillator-demodulators shall be –24 Vdc with sufficient regulation and ripple suppression to meet the accuracy requirements specified in Table 1.

7.3 System Output Relays

7.3.1 The output relays described in this section shall be used for interconnecting the MPS to all other devices used as part of the auto-shutdown loop. The optional digital interfaces of 4.11.4 f) and 4.13.1 and the optional analog outputs of 4.11.4 e) shall not be used for machinery protection purposes.

7.3.2 As a minimum, one pair of relays—alarm (alert) and shutdown (danger)—shall be provided for each of the following monitored variable types per machine train:

a) axial position,

b) radial shaft vibration,

c) casing vibration,

d) bearing temperature,

e) piston rod drop.

7.3.3 One circuit fault relay shall be provided per monitor system.

7.4 Monitor Systems

• 7.4.1 Radial Shaft Vibration Monitoring

• **7.4.1.1** The full-scale range for monitoring radial shaft vibration shall be from 0 to 125 μm (0 to 5 mil) true peak-to-peak displacement. Peak-to-peak values factored from any other intermediate value or calculated measurement, other than the transducer or signal interface is not acceptable. If specified, the standard optional full-scale range shall be from 0 to 250 μm (0 to 10 mil) true peak-to-peak displacement.

7.4.1.2 The radial shaft vibration circuit fault system shall be set to actuate at 125 μm (5 mil) less than the upper limit and 125 μm (5 mil) more than the lower limit of the transducer's linear range. The minimum allowable setting for the lower limit shall be 250 μm (10 mil) absolute gap.

7.4.1.3 Radial shaft vibration shall be monitored in paired orthogonal ("X-Y") channels from the two transducers mounted at each bearing.

7.4.1.4 The radial shaft vibration shutdown system shall be field changeable so that one (single logic) or both (dual voting logic) orthogonal ("X-Y") transducer signals shall persist at or above the setpoint to activate a shutdown (danger) relay. Dual voting (two-out-of-two) logic shall be standard. See the Notes following 7.4.1.5.

• **7.4.1.5** If specified, single voting (one-out-of-two) logic shall be supplied.

NOTE 1 Considerations for a single (one-out-of-two) versus a dual voting (two-out-of-two) system include the potential for a significant elliptical shaft orbit (due to misalignment or other potential preload conditions) where one transducer detects shutdown limits while the other transducer remains within acceptable limits. With a significant elliptical orbit, a single voting system provides protection while a dual voting system does not. The disadvantage of a single voting system is the possibility of false shutdowns and unnecessary loss of production. Where the probability of a significant elliptical shaft orbit is low, the use of a dual voting system provides a higher level of reliability and fewer false shutdowns. A conscientious decision regarding a single versus a dual voting system should be made.

NOTE 2 In a dual voting logic system, although each channel may have reached or violated its respective shutdown (danger) setpoints at different times, the shutdown (danger) relay will not activate until both channels persist at or above the shutdown (danger) setpoint for the time delay specified in 7.1.5 a). In the event of failure of a single radial shaft vibration channel transducer or circuit, only the circuit-fault alarm will activate [i.e. the shutdown (danger) relay will not activate].

• **7.4.1.6** If specified, a controlled-access setpoint multiplier function shall be provided with the following capabilities.

a) Actuation by an external contact closure causes the alarm (alert) and shutdown (danger) setpoints to be increased by an integer multiple, either two (2) or three (3). A multiplier of three (3) shall be standard.

b) Positive indication (e.g. lighted), shall be provided on the monitor system when the multiplier is invoked.

c) Elevation of the setpoint shall not attenuate the actual input signal nor alter the proportional digital or analog outputs representing the channel's amplitude.

NOTE The use of setpoint multiplication is strongly discouraged unless it is clearly required. See Annex I for guidance on when setpoint multiplication may be required.

7.4.1.7 Altering a vibration measurement to arithmetically subtract (suppress) mechanical or electrical runout or electrical noise shall not be allowed.

7.4.2 Axial Position Monitoring

7.4.2.1 The full-scale range for axial position monitoring shall be from –1 mm to +1 mm (–40 mil to +40 mil) axial movement.

NOTE In some cases 2 mm linear range may not be enough to measure the entire float range of the thrust bearing.

7.4.2.2 The axial position circuit-fault system shall be set to actuate at the end of the transducer's linear range but not closer than 250 μm (10 mil) of absolute probe gap.

7.4.2.3 Axial position shall be monitored in paired channels. The monitoring system shall be capable of displaying the deviation from zero for both channels. The two channels may share common alarm (alert) and shutdown (danger) setpoints but shall have separate zeroing and gain adjustments.

7.4.2.4 The axial position shutdown system shall be field changeable so that one (single logic) or both (dual voting logic, see 7.4.2.5) transducer signals shall reach or violate the shutdown (danger) setpoint to actuate the shutdown (danger) relay. Dual voting (two-out-of-two) logic shall be standard.

7.4.2.5 In an axial position dual voting logic system, although each channel may have reached or violated its respective preset shutdown (danger) setpoints at different times, both channels shall jointly and continuously be at or above the shutdown (danger) setpoints for the time delay specified in 7.1.5 a) before the shutdown (danger) relay activates. In the event of the failure of a single transducer or circuit, only the circuit-fault alarm and the alarm (alert) shall activate [i.e. the shutdown (danger) relay will not activate]. The shutdown (danger) relay shall activate when any of the following conditions occur:

a) both axial position transducers or circuits fail.

b) either channel has failed, and the other channel has violated the shutdown (danger) setpoint.

c) both channels jointly violate the shutdown (danger) setpoint.

7.4.2.6 Each axial position monitoring channel shall be field changeable so that the display will indicate either upscale or downscale with increasing probe gap. Indicating upscale with increasing probe gap shall be standard.

7.4.3 Piston Rod Drop Monitoring

7.4.3.1 Piston rod drop monitoring shall be provided (see Annex P).

NOTE This measurement is made to prevent the piston from contacting the cylinder liner by monitoring the rider band wear (see Figure 13 and Figure 17).

7.4.3.2 Unless otherwise specified, the piston rod drop monitor system shall include a once-per-crank-revolution signal using a phase reference transducer of 6.1.5 for timing the measurement location on the piston rod and for diagnostic purposes (see Figure 18).

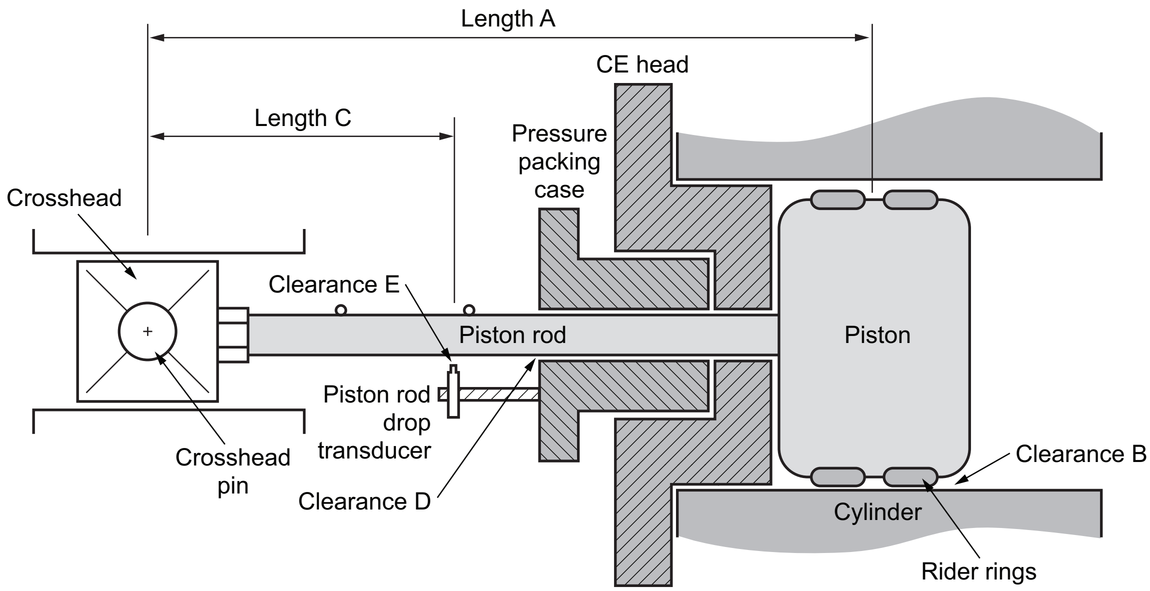
• **7.4.3.3** The piston rod drop monitor system shall be supplied with one channel per piston rod. If specified, two channels per piston rod for X-Y measurements shall be provided (see 6.1.3.7).

7.4.3.4 The piston rod drop monitor display range shall be from 9.99 mm (400 mil) rod rise to 9.99 mm (400 mil) rod drop with a minimum of 25 μm (1 mil) resolution.

NOTE See Figure 17 to determine rod drop limiting clearance. The limiting clearance may be the clearance between the rod and the pressure packing case.

7.4.3.5 The piston rod drop monitor circuit-fault system shall be set to actuate at the end of the transducer's linear range but not closer than 1 mm (40 mil) of absolute proximity probe gap.

7.4.3.6 Unless otherwise specified, the piston rod drop monitor's shutdown (danger) function shall activate if any individual sensor reaches or violates the shutdown (danger) setpoint for any channel.



Length A (crosshead pin to piston center) __________
Clearance B (clearance between piston and cylinder, bottom) __________
Length C (crosshead pin to piston rod drop transducer) __________
Clearance D (packing case to piston rod, bottom) __________
Clearance E (piston rod to transducer tip, rod drop) __________

Calculation 1: Piston rod drop limiting clearance.
This calculation is required to determine whether the component limiting the running clearance is the pressure packing case clearance or the piston-to-cylinder clearance.

a) If A x D/C < B, then the pressure packing case clearance is limiting: otherwise the piston-to-cylinder clearance is limiting.
b) If the piston-to-cylinder clearance is limiting, the maximum rod drop at the transducer is C x B/A.

Calculation 2: Convert piston rod drop to piston drop.
A change in clearance E represents a loss of piston-to-cylinder clearance as follows:
piston position = ΔE x A/C.

Figure 17—Piston Rod Drop Calculations

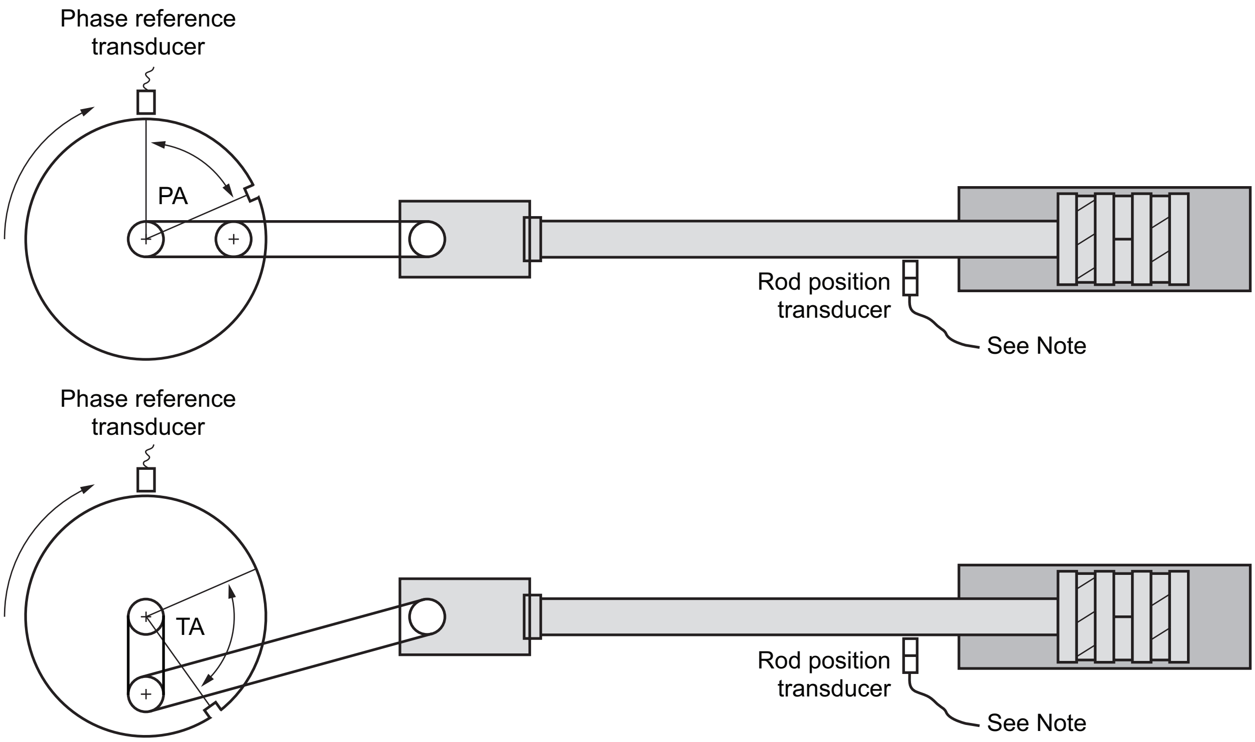
7.4.3.7 The piston rod drop monitor shall be able to calculate piston rise or piston drop based on the position of the piston rod, the position of the proximity probe, and measurements of different machinery components.

7.4.3.8 The piston rod drop monitor system shall be capable of being reset to its initial rider band wear setting after reaching operating temperature to compensate for thermal growth of the piston.

NOTE The initial running position of the piston rod will change because of thermal growth of the piston and pressures encountered when in operation.

7.4.3.9 The monitor scale factor shall be field changeable to either 7.87 mV/µm (200 mV/mil) or 3.94 mV/µm (100 mV/mil) to match the output of the transducer system employed. Unless otherwise specified, 7.87 mV/µm (200 mV/mil) shall be standard.

7.4.3.10 The piston rod drop monitor system scale factor shall be adjustable within ±50 % of the nominal sensitivity value to accommodate different materials, coatings, and coating thicknesses on the piston rod.



Piston angle (PA) = The number of degrees, in the direction of rotation, between the phase reference mark and the phase reference transducer when the piston is at top dead center (TDC).

Trigger angle (TA) = The number of degrees, in the direction of rotation, between TDC and where in the stroke you want the reading to be taken. [Should not be too close to TDC or bottom dead center (BDC).]

NOTE Rod position transducer mounting should consider the direction the rod will move (toward or away) from the probe as the rider bands wears.

Figure 18—Piston Rod Position Measurement Using Phase Reference Transducer for Triggered Mode

NOTE Piston rods or plungers may be manufactured from (or coated with) a variety of materials and are often coated with chrome or tungsten carbide. These factors can affect transducer sensitivity requiring field calibration of the piston rod drop monitor system. For nonstandard materials and calibrations the adjustable scale factor allows the accuracy to be calibrated to the material type. The MPS vendor should be advised of materials and composition (including any coating) of the rod to be monitored to provide proper transducer calibration.

7.4.3.11 The piston rod drop monitor system shall be capable of displaying rider band wear in two separate modes.

a) *Triggered Mode*—Display rider band wear based on the instantaneous gap voltage at a specific and consistent point on each piston stroke.

b) *Average Mode*—Display rider band wear based on the average gap voltage throughout the stroke.

NOTE 1 The piston rod drop transducer system measures all piston rod movements. These movements are caused by not only rider band wear but may also include one or more of the following:

a) rod mechanical runout due to crosshead-to-cylinder misalignment in the measurement plane,

b) rod deflection,

c) forces imposed by load and process condition changes.

These conditions occur in all reciprocating machines to varying extents and can potentially lead to erroneous conclusions regarding rider band wear when displayed in the average mode. In order to minimize these effects and obtain the most reliable indication of rider band wear, it is necessary to use the triggered mode. To use the triggered mode properly, find a point on the stroke where the influences of Items a) to c) are minimized. This is done through field testing during commissioning of the piston rod drop monitor.

NOTE 2 The most effective way of interpreting piston rod drop measurements is through the application of long- and short-term trending. This trending allows users to reliably determine rider band wear.

7.4.3.12 The piston rod drop monitor shall be capable of indicating piston rod runout when the crankshaft is slowly rotated (2 rpm or below).

NOTE The triggered mode should not be used for this measurement.

7.4.4 Casing Vibration Monitoring

7.4.4.1 Requirements in this section apply to monitoring casing vibration utilizing acceleration transducers on machines such as gears, pumps, fans, and motors equipped with rolling element bearings. Unless otherwise specified, machines with fluid film bearings that are designated for monitoring shall be equipped with shaft displacement monitoring in accordance with the system arrangements in Annex H.

NOTE 1 When casing vibration is used for machine protection, velocity measurements are recommended (see Annex E). Acceleration measurements should be used to indicate condition and not for machine protection.

NOTE 2 While unfiltered overall vibration is necessary for test stand acceptance measurements (such as outlined in API 610), it is generally not recommended for machinery protection or continuous monitoring applications. Experience has shown that the default filtered velocity range in 7.4.4.5 b) is generally desirable for eliminating spurious noise sources and potential false alarms.

7.4.4.2 The monitored frequency range of each casing vibration channel shall be fixed with two field-changeable filters, high and low pass, or equivalent. Filters, or equivalent, used to set the frequency range shall have the following characteristics.

a) Unity gain and no loss in the passband greater than 0.5 dB, referenced to the input signal level.

b) A minimum roll-off rate of 24 dB per octave at the high and low cutoff frequency (–3 dB).

c) Filtering shall be accomplished prior to integration.

d) Unless otherwise specified, casing velocity shall be monitored within a filter passband from 10 Hz to 1000 Hz.

7.4.4.3 The casing vibration circuit fault system shall activate whenever an open circuit or short circuit exists between the monitor system and accelerometer. The circuit fault system shall be latching and shall inhibit the operation of the affected channel until the fault is cleared and the channel reset.

• **7.4.4.4** If specified, a controlled-access setpoint multiplier function shall be provided with the following capabilities.

a) Actuation by an external contact closure causes the alarm (alert) and shutdown (danger) setpoints to be increased by an integer multiple, either two (2) or three (3). A multiplier of three (3) shall be standard.

b) Positive indication (e.g. lighted) shall be provided on the monitor system when the multiplier is invoked.

c) Elevation of the setpoint shall not attenuate the actual input signal nor alter the proportional digital or analog outputs representing the channel's amplitude.

NOTE The use of setpoint multiplication is strongly discouraged unless it is clearly required. See Annex I for guidance on when setpoint multiplication may be required.

7.4.4.5 Unless otherwise specified, casing vibration on gears, pumps, fans, and motors equipped with rolling element bearings shall be monitored as follows.

a) Gear casing vibration shall be monitored in acceleration and velocity modes from a single accelerometer.

   i) Acceleration shall be monitored in a frequency range between 1000 Hz and 10 kHz from 0 to 500 m/s^2 true peak (0 to 50 g true peak).

   ii) Velocity shall be monitored in a frequency range between 10 Hz and 1000 Hz; amplitude from 0 to 25 mm/s rms (0 to 1 ips rms).

b) Pumps, fans, and motors with rolling element bearings (see Notes following 7.4.4.1).

   i) Velocity shall be monitored in a frequency range from 10 Hz to 1000 Hz: amplitude from 0 to 25 mm/s rms (0 to 1 ips rms).

• ii) If specified, acceleration shall be monitored from the same transducer in a frequency range from 10 Hz to 5 kHz; amplitude from 0 to 100 m/s^2 true peak (0 to 10 g true peak). Root mean squre (rms) values factored from any other intermediate value or calculated measurement other than the transducer or signal interface are not acceptable.

   iii) Equipment operating at shaft speeds from 750 rpm down to 300 rpm should be monitored in a frequency range from 5 Hz to 1000 Hz.

   NOTE If the gear mesh frequency is greater than 5 kHz, then an extended frequency range accelerometer may be required.

7.4.4.6 If specified, a casing vibration monitor system shall include one or more of the following options:

• a) monitor and display of single channel acceleration or velocity,

• b) monitor and display two channels in either acceleration or velocity,

• c) monitor and display alternate filter or frequency ranges,

• d) monitor and display unfiltered overall vibration (see Note 2 following 7.4.4.1),

• e) monitor and display in true rms,

• f) monitor and display in true peak,

• g) alternate full-scale ranges,

• h) dual voting logic (AND Logic),

• i) OR Logic.

7.4.5 Temperature Monitoring

7.4.5.1 The full-scale range for temperature monitoring shall be available in either metric (SI) or USC units as specified, with a minimum range of 0 °C to 150 °C (32 °F to 300 °F). A resolution of 1° independent of engineering units shall be provided. When thermocouples are used, temperature monitor systems shall be suitable for use with grounded and ungrounded thermocouples.

7.4.5.2 A fault in the temperature monitor or its associated transducers shall initiate the circuit-fault status alarm. Downscale failure (i.e. a failure in the zero direction) shall be standard.

7.4.5.3 Temperature monitoring shall include the capability of displaying all monitored values. Unless otherwise specified, the display shall include automatic capability to display the highest temperature.

7.4.5.4 The temperature monitoring shutdown (danger) function shall be field changeable to allow either of the following two possible configurations:

a) any individual sensor shall reach or violate the shutdown (danger) setpoint,

b) dual voting logic between predetermined pairs of sensors shall reach or violate the shutdown (danger) setpoint.

7.4.5.5 Dual voting logic shall be standard when two sensors are installed in the load zone of the bearing. Single violations (OR Logic) shall be standard for all other sensor configurations.

7.4.6 Speed Indicating Tachometer

• **7.4.6.1** If specified, a speed indicating tachometer shall be provided. It shall have the ability to record and store the highest measured rotational speed (rpm), known as peak speed.

• **7.4.6.2** If specified, controlled access reset capability for the peak speed function shall be available both locally and remotely.

7.4.6.3 The system shall accept transducer inputs from either standard probes or magnetic speed sensors.

7.5 Location of Monitor Systems

• **7.5.1** The purchaser shall specify whether monitor systems are to be located indoors or outdoors.

7.5.2 Outdoor installations shall be designed and located to avoid adverse vibrational and environmental effects.

7.5.3 Area classification, orientation, prevailing lighting conditions, display brightness, and legibility shall all be considered.

8 Electronic Overspeed Detection System

8.1 General

8.1.1 The vendor of the turbine or other prime mover that has the ability to overspeed shall have responsibility for providing the ODS.

8.1.2 The manufacturer of the monitoring system shall provide documentation affirming the system's compliance with and/or exceptions to all aspects of this standard except those that are configuration and/or installation related.

8.1.3 The entity(ies) responsible for installation and configuration of the system shall provide documentation affirming the system's compliance with and/or exceptions to all aspects of this standard that are configuration and/or installation related.

NOTE Certain aspects of the system are hardware dependent, such as performance and most aspects of reliability. In these cases, the manufacturer of the system is expected to verify the system satisfies the requirements of the standard. However, many aspects of the standard are installation dependent, such as number and placement of sensors and the configurable capabilities of a system (e.g. alarm and relay configuration).

8.1.4 The system shall be provided with fully redundant power supplies in accordance with 4.10.

• **8.1.5** If specified, variable frequency drive (VFD) motors shall include an electronic ODS.

8.1.6 The party responsible for the MPS shall verify that the electronic overspeed protection system response time meets the required system response time to prevent the rotor speed of all rotors in the train from exceeding their maximum rated rotor speed.

8.2 Accuracy

The accuracy of the overspeed system shall be in accordance with Table 1.

8.3 Segregation

8.3.1 The speed sensors used as inputs to the electronic ODS shall not be shared with any other system.

8.3.2 Electronic overspeed detection shall be separate and distinct from the speed control system, with exception of final control elements.

NOTE The intent of this subsection is to ensure overspeed protection in the event of speed control system failure.

• **8.3.3** If specified, the surge detection system (Section 9) and/or emergency shutdown system (ESD) (Section 10) may be combined with the overspeed detection functions in a single system. A failure of these other functions shall not affect the overspeed system.

8.3.4 Combining the overspeed system with any other control, protection, or monitoring systems (except as allowed by 8.3.3) shall not be allowed. This restriction includes the monitoring systems of Section 7.

NOTE Combining the ODS with other systems may degrade the overall system response time, impact ease of serviceability/ isolation, or otherwise interfere with overspeed integrity.

8.3.5 Each driving machine requiring overspeed detection shall have its own overspeed system. Combining multiple driving machines into a single ODS shall not be allowed.

8.3.6 When digital or analog communication interfaces are provided, they shall not be used as part of the shutdown system. Failure of a communication link shall not compromise the ability of the overspeed system to carry out its protective functions.

NOTE The intent of this subsection is to allow status and other data from the electronic ODS to be shared with process control, machine control, ESD, or other control and automation systems via digital or other interfaces, but without compromising the integrity of the overspeed shutdown function .

8.4 Functions

8.4.1 Number of Circuits and Alarm Logic

8.4.1.1 Overspeed detection shall use three independent measuring circuits and two-out-of-three voting logic for each shaft.

• **8.4.1.2** If specified, aeroderivative gas turbines may use two independent measuring circuits and one-out-of-two voting logic for each shaft.

NOTE 1 Electronic overspeed detection monitors and transducers are only two of the components in a complete overspeed protection system. This standard does not address these other components such as solenoids, interposing relays, shutdown valves, and so forth. Details pertaining to these other components can be found in the relevant API standard corresponding to the specific machine type (e.g. API 610, API 611, API 612, API 616).

NOTE 2 A two-out-of-three configuration enhances reliability while providing more convenient system verification and reduction in likelihood of spurious shutdowns (see Annex M). A two-out-of-three configuration does not circumvent the requirement for the overspeed system to meet the SIL specified by the purchaser.

8.4.1.3 An overspeed condition sensed by any one circuit shall initiate an alarm.

8.4.1.4 An overspeed condition sensed by two out of three circuits shall initiate a shutdown.

8.4.1.5 Failure of a speed sensor, power supply, or logic device in any circuit shall initiate an alarm only.

8.4.1.6 Failure of two or more channels shall initiate a shutdown.

8.4.1.7 A manual reset shall be required for any of the conditions in 8.4.1.3 through 8.4.1.6.

8.4.2 System Output Relays

All the requirements of 4.12 shall apply except as follows.

a) As a minimum, one pair of relays—shutdown (danger) and circuit fault—shall be provided for each channel of the electronic ODS. These relays shall not be shared or voted with any other monitored variables.

b) The shutdown relay on all channels of the electronic ODS shall be actuated when the voting logic as specified in (8.4.1) detects an overspeed setpoint violation.

c) Final element solenoid(s) power requirements may dictate the need for a higher power interposing relay(s). Machinery vendor shall provide final element solenoid power requirements to allow proper specification of interposing relays if required.

d) Any additional response delay from the addition of an interposing relay shall be considered in the response time calculation. This is critical in de-energize-to-shutdown applications as the time to energize a relay is typically less than the time to de-energize.

8.4.3 Inputs, Outputs, and Configuration

8.4.3.1 The electronic ODS shall accept speed sensor inputs from either magnetic speed sensors (5.1.5) or proximity probes (5.1.1). Unless otherwise specified, the inputs shall be configured to the standard passive magnetic speed sensor of 5.1.5.2.

8.4.3.2 Each overspeed circuit shall accept inputs from a frequency generator for verifying the shutdown speed setting.

8.4.3.3 Each overspeed circuit shall provide an output for speed readout.

8.4.3.4 All settings incorporated in the overspeed circuits shall be field changeable and protected through controlled access.

8.4.3.5 A peak hold feature with controlled access reset shall be provided to indicate the maximum speed reached since last reset.

NOTE Depending on system design, it may be necessary to reset the peak hold feature after testing to ensure that maximum rotor speed reached during an actual overspeed event is captured.

• **8.4.3.6** If specified, the design of the electronic ODS shall conform to standards IEC 61508, IEC 61511, IEC 62061, or ISO 13849.

8.4.3.7 Online testing functions shall be provided. Activation or deactivation of these functions shall only be permitted through controlled access.

● **8.4.3.8** If specified, the electronic ODS shall include automatic overspeed testing functionality.

8.4.3.9 Automatic overspeed test functionality shall be determined by the responsible party, unless the system is an IEC 61508 or IEC 61511 certified system where it is dictated by the certification report.

8.4.3.10 Overspeed systems shall not have a system bypass (see 4.11.8).

8.4.4 Response Time and Verification

8.4.4.1 The system shall sense an overspeed event and change the state of its output relays within 40 ms or as determined in Annex O, whichever is more restrictive.

8.4.4.2 The maximum allowable rotor speed shall be determined as follows.

a) For steam turbines without reheat, the calculation methodology of Annex O shall be used to determine the maximum allowable rotor speed. Worst case component delay times shall be used in Annex O calculations to verify that the system's worst case response time is fast enough to safely shutdown the machine.

b) For all other machines refer to the applicable API standard.

● **8.4.4.3** If specified, the machine vendor or responsible party shall verify that the response time of the entire overspeed protection system including final control elements is fast enough to prevent the prime mover and any of its driven machines from exceeding their maximum allowable speeds using the following criteria:

a) for steam turbines, the requirements of API 611/API 612 (as appropriate for the specific turbine classification) or OEM limits, whichever is more restrictive;

b) for all other machines, OEM limits.

NOTE 1 The intent of this subsection is to ensure that the entire overspeed protection system meets the required response time to safely shut down the machine, no matter what system architecture is utilized.

NOTE 2 The use of intrinsic safety barriers to meet hazardous area classification requirements may introduce signal delays that preclude the system from meeting acceptable response time criteria. Care should be taken to consider these effects when designing the electronic ODS and choosing components. Alternative methods should be considered as required to meet the area classification requirements.

NOTE 3 Caution should be used when making future changes or additions to the logic in the logic solver as these changes can potentially delay the logic solver response time and impact the response time of the overspeed shutdown function.

8.4.4.4 The OEM limits of 8.4.4.3 shall use the calculation methodology for maximum rotor speed listed in the respective API standards to determine the required system response time.

8.4.4.5 Annex O calculation methodology shall be used to calculate the maximum allowable response time of an overspeed protection system used on a steam turbine. Worst case component delay times (T_S and T_V) shall be used in the calculation.

● **8.4.4.6** If specified, after complete field installation of the machine and its associated overspeed protection system, the vendor or responsible party shall provide test results of the installed system to demonstrate that it does not exceed the required response time of 8.4.4.4. This test shall conform to the following.

a) The actual measured and logged system response time will be compiled for at least three overspeed shutdown events or simulated overspeed shutdown events.

b) The simulated shaft rotational speed at which each electronic shutdown is initiated shall meet the criteria listed in Table 1.

c) The shaft rotational speed at which each mechanical shutdown test is initiated shall not exceed ±0.5 % of the speed setpoint value due to acceleration rate changes in the actual shaft in relationship to the space between teeth in the event wheel and the peak rotor kinetic energy as defined in Annex O.

NOTE 1 The intent of this subsection is to ensure that the entire overspeed protection system meets the required response time to safely shut down the machine, no matter what system architecture is utilized.

NOTE 2 It is recommended that the response time of the electronic overspeed protection system be periodically measured and logged as proof that the system continues to meet the required response time. Routine test intervals are determined by the responsible party, unless the system is an IEC 61508 or IEC 61511 certified system where it is dictated by the certification report.

9 Surge Detection Systems

9.1 General

9.1.1 The function of the surge detection system shall be to detect surges and provide output for use in minimizing the number of surge cycles.

9.1.2 An electronic surge detection system shall be supplied for axial flow compressors.

• **9.1.3** If specified, surge detection shall be supplied on centrifugal compressors.

NOTE 1 Surge detection is required on axial compressors, and should be considered for centrifugal compressors (both inline and integrally geared). In any application for which the consequence of surge-related damage is unacceptable, such as machines with high pressure ratios or power densities, an independent surge detection system may be justified.

NOTE 2 For centrifugal compressors with open impellers, the blade length is much shorter than in axial flow compressors. For centrifugal compressors with closed impellers, the blades are fixed between the hub and shroud. Both impeller styles are more robust against flow oscillations than axial compressor blades.

NOTE 3 Centrifugal compressors are somewhat less sensitive to surge, and many industry applications utilize antisurge control only.

NOTE 4 Compressors with multiple process stages may need surge detection on each stage.

9.2 Accuracy

Flow accuracy is much more dependent on the flow metering device than the flow transducer. Appropriate upstream and downstream straight runs along with pressure and temperature compensation should be accounted for in surge detection applications. Surge detection flow measurement is not expected to require custody transfer accuracy; however, it should include good engineering practice to ensure the protection system is provided with accurate information for proper protection.

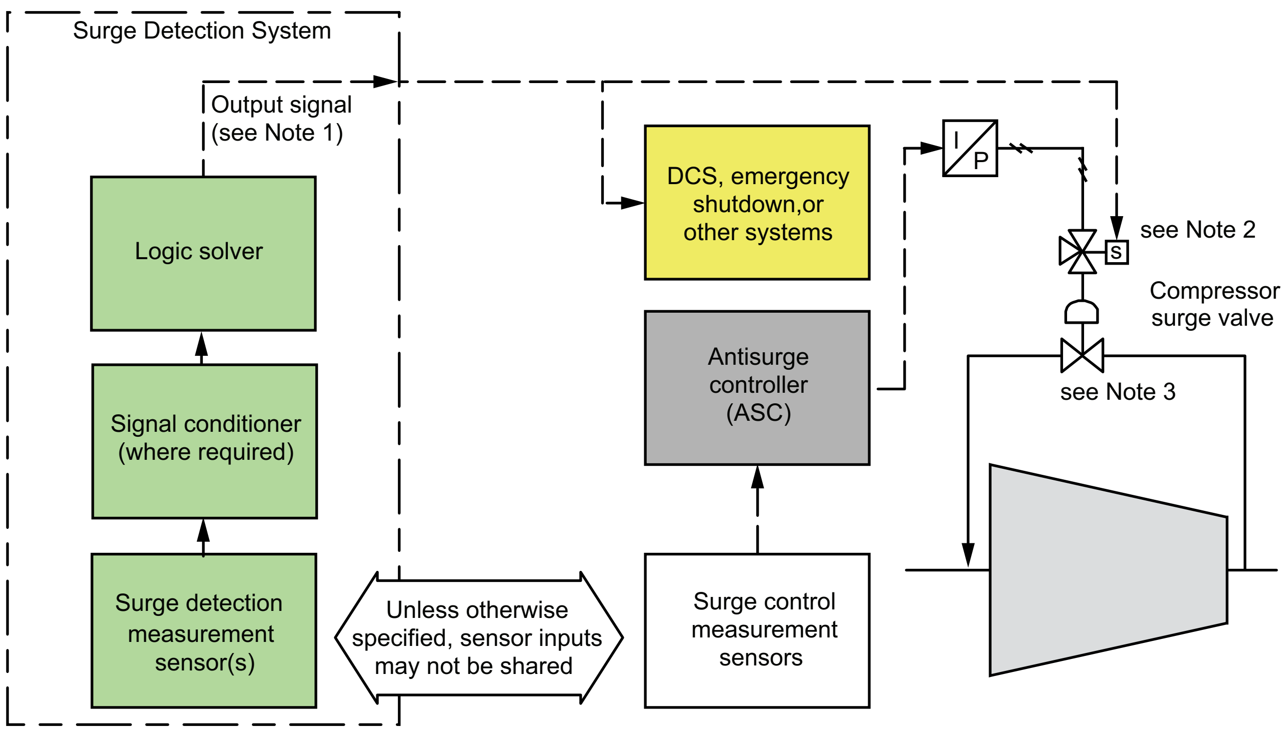
9.3 Segregation

9.3.1 Operation of the surge detection system shall be independent of the antisurge control function, except as noted in 9.3.2 through 9.3.4. Any failure of the antisurge control system shall not affect the surge detection. Any failure of the surge detection system shall not affect the antisurge control.

NOTE The purpose of the surge detection system is to protect the compressor from surge in the event of a failure of the antisurge control system (See Annex K.) Functional segregation of the two systems and adequate redundancy of any shared components (such as logic solvers and/or input sensors) is therefore essential to help prevent common-point failures.

9.3.2 The electronic surge detection system is only one component in the compressor system. The surge detection system is comprised of sensors, transducers, logic solver, surge counter, and outputs that may be used by other logic and annunciating systems. The architecture for the surge detection system shall follow the design shown in Figure 19.

NOTE The primary purpose of the surge detection system is to generate an alarm that compressor is experiencing multiple surge cycles. This alarm can indicate the failure of the antisurge control system. Functional segregation of the surge detection system and antisurge control and adequate redundancy of any shared components is therefore essential to help prevent common-point failures.



NOTE 1 Output signal may be used in various systems.

NOTE 2 Actuator may be pneumatic or hydraulic.

NOTE 3 Recycle loop shown, but other configurations are possible.

Figure 19—Surge Detection and Antisurge Control Systems

9.3.3 Unless otherwise specified, inputs used for compressor surge detection shall be independent from the antisurge control. When redundant inputs are implemented, they can be shared between compressor surge detection and antisurge control system.

9.3.4 Unless otherwise specified, sensors used for compressor surge detection shall be independent from the antisurge control.

• **9.3.5** If specified, the ESD may be combined with the surge detection system. The ESD shall be independent from the antisurge control system.

9.3.6 Antisurge valves and valve actuators can be shared for antisurge control and surge detection.

9.3.7 A common logic solver can be used across multiple stage groups.

9.4 Functions

9.4.1 Detection Methods

9.4.1.1 General

9.4.1.1.1 The compressor surge detection system shall be capable of detecting each surge cycle. If several trigger methods are used for surge detection, the electronic logic solver shall ensure each surge is counted only once.

9.4.1.1.2 A compressor surge is characterized by a rapid decrease and recovery of flow or discharge pressure, or a rapid increase and recovery of inlet temperature, or a combination of these. One or more of the following methods shall be used to detect a surge cycle.

9.4.1.2 Flow Decrease

In the flow decrease method, the compressor flow drops significantly below a fixed flow reference point, typically the lowest surge flow, or there is a rapid decrease in flow. The flow measurement shall be measured as follows:

a) use the principles of differential pressure across a flow restriction,

b) scale the flow transmitter to detect the differential pressure in the surge flow range.

NOTE In some cases, the flow transmitter used for surge detection may need to be configured with a smaller range than the full range flow to reliably sense the flow change.

9.4.1.3 Inlet Temperature Change

9.4.1.3.1 In the inlet temperature change method, the compressor inlet temperature rises considerably above the upstream gas temperature. The compressor inlet temperature shall be measured as follows:

a) the sensor shall be a thermocouple,

b) the thermocouple shall be placed as close to the compressor stage as possible,

c) the sensor tip diameter shall not exceed 1 mm and shall not be inserted in a thermowell.

NOTE The tip diameter and thermowell restrictions help achieve a fast response time for the thermocouple.

9.4.1.3.2 To improve surge detection, the inlet temperature should be temperature compensated with the upstream gas temperature (Figure 20). This will require a second temperature measurement located upstream of the compressor inlet. This sensor is typically a robust process temperature sensor installed within a thermowell and may have a large time lag.

9.4.1.3.3 Alternatively, if temperature rate-of-change is used instead of comparison to the process temperature, then a single inlet thermocouple (less than 1 mm and no thermowell) can be used.

NOTE This method is not suitable for use in hazardous gas applications because of safety concerns.

9.4.1.4 Pressure Decrease

In the pressure decrease method, the compressor experiences a rapid decrease in discharge pressure.

NOTE This method should be used with caution as other causes of a drop in discharge pressure may exist and may result in false surge indications.

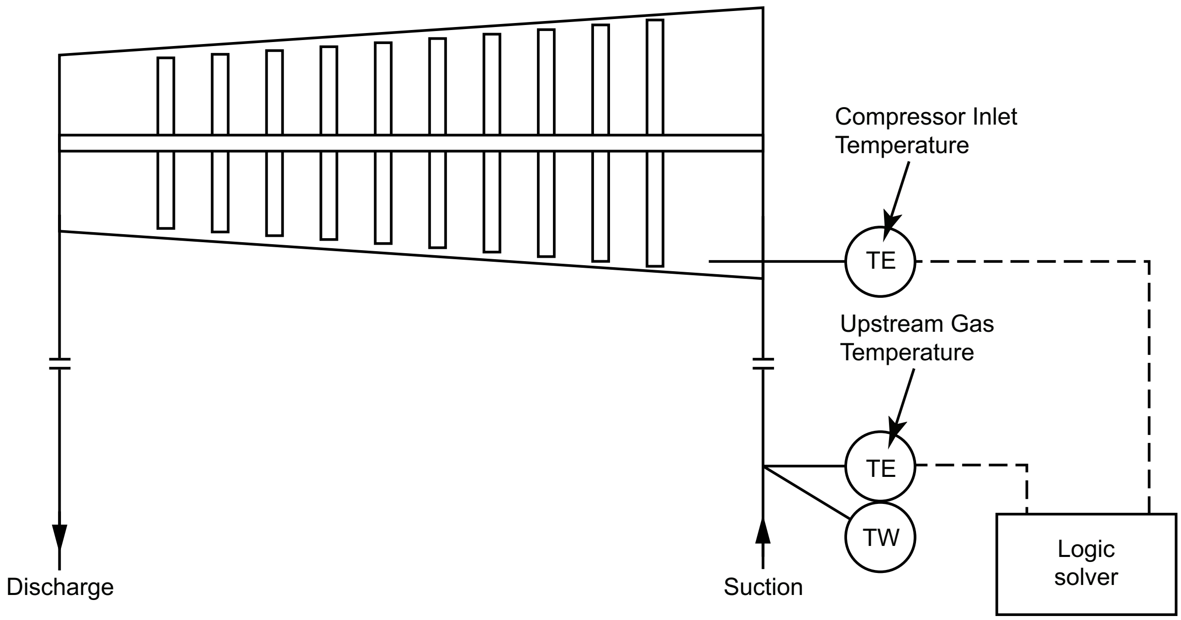


Figure 20—Surge Detection with Compressor Inlet Temperature

9.4.1.5 Others

9.4.1.5.1 Any other proven method may be used for compressor surge detection when mutually agreed to by purchaser and vendor.

9.4.1.5.2 A fixed threshold limit or a rate of change of the sensor signal shall be used to detect surge as indicated in 9.4.1.2 through 9.4.1.4. The magnitude of the rate of change shall be of significantly greater value than the change the compressor sees under normal operating conditions, and should be validated through surge testing when possible. See Annex K for surge testing considerations.

9.4.1.5.3 A nonresettable counter shall be triggered once for each surge.

9.4.2 System Output Relays

All output relays shall conform to 4.12.

9.4.3 Inputs, Outputs, and Configuration

9.4.3.1 An alarm output shall be generated whenever a surge is detected.

NOTE Individual input channel alarm (alert) are not normally required in surge detection. Pre-surge alerts may be useful in certain applications but are not mandated.

• **9.4.3.2** If specified, the surge detection system shall be capable of initiating further actions such as fast opening of the antisurge valves or shutdown of the main driver. These actions may be initiated after a user-defined or machine vendor-defined number of surges has been detected within a user-defined or machine vendor-defined time window. Definition of the time window and number of surges before action is taken should be determined as part of a system evaluation and mutually agreed between the purchaser and vendor.

9.4.3.3 All surge detection devices shall be capable of being tested. Testing shall be performed during initial commissioning and after major changes that may affect the aerodynamic properties of the compressor system.

Consideration shall be given to calibration of the surge detection system with field surge testing to validate complete system functionality.

9.4.3.4 The surge detector shall be capable of disarming the alerting and counting functions during compressor start-up or shutdown.

NOTE Without the ability to disarm surge alerting, the flow and/or pressure drop during compressor rundown may be acted on as a compressor surge and generate false alarms and surge counting. False surge detection can also be generated by the increase in temperature on a stopped compressor. After a stop, the compressor inlet temperature will increase because of heat dissipation.

• **9.4.3.5** If specified, the surge detection system shall include a provision for continuously recording the surge detector measurement sensor readings and output signals. The data logging rate shall be 500 ms or faster and shall provide the ability to store values for a period of time both prior to and after surge detection.

9.4.4 Response Time

9.4.4.1 All components including, but not limited to, the logic solver, valves, solenoids, interposing relays, etc. shall be evaluated for adequate functionality and response time.

NOTE The use of intrinsic safety barriers, isolators, or other signal conditioning equipment may introduce signal delays that preclude the system from meeting the acceptable response time criteria as determined on a case-by-case basis using theoretical, shop test, or field test methods. Care should be taken to consider these effects when designing the electronic surge detection system and choosing components.

9.4.4.2 The electronic logic solver (see Figure 19) shall have a total program execution time of 100 ms or less.

9.4.4.3 The response time of any input device used for the measurement of a critical process variable for use by the surge detection algorithm shall be less than or equal to 200 ms.

NOTE 1 Repeatability and response time are the critical considerations in selecting an input device for surge detection. Accuracy is a less important criterion for surge detection but may be more important for antisurge control. Care should be taken to ensure that the needs of both the antisurge and surge detection systems are considered if sourcing common input devices.

NOTE 2 Engineering experience indicates that response times of less than or equal to 200 ms are adequate, and input devices are commercially available to meet this requirement. General process transmitters may not meet this requirement. For the purpose of this section, response time means that 90 % of the process step change is recognized by the device as listed by the manufacturer.

9.4.4.4 Unless otherwise specified, the overall compressor surge detection response time, as measured at the surge detector output, shall be less than 500 ms.

NOTE Industry and engineering experience indicate that response times of less than or equal to 500 ms are adequate and surge detection functions are commercially available to meet this requirement.

9.4.4.5 All transducers and sensors used for surge detection should be located in close proximity to the suction or discharge flanges of compressor to minimize the resultant lag time in measurement.

10 Emergency Shutdown Systems (ESDs)

10.1 General

10.1.1 The function of the ESD is to act as the logic solver that consolidates all shutdown commands to ensure proper timing and sequencing for a safe shutdown.

10.1.2 The ESD shall be designed to comply with the requirements of IEC 61508, IEC 61511, and this standard. The complexity of the ESD will be determined by the required SIL.

NOTE 1 The ESD may be simple (e.g. set of relay contacts in series) or complex (e.g. PLC type) based on the type of machine train and application (e.g. steam or gas turbines, electric drives, expanders, pumps, or compressors).

NOTE 2 Simple ESD (relay contacts) might not fulfill all requirements of this section.

• **10.1.3** If specified, the design of the shutdown logic solver shall conform to IEC 62061 (machinery safety), ISO 21789 (gas turbine safety), and ISO 13849 (machinery safety), as applicable for the machine type.

10.1.4 The ESD performs the machine train shutdown logic by integrating all shutdown functions and interfaces with the final element(s). The default architecture shall be distributed (see 10.4.2).

NOTE In machine trains where the ESD and/or the overspeed protection system include automated test routines of the final element(s) [e.g. relay(s), solenoid(s)], an integrated architecture may be necessary to ensure that the systems' test routines do not affect each other, compromising system integrity.

• **10.1.5** If specified, the ODS, ESD, and surge detection system may be integrated into the same hardware platform (see 10.4.3).

NOTE Surge detection system is fully independent from antisurge control system (see Annex K).

10.1.5.1 Unless otherwise specified, the ESD supplier shall provide the reliability/performance documentation necessary to validate the SIL for each function.

10.1.5.2 The entity(ies) responsible for installation and configuration of the ESD shall provide documentation affirming the system's compliance with (and/or exceptions to) all aspects of this standard that are configuration- and/or installation-related.

NOTE Certain aspects of the system are hardware dependent, such as performance and most aspects of reliability. However, many aspects of the standard are installation dependent, such as the configurable capabilities of a system (e.g. alarm and relay configuration). The hardware vendor will not be able to affirm total system compliance in cases where they do not also perform installation and configuration.

• **10.1.6** If specified or required by the applicable machine standard(s), the system design shall ensure that no single circuit failure will disable the ESD from meeting its functional requirements.

10.1.7 The ESD shall meet the environmental requirements listed in Table 1 and Section 4 and any hazardous area requirements per 4.9.

10.1.8 The ESD shall be provided with an internal time clock.

10.1.9 The ESD shall have provisions for synchronizing the internal time clock's time and date with an external master clock.

10.1.10 The ESD shall maintain an event list to log module/system alarms and diagnostic tests results.

10.1.11 The event list shall be stored in the system's nonvolatile memory.

10.1.12 The event list shall be maintained in the event of a total loss of power or loss of communications.

10.1.13 Unless otherwise specified, the ESD event list requirements are as follows:

a) event time stamp shall have 1 ms resolution

b) 30-day retention or 10,000 events,

c) event log based on a first-in/first-out sequence.

10.2 Functional Requirements

10.2.1 The ESD shall satisfy the following requirements.

a) The level of redundancy of the system shall be determined by the corresponding API machinery standard and a SIL analysis (see Annex L).

b) Unless otherwise specified, the system shall be capable of responding to a shutdown condition in less than 100 ms.

NOTE The 100 ms time requirement only includes the time from the change detected in the input to the change in the output. If using a digital system, this would imply a scan rate of less than 50 ms.

c) Any shutdown condition sensed shall, at a minimum, shut down the driver and both initiate and indicate an alarm of the specific condition. In simple systems, this may be accomplished at the individual monitor systems (e.g. indication at a local panel).

d) Failure of a shutdown sensor, power supply, or logic device in any circuit shall, as a minimum, initiate and indicate a condition-specific alarm.

e) Items c) and d) shall require manual alarm reset (i.e. latching alarms).

f) All configuration and settings incorporated in the shutdown logic solver shall be field changeable and protected through controlled access.

g) Required test intervals are determined by the responsible party unless the system is an IEC 61508 or IEC 61511 certified system, in which case tests are dictated by the SIL verification report.

• **10.2.2** The purchaser shall specify the safety critical shutdown signals to the ESD that can affect plant personnel safety.

10.2.3 The vendor with unit responsibility shall specify machine protection shutdown signals.

• **10.2.4** If specified, any condition external to the ESD that initiates a shutdown shall activate the ESD shutdown logic.

10.2.5 The level of redundancy and fault tolerance for the shutdown logic solver shall, as a minimum, meet the same uninterrupted service requirements as the main machine control system. See applicable API standard for the respective requirements.

10.2.6 Initiation of any shutdown condition shall cause the system's shutdown valve(s) and governor-controlled valve(s) to close and/or the main driver circuit breaker(s) to open.

10.2.7 Both the shutdown and governor-controlled valves shall be designed to fail close on loss of actuator power or control signal (hydraulic, pneumatic, or electrical).

10.2.8 If the ESD is supplied by the machine vendor, the machine vendor shall have responsibility for the entire ESD.

10.2.9 If the ESD is not supplied by the machine vendor, the supplier shall provide the total shutdown system response time and the machine vendor shall review and accept or reject the proposed system.

10.2.10 The ESD shall utilize internal, automatic self-testing that provides (at a minimum) all of the following:

a) microprocessor operation,

b) program execution,

c) input output integrity,

d) communication port operation.

e) an event log containing all self-test failures.

10.3 ESD Security

10.3.1 The stored software application program shall be protected under management-of-change processes and at least two levels of programming security.

10.3.2 A keylock switch or other interlocking device shall be provided, inhibiting access to configuration and programming functions when in the off position.

10.3.3 Password encryption capability meeting industry standards shall be provided.

10.3.4 A keypad and display shall be provided for password entry.

10.3.5 A log of changes and user ID associated with the change shall be provided.

10.3.6 At least 16 user IDs shall be provided.

10.3.7 Program shall be protected by nonvolatile semiconductor memory such that indefinite power loss does not result in program loss.

10.3.8 A communication port allowing updates to and backups of the ESD programming shall be provided.

• **10.3.9** If specified, remote access shall be provided for troubleshooting purposes. The ESD vendor and the end user shall implement security measures to ensure that the functions of the ESD are not compromised while a machine is under power.

10.4 ESD Arrangement

10.4.1 General

10.4.1.1 ESD may be broadly categorized into two types: distributed (see 10.4.2) and integrated (see 10.4.3).

10.4.1.2 Unless otherwise specified, the ESD shall be of distributed type such that it is separate from and independent of all other monitoring systems defined by this standard.

• **10.4.1.3** If application requirements or testing requirements dictate and with purchaser approval, an integrated ESD and overspeed system may be provided (see 10.4.3).

NOTE Distributed systems with separate automated testing intervals could coincide and cause a spurious shutdown.

10.4.1.4 If any system is integrated with the ESD, the vendor with unit responsibility shall ensure that the most stringent requirements of all the individual systems are met by the combined system (see 10.4.3).

10.4.2 Distributed System

10.4.2.1 The vendor with unit responsibility shall clearly define the final element interface and ODS/ESD shutdown circuit power requirements.

• **10.4.2.2** If redundant trip outputs to the final element are specified, careful consideration shall be given to the configuration and any online testing requirements in accordance with IEC 61508 and IEC 61511.

10.4.2.3 The ESD and the overspeed system shall both have direct control of the final shutdown element (see Figure 21).

10.4.2.4 The ESD and the overspeed system shall both receive final shutdown element feedback (see Figure 21).

10.4.2.5 The ESD shall receive and process all shutdown signals except overspeed.

10.4.2.6 The ESD shall receive the shutdown status signal from the overspeed system.

10.4.2.7 The number of inputs and ouputs to/from ESD to the final element shall be based on SIL analysis in accordance with IEC 61511 and IEC 61508 guidelines.

10.4.3 Integrated System

10.4.3.1 The vendor with unit responsibility shall clearly define the final element interface and ODS/ESD shutdown circuit power requirements.

• **10.4.3.2** If redundant trip outputs to the final element are specified, careful consideration shall be given to the configuration and any online testing requirements in accordance with IEC 61508 and IEC 61511.

10.4.3.3 In an integrated arrangement, all shutdown signals shall come into the combined overspeed system/ESD (see Figure 22).

10.4.3.4 The combined overspeed system/ESD shall have direct control of the final shutdown element.

10.4.3.5 The combined overspeed system/ESD shall receive feedback directly from the final shutdown element.

10.4.3.6 The number of inputs and outputs to/from the ESD to the final element shall be based on SIL analysis in accordance with IEC 61511 and IEC 61508 guidelines.

10.5 ESD Interface

10.5.1 General

See 4.12 for requirements of the system output relay design.

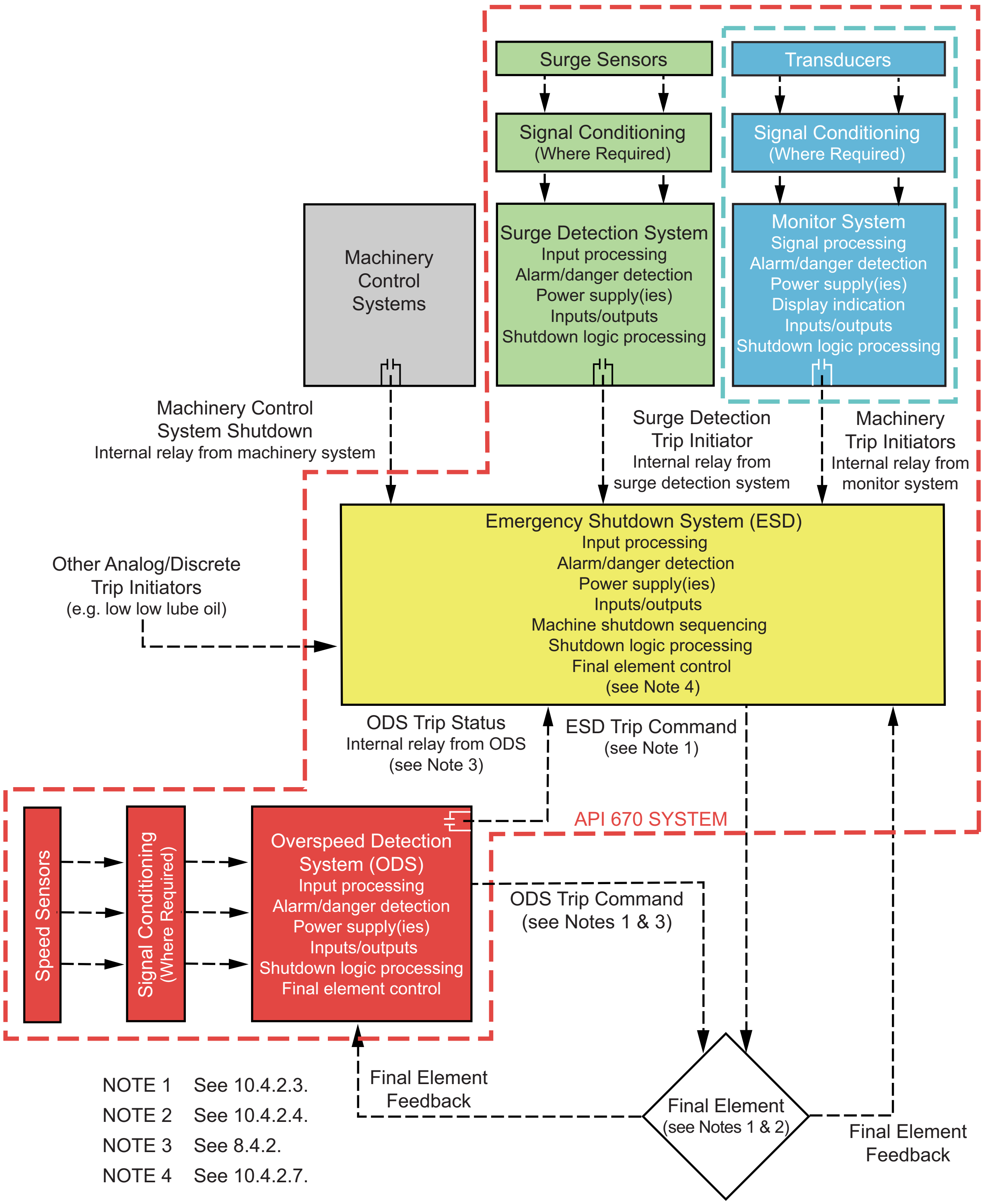
10.5.2 Monitor System Interface Wiring

All monitor system interface signals required in 4.12 and 7.3 shall be dry contact, direct wired to the ESD when located within the same MPS cabinet. Intermediate terminal strips shall be minimized when located separately.

NOTE The intent of this requirement is to minimize the failure points that could potentially exist in multiple junction points.

• 10.5.3 Monitor System Shutdown Initiators

If specified, connecting a series of shutdown relays for similar shutdown functions is acceptable (i.e. radial shutdown on compressor, radial shutdown on gearbox, and radial shutdown on driver can be connected in series for a common radial vibration shutdown input to the ESD.)



NOTE 1 See 10.4.2.3.

NOTE 2 See 10.4.2.4.

NOTE 3 See 8.4.2.

NOTE 4 See 10.4.2.7.

Figure 21—Typical System Arrangement Using Distributed Architecture

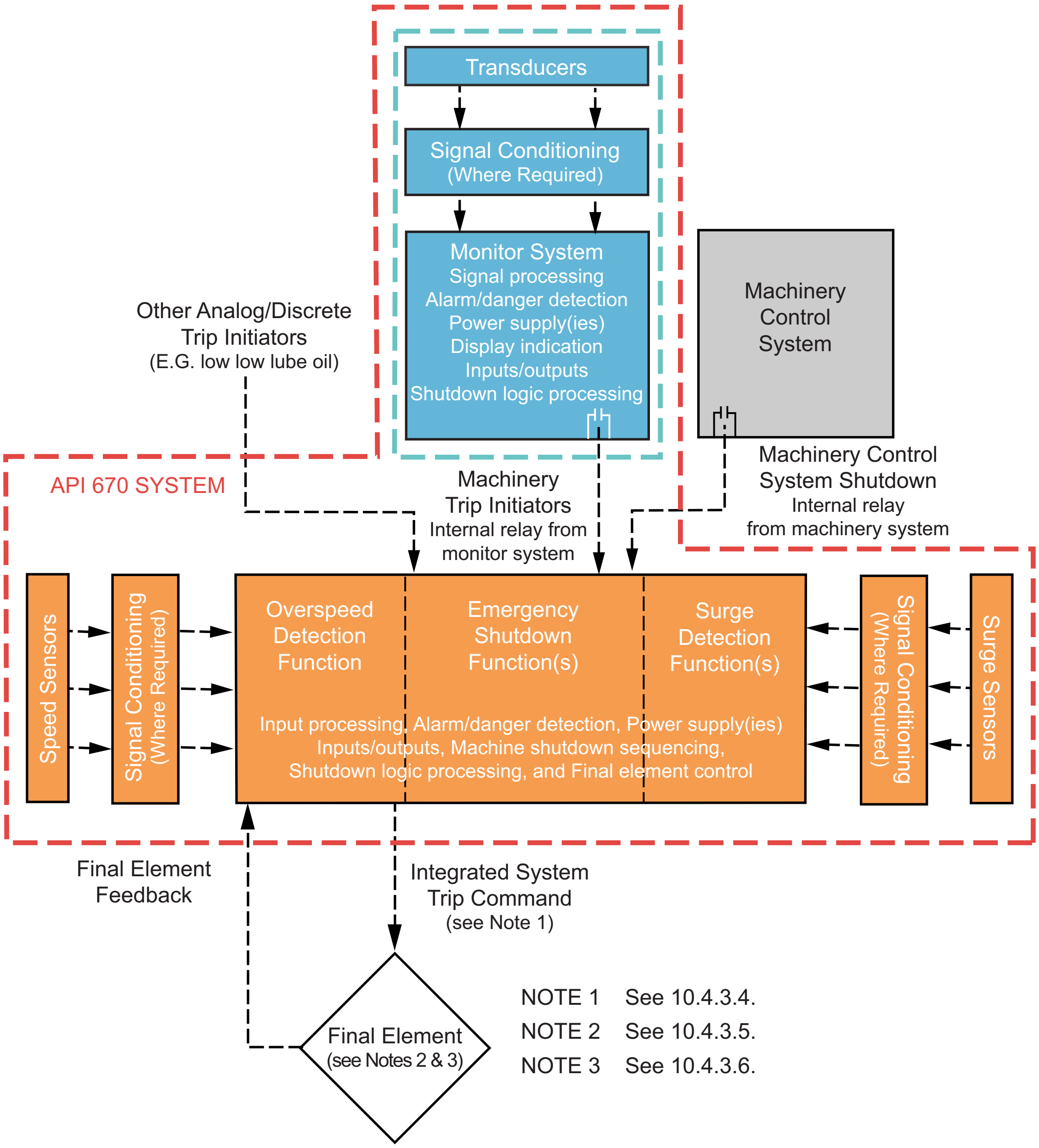


Figure 22—Typical System Arrangement Using Integrated Architecture

10.5.4 Electronic ODS Interface

See 4.11.8 for requirements of the electronic overspeed status design.

10.5.5 Electronic ODS Interface Wiring

All ODS hardwired interface signals required in 4.12 and 8.4.2 shall be dry contact, direct wired to the ESD when located within the same MPS cabinet. Intermediate terminal strips shall be minimized when located separately.

NOTE The intent of this requirement is to minimize the failure points that could potentially exist in multiple junction points.

10.6 Display, Indications

An ESD shall include the following display/indication functions.

- • a) A means of displaying all measured alarm and shutdown variables used in the ESD and, if specified, the corresponding setpoints generated in the ESD.

b) The display may be integral or nonintegral to the ESD hardware.

c) If the display is not integral to the hardware, then the following minimum local status indication (positive illumination, for example, lighted in the annunciated condition) shall be provided (as applicable).

  1) Power status.

  2) When the display is linked via a digital communications link then an indication of the status of that communications link shall be provided.

  3) System diagnostic fault.

10.7 System Inputs

10.7.1 General System Inputs

10.7.1.1 The purchaser shall specify all input signals to the ESD. As a minimum, the following shutdown input signals shall be included in the ESD:

a) machine controller shutdown command;

b) monitor system shutdown command;

c) final shutdown element safe position;

d) (if supplied) shutdown solenoid safe position;

e) ODS shutdown status;

f) overspeed shutdown status on turbines, expanders, and VFDs;

NOTE This specifically refers to the status and not the actual shutdown signal. The shutdown signal directly connects to the final element (see 8.3.6).

g) shutdown initiated by unit speed controller (on variable speed machines);

h) bearing lube oil pressure;

- • i) radial vibration (if specified);

- • j) axial position (if specified);

k) unit speed controller failure (on variable speed machines).

NOTE These shutdown input signals are necessary to activate the machine and process shutdown systems if the machine is manually/hydraulically shutdown.

Refer to the respective equipment standard (e.g. API 611, API 612, API 614, API 616, and API 617) for a list of the required safety critical shutdown inputs.

10.7.1.2 As a minimum, redundant shutdown command signals shall be provided from each of the following systems:

a) monitor system,

b) machine control system.

10.7.1.2.1 These shutdown command signals shall be performed via mechanical or solid state relays and shall utilize a fail-safe de-energized to shutdown. The shutdown logic solver shall use a one-out-of-two voting logic to determine an input shutdown command.

10.7.1.2.2 If mechanical relays are used, they shall be the epoxy sealed electromechanical type.

• **10.7.1.2.3** If specified, hermetically sealed electromechanical type relays shall be provided.

10.7.1.2.4 All mechanical relays shall be double-pole, double-throw type with electrically isolated contacts, and all contacts shall be available for wiring.

10.7.1.2.5 If solid state relays are used by any of the above listed systems to communicate shutdown command signals to the shutdown logic solver or supervisory module, the solid state relay's leakage current shall be below that of the logic solver input channel's de-energized threshold level to ensure that an accurate shutdown command signal is received.

NOTE This is necessary to activate the machine and process shutdown systems if the machine is manually/hydraulically shut down.

10.7.2 Inputs from Other Devices

Refer to the respective machinery standard (e.g. API 610, API 611, API 612, API 616, and API 617) for a list of the required shutdown command signals to be monitored by the shutdown logic solver.

10.7.3 Inputs from Final Shutdown Element and Interposing Circuits

10.7.3.1 The safe position indication signal from the final shutdown element shall be used by the logic solver to monitor the system's total shutdown circuit response time.

• **10.7.3.2** This safe position indication signal shall indicate that the machine's input energy source has been removed (e.g. valve closed, breaker open).

10.7.3.3 Safe position indication signals from final shutdown elements shall be performed via limit switches and shall utilize an energize-when-safe action.

10.7.3.4 The limit switches used shall be the epoxy sealed electromechanical type.

• **10.7.3.5** If specified, hermetically sealed electromechanical type limit switches shall be provided.

• **10.7.3.6** If specified, an analog signal indicating final shutdown element position using a linear variable differential transformer or similar shall be monitored by the ESD to indicate that the machine's input energy source has been removed (e.g. valve closed, breaker open).

• **10.7.3.7** If specified, a feedback signal indicating associated interposing relays or shutdown solenoid position shall be monitored/accepted by the ESD to indicate proper action and response time of the solenoid assembly and associated circuit.

10.8 System Outputs

10.8.1 ESD Output to Final Shutdown Element

10.8.1.1 The shutdown command output signal(s) shall be performed via mechanical relays with a fail-safe normally energized action.

10.8.1.2 The output relay(s) used shall be the epoxy-sealed electromechanical type.

• **10.8.1.3** If specified, hermetically-sealed electromechanical type relays shall be provided.

10.8.1.4 Unless otherwise specified, all relays shall be single-pole, double-throw type with electrically isolated contacts.

• **10.8.1.5** If specified, double-pole, double throw type relays with electrically isolated contacts shall be provided with all contacts available for wiring.

10.8.2 System Fault Relay

• If specified, a system diagnostic fault relay shall be available for indication of internal ESD faults.

11 Inspection, Testing, and Preparation for Shipment

11.1 General

11.1.1 After advance notification of the MPS vendor by the purchaser, the purchaser's representative shall have entry to all vendor and subvendor plants where manufacturing, testing, or inspection of the equipment is in progress.

11.1.2 The MPS vendor shall notify subvendors of the purchaser's inspection and testing requirements.

11.1.3 The MPS vendor shall provide sufficient advance notice to the purchaser before conducting any inspection that the purchaser has specified to be witnessed or observed.

• **11.1.4** The purchaser will specify the extent of participation in inspection and testing (including shop testing and inspection) and the amount of advance notification required.

11.1.5 Equipment for the specified inspection and tests shall be provided by the MPS vendor.

11.1.6 The purchaser's representative shall have access to the MPS vendor's quality control program for review.

11.2 Inspection

Unless otherwise specified, the MPS vendor shall keep the following data available in electronic format for at least 10 years for examination by the purchaser or his/her representative upon request:

a) purchase specifications for all major items on bills of materials,

b) test and calibration data to verify that the requirements of the specification have been met.

11.3 Testing

11.3.1 General

11.3.1.1 Equipment shall be tested in accordance with 11.3.2.

11.3.1.2 The MPS vendor shall notify the purchaser not less than five working days before the date the equipment will be ready for testing. If the testing is rescheduled, the MPS vendor shall notify the purchaser not less than five working days before the new test date.

11.3.2 Machinery Protection System Vendor Testing

11.3.2.1 As a minimum, the MPS vendor shall individually bench test each component of the monitor system to ensure compliance with the accuracy requirements of Table 1.

• **11.3.2.2** If specified, a factory acceptance test of the MPS shall be conducted. Details of this test shall be mutually agreed upon by the MPS vendor and the owner.

NOTE This test may include (but is not limited to) integration with process control, ESD, machinery data acquisition and diagnostic, or other systems; simulation of transducer system inputs and proper operation of output; and display and communication capabilities.

11.3.2.3 The MPS vendor shall have test documentation and certification available for inspection by the purchaser.

11.4 Preparation for Shipment

11.4.1 The MPS vendor shall provide the purchaser with the instructions necessary to preserve the integrity of the storage preparation after the equipment arrives at the job site and before start-up.

11.4.2 The equipment shall be prepared for shipment after all testing and inspection have been completed and the equipment has been released by the purchaser.

11.4.3 The equipment shall be identified with item and serial numbers. Material shipped separately shall be identified with securely affixed, corrosion-resistant metal tags indicating the item and serial number of the equipment for which it is intended. Where the equipment does not provide sufficient room for attachment of metal tags, a mutually agreed upon means for indicating item and serial number shall be used. In addition, crated equipment shall be shipped with duplicate packing lists, one on the inside and one on the outside of the shipping container.

11.4.4 One copy of the manufacturer's standard installation instructions shall be packed and shipped with the equipment.

• **11.4.5** The purchaser shall specify to the vendor any specialized requirements for packing, sealing, marking, or storage of the equipment.

11.5 Mechanical Running Test

Unless otherwise specified, transducer systems of the same type and manufacture as those purchased for the installation shall be in use during the factory mechanical running test of monitored equipment.

11.6 Field Testing

11.6.1 All features of the monitor system specified in Section 4 shall be functionally tested by the construction agency (see Annex F).

11.6.1.1 Results shall be documented in accordance with 12.3.

11.6.1.2 The construction agency shall verify that the alarm (alert) and shutdown (danger) setpoints are adjusted to the values agreed upon by the purchaser.

• **11.6.2** If specified each monitor system shall be tested in the field to verify calibration in the testing temperature range (see 4.1).

11.6.2.1 These tests shall be conducted in accordance with 11.6.2 through 11.6.6 by the construction agency using the actual monitoring system components to be installed on the machine.

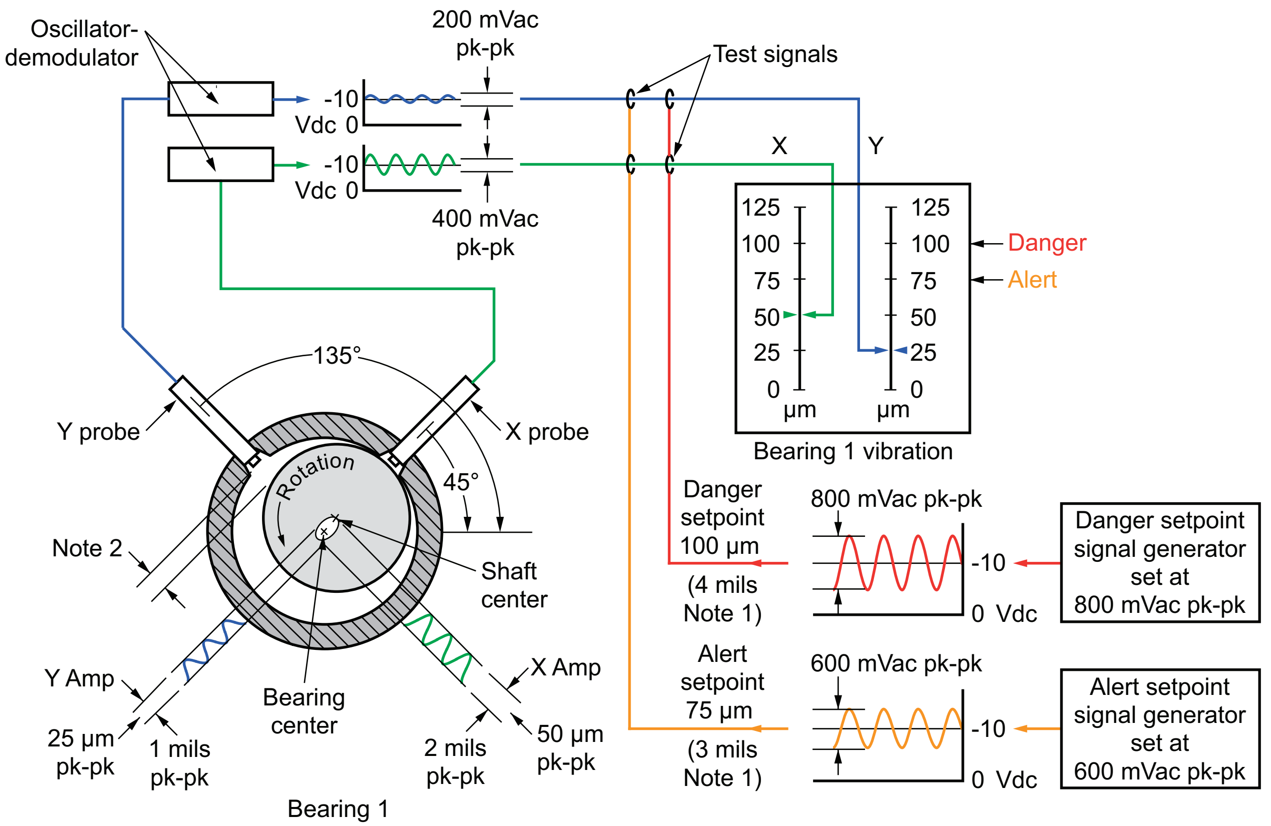
11.6.2.2 Results shall be documented in accordance with 12.3.

NOTE Figure 23 and Figure 24 illustrate typical overall system functions.

11.6.3 For proximity probe transducer systems, a graph of the gap (a minimum of 10 points in either micrometers or mils) versus the transducer's output voltage shall be provided by the construction agency and supplied to the owner (see Figure 25).

11.6.3.1 This procedure shall be performed in accordance with the requirements of the MPS vendor (see Annex G).

• **11.6.3.2** If specified, calibration to the installed probe area shall be performed.



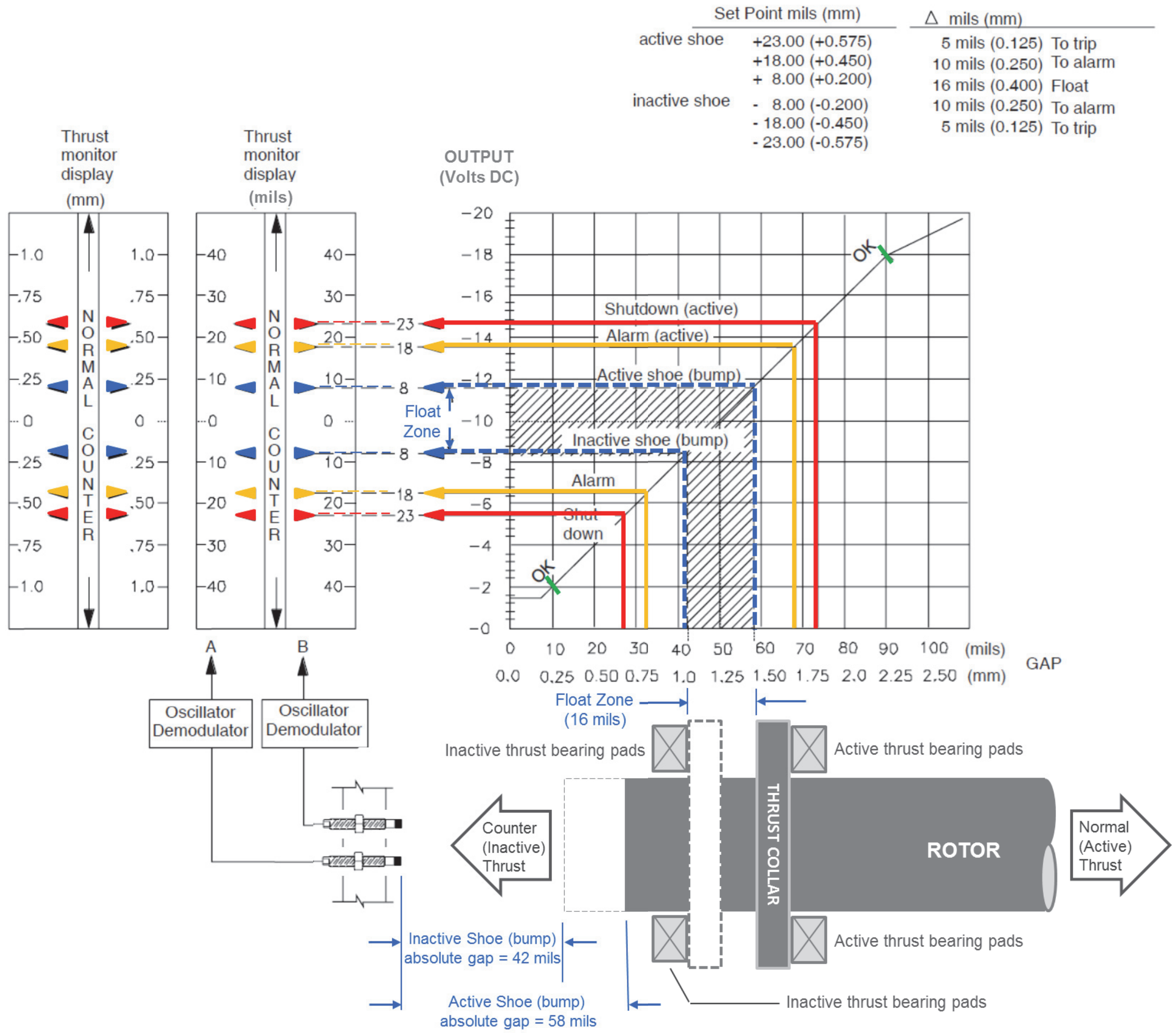
NOTE 1 The example shown is for illustration only and does not necessarily represent any actual condition or machine.

NOTE 2 Probe cold gap setting is typically 1250 µm (50 mils), which corresponds to approximately 10 Vdc.

Figure 23—Calibration of Radial Monitor and Setpoint for Alarm and Shutdown

11.6.4 Temperature monitors shall be tested by substitution of the job temperature sensor with an appropriate sensor simulator. A minimum of three points (20 %, 50 %, and 80 % of span) shall be simulated and the monitor readings recorded.

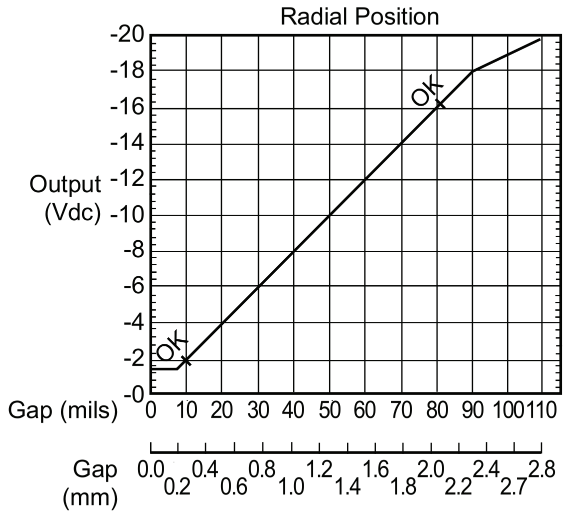
• **11.6.5** If specified for casing vibration systems, a shaker simultaneously exciting the job accelerometer and a calibrated reference accelerometer shall be used for testing.



NOTE 1 The monitor is calibrated for 200 millivolts per mil and has a cold float zone of 16 mils. The monitor's range is from +40 mils to -40 mils. The calibration procedure consists of the following steps: (1) verifying the calibration curve, (2) bumping the shaft to the active shoe, (3) adjusting the probe for a meter indication of 8 mils (a transducer output of approximately 11.6 Vdc), (4) bumping the float to confirm the thrust, and (5) setting the alarm and shutdown points.

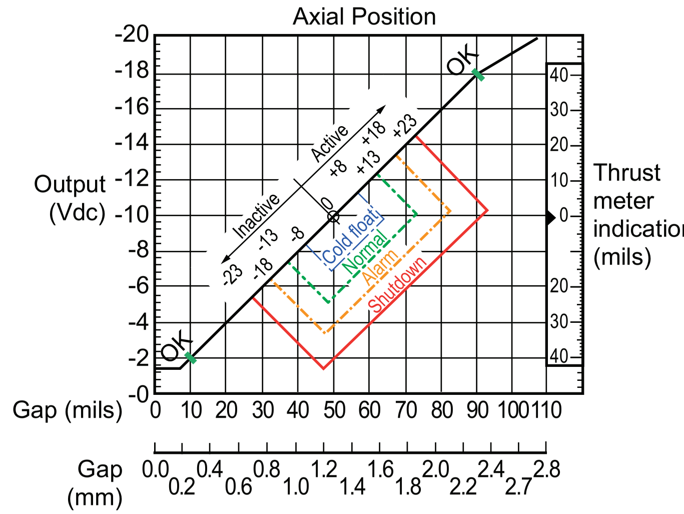
NOTE 2 The example shown is for illustration purposes only and does not necessarily represent any actual condition or machine.

Figure 24—Calibration of Axial Position (Thrust) Monitor



Calibration gap (mils)		Output (Vdc)	
10		-2.0	
20		-4.0	
30		-6.0	
40		-8.0	
50		-10.0	
60		-12.0	
70		-14.0	
80		-16.0	
90		-18.0	

Machine tag number: ________________
Probe tag number: ________________
Probe serial number: ________________
Model: ____________ Length: ________
Extension cable number: ____________
Probe resistance (ohm): ____________
Probe and cable resistance (ohm): ______
Oscillator - demodulator:
Type/serial number: ______________
Supply voltage: ____________________
Cold gap set: ______________________
Alarm set point: ___________________
Shutdown set point: ________________
Date: ____________



Output (Vdc)		Meter indication
-2.0		-40
-4.0		-30
-6.0		-20
-8.0		-10
-10.0		0
-12.0		+10
-14.0		+20
-16.0		+30
-18.0		+40

Machine tag number: ________________
Probe tag number: ________________
Probe serial number: ________________
Model: ____________ Length: ________
Extension cable number: ____________
Probe resistance (ohm): ____________
Probe and cable resistance (ohm): ______
Oscillator - demodulator:
Type/serial number: ______________
Supply voltage: ____________________
Cold gap set: ______________________
Alarm set point: ___________________
Shutdown set point: ________________
Date: ____________

NOTE Referenced to 200 millivolts.

Figure 25—Typical Field Calibration Graph for Radial and Axial Position (Gap)

11.6.5.1 The accelerometer shall be tested over the frequency and amplitude ranges listed in Table 4 and Table 5.

11.6.5.2 The monitor system shall be tested to full-scale amplitude by electronic simulation.

11.6.6 Tachometer and electronic ODS's shall be tested to full-scale range by electronic simulation.

11.6.7 The construction agency shall perform a field test of the entire MPS to verify operation to design specification requirements.

11.6.7.1 This test shall include system performance and functionality of its integration with other control, automation, and information systems.

11.6.7.2 Details of this test shall be mutually agreed upon by the construction agency and the owner. Results shall be documented in accordance with 12.3.

NOTE This test may include (but is not limited to) integration with process control, ESD, machinery data acquisition and diagnostic, or other systems; simulation of transducer system inputs and proper operation of output; and display and communication capabilities.

Table 4—Accelerometer Test Points (SI)

Frequency Hz	**Acceleration**		**Velocity**	
	m/s^2 rms	m/s^2 peak	mm/s rms	mm/s peak
10 [a]	1	1.41	15.92	22.51
20	7	9.90	55.70	78.78
50	7	9.90	22.28	31.51
100 [a]	7	9.90	11.14	15.76
159.15 [b]	7	9.90	7.00	9.90
200	7	9.90	5.57	7.88
500	7	9.90	2.23	3.15
1,000 [a]	7	9.90	1.11	1.58
1,000	15	21.21	2.39	3.38
2,000	30	42.43	2.39	3.38
5,000 [a]	30	42.43	0.95	1.35
10,000	30	42.43	0.48	0.68

NOTE All values are based on sinusoidal waveforms.

[a] These values are required test points.

[b] At 159.15 Hz, 1 m/s^2 = 1 mm/s (crossover frequency).

12 Vendor's Data

12.1 General

12.1.1 The information required in this section shall be furnished by the machinery vendor with unit responsibility or by the responsible agency specified in Annex B. The machinery vendor shall complete and forward the Vendor Drawing and Data Requirements Form to the address or addresses noted on the inquiry or order (see Annex G). This form shall detail the schedule for transmission of drawings, curves, and data as agreed to at the time of the order, as well as the number and type of copies required by the purchaser.

Table 5—Accelerometer Test Points (USC Units)

Frequency Hz	Acceleration		Velocity	
	g peak	g rms	ips peak	ips rms
10 [a]	0.15	0.11	0.92	0.65
20	1	0.71	3.08	2.17
50	1	0.71	1.23	0.87
61.44 [b]	1	0.71	1.00	0.71
100 [a]	1	0.71	0.62	0.43
200	1	0.71	0.31	0.22
500	1	0.71	0.12	0.09
1000 [a]	1	0.71	0.06	0.04
1,000	2	1.41	0.12	0.09
2,000	4	2.83	0.12	0.09
5,000 [a]	4	2.83	0.05	0.03
10,000	4	2.83	0.02	0.02

NOTE All values are based on sinusoidal waveforms.

[a] These values are required test points.

[b] At 61.44 Hz, 1 g = 1 ips (crossover frequency).

12.1.2 The data shall be identified on transmittal (cover) letters and in title blocks or title pages with the following information:

a) the purchaser/owner's corporate name;

b) the job/project number;

c) the equipment item or tag number and service name;

d) the purchase order number;

e) any other identification specified in the inquiry or purchase order;

f) the machinery vendor's identifying proposal number, shop order number, serial number, or other reference required to identify return correspondence completely.

12.1.3 A coordination meeting covering the API 670 MPS shall be held (preferably at the entity holding unit responsibility for the entire machinery train in the case of new machines) within four to six weeks after the purchase commitment.

12.1.4 Unless otherwise specified, the machinery vendor having unit responsibility will prepare and distribute an agenda prior to this meeting that, as a minimum, shall include review of the following items relative to the API 670 MPS:

a) the purchase order, scope of supply, unit responsibility, and subvendor's items;

b) the datasheets;

c) applicable specifications and previously agreed-upon exceptions;

d) schedules for transmittal of data, production, and testing;

e) the quality assurance program and procedures;

f) inspection, expediting, and testing;

g) schematics and bills of material;

h) the physical orientation of the rotating equipment with relation to the API 670 system components;

i) other technical items.

12.2 Proposals

12.2.1 General

• **12.2.1.1** The machinery vendor shall forward the original proposal and the specified number of copies to the addressee noted in the inquiry documents.

12.2.1.2 As a minimum, the proposal shall include the data identified in 12.2.2 and 12.2.3, as well as a specific statement that the system and all its components are in strict accordance with this standard. If the system and components are not in strict accordance, the machinery vendor shall include a list that details and explains each deviation.

12.2.1.3 The machinery vendor shall provide details to enable the purchaser to evaluate any proposed alternative designs. All correspondence shall be clearly identified in accordance with 12.1.2.

12.2.2 Drawings

12.2.2.1 The drawings indicated on the Vendor Drawing and Data Requirements Form shall be included in the proposal (see Annex G). As a minimum, the following data shall be furnished:

a) a general arrangement or outline drawing for each monitoring system, including overall dimensions, installation details, and maintenance clearance dimensions;

b) schematics of all control and electrical systems with bills of materials shall be included.

12.2.2.2 If typical drawings, schematics, and bills of materials are used, they shall be marked up to reflect the actual equipment and scope proposed and shall have the same specific project information as noted in 12.1.4 a) to 12.1.4 i).

12.2.3 Technical Data

The following data shall be included in the proposal.

a) The purchaser's datasheets, with complete machinery vendor's information entered thereon and literature to fully describe details of the offering.

b) The Vendor Drawing and Data Requirements Form, indicating the schedule according to which the machinery vendor agrees to transmit all the data specified as part of the contract (see Annex G).

c) A schedule for shipment of the equipment, in weeks after receipt of the order.

d) A list of spare parts recommended for start-up and normal maintenance purposes.

e) A list of the special tools furnished for maintenance. The machinery vendor shall identify any metric items included in the offering.

f) A statement of any special weather protection and winterization required for start-up, operation, and periods of idleness under the site conditions specified. The statement shall show the protection to be furnished by the purchaser, as well as that included in the machinery vendor's scope of supply.

g) A description of any special requirements specified in the purchaser's inquiry.

h) A description of how the system meets specified area classification requirements, as discussed in 4.9.1.

i) Any special requirements or restrictions necessary to protect the integrity of the MPS.

j) Any component designed for finite life in 4.17.1.

k) Any scheduled maintenance practice or inspection that would not meet the prescribed uninterrupted continuous operational interval of 4.17.2.

12.3 Contract Data

12.3.1 General

12.3.1.1 The contract data specified in Annex G shall be furnished by the machinery vendor or responsible agency specified in Annex B. Each drawing, bill of material, and datasheet shall have a title block in its lower right-hand corner that shows the date of certification, a reference to all identification data specified in 12.1.2, the revision number and date, and the title.

12.3.1.2 The purchaser shall promptly review the machinery vendor's data when he/she receives them; however, this review shall not constitute permission to deviate from any requirements in the order unless specifically agreed upon in writing. After the data have been reviewed, the machinery vendor shall furnish certified copies in the quantity specified.

12.3.2 Drawings

The drawings furnished shall contain sufficient information so that with the drawings and the manuals specified in 12.3.5, the construction agency or owner can properly install, operate, and maintain the ordered equipment. Drawings shall be clearly legible, shall be identified in accordance with 12.3.1.1, and shall be in accordance with ASME Y14.2M. As a minimum, each drawing shall include the details for that drawing listed in Annex G.

12.3.3 Technical Data

The data shall be submitted in accordance with Annex G and identified in accordance with 12.3.1.1. Any comments on the drawings or revisions of specifications that necessitate a change in the data shall be noted by the machinery vendor. These notations will result in the purchaser's issue of completed, corrected datasheets as part of the order specifications.

12.3.4 Parts Lists and Recommended Spares

12.3.4.1 The machinery vendor shall submit complete parts lists for all equipment and accessories supplied and shall include the following:

a) the manufacturer's unique part numbers, materials of construction, and delivery times;

b) materials identified as specified in Section 4 through Section 10;

c) each part completely identified and shown on cross-sectional or assembly-style drawings so that the purchaser may determine the interchangeability of the part with other equipment;

d) parts that have been modified from standard dimensions or finish to satisfy specific performance requirements shall be uniquely identified by part number for interchangeability and future duplication purposes;

e) standard purchased items identified by the original manufacturer's name and part number.

12.3.4.2 The machinery vendor shall indicate on the above parts lists which parts are recommended spares for start-up and which parts are recommended for normal maintenance [see 12.2.3 d)]. The machinery vendor shall forward the lists to the purchaser promptly after receipt of the reviewed drawings and in time to permit order and start-up. The transmittal letter shall be identified with the data specified in 12.1.2.

12.3.5 Installation, Operation, Maintenance, and Technical Data Manuals

12.3.5.1 General

The machinery vendor shall provide sufficient written instructions and a list of all drawings to enable the purchaser and the owner to correctly install, operate, and maintain all of the equipment ordered. This information shall be compiled in a manual or manuals with a cover sheet that contains all reference-identifying data specified in 12.1.2, an index sheet that contains section titles, and a complete list of referenced and enclosed drawings by title and drawing number. The manual shall be prepared for the specified installation; a typical manual is not acceptable.

12.3.5.2 Installation Manual

Any special information required for proper installation design that is not on the drawings shall be compiled in a manual that is separate from the operating and maintenance instructions. This manual shall be forwarded at a time that is mutually agreed upon in the order or at the time of the final issue of prints. The manual shall contain information such as special calibration procedures and all other installation design data.

12.3.5.3 Operating and Maintenance Manual

The manual containing operating and maintenance data shall be forwarded no more than two weeks after all of the specified tests have been successfully completed. This manual shall include a section that provides special instructions for operation at specified extreme environmental conditions, such as temperatures. As a minimum, the manual shall also include all of the data listed in Annex G.

• 12.3.5.4 Technical Data Manual

If specified, the vendor with unit responsibility shall provide the purchaser with a technical data manual within 30 days of completion of shop testing (see Annex G for detail requirements).

Annex A
(informative)

Machinery Protection System Datasheets

PAGE ________ OF ________

MACHINERY PROTECTION SYSTEM DATA SHEET

JOB NO. ____________ ITEM NO. ____________
PURCH. ORDER NO. ____________ DATE ____________
INQUIRY NO. ____________ BY ____________
REVISION NO. ____________ DATE ____________

APPLICABLE TO: ○ PROPOSAL ○ PURCHASE ○ AS BUILT DATE ____________ REVISION ____________
FOR ____________ UNIT ____________
SITE ____________
SERVICE ____________
INSTRUMENT MANUFACTURER ____________
NOTE: ○ INDICATES INFORMATION TO BE COMPLETED BY PURCHASER □ BY MACHINERY VENDOR
○ BY PURCHASER OR MACHINERY VENDOR

MACHINERY TRAIN COMPONENTS

NUMBER OF:
_____ PUMPS _____ ROTARY COMPRESSOR
_____ STEAM TURBINES _____ GEAR UNITS
_____ GAS TURBINES _____ ELECTRIC MOTORS
_____ CENTRIFUGAL COMPRESSOR ____ OTHER (DESCRIBE) ______
_____ RECIPROCATING COMPRESSOR

SCOPE OF RESPONSIBILITIES

○ ANNEX B ____________
○ FINAL INSTALLATION ____________
○ MONITOR SYSTEM ____________
○ SIGNAL CABLES ____________
○ TRANSDUCERS & SENSORS ____________
○ ANNEX F REQUIREMENTS ____________
____

SCOPE OF SUPPLY

○ TRANSDUCERS / SENSORS ____________
____
○ MACHINERY PROTECTION SYSTEMS
○ VIBRATION PROTECTION SYSTEM
○ SURGE DETECTION SYSTEM
○ OVERSPEED PROTECTION SYSTEM
○ EMERGENCY SHUTDOWN SYSTEM

SITE DATA

DESIGN TEMP. °C OR °F _____ SUMMER MAX. _____ WINTER MIN. _____
DESIGN WET BULB TEMP. °C OR °F ____________
○ WINTERIZATION REQUIRED
○ TROPICALIZATION REQUIRED MONITOR SYSTEMS (7.5)
○ UNUSUAL CONDITIONS ○ INDOORS
○ DUST ○ OUTDOORS
○ FUMES
○ OTHER (DESCRIBE)

ELECTRICAL EQUIPMENT HAZARD CLASS (4.9.1)
CLASS ____________ GROUP ____________ DIVISION ____________
TEMPERATURE RATING (T-RATING) ____________
ZONE ____________ GAS GROUP ____________
TEMPERATURE RATING (T-RATING) ____________
○ RADIO FREQUENCY INTERFERENCE (4.9.3) ____________
____

OPERATING TEMPERATURE RANGE

○ STANDARD, ALL COMPONENTS (4.1)
○ NONSTANDARD REQUIREMENTS
○ PROBE & EXTENSION CABLE °C OR °F FROM _____ TO _____
○ OSCILLATOR-DEMODULATOR °C OR °F FROM _____ TO _____
○ TEMP. SENSOR & LEAD °C OR °F FROM _____ TO _____
○ MONITOR AND POWER SUPPLY °C OR °F FROM _____ TO _____
○ ACCELEROMETER °C OR °F FROM _____ TO _____
○ CHARGE AMPLIFIER °C OR °F FROM _____ TO _____
○ OTHER SYSTEM COMPONENTS °C OR °F FROM _____ TO _____

OPERATING ENVIRONMENT

○ STANDARD COMPONENTS (4.4)
○ SPECIFIED CHEMICALS (4.4.2 AND 4.4.3) ____________
○ SHOCK (4.3) ____________
○ VIBRATION (STRUCTURAL RESONANCE) ____________

PROXIMITY PROBE DATA (5.1.1)

○ STD. 7.6-8.3 mm TIP DIA. REV. MOUNT WITH 0.5 METER INTEGRAL CABLE (5.1.1.2)
○ OPTIONAL PROBES WITH THE FOLLOWING STANDARD OPTIONS: (5.1.1.3)
○ TIP DIAMETER OF 7.6 TO 8.3 mm (0.300 TO 0.327 INCHES) WITH 3/8-24-UNF-2A USC PROBE THREADS (5.1.1.3a)
○ TIP DIAMETER OF 4.8-5.3 mm (0.190-0.208 INCHES) WITH 1/4-28 UNF-2A USC THREADS (5.1.1.3 b)
○ TIP DIAMETER OF 7.6 TO 8.3 mm (0.300 to 0.327 in) WITH M10 x 1 METRIC THREADS (5.1.1.3c)
○ TIP DIAMETER OF 4.8 TO 5.33 mm (0.190 TO 0.208 in.) AND M8 x 1 METRIC THREADS (5.1.1.3d)
○ LENGTHS OTHER THAN APPROXIMATELY 25 mm (1 INCH) (5.1.1.3 e)
○ FLEXIBLE STAINLESS STEEL ARMORING ATTACHED TO THE PROBE BODY AND EXTENDING TO APPROXIMATELY 125 mm (5 INCHES) OF THE CONNECTOR (5.1.1.3 f AND 5.1.1.3 g)
○ 11mm PROBES FOR RECIPROCATING COMPRESSOR APPLICATIONS (P.4.1.1)
○ 11mm PROBES FOR OTHER APPLICATIONS (E.G. GEARBOX)
○ 7.6-8.3 mm TIP DIA. REV. MOUNT WITH 1 METER INTEGRAL CABLE (5.1.1.5)
○ OTHER (EXPLAIN)
____
____
____

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MACHINERY PROTECTION SYSTEM DATA SHEET

1	**NUMBER OF PROBES IN TRAIN**	**EXTENSION CABLE DATA (5.1.2)**
2	○ STANDARD COMPLEMENT (ANNEX H)	○ STANDARD 4.5 METER (177 INCHES) LENGTH,
3	○ NONSTANDARD COMPLEMENT REQUIRED	NONARMORED (5.1.2)
4	PRIMARY RADIAL ______	○ 4.0 METER (158 INCHES) LENGTH, NONARMORED (5.1.2)
5	SPARE RADIAL ______	○ CABLE WITH WEATHERPROOF, FLEXABLE ARMOR (6.2.3.4)
6	PRIMARY AXIAL ______	[○] CABLE CONNECTOR ELECTRICAL ISOLATION (6.2.3.4)
7	SPARE AXIAL ______	○ INSULATING SLEEVE
8	PHASE REFERENCE ______	○ INSULATING WRAP (DESCRIBE) ______
9	SPEED INDICATING ______	______
10	OVERSPEED SENSING ______	○ OTHER (DESCRIBE) ______
11	SPARE OVERSPEED SENSING ______	______
12	ROD DROP ______	**PIEZO ELECTRIC ACCELEROMETER DATA (5.2.1)**
13	**PROBE ARRANGEMENT (ANNEX H)**	GENERAL:
14	RADIAL TRANSDUCERS	[○] INSTRUMENT MANUFACTURER'S MODEL NO. ______
15	○ STANDARD ARRANGEMENT (6.1.1)	[○] ACCELEROMETER POWER REQ. ______ 24VDC ______ (mA)
16	○ DEVIATION FROM STANDARD RADIAL PROBE ARRANGEMENT	○ EXTERNAL CHARGE AMPLIFIER
17	REQUIRED: (DESCRIBE) ______	○ SPECIAL BODY MATERIAL ______
18	______	○ MOUNTING ENVIRONMENT TEMPERATURE °C OR °F ______
19	AXIAL TRANSDUCERS (6.1.3)	TRANSDUCER MOUNTING:
20	○ STANDARD SHAFT END OR INTEGRAL AXIAL SURFACE	○ ANNEX C, FIGURE: C1 ____ C2 ____ C3 ____
21	○ OPT. ONE PROBE ON SHAFT & ONE PROBE ON	○ OTHER ______
22	INTEGRAL THRUST COLLAR (6.1.3.2)	○ STANDARD ACCELEROMETER MOUNTING (5.2.1.7)
23	OTHER (DESCRIBE) ______	○ STANDARD ACCELEROMETER (5.2.1.1 TO 5.2.1.9)
24	[○] PROBES MOUNTED TO MEASURE INCREASING GAP	○ ACCELEROMETER WITH THE FOLLOWING OPTIONS: (5.2.1.10)
25	FOR NORMAL OPERATION (7.4.2.6)	○ INTEGRAL STUD FOR FLUSH MOUNTING (5.2.1.10 a)
26	[○] PROBES MOUNTED TO MEASURE DECREASING GAP	○ INTEGRAL STUD FOR NON-FLUSH MOUNTING (5.2.1.10b)
27	FOR NORMAL OPERATION (7.4.2.6)	○ MOUNTING STUD—USC THREADS OTHER THAN 1/4-28 UNF
28	PHASE REFERENCE TRANSDUCERS/ONE EVENT PER REVOLUTION	SPECIFY THREADS (5.2.1.10 c) ______
29	○ DRIVER	○ MOUNTING STUD —METRIC THREADS (5.2.1.10 d)
30	○ GEARBOX	SPECIFY THREADS ______
31	○ INPUT SHAFT	○ INTEGRAL ACCELEROMETER CABLE (5.2.1.10 e)
32	○ OUTPUT SHAFT	○ OTHER (DESCRIBE) (m) (INCHES) ______
33	○ DRIVEN EQUIPMENT	
34	○ SPARE TRANSDUCER (6.1.5.2)	○ EXTENSION CABLE PROTECTION (6.2.3)
35	○ OTHER (DESCRIBE) ______	○ STANDARD CONDUIT ______
36	ROD DROP PROBES	○ OPTIONAL WEATHERPROOF FLEXIBLE ARMOR (6.2.3.4)
37	○ BOTTOM ONLY (6.1.4.1)	○ NUMBER OF ACCELEROMETERS PER BEARING ______
38	○ TOP ONLY (6.1.4.2)	○ NUMBER OF ACCELEROMETERS PER CASING
39	○ DUAL PROBES TOP AND BOTTOM (6.1.4.2)	(E.G. GEARBOX APPLICATIONS) ______
40	○ HORIZONTAL FOR DIAGNOSTICS (6.1.4.7)	○ NUMBER OF CHANNELS IN TRAIN ______
41	SPEED INDICATOR PROBES (6.1.6)	
42	○ STANDARD (6.1.5.1)	[○] INSTRUMENT MANUFACTURER'S MODEL NO. ______
43	○ STANDARD PROBE SENSING MULTI-TOOTH SURFACE (6.1.6 a)	[○] DIMENSIONS (mm) (INCHES) ______ X ______ X ______
44	○ MAGNETIC SENSOR SENSING MULTI-TOOTH SURFACE (6.1.6 b)	**VELOCITY SENSOR DATA (5.2.3)**
45	OVERSPEED SENSING PROBES (6.1.7)	○ STANDARD VELOCITY SENSOR (5.2.3.1)
46	○ NOTE: SEE SPEED SENSOR DATA SHEET	○ OPTIONAL 1/4-18 NPT INTEGRAL STUD (5.2.3.11 a)
47	**OSCILLATOR-DEMODULATOR (5.1.4)**	○ OPTIONAL 1/4-28 UNF FLUSH MOUNT STUD (5.2.3.11 b)
48	○ SUPPLIED WITH DIN RAIL MOUNTING (5.1.4.9)	○ OPTIONAL METRIC THREADS (5.2.3.11 c)
49	○ OTHER (SPECIFY) ______	○ INTEGRAL VELOCITY SENSOR CABLE (5.2.3.11 d)
50	______	○ OTHER APPLICATIONS ______
51	______	______
52		

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TEMPERATURE SENSOR DATA (5.3.1)

○ SENSORS NOT REQUIRED
○ STANDARD 100-ohm, PLATINUM, THREE-LEAD RESISTANCE TEMPERATURE DETECTOR (RTD) (5.3.1.1 AND 5.3.1.2)
○ TYPE J IRON-COPPER-NICKEL THERMOCOUPLE (5.3.1.3)
○ TYPE K TEMPERATURE SENSOR (5.3.1.3)
○ TYPE N TEMPERATURE SENSOR (5.3.1.3)
○ OTHER (DESCRIBE) ____________
○ FLEXIBLE STAINLESS STEEL OVERBRAIDING ON LEADS (5.3.1.5)

TEMPERATURE SENSOR MOUNTING (6.1.9)

○ EMBEDDED SENSORS
○ SPRING-LOADED SENSORS (BAYONET TYPE) (6.2.4.3)
○ OTHER (DESCRIBE) ____________
○ ELECTRICALLY INSULATED FROM BEARING (6.2.4.5)
____

RADIAL BEARING TEMPERATURE SENSOR ARRANGEMENT

○ SENSORS REQUIRED
○ SENSORS NOT REQUIRED
☐ SLEEVE TYPE, L/D RATIO > 0.5 (6.1.9.1.2 a)
☐ SLEEVE TYPE, L/D RATIO ≤ 0.5 (6.1.9.1.2 b)
☐ TILT-PAD TYPE, L/D RATIO > 0.5 (6.1.9.1.3 a)
☐ TILT-PAD TYPE, L/D RATIO ≤ 0.5 (6.1.9.1.3 b)
  ☐ LOAD-ON PAD (6.1.9.1.3 c)
  ☐ LOAD-BETWEEN-PADS (6.1.9.1.3 d)
☐ OTHER (DESCRIBE) ____________
____

THRUST BEARING TEMPERATURE SENSOR ARRANGEMENT

○ SENSORS REQUIRED
○ SENSORS NOT REQUIRED
○ STANDARD TWO SENSORS IN ACTIVE BEARING (6.1.9.2.1)
  SENSORS ________ DEGREES APART
○ STANDARD TWO SENSORS IN INACTIVE BEARING (6.1.9.2.3)
  SENSORS ________ DEGREES APART
OTHER (DESCRIBE) ____________

MACHINERY PROTECTION SYSTEM

☐ MONITOR MOUNTING DIMENSION (mm) (INCHES)
HEIGHT ________ WIDTH ________ DEPTH ________
○ LOCATION (7.5.1) ○ INDOOR ○ OUTDOOR
SAFETY INSTRUMENTED SYSTEM (SIS)
○ IDENTIFY COMPLIANCE WITH APPLICABLE LAW (4.11.1 a)
○ RISK ASSESSMENT FOR ENTIRE PROCESS (4.11.1.b)
○ LIST OF ALL SAFETY INSTRUMENTED FUNCTIONS AND SIL RATING (4.11.1 c)

MACHINERY PROTECTION SYSTEM cont.

○ SPECIFY DATA AND CERTIFICATES FOR SIL COMPLIANCE (4.11.1 d)
○ SPECIFY IF METHODS APPLY TO RISKS BEYOND HSE (4.11.1 e)
POWER SUPPLY REQUIREMENTS
○ REMOTE TIMESET
  INPUT ○ ________ VAC ________ Hz
  ○ ________ VDC
  ○ STANDARD (4.10.1)
  ○ OTHER (SPECIFY) (4.10.2) ____________
  ○ REDUNDANT POWER SUPPLY REQUIRED (4.10.10)
  SIGNAL PROCESSING / OUTPUTS
  ○ STANDARD DIGITAL OUTPUT (4.13.1)
  ○ ANALOG ○ 4 to 20 mA (4.11.4 e) ○ GRAPHIC
  ○ DIGITAL COMMUNICATIONS PORT (4.11.4.f)
○ REDUNDANT CIRCUIT REQUIREMENT (4.11.6 a)
  ○ RADIAL VIBRATION CHANNELS (7.4.1)
  ○ AXIAL POSITION CHANNELS (7.4.2)
  ○ PISTON ROD DROP CHANNELS (7.4.3)
  ○ CASING VIBRATION CHANNELS (7.4.4)
  ○ TEMPERATURE CHANNELS (7.4.5)
  ○ SPEED INDICATION CHANNELS (7.4.6)

NOTE: Speed indication channels may be single or redundant; overspeed channels are always redundant and are separately specified on the Overspeed Datasheet. (8.4.1)

○ PERIOD OF UNINTERRUPTED OPERATION ____________
  ○ OTHER (DESCRIBE) (4.17.2) ____________
○ SHUTDOWN INDICATION CONFORM TO VOTING LOGIC (4.11.5 e)
○ SYSTEM SHUTDOWN BYPASS (4.11.7 f)
○ TAMPERPROOF SHUTDOWN DISARM W/VISIBLE INDICATOR (4.11.5.f)
○ SHUTDOWN DISARM - TWO ISOLATED EXTERNAL ANNUNCIATOR CONTACTS (4.12.11 f)
○ CONNECTORS OTHER THAN BNC (4.11.4 d) ____________
RELAYS
  ○ ALARM (ALERT)
    ○ STANDARD NORMALLY ENERGIZED
    ○ OPTIONAL NORMALLY DEENERGIZED
  ○ SHUTDOWN (DANGER)
    ○ STANDARD NORMALLY DEENERGIZED
    ○ OPTIONAL NORMALLY ENERGIZED
○ HERMETICALLY SEALED ELECTRO-MECHANICAL TYPE RELAYS (4.12.4 a)
○ SOLID STATE TYPE RELAYS (4.12.4 b)
○ CONTACTS RATED AT A RESISTIVE LOAD OF 5 AMPERES AT 120 VOLTS AC (4.12.9)

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MACHINERY PROTECTION SYSTEM (cont.)

ADDITIONAL DISPLAY AND/OR DIGITAL OUTPUTS (4.13.2)

	DISPLAY	OUTPUT
CHANNEL ALARM STATUS (4.13.2 a)	○	○
ARMED/DISARMED SHUTDOWN STATUS ALL MACHINES (4.13.2 b)	○	○
ALARM STORAGE FOR STORING THE TIME, DATE, AND VALUE FOR A MINIMUM OF 64 ALARMS (4.13.2 c)	○	○
CHANNEL VALUE ± 2% FULL-SCALE RANGE RESOLUTION (4.13.2 d)	○	○
MEASURED VALUE AS A % OF ALARM (ALERT) AND SHUTDOWN (DANGER) VALUES TO 1% RESOLUTION (4.13.2 e)	○	○
CHANNEL STATUS; ARMED/DISARMED (4.13.2 f)	○	○
TRANSDUCER OK LIMITS (4.13.2 g)	○	○
HARDWARE AND SOFTWARE DIAGNOSTICS (4.13.2 h)	○	○
COMMUNICATIONS LINK STATUS (4.13.2 I)	○	○
ALARM SETPOINTS (4.13.2 j)	○	○
GAP VOLTAGE WHEN APPLICABLE (4.13.2 k)	○	○
TIME STAMP AND DATE FOR ALL TRANSMITTED DATA (4.13.2 l)	○	○
LOG OF SYSTEM ENTRY TO INCLUDE DATE, TIME, INDIVIDUAL ACCESS CODE AND RECORD OF CHANGES (4.13.2 m)	○	○
SETPOINT MULTIPLIER INVOKED (4.13.2 n)	○	○

OTHER (DESCRIBE) ________________________________

____

RADIAL SHAFT VIBRATION & AXIAL POSITION CHANNEL (7.4.1 AND 7.4.2)

TYPE OF DISPLAY (7.1.8)
○ ANALOG
○ DIGITAL
  ○ LIQUID CRYSTAL DIODES
  ○ LIGHT EMITTING DIODES
○ GRAPHIC DISPLAY
○ BLIND MONITOR WITH NON-INTEGRAL DISPLAY (7.1.10)
○ OTHER (DESCRIBE) ______________________________

NUMBER OF PROBES MONITORED
__________ RADIAL
__________ AXIAL

READOUT RANGE

RADIAL DISPLAY (7.4.1.1)
○ STANDARD 0 TO 125 MICROMETERS
○ STANDARD 0 TO 5 MILS
○ OPTIONAL 0 TO 250 MICROMETERS
○ OPTIONAL 0 TO 10 MILS

AXIAL DISPLAY
○ –1.0 TO +1.0 mm
○ –40 TO +40 MILS
○ OTHER (DESCRIBE)
____

○ CONTROLLED ACCESS SETPOINT MULTIPLIER FUNCTION (7.4.1.6)
  ○ STANDARD 3X (7.4.1.6a)
  ○ STANDARD OPTION 2X (7.4.1.6a)
○ OTHER (DESCRIBE) ______________________________________

____

RADIAL SHAFT VIBRATION & AXIAL POSITION CHANNEL (7.4.1 AND 7.4.2) cont.

SHUTDOWN SYSTEM (7.4)
○ STANDARD DUAL VOTING LOGIC (7.4.1.4)
○ SINGLE VOTING LOGIC (7.4.1.5)

RECIPROCATING COMPRESSOR MONITORING

○ PISTON ROD DROP MONITORING REQUIRED (7.4.3.1)
  ○ STANDARD MONITOR SYSTEM SUPPLIED WITH ONE CHANNEL PER PISTON ROD (7.4.3.3)
  ○ STANDARD OPTION—TWO CHANNELS PER PISTON ROD (7.4.3.3)
    ○ TOP AND BOTTOM (6.1.4.2)
    ○ X - Y (6.1.4.7)

CASING VIBRATION CHANNEL (7.4.4)

○ CASING VIBRATION NOT REQUIRED
○ CASING VIBRATION REQUIRED
  NUMBER OF ACCELEROMETERS MONITORED __________________
  NUMBER OF VELOCITY SENSORS MONITORED __________________
○ STANDARD MONITOR (7.4.4.1)
○ PUMP, FAN, OR MOTOR WITH ROLLING ELEMENT BEARINGS
  FREQUENCY RANGE (7.4.4.1) ________________________________
○ CONTROLLED ACCESS SETPOINT MULTIPLIER FUNCTION (7.4.4.4)
  ○ STANDARD 3X (7.4.4.4 a)
  ○ STANDARD OPTION 2X (7.4.4.4 a)
○ OTHER (DESCRIBE) ______________________________________
○ PUMPS, FANS, AND MOTORS WITH ROLLING ELEMENT BEARINGS MONITORED IN RANGE FROM 10 Hz. TO 5 KILOHERTZ (7.4.4.5 b)
○ CASING VIBRATION MONITOR SYSTEM OPTIONS (7.4.4.6)
  ○ MONITOR AND DISPLAY OF SINGLE CHANNEL (7.4.4.6 a)
    ○ ACCELERATION ○ VELOCITY
  ○ MONITOR AND DISPLAY TWO CHANNELS IN EITHER (7.4.4.6 b)
    ○ ACCELERATION ○ VELOCITY
  ○ MONITOR AND DISPLAY ALTERNATE FILTER OR FREQ. RANGE (7.4.4.6 c)
    SPECIFY ____
  ○ MONITOR AND DISPLAY UNFILTERED OVERALL VIBRATION (7.4.4.6 d)
  ○ MONITOR AND DISPLAY AMPLITUDE IN TRUE RMS (7.4.4.6 e)
  ○ MONITOR AND DISPLAY TRUE PEAK (7.4.4.6 f)
  ○ ALTERNATE FULL SCALE RANGES (7.4.4.6 g)
    SPECIFY ______________________
  ○ DUAL VOTING LOGIC ("AND" LOGIC) (7.4.4.6 h)
  ○ SINGLE VOTING LOGIC ("OR" LOGIC) (7.4.4.6 i)
○ VELOCITY SENSOR UTILIZING MOVING-COIL INSTEAD OF INTERNALLY INTEGRATING ACCELEROMETER (5.2.3.2)

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TEMPERATURE MONITORING (7.4.5)

MONITOR CONFIGURATION

○ TOTAL NUMBER OF SENSORS MONITORED ____________________

NUMBER OF BEARINGS MONITORED

○ RADIAL ____________________

○ ACTIVE THRUST ________________

○ INACTIVE THRUST ______________

○ OTHER (DESCRIBE) ____

____

TYPE OF DISPLAY

○ STANDARD DIGITAL

 ○ LIQUID CRYSTAL DISPLAY

 ○ LIGHT EMITTING DIODES

 ○ OTHER ____

○ OTHER ____

READOUT RANGE (7.4.5.1)

○ STANDARD 0°C TO+150°C

○ OPTION 0°F TO +300°F

○ OTHER (DESCRIBE) ____

SHUTDOWN SYSTEM

○ STANDARD DUAL VOTING LOGIC

 ○ EACH RADIAL BEARING

 ○ ACTIVE THRUST BEARINGS

 ○ INACTIVE THRUST BEARINGS

 ○ OTHER (DESCRIBE) ____________________________________

 ____

○ SINGLE CHANNEL

TACHOMETER (7.4.6)

○ TACHOMETER NOT REQUIRED

○ TACHOMETER REQUIRED

○ ABILITY TO RECORD/STORE HIGHEST SPEED (7.4.6.1)

○ CONTROLLED ACCESS RESET REQUIRED (7.4.6.2)

SYSTEM WIRING & CONDUIT (4.14)

VIBRATION & POSITION SIGNAL CABLE

○ SINGLE CIRCUIT CABLE (ANNEX D.2)

 ○ OPTIONAL FEP FOR SEVERE ENVIRONMENTAL USE (D.2.2)

○ MULTIPLE-CIRCUIT CABLE (ANNEX D.3)

 ○ OPTIONAL FEP FOR SEVERE ENVIRONMENTAL USE (D.3.2)

TEMPERATURE SIGNAL CABLE

○ SINGLE CIRCUIT THERMOCOUPLE (ANNEX D.4)

○ OTHER (DESCRIBE) ____

____

OSCILLATOR-DEMODULAR MOUNTING BOXES

○ ONE PER MACHINE CASE

○ TWO PER MACHINE CASE

○ OTHER (DESCRIBE) ____

____

SYSTEM ENCLOSURES AND ENVIRONMENTAL REQUIREMENTS (4.9)

LOCATION ○ INDOOR ○ OUTDOOR

HOUSING/MOUNTING BOX

○ NEMA TYPE ____________

DRY AIR PURGE REQUIREMENTS (4.9.2)

 ○ NONE REQUIRED

 ○ REQUIRED PER ISA-S12.4 & NFPA 496

  ☐ TYPE X

  ☐ TYPE Y

  ☐ TYPE Z

○ CONFORMAL COATING ON PRINTED CIRCUIT BOARDS FOR PROTECTION (4.9.4)

VENDOR'S DATA (12.0)

○ NO. OF COPIES OF REQUIRED DOCUMENT (12.3.1.2)____________________

○ REQUIRED BY (SPECIFY DATE) ________________________________

○ NO. OF PRINTS AND/OR REPRODUCIBLES REQUIRED ________________

○ REQUIRED BY (SPECIFY DATE) ________________________________

○ OTHER (DESCRIBE) ____

____

____

____

____

TESTING INSPECTION AND PREP FOR SHIPMENT (11.0)

○ FIELD TESTING PER ANNEX F (11.6.1)

○ INSPECTION REQUIRED OF MONITORING SYSTEM IN INSTRUMENT MANUFACTURERS FACILITY (11.1.4)

○ 10 DAY NOTICE REQUIRED BEFORE TEST

○ MONITORING SYSTEM TO BE USED DURING MECHANICAL RUNNING TEST (DESCRIBE EXTENT TO BE USED)

____

____

____

____

____

○ PROBES CALIBRATED TO INSTALLED PROBE TARGET AREA (11.6.3)

 ○ OPTIONAL CALIBRATION PERFORMED IN THE INSTALLED AREA (11.6.3.2)

 ○ OPTIONAL SHAKER TABLE CALIBRATION FOR CASING VIBRATION MEASUREMENTS (11.6.5)

MISCELLANEOUS

SPECIAL PACKING, SEALING, MARKING OR STORAGE REQUIREMENTS:

DESCRIBE (11.4.5):

____

____

____

____

____

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Surge Detection System (9.0)

COMPRESSOR TYPE
- ○ AXIAL FLOW NUMBER OF ___________
- ○ CENTRIFUGAL NUMBER OF ___________

SYSTEM OUTPUTS

- ○ STANDARD OUTPUTS
- ○ OPTIONAL FURTHER ACTIONS (9.4.3.2)
  - ○ OPENING OF ANTI_SURGE VALVES
  - ○ SHUTDOWN OF MAIN DRIVER
  - ○ OTHER____
- ○ OPTIONAL FURTHERRECORDING OPTIONS (9.4.3.5)
  - ○ RECORDING SENSOR READINGS
  - ○ RECORING OUTPUT SIGNALS
  - ○ OTHER____

SYSTEM RESPONSE

- ○ STANDARD 500ms. Response time (9.4.4.4)
  - ○ OTHER ____

ESD SYSTEM REQUIREMENTS (10.0)

- ○ ESD SYSTEM USED AS A SAFETY INSTRUMENTED SYSTEM (4.11.1)
- ○ STANDARD SYSTEM CONFORMING TO IEC61508, IEC61511 (10.1.2)
  - ○ OPTIONAL SYSTEM CONFORMING TO IEC 62061, ISO 21789 AND ISO 13849 (10.1.3)
- ○ STANDARD DISTRIBUTED ESD SYSTEM (10.1.4)
  - ○ OPTIONAL OVERSPEED INTEGRATED W/ESD SYSTEM (10.4.3 AND 10.1.5)
  - ○ OPTIONAL SURGE DETECTION INTEGRATED W/ESD SYSTEM (10.4.3 AND 10.1.5)
- ○ STANDARD SYSTEM DESIGN
  - ○ OPTIONAL DESIGN WITH NO SINGLE CIRCUIT FAILURE DISABLING THE SYSTEM (10.1.6)
- ○ STANDARD ISOLATED ESD SYSTEM
  - ○ OPTIONAL EXTERNAL CONDITIONS ACTIVATING THE ESD (10.2.4)
- ○ STANDARD NO REMOTE ACCESS
  - ○ OPTIONAL REMOTE ACCESS TO ESD (10.3.9)
- ○ STANDARD EACH SHUTDOWN PARAMETER TO THE ESD SEPARATE (10.5.2)
  - ○ OPTIONAL CONNECTING SIMILAR RELAYS IN SERIES (10.5.3)
- ○ STANDARD DISPLAY OPTIONS
  - ○ OPTIONAL SETPOINT DISPLAY OPTIONS
- ○ STANDARD INPUT SIGNALS
  - ○ OPTIONAL RADIAL VIBRATION SIGNAL
  - ○ OPTIONAL AXIAL POSITION SIGNAL
  - ○ OTHER (SPECIFY)______________________________________
  - ____
  - ____

ESD SYSTEM REQUIREMENTS (10.0) cont.

- ○ STANDARD RELAY INPUTS (10.7.1.2.1)
- ○ OPTIONAL HERMETICALLY SEALED ELECTROMECHANICAL RELAYS (10.7.1.2.3)
- ○ STANDARD INPUTS FROM FINAL SHUTDOWN ELEMENT (10.7.3)
  - ○ OPTIONAL HERMETICALLY SEALED ELECTROMECHANICAL LIMIT SWITCHES (10.7.3.5)
  - ○ OPTIONAL ANALOG SIGNAL USING LVDT OR SIMILAR (10.7.3.6)
  - ○ OPTIONAL SIGNAL INDICATION INTERPOSING RELAY OR SOLENOID POSITION(10.7.3.7)
- ○ STANDARD OUTPUT TO FINAL SHUTDOWN ELEMENT(10.8.1)
  - ○ OPTIONALHEREMETICALLY SEALED ELECTROMECHANICAL TYPE RELAYS (10.8.1.3)
  - ○ OPTIONAL DOUBLE-POLE, DOUBLE THROW RELAYS WITH ELECTRICALLY ISOLATED CONTACTS (10.8.1.5)
- ○ STANDARD NO SYSTEM FAULT RELAY (10.8.2)
  - ○ OPTIONAL SYSTEM FAULT RELAY FOR INDICATION OF INTERNAL ESD FAULTS (10.8.2)

SAFETY CRITICAL SHUTDOWN PARAMETERS (10.2.2)

SPECIFY ALL SAFETY CRITICAL SHUTDOWN SIGNALS TO THE ESD THAT CAN AFFECT PERSONNEL SAFETY (10.2.2) ___________________

____

____

____

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PAGE ________ OF ________

JOB NO. ____________________ ITEM NO. ____________________

PURCH. ORDER NO. ____________________ DATE ____________________

INQUIRY NO. ____________________ BY ____________________

REVISION NO. ____________________ DATE ____________________

OVERSPEED DATA SHEET

○ ELECTRONIC OVERSPEED DETECTION SYSTEM REQUIRED (8.1.1)
  ○ OPTIONAL OVERSPEED FOR VFD MOTORS (8.1.5)

OVERPSEED SYSTEM REQUIREMENTS

○ OVERSPEED SYSTEM PART OF A SAFETY INSTRUMENTED SYSTEM (4.11.1)
○ STANDARD DISTRIBUTED OVERSPEED SYSTEM (8.3)
  ○ OPTIONAL OVERSPEED INTEGRATED W/ESD SYSTEM (8.3.3)
  ○ OPTIONAL OVERSPEED INTEGRATED W/SURGE SYSTEM (Note 2)
○ STANDARD 2 OUT OF 3 VOTING LOGIC (8.4.1.1)
  ○ OPTIONAL 1 OUT OF 2 VOTING FOR AERODERIVATIVES (8.4.1.2)
○ STANDARD NON-RATED SYSTEM
  ○ OPTIONAL SYSTEM CONFORMING TO IEC61508, IEC61511, IEC 62061 (8.4.3.6)

○ STANDARD MANUAL TESTING
  ○ OPTIONAL AUTOMATIC TESTING FUNCTIONALITY
○ STANDARD RESPONSE TIME (8.4.4.1)
  ○ OPTIONAL API 611/612 OR OEM REQUIREMENTS (8.4.4.3 a)
  ○ OPTIONAL OEM REQUIREMENTS (8.4.4.3 b)
○ STANDARD NO FIELD REPORT (8.4.4.6)
  ○ OPTIONAL FIELD TEST REPORT (8.4.4.6)
○ OTHER (EXPLAIN)____
____

CUSTOMER PROFILE

○ MACHINERY VENDOR
○ OWNER
○ OTHER ____

○ SYSTEM INTEGRATION PERFORMED BY ______________________

MACHINE DETAILS

○ DRIVER
  ○ STEAM TURBINE
  ○ GAS TURBINE
  ○ TURBO EXPANDER
  ○ OTHER ____

○ MANUFACTURER ____
○ MODEL NO. ____
○ POWER ____
○ RATED SPEED ____
○ OVERSPEED TRIP SPEED ________________________________
○ FASTEST TIME IN WHICH MACHINE SPEED CAN DOUBLE DURING START UP ____

DRIVEN MACHINE
  COMPRESSOR
  PUMP
  GENERATOR
  OTHER ____

MANUFACTURER
MODEL NO. ____
POWER ____
RATED SPEED ____

SPEED SENSORS

○ SPEED SENSOR TYPE:

  ○ PROXIMITY PROBE (see Probe Data of page 1 of MPS data sheet)
  ○ STANDARD OPTION MAGNETIC[1]
    ○ OPTIONAL POLE PIECE TYPE:
      ○ CYLINDRICAL
      ○ CONICAL
    ○ OPTIONAL THREAD TYPE:
      ○ 3/4-20 UNEF-2A
      ○ M16 x 1.5 METRIC
      ○ OTHER: ________________________
    ○ OPTIONAL HOUSING TYPE:
      ○ EXPLOSION PROOF WITH INTEGRAL CABLE AND CONDUIT THREADS AT INTEGRAL CABLE EXIT
    ○ OPTIONAL NON INTEGRAL CABLE TYPE:
    ○ OPTIONAL ACTIVE (EXTERNALLY POWERED) TYPE:

○ TIP OR POLE PIECE DIAMETER ________________________________
○ LINEAR RANGE (PROXIMITY PROBE ONLY) ________________________________
○ MANUFACTURER ____
○ MODEL NO. ____

ARE THESE SPEED SENSORS SHARED WITH THE GOVERNOR?

  ○ YES (Note 2)
  ○ NO

PAGE ______ OF ______

SPEED SENSOR DATA SHEET

JOB NO. ______ ITEM NO. ______

PURCH. ORDER NO. ______ DATE ______

INQUIRY NO. ______ BY ______

REVISION NO. ______ DATE ______

SPEED SENSING SURFACE

○ LOCATION:

- ○ DRIVER SIDE OF COUPLING (Note 3)
- ○ OTHER[3] ______

○ DESIGN:

- ○ NON-PRECISION OR GEAR (Notes 2 AND 4) (FIGURE J.2)
- ○ PRECISION (FIGURE J.3)

○ EVENTS PER REVOLUTION ______

○ DIMENSIONS (FIGURE J.2):

- ○ TOOTH LENGTH A = ______
- ○ TOOTH DEPTH B = ______
- ○ NOTCH LENGTH C = ______
- ○ TOOTH WIDTH F = ______

○ ARE ANY DIMENSIONS ABOVE SMALLER THAN ALLOWED IN TABLES J.2 OR J.3 (AS APPLICABLE):

- ○ YES (Note 5)
- ○ NO

○ IS CENTERLINE OF SPEED SENSING SURFACE SUBJECT TO PEAK-TO-PEAK RADIAL VIBRATION AMPLITUDES GREATER THAN B/4 (1/4 TOOTH DEPTH):

- ○ YES (Note 5)
- ○ NO

○ IS THE FOLLOWING RELATIONSHIP TRUE:

$$\frac{\textit{(Events / rev) x (Trip Speed) x (A + C)}}{\textit{A or C (whichever is greater)}} > \textit{720,000 RPM}$$

- ○ YES (Note 5)
- ○ NO

SUPPLEMENTAL PROXIMITY PROBE INFORMATION

○ MAXIMUM PEAK-TO-PEAK RADIAL VIBRATION OF SPEED SENSING SURFACE ______

○ MAXIMUM VARIATION IN TOOTH DEPTH (DIMENSION B) ______

○ MAXIMUM RUNOUT OF SPEED SENSING SURFACE DUE TO NON-CONCENTRICITY ______

○ SIGNAL CABLE LENGTH BETWEEN OSCILLATOR/DEMODULATOR AND MONITOR ______

○ PEAK-TO-PEAK OUTPUT VOLTAGE OF TRANSDUCER VIEWING SPEED SENSING SURFACE ______

SUPPLEMENTAL MAGNETIC SPEED SENSOR INFORMATION (Note 1)

○ MINIMUM RPM TO BE SENSED ______

○ SURFACE SPEED OF SPEED SENSING SURFACE AT THIS MINIMUM RPM ______

○ PEAK-TO-PEAK VOLTAGE OUTPUT AT MINIMUM RPM ______

○ MAXIMUM SURFACE SPEED AT MAXIMUM (TRIP) RPM ______

○ PEAK-TO-PEAK VOLTAGE OUTPUT AT MAXIMUM (TRIP) RPM ______

○ POLE PIECE TYPE:

- ○ CYLINDRICAL
- ○ CONICAL
- ○ CHISEL

○ POLE PIECE DIAMETER ______

○ GEAR OR TOOTH PITCH ______

○ GEAR OR WHEEL DIAMETER ______

Notes:

1. When magnetic speed sensors are used, the section of the data sheet titled "SUPPLEMENTAL MAGNETIC SPEED SENSOR INFORMATION" should be completed.
2. Transducers shared between the overspeed detection system and the governor are not permitted under this standard (see Section 6.1.7.1).
3. Since a coupling failure and consequent instantaneous loss of load is a common cause of driver overspeed, this standard does not permit speed sensing of the driven shaft for overspeed applications (see Section 6.1.7.4).
4. A speed sensing surface used as a gear for driving other mechanical components is not permitted under this standard (see Section 6.1.7.4).
5. A "yes" response requires additional information to be supplied to the machinery protection system vendor to ensure the proposed speed sensing surface is compatible with the speed sensors and monitor. The section of the data sheet titled "SUPPLEMENTAL PROXIMITY PROBE INFORMATION" should be completed and reviewed with the machinery protection system vendor.

Annex B
(informative)

Typical Responsibility Matrix Worksheet [a]

JOB NO. ____________________ ITEM NO. ___________
PURCHASE ORDER NO. ______ DATE _______________
REQUISITION NO. ___________ DATE _______________
INQUIRY NO. _______________ DATE _______________
PAGE _____ OF ____ BY _______________________

FOR ____ REVISION ____
SITE ____ UNIT ____
SERVICE ____________________________________ NO. REQUIRED ____________________________________

Responsibility	**Machinery Protection System Vendor**	**Machinery Vendor [b]**	**Construction Agency**	**Owner**	**Other (Specify: __________)**
Project coordination (see 12.1.3)					
System design					
Instrument purchase					
Panel design and assembly					
Grounding plan (see 4.15)					
Supply of drawing and data per Annex G					
Installation on machinery train					
Mechanical running test with contract instrumentation (see 11.5)					
Factory acceptance test (see 11.3.2.2)					
System integration verification [c]					
Field test (see 11.6)					

Discussion:

[a] The purpose of this form is to assist in project coordination. It should be completed by the purchaser by placing an “X” in the appropriate boxes to indicate responsibility for each function (see 4.7).

[b] Responsibility would normally be placed with the prime machinery vendor having unit responsibility for the entire machinery train. If responsibilities are divided among individual machinery vendors, appropriate statements should be noted above or on an attached sheet.

[c] This pertains to the digital output options (see 4.13.1 and 4.13.2) that may be integral to the machinery control system. This task is normally the responsibility of the construction agency.

NOTE Each category in the responsibility worksheet may need to be broken into subcategories to provide the level of detail needed to properly specify the installation.

Annex C
(normative)

Accelerometer Application Considerations

C.1 General

C.1.1 The accelerometer is a contact sensor (as opposed to a noncontact proximity probe) that measures the motion of the surface to which it is attached. Its many benefits include linearity over a wide frequency and dynamic range. Accelerometers have typically been used in higher frequency applications (over 1 kHz) for machinery monitoring and diagnostics. In order to apply the accelerometer and get reliable measurements, proper attention shall be paid to the following areas.

a) Sensor mounting configurations.

b) Frequency range of interest.

c) Amplitude range of interest.

d) Use for machine protection or for diagnostics.

e) Characteristics of the particular accelerometer under consideration.

f) Cabling and signal conditioning.

g) Environmental considerations.

C.1.2 There are many good reference sources discussing these considerations. The manufacturer of the particular accelerometer can also be consulted for answers to application questions. The primary focus of this annex is to address sensor mounting, cabling, and signal conditioning considerations for use with MPS's. Typically, accelerometers are recommended for use up to about one-third to one-half of their mounted resonant frequency. Therefore, mounting techniques can limit the useful frequency range of the accelerometer. Knowing these limitations and applying the proper technique are necessary to meet the requirements of the monitoring application. Cabling and signal conditioning can affect the accelerometer output signal and therefore are also important considerations in the overall design of the measurement system.

C.2 Accelerometer Mounts and Mounting Considerations

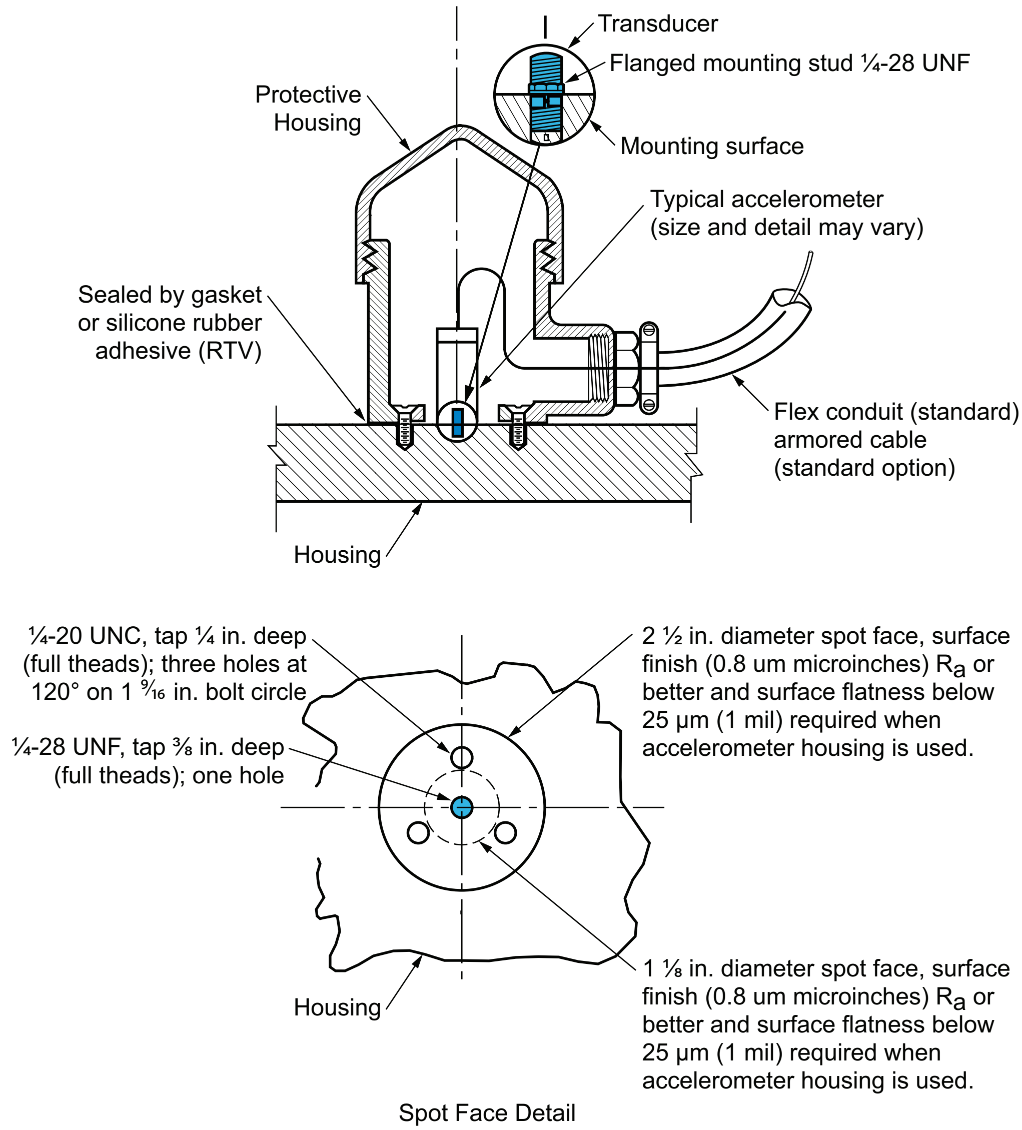
C.2.1 General

Since the accelerometer is a contact device, care in mounting is of particular importance because improper installation can affect the performance of the device and give unreliable and unexpected output signals.

C.2.2 Flush Mounting

Figure C.1 shows a typical flush-mounting application allowing the accelerometer base to fully contact the mounting surface. This mounting technique is necessary for applications where frequencies above 2 kHz shall be monitored such as gear mesh frequencies on gearboxes, blade or vane passing frequencies on pumps and compressors, and rolling element bearing frequencies for predictive maintenance diagnostics. The following are offered as guidelines for proper flush mounting.

a) Requirements for the surface finish, flatness, and size of the mounting surface are as shown in Figure C.1.



NOTE Spot face is shown but a raised boss with proper surface is acceptable.

Figure C.1—Typical Flush-mounted Accelerometer Details

b) The accelerometer shall seat itself to the mounting surface over its entire base to prevent mounting-post resonance. Mounting-post resonance occurs when the accelerometer base is not flush against the mounting surface and the mounting stud becomes a structural element, lowering the mounted resonance frequency. To prevent this from occurring, the stud axis shall be perpendicular to the mounting surface and the tapped hole shall be deep enough to prevent the stud from bottoming. The mounting hole shall be perpendicular to the surface within 5° of arc or less.

c) Excessive mounting torque might distort the accelerometer case, thus affecting the accelerometer response characteristics. Too little torque will result in a loose accelerometer that can lead to large errors at higher frequencies. Torque requirements vary with stud size, but published values range from 0.6 N-m to 2.7 N-m (5 lb-in. to 24 lb-in.). Manufacturer recommendations should be followed.

d) The mounting interface should be clear of any particles or debris that could prevent the accelerometer from coming down flat on the mounting surface. A thin layer of silicone grease may be applied between the accelerometer and the mounting surface to fill minute voids and improve the stiffness of the mounting.

C.2.3 Nonflush Mounting

C.2.3.1 Figure C.2 shows a nonflush-mounted accelerometer application. This mounting configuration uses tapered pipe threads. The advantage of this type of mounting configuration is that it only requires a drilled and tapped hole to be made at the measurement location for proper mounting. The accelerometer is already built onto the stud and sealed in its case. However, this type of accelerometer mount is not appropriate for applications where frequencies above 2 kHz will be monitored. This design is often used for solid state velocity sensors (accelerometers with a built-in acceleration-to-velocity integrator).

C.2.3.2 The following should be considered when using this type of accelerometer configuration for monitoring.

a) The machine point at which the accelerometer is to be mounted should be massive enough to accommodate the mass of the accelerometer without altering the response of the structure. The machines considered for permanent monitoring in this specification will typically be suitable for this method of mounting.

b) The drilled and tapped mounting hole should be perpendicular to the measurement surface within 5° of arc or less.

c) The manufacturer's torque specifications should be followed to avoid damaging the case by overtightening or affecting the frequency response through looseness. A thread-locking compound may be used.

C.2.4 Use of Adhesives and Bonding Agents

The use of bonding agents (such as bee's wax, dental cement, epoxy cement, and methyl cyanoacrylate cement) for mounting is not discussed here because these agents are not considered suitable for permanent installations.

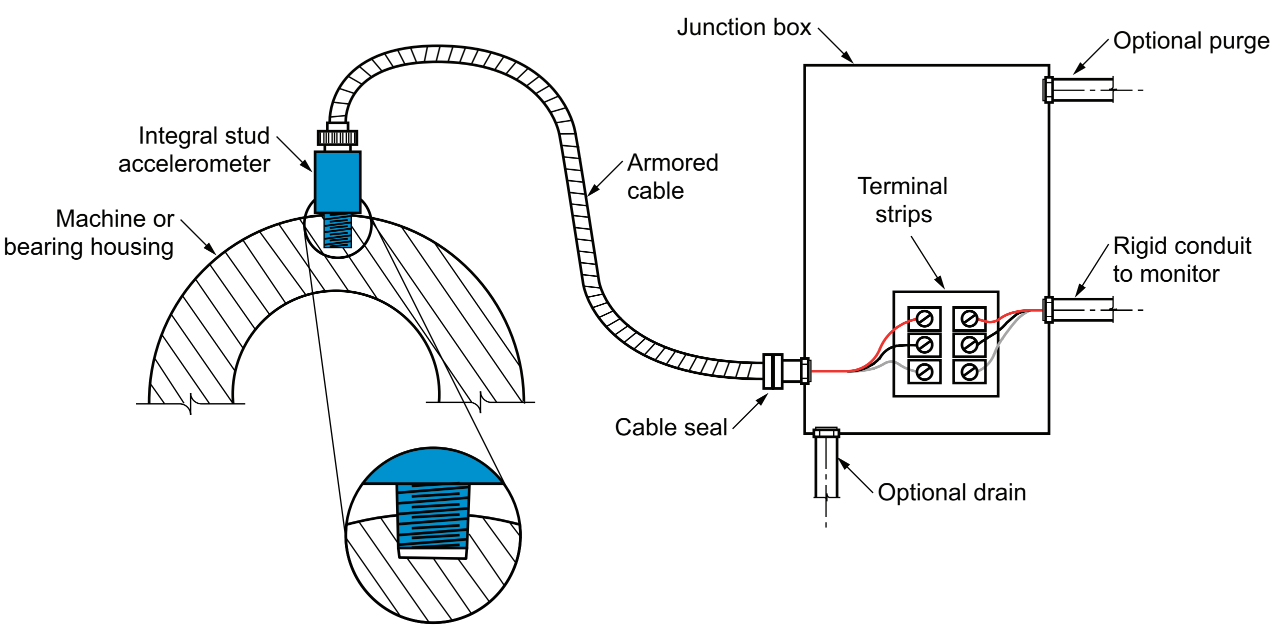


Figure C.2—Typical Nonflush-mounted Arrangement Details for Integral Stud Accelerometer

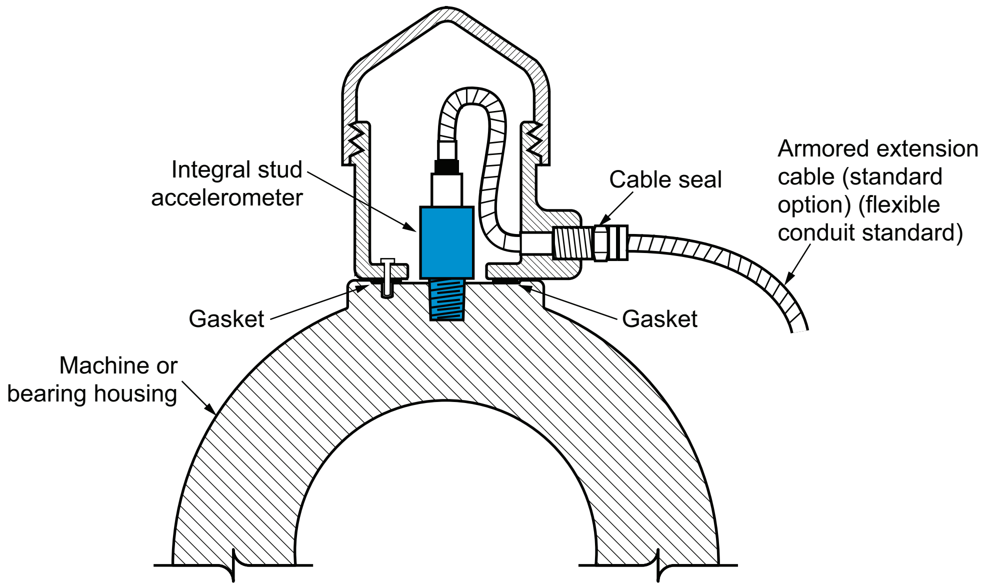


Figure C.3—Typical Nonflush-mounted Arrangement for Integral Stud Accelerometer with Protection Housing

C.2.5 Accelerometer Housings versus Unprotected Mounting

A common method of protecting the accelerometer and its connector is to mount it within a housing. Installation kits available from various sources consist of a modified electric junction box or explosion-proof housing. The housing shall be separated from the accelerometer (to prevent affecting the accelerometer's frequency response), normally by cutting a hole in the bottom of the box or housing (see Note). Installation requires care to prevent contact between the accelerometer case and its housing. The housing cover shall allow room for the proper cable bend radius, particularly important when top-mounted cable connectors are used. The box shall also be mounted on a relatively wide and flat surface to permit proper sealing of the base and to prevent water intrusion. See Figure C.1 for an example of an accelerometer housing.

NOTE Cutting the bottom of an explosion-proof box compromises its explosion proof rating. Use other means to meet area classification requirements.

C.3 Installation and Protection of Cables

Mechanical protection of the cable can be achieved by running the cable in rigid conduit. However, maintenance requirements dictate easy removal and reinstallation of the conduit section closest to the machinery. The use of flexible conduit is not necessarily the best solution because it is not easy to remove, does not always stay in place, and often results in cable damage caused by the sharp edges of the internal reinforcing coil. Consider using armored cables as shown in Figure C.3. This type of cable is relatively flexible and can be routed next to the machinery below guards or flanges. If properly routed and securely clamped, it cannot be used as a footstep. Unlike applications using conduit, installation or removal of this type of cable does not require an electrician. The following precautions apply.

a) If the accelerometer is left unprotected, water intrusion in the connector can be alleviated by filling the connector with a silicon grease. A commercially available silicon sealing compound or a specially designed protective boot can be used to seal the connector entry to the accelerometer.

b) The conduit or junction box shall be sealed at the cable entry point. Rubber grommets or removable, nonadhesive sealants should be used.

c) The cable shall be routed to avoid excessive temperatures. Cable material limits shall be considered. As an example, PTFE-insulated cables cannot normally be used above 200 °C (400 °F).

d) Where the hazardous area classification requires it, consideration should be given to the use of barriers of the zener type located as close as possible to the power source in a safe area. Intrinsically safe installations can be achieved by using this type of energy-limiting device. However, the MPS vendor should be consulted for overall system design considerations.

e) Avoid running the cable near sources of electromagnetic interference such as large motors or high-voltage wiring.

Annex D
(normative)

Signal Cable

D.1 General

This annex covers the minimum requirements for single- and multiple-circuit signal cable for vibration, axial position, speed sensing, and RTD transducers and single- and multiple-circuit signal cable for thermocouples. All of these cables require mechanical support and protection such as by cable armor, conduit, tray system, or combination thereof. The insulation shall conform to Article 725 of NFPA 70 (*National Electrical Code*), Class 2P and shall withstand, with no shorts, a 1-minute test potential of 1000 Vdc plus two times the rated voltage between conductor-to-conductor and conductor-to-shield. More detailed information on signal transmission systems is available in API 552.

D.2 Shielded Single-circuit Signal Cable for Vibration, Axial Position, Speed Sensing, or RTD Transducers

D.2.1 Conductors

Shielded single-circuit cable for vibration, axial position, and speed sensing transducers shall contain three twisted conductors. The conductors shall be 16 AWG to 22 AWG, or 0.336 mm^2 to 1.374 mm^2, seven-strand (minimum), Class B, concentric-lay, tinned copper wire as specified in NEMA WC 5, Part 2 (IPCEA S-61-402). The lay of the conductor's twist shall be from 38 mm to 64 mm (1.5 in. to 2.5 in.). The conductors shall be color-coded black, white, and red. The drain wire attached to the cable shield shall have the same specification as the three twisted conductors. Prior to installation of the cable, a green or green and yellow stripe sleeving shall be installed over the drain wire.

• D.2.2 Primary Insulation

The conductors' primary insulation shall be rated for 300 V, 100 °C (200 °F) and pass the Underwriters' Laboratories VW-1 flame test. The standard primary insulation shall be polyvinyl-chloride (PVC) with a thickness of 0.38 mm (15 mil). If specified, fluorinated ethylene propylene (FEP) with a thickness of 0.25 mm (10 mil) will be the standard option for severe environment use.

NOTE Consideration should be given to the use of halogen-free cables in enclosed areas that are normally occupied where a fire risk could expose personnel to toxic fumes.

D.2.3 Shield

The cable shield shall be polyester/aluminum film tape with 100 % coverage and drain wire, or tinned copper wire braid with 90 % coverage. The tape shall be helically applied with a minimum of a 25 % overlap. The aluminum-coated side of the film shall be at least 0.9 μm (0.35 mil) thick and shall be in continuous contact with the drain wire, which shall be the same wire gage as the inner conductors of the cable and meet the other requirements of D.2.1. A braided shield shall have a single conductor attached to it. The single conductor shall be the same wire gage as in the inner conductors of the cable and meet the other requirements of D.2.1.

• D.2.4 Overall Jacket

The cable's standard jacket shall be PVC with a nominal thickness of 0.75 mm (30 mil) and meet the other requirements of D.2.2. If specified, FEP with a thickness of 0.25 mm (10 mil) will be the standard option for severe environment use.

NOTE Consideration should be given to the use of halogen free cables in enclosed areas that are normally occupied where a fire risk could expose personnel to toxic fumes.

D.3 Multiple-circuit Signal Cable (with Group Shields) for Vibration, Axial Position, Speed Sensing, or RTD Transducers

D.3.1 Conductors

Multiple-circuit cable with group shields is recommended (see Note). Multiple-circuit cable with group shields for vibration or axial position transducers shall contain three twisted conductors per group. The conductors shall be 16 AWG to 22 AWG, seven-strand, Class B, concentric-lay, tinned copper wire as specified in NEMA WC 5, Part 2 (IPCEA S-61-402). The lay of the conductors' twist shall be from 38 mm to 64 mm (1.5 in. to 2.5 in.). The conductors in each group shall be color-coded black, white, and red, and each group of three shall be identifiable by using colors or numbers.

NOTE Group shields are recommended to minimize cross talk between monitoring channels.

D.3.2 Primary Insulation

The conductors' primary insulation shall be the same as stated in D.2.2.

D.3.3 Overall Shield

The shield of each three-conductor group and the overall shield (see Note) of the multiple-circuit cable shall be polyester/aluminum-coated film or braided tinned copper. The shield specifications shall be the same as stated in D.2.3.

NOTE Overall shields are recommended to provide isolation from external noise.

D.3.4 Communications Wire

The cable shall contain a 16 AWG to 22 AWG, seven-strand, Class B, concentric-lay, copper communication wire whose insulation is 1.9 mm (75 mil) thick. The communication wire shall be coded with a color other than the group color.

D.4 Signal Cable for Thermocouples

D.4.1 Conductors

Single-circuit signal cable for thermocouples shall consist of a twisted pair of conductors. Single- or multiple-circuit cables are acceptable. The conductors shall be 16 AWG to 22 AWG solid (stranded can be used) wire, matched and calibrated as specified in ANSI MC96.1. The lay of the conductors' twist shall be a maximum of 51 mm (2 in.). The conductors shall be color coded as specified in Table D.1.

D.4.2 Primary Insulation

The conductors' primary insulation shall be the same as stated in D.2.2.

D.4.3 Shield

The cable shield shall be the same as stated in D.2.3.

D.4.4 Pair Jacket

The cable's pair jacket shall have a nominal thickness of 0.9 mm (35 mil), be of the color specified in Table D.1, and meet the other requirements stated in D.2.2.

Table D.1—Color Coding for Single-circuit Thermocouple Signal Cable

Type [a]	Conductor		
	Pair Jacket	Positive	Negative
TX	Blue	Blue	Red
JX	Black	White	Red
EX	Purple	Purple	Red
KX	Yellow	Yellow	Red
SX	Green	Black	Red
BX	Gray	Gray	Red

[a] Type designations are from ANSI MC96.1, Table VI.

Annex E
(normative)

Gearbox Casing Vibration Considerations

E.1 General

The requirements for monitoring casing vibration on a variety of machine types are specified in 7.4.4. This annex provides additional considerations specific to gearboxes. Section 7.4.4.5 a) requires the use of a dual-path monitor for gear casing measurements. It receives its input signal from an accelerometer mounted on a gear bearing housing (API 613 for special-purpose gear units directs that one accelerometer be mounted horizontally on the output bearing housing, one accelerometer be mounted horizontally on the input bearing housing, and that they be mounted below the split line unless otherwise specified). This signal is divided into two separate paths in the monitor. The first path is band-pass filtered and read out directly in peak acceleration units (g's or meters per second squared). This path observes the frequencies between 1000 Hz and 10 kHz. These frequencies are associated with gear mesh and provide information on mesh condition. The second path is integrated to rms velocity units (in inches per second or millimeters per second). This signal is band-pass filtered to observe frequencies between 10 Hz and 1000 Hz. These frequencies are associated with the vibration of the rotating elements. It provides additional machine condition information to supplement a shaft vibration monitor.

E.2 Signal Detection Schemes

E.2.1 Two signal detection schemes are used simultaneously in the gearbox casing vibration monitor. They are true peak and true rms.

E.2.2 A true peak detector responds (within certain limitations of the amplifier) to excursions of the signal from zero to a maximum (or minimum). This technique is equally sensitive to both periodic and short duration (low duty cycle) vibration events in the waveform. Because gears tend to generate the short duration (spike) vibration events when malfunctioning, peak detection is the standard for monitoring gear-related activity.

E.2.3 A true rms detector responds to the total area within the vibration waveform. It is less sensitive to short duration vibration events and tends to average them out as a form of filter.

NOTE Details of the actual mathematics of rms detection are available in many texts.

E.2.4 While the standard dual-path detection scheme for gearbox casing vibration uses a combination of true peak and rms measurements, 7.4.4.6 allows the user to optionally specify both paths in either peak or rms units. Use of one technique over the other is usually determined by geographical and historical preferences. Advocates of a peak measurement prefer it because it is easy to understand and it responds to the short duration events described in E.2.2. Advocates of an rms measurement prefer its smoothing effect and the lower values it yields as described in E.2.3.

E.2.5 Several important additional factors shall also be considered:

a) The detection circuitry in the monitor shall be consistent with the displayed units. If peak is displayed, a peak circuit detector shall be used in the monitor circuitry. Confusion occurs when an rms detector is used in the monitor and its output is scaled by 1.414 to display as peak units. This conversion is only valid for purely sinusoidal signals, which is rarely the situation except during calibration. An instrument displaying peak as 1.414 × rms may yield significantly lower values than one with a true peak detector when observing the same vibration signal. Many portable instruments use this approach, which can create confusion when comparing readings. To avoid confusion, it is recommended that peak measurements derived from rms be referred to as "derived peak" to distinguish them from "true peak" measurements.

b) Use the same units for both acceptance testing and permanent monitoring. This allows direct comparison and reduces confusion.

c) An AC voltmeter is commonly used for instrument calibration. Voltmeter calibration traceability is most common in rms terms. Calibration of a peak detecting instrument using rms $\times$ 1.414 may be utilized, but it is only valid for a pure sine wave signal.

d) Alarm limits shall reflect the units used. Use of empirically determined peak limits with an instrument using rms detection may result in machine damage. The reverse may provide unwanted alarms.

Selection of a scheme depends on experience. Companies with a database of machinery measurements and vibration limits in peak terms may not be comfortable using rms and vice versa. Each scheme can be made to work by knowledgeable people. Care and understanding shall be applied to each application to ensure that adequate machine protection is provided.

Annex F
(normative)

Field Testing and Documentation Requirements

F.1 General

F.1.1 This annex outlines minimum field testing and documentation requirements for MPS components. It is intended as a convenience to the purchaser and the owner in clearly specifying the total job requirements.

F.1.2 Verification and documentation shall be submitted to the owner as follows.

a) Machinery vendors shall submit documentation at least two weeks prior to any factory mechanical testing.

b) Construction agencies shall submit documentation at least four weeks prior to machine start-up.

F.2 Tools and Instrumentation

The codes in Table F.1 are used to designate tools and instruments needed to calibrate and test various portions of the MPS.

F.3 Vendor Requirements

The purchaser shall use the form in Table F.2 to indicate the required activities and the responsible agency or vendor required to perform each specified activity.

Table F.1—Tools and Instruments Needed to Calibrate and Test Machinery Protection Systems

Code	Tool or Instrument	Typical Application
A	DC voltage nulling instrument	Shaft electrical and mechanical runout testing and documentation
B	Dual channel storage oscilloscope with plotting software	Shaft electrical and mechanical runout testing and documentation
C	Proximity probe calibration test kit	System calibration, functional, and accuracy testing
D	Calibrated digital multimeter and frequency measuring device	System calibration, functional, and accuracy testing
E	Variable frequency waveform and pulse generator with DC offset	Simulation testing for vibration, position, tachometer, and overspeed detection channels
F	Variable frequency shaker with calibrated reference accelerometer	Accelerometer testing
G	Oscilloscope	Simulation testing for vibration, position, tachometer, and overspeed detection channels
H	Temperature sensor simulator	Simulation testing for temperature channels

Table F.2—Data, Drawing, and Test Worksheet

I	R	M	C	O	Activity	Tool and Instrument Codes [a] (Reference)
1					Location of rotor nodal points	[6.1.2.1 e); 6.1.2.1 f); Table G.2, Item 7]
2					Electrical/mechanical runout documentation	A, B, C, D [6.1.2.2 d); 6.1.3.6; Table G.2, Item 6)
3					Calibration curve for each proximity probe transducer	C, D (11.6.3; Table G.2, Item 6)
4					Acceleration or velocity shaker test	D, E, F (11.6.5; Table G.2, Item 6)
5					System arrangement plan	(Table G.2, Item 4)
6					Monitor system calibration check	C, D, E, F, H [4.5; 11.6.2; Table G.2, Item 20g)]
7					Recommended alarm and shutdown setpoints	(Table G.2, Item 8)
7.1					Shaft vibration	(Table G.2, Item 8)
7.2					Shaft axial position	(Table G.2, Item 8)
7.3					Radial bearing temperature	(Table G.2, Item 8)
7.4					Thrust bearing temperature	(Table G.2, Item 8)
7.5					Casing acceleration	(Table G.2, Item 8)
7.6					Casing velocity	(Table G.2, Item 8)
7.7					Piston rod drop	(Table G.2, Item 8)
7.8					Overspeed detection	(Table G.2, Item 8)
8					Operation for hazardous area compliance testing	(4.9.1)
9					Channel accuracy test	C, D, E, F, H (Table 1)
9.1					Radial shaft vibration	C, D, E (Table 1; 11.6.3)
9.2					Axial position	C, D, E (Table 1; 11.6.3)
9.3					Casing vibration	D, E, F (Table 1; 11.6.5)
9.4					Temperature	D, H (Table 1; 11.6.4)
9.5					Piston rod drop	C, D, E (Table 1; 11.6.3)
9.6					Overspeed detection	D, E (Table 1; 11.6.6)
10					Buffered output versus input accuracy	C, D, E, F [Table 1; 4.11.4 d); 11.6.2]
11					Power supply short-circuit test	D (4.10.4; 11.6.1)
12					Output relay tests	(11.6.1)
12.1					Circuit fault	C, D, E [7.1.3 a); 7.3.3; 7.4.1.2; 7.4.2.2; 7.4.3.5; 7.4.4.3; 7.4.5.2; 8.4.1.5; 8.4.1.6; 10.2.1 d); 10.2.5; 10.8.2; 11.6.1]
12.2					Shaft axial position alarm	C, D, E (4.11.5; 7.4.2.3; 11.6.1)
12.3					Shaft axial position shutdown	C, D, E (4.11.5; 7.4.2.3; 7.4.2.4; 11.6.1)
12.4					Radial shaft vibration alarm	C, D, E (4.11.5; 7.4.1.5; 7.4.1.6; 11.6.1)
12.5					Radial shaft vibration shutdown	C, D, E (4.11.5; 7.4.1.4; 7.4.1.5; 7.4.1.6; 11.6.1)
12.6					Casing vibration alarm	D, E, F (4.11.5; 7.4.4.4; 11.6.1)

Table F.2—Data, Drawing, and Test Worksheet (Continued)

I	R	M	C	O	Activity	Tool and Instrument Codes [a] (Reference)
12.7					Casing vibration shutdown	D, E, F (4.11.5; 7.4.4.4; 11.6.1)
12.8					Temperature alarm	D, H (4.11.5; 11.6.1)
12.9					Temperature shutdown	D, H (4.11.5; 7.4.5.4; 7.4.5.5; 11.6.1)
12.10					Piston rod drop alarm	C, D, E (4.11.5; 11.6.1)
12.11					Piston rod drop shutdown	C, D, E (4.11.5; 7.4.3.6; 11.6.1)
12.12					Overspeed detection alarm	D, E, G (8.4.1.3; 8.4.1.5; 11.6.1)
12.13					Overspeed detection shutdown	D, E, G (8.4.1.4; 8.4.1.6; 11.6.1)
13					System shutdown disarm test	C, D, E (4.12.11; 11.6.1)
14					Communication interface functional test	C, D, E, F, G, H [4.13; 4.11.7 b); 11.6.1]
14.1					Analog 4 mA to 20 mA outputs	C, D, E, F, H [4.11.4 e); 11.6.1]
14.2					Digital communications port	[4.13; 4.11.7 b); 11.6.1]
15					First out alarm and shutdown test	C, E, F, H [4.11.5 h); 11.6.1]
16					Circuit fault functional test	C, D, E [4.11.4 b); 4.11.4 c); 11.6.1]
17					Shutdown system functional test	E, H [4.11.5; 4.11.7 d); 4.11.7 e); 11.6.1]
18					Individual channel shutdown disarm test	C, D, E [4.11.5 f); 11.6.1]
19					Voting logic tests	(11.6.1)
19.1					Shaft axial position	D, E (7.4.2.4;7.4.2.5; 11.6.1)
19.2					Radial shaft vibration	D, E (7.4.1.4; 7.4.1.5; 11.6.1)
19.3					Casing vibration	D, E (4.11.5; 11.6.1)
19.4					Temperature	D, H (7.4.5.4; 7.4.5.5; 11.6.1)
19.5					Piston rod drop	D, E (7.4.3.6; 11.6.1)
19.6					Overspeed detection	D, E (8.4.1; 8.4.2; 11.6.1)
20					Casing vibration filter cutoff frequency	D, E, [7.4.4.2; 7.4.4.5; 7.4.4.6 c); 11.6.1]
21					Temperature sensor downscale failure verification test	(7.4.5.2; 11.6.1)
22					System wiring signal loss test	D, E, G (11.6.1)
23					Wiring connection verification test	(11.6.1)
24					Radio transmission RFI verification test	(4.9.3)
25					System integration test	C, D, E, F, G (11.6.7)
26					Final system arrangement plan	(12.3.2; Table G.2, Item 1)

Directions:

I—Activity item number.

R—An X in this box indicates a required activity to be performed by the machinery protection system vendor.

M—An X in this box indicates a required activity to be performed by the machinery vendor.

C—An X in this box indicates a required activity to be performed by the construction agency.

O—An X in this box indicates a required activity to be performed by other agency (specify agency).

[a] Tool and instrument codes are listed in Table F.1.

Annex G
(informative)

Contract Drawing and Data Requirements

Table G.2 is a sample distribution record (schedule). The listed drawing and data types are required; however, the manufacturers may use different names for the same drawing. The items in the description column should be modified in the early stages of the order using the drawing names supplied by the manufacturer.

For purposes of illustration, Table G.1 includes a typical major milestone timeline.

Table G.1—Typical Milestone Timeline

Milestone	Reference	Typical Schedule	Activity
T1			Initial specification and request for quotation
T2			Proposal
T3			Contract
T3.1	12.1.3	Four to six weeks after T3	Coordination meeting, covering the machinery protection system, involving vendor with unit responsibility, purchaser, and machinery protection system vendor
A	11.6, Figure 23, Figure 24, 12.3.2, 12.3.3	Six weeks after T3	Purchaser obtains and supplies to owner: setpoints, parts list and recommended spares, system arrangement plans, system schematics, and datasheets
B		Four weeks prior to T4	Construction agency obtains channel tagging requirements from owner (including content, location, material, and method of attachment) and forwards the data to the machinery protection system vendor
T4			Machinery protection system vendor shipping date
A	12.3.5.2, 12.3.5.3	Five days after T4	Machinery protection system vendor supplies standard manuals
B	6.1.1	Before machining	Purchaser obtains from machinery vendor and supplies to owner the location of rotor nodal points
C	Annex F	Two weeks prior to T5	Machinery vendor supplies verification and documentation data
D	Annex F, 11.6, Figure 25, Table 4, Table 5	Before T5	Machinery vendor supplies to purchaser calibration data on each transducer
E	Applicable API standard for each machine class	Before T5	Machinery vendor supplies to purchaser runout data on each probe location on each shaft.
T5			Machine shop test date
T6			Machine shipping date
A	Annex F, Figure 25, 11.6	Four weeks prior to T7	Purchaser forwards contract data to owner
B	Annex F, 11.6, Figure 25, Table 4, Table 5	Four weeks prior to T7	Purchaser forwards calibration data on each transducer to owner
C	Applicable API standard for each machine class	Four weeks prior to T7	Purchaser forwards runout data for each transducer to owner
T7			Functional test
A	12.3.5.4	Four weeks after T7	Construction agency provides purchaser technical data manual
B	12.3.4.2	Before T8	Reviewed spare parts list is given to purchaser with time enough to purchase and receive spares for field start-up
C	Annex F	Four weeks prior to T8	Construction agency supplies verification and documentation data
T8			Field start-up

NOTE This table is typical of projects for which the machinery vendor is unit responsible and hence procures the complete machinery vibration protection system. With the widespread use of distributed control systems in the industry, more and more machinery protection systems are being installed in local equipment rooms and central control rooms, rather than local to the machine train. For these types of projects, the engineering contractor often assumes responsibility for all aspects of the machinery protection system supply including: procuring the protection monitor panels, coordinating the transducer supply from the machinery protection system vendor to the machinery vendor, and coordinating any required third-party system integration testing.

Table G.2—Sample Distribution Record (Schedule)

CONTRACT DRAWING AND DATA REQUIREMENTS

JOB NO. ______________________ ITEM NO. ______________
PURCHASE ORDER NO. _________ DATE _________________
REQUISITION NO. _______________ DATE _________________
INQUIRY NO. ___________________ DATE _________________
PAGE _______ OF _____ BY _________________________

FOR ____
SITE ____
SERVICE ____________________________________

REVISION ____
UNIT ____
NO. REQUIRED ____

Responsible Agency [a] (Annex B)

Proposal [b] Bidder to furnish ________ copies of data for all items indicated by an X.

Review [c] Vendor to furnish ________ copies and ________ transparencies of drawings and data indicated.

Final [c] Vendor to furnish ________ copies and ________ transparencies of drawings and data indicated.
Vendor to furnish ________ operating and maintenance manuals.

DISTRIBUTION RECORD

Final—Received from vendor
Due from vendor [d]
Review—Returned to vendor
Review—Received from vendor
Review—Due from vendor [d]

				DESCRIPTION					
				1. Certified general arrangement or outline drawing and list of connections (12.2.2)					
				2. Cross-sectional drawings and bill of materials (12.2.2)					
				3. Control and electrical system schematics and bills of materials (12.2.2)					
				4. Electrical and instrumentation system arrangement plans (12.2.2)					
				5. Grounding plan (4.15)					
				6. Calibration curves (11.6.3, 11.6.5)					
				7. Rotor nodal point analysis data (6.1.2.1)					
				8. Recommended alarm (alert) and shutdown (danger) setpoints (11.6.1.2 and Figure 24)					
				9. Datasheets (12.2.3, 12.3.3)					
				10. Dimensions and data (12.2.2)					
				11. Installation manual (12.3.5.2)					
				12. Operating and maintenance manual (12.3.5.3)					
				13. Parts list and recommended spares (12.2.3, 12.3.4)					
				14. Engineering, fabrication, and delivery schedule (progress reports) (11.1.2, 11.1.3)					
				15. List of drawings and data (12.3)					
				16. Shipping list (12.3)					
				17. Special weather protection and winterization requirements (12.2.3)					
				18. Special system integrity protection requirements (12.2.3)					
				19. List of special tools furnished for maintenance (12.2.3)					
				20. Technical data manual (12.3.5.4)					
				21. Material safety data sheets					

[a] 1. Machinery protection system vendor; 2. Machinery vendor; 3. Construction agency; 4. Owner; 5. Other (____________________).
[b] Proposal drawings and data do not have to be certified or as-built.
[c] Purchaser will indicate in this column the time frame for submission of materials using the nomenclature given at the end of this form.
[d] Bidder to complete these two columns to reflect his/her actual distribution schedule and include this form with his/her proposal.

Notes:

1. Send all drawings and data to ____

____

2. All drawings and data to show project, appropriation, purchase order, and item numbers in Addition to the plant location and unit. In addition to the copies specified above, one set of the Drawings/ instructions necessary for field installation to be forwarded with the shipment.

Nomenclature:

_________ S—number of weeks prior to shipment.

_________ F—number of weeks after firm order.

_________ D—number of weeks after receipt of approved drawings.

Vendor ____

Date ___________________________ Vendor Reference _____________________________

Signature ____

(Signature acknowledges receipt of all instructions)

Table G.2 Description

1) Certified general arrangement outline drawing and list of connections, including the following:

   a) size, rating, and location of all customer connections;

   b) approximate overall handling weights;

   c) overall dimensions;

   d) dimensions of mounting plates and locations of bolt holes for hardware installation;

   e) maintenance and disassembly clearances;

   f) list of reference drawings.

2) Cross-sectional drawings and bill of materials, including the following:

   a) machine-mounted sensors and probe holders;

   b) vendor-supplied extension cables and connectors;

   c) monitor rack assemblies;

   d) list of reference drawings.

3) Control and electrical system schematics and wiring diagrams and bills of materials for all systems. Schematics to show all adjustment points for alarm and shutdown limits (setpoints).

4) Electrical and Instrumentation arrangement plans for all systems (see Annex H for typical arrangement plans). The following information to be provided for all system parts:

   a) description,

   b) MPS vendor part number,

   c) MPS vendor name.

5) System grounding plan.

6) Calibration curves including the following.

   a) Calibration curves for each shaft radial vibration transducer, casing vibration transducer, shaft axial position transducer, bearing temperature transducer, piston rod drop transducer and machine overspeed transducer showing sensor linearity within specified tolerances (see 11.6.3.2 and Figure 25). The MPS vendor's serial/ model number for all transducers, and the target material used for calibrating shaft radial vibration transducers and shaft axial position transducers to be included on the calibration data.

   b) Electrical and mechanical runout test data at sensor mounting locations for shaft radial vibration proximity transducers. The runout data to be phase related to the permanent or temporary once-per-revolution marker.

7) Rotor nodal analysis data showing the location of the predicted nodal points relative to the bearing centerlines and the radial shaft vibration probes.

8) Alarm (alert) and shutdown (danger) setpoints for radial shaft vibration, casing vibration, shaft axial position, bearing temperature, piston rod drop, and machine overspeed as recommended by the machinery vendor. The limits to be stated in terms of the monitor display (e.g. unfiltered mils peak-to-peak, g peak, or inches per second peak).

9) Datasheets.

10) Dimensions (including nominal dimensions with design tolerances) and data for the following parts:

    a) special transducers,

    b) special mounting fixtures.

11) Installation manual describing the following:

    a) storage procedure,

    b) mounting details,

    c) wiring connections,

    d) installation and calibration instructions,

    e) datasheets,

    f) special weather protection and winterization requirements,

    g) special system integrity protection requirements.

12) Operating and maintenance manual including the following:
    a) wiring connections,
    b) installation and calibration instructions,
    c) special weather protection and winterization requirements,
    d) board level troubleshooting instructions,
    e) basic operation details,
    f) alarm (alert) and shutdown (danger) setpoint adjustments,
    g) system bypass operation.
13) Parts list and recommended spares with stocking level recommendations.
14) Progress report and delivery schedule, including vendor buyouts and milestones.
15) List of all vendor drawings and data, including titles, drawing/document numbers, schedule for transmission, and latest revision number and dates.
16) Shipping list, including all major components that will ship separately.
17) Statement of any special weather protection and winterization required for start-up, operation, and idleness.
18) Special requirements or restrictions necessary to protect the integrity of the MPS.
19) List of special tools furnished for maintenance. Any metric items to be identified.
20) Technical data manual, including the following:
    a) storage procedures;
    b) calibration data, per Item 6) above;
    c) drawings, in accordance with 12.2.2, 12.3.2;
    d) tagging information;
    e) spare parts list, in accordance with Item 13) above;
    f) utility data (power source and purge requirements);
    g) MPS field test documentation, including: installation and calibration details, curves and data, rotor mechanical and electrical runouts, and recommended alarm (alert) and shutdown (danger) setpoints;
    h) rotor nodal points, in accordance with Item 7) above;
    i) as-built datasheets, per Item 9) above;
    j) MPS integration test results.
21) Material Safety Data Sheet (OSHA Form 20), as applicable.

Annex H
(informative)

Typical System Arrangement Plans

H.1 This annex presents typical system arrangements for turbomachinery with hydrodynamic bearings including a turbine (Figure H.1), a double-helical gear (Figure H.2), a centrifugal compressor or pump (Figure H.3), and an electric motor (Figure H.4). A typical arrangement for a pump with rolling element bearings is included as Figure H.5. Figure H.6 shows a typical arrangement for a horizontal reciprocating compressor.

H.2 As a minimum, the arrangement plan furnished for each machinery train (see Table G.2) shall illustrate the following items on the typical system arrangements.

a) The position of each probe in relation to the machine bearing.

NOTE The direction of shaft rotation does not affect the X and Y probe location. The X and Y probes are always located as defined in 6.1.2.1. For piston rod drop probes, see Note following 6.1.4.7 for probe nomenclature conventions.

b) The machine direction of active thrust (where applicable).

c) The machine direction of rotation. This shall be accomplished viewing all drivers from the high-pressure or outboard end and all driven machines from the driven end.

d) A complete description of the system, including the following items, as well as any other information applicable to the layout of the particular system:

   i) the number, type, and position of probes;

   ii) the type of bearings;

   iii) the clock position of radial probes, with degrees referenced to the vertical top dead center (TDC) as zero;

   iv) the clock position of phase reference probes, with degrees referenced to the vertical TDC as zero;

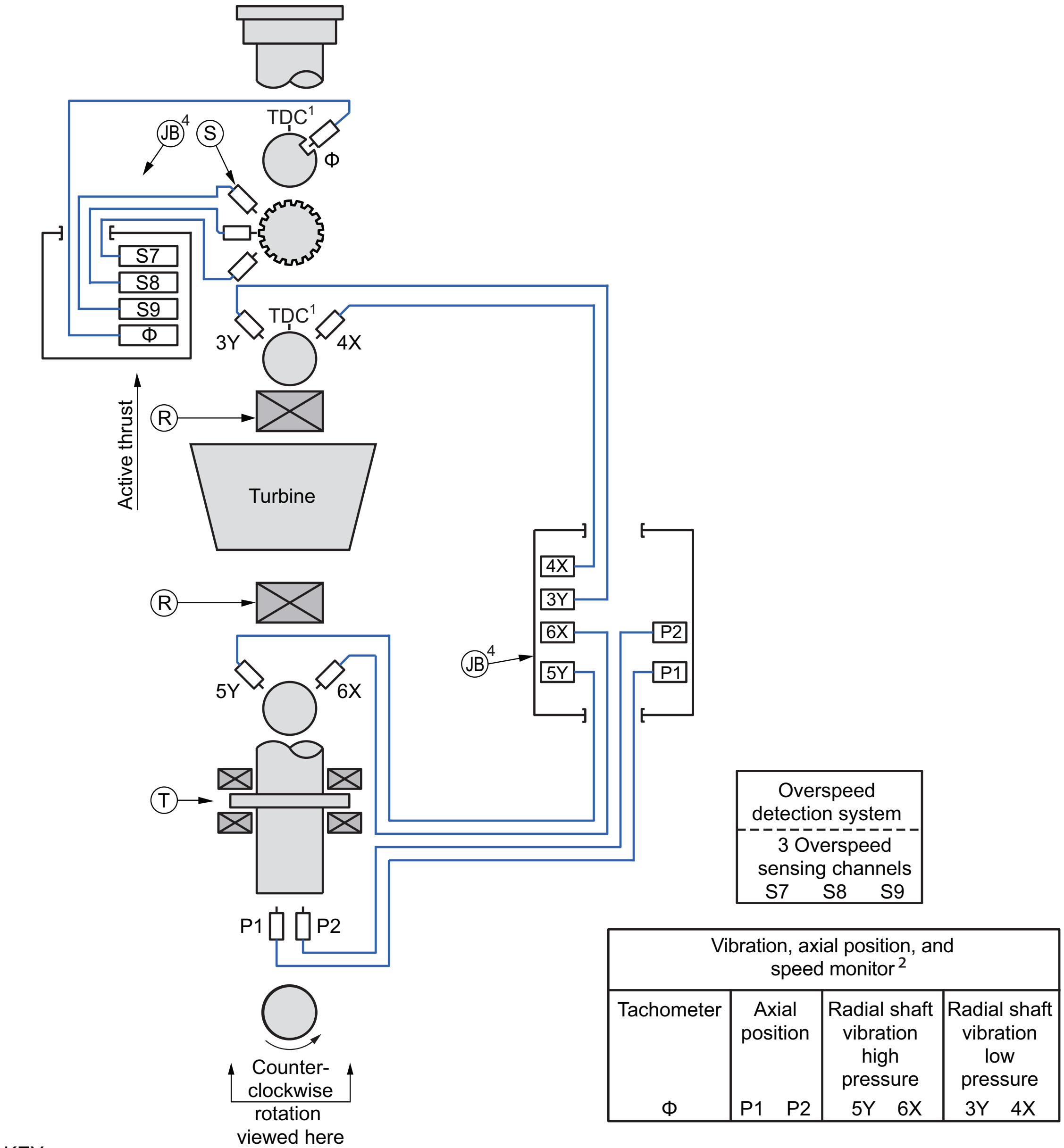
   v) the location of axial probes;

   vi) the arrangement of the machine and junction boxes.

e) The layout of the radial shaft vibration, axial position, casing vibration, tachometer, overspeed detection, rod drop, and temperature monitors and all machine signal locations on the monitor.

f) The type of machine.

g) The owner’s machine identification number.



KEY

- P1 Axial position probe (instrument manufacturer ID data[3])
- P2 Axial position probe (instrument manufacturer ID data[3])
- 3Y Low pressure end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
- 4X Low pressure end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
- 5Y High pressure end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
- 6X High pressure end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
- Φ Phase reference transducer, 45° right of TDC[1] (instrument manufacturer ID data[3])
- R Radial bearing (description)
- T Thrust bearing (description)
- JB Junction box
- S7-S9 Overspeed sensors

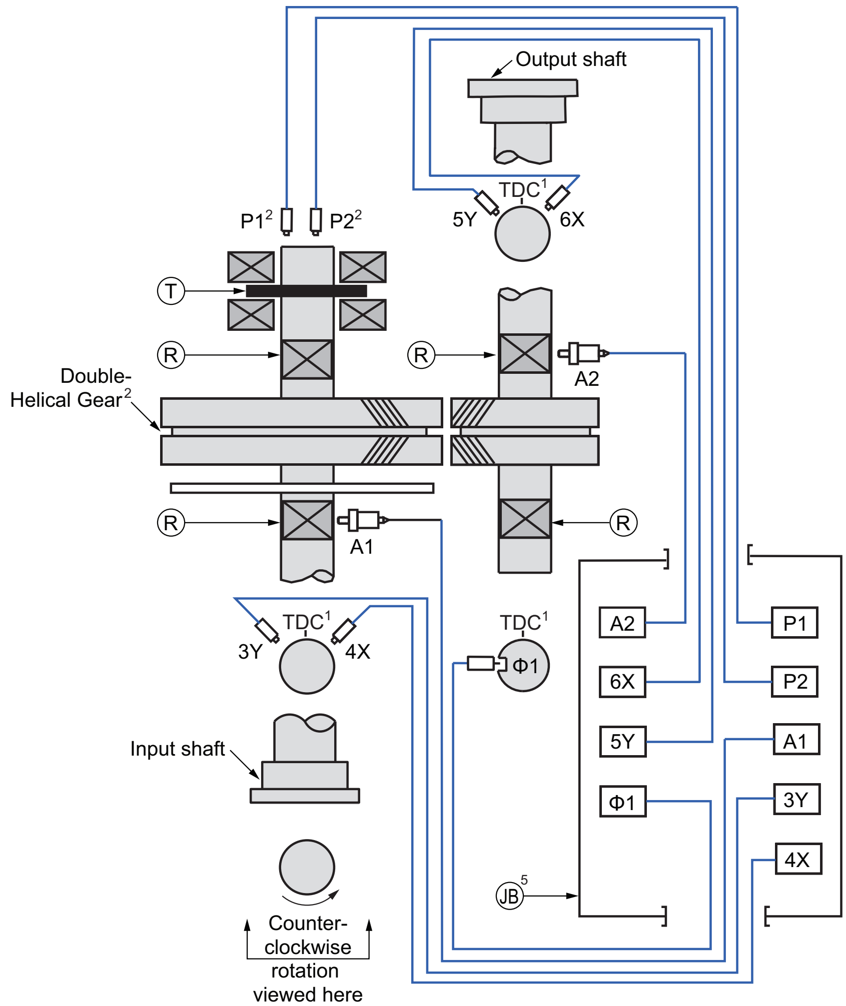
NOTE 1 TDC indicates top dead center (6.1.5.2).

NOTE 2 Typical temperature sensors and monitors are shown in Figure H.3.

NOTE 3 Instrument manufacturer ID data includes vendor's model and part numbers.

NOTE 4 Labels inside the junction box represent the signal conditioning interface modules to which the sensors interface.

Figure H.1—Typical System Arrangement for a Turbine with Hydrodynamic Bearings



Vibration and axial position monitor[3]

Radial shaft vibration (input shaft)		Bearing cap vibration (input shaft)	Axial shaft position[2]		Radial shaft vibration (output shaft)		Bearing cap vibration (output shaft)
3Y	4X	A1	P1	P2	5Y	6X	A2

KEY

- A1 Input shaft coupling end horizontal radial accelerometer 90° off TDC[1] (instrument manufacturer ID data[4])
- A2 Output shaft coupling end horizontal radial accelerometer 90° off TDC[1] (instrument manufacturer ID data[4])
- P1 Input shaft thrust bearing end axial position probe #1 (instrument manufacturer ID data[4])
- P2 Input shaft thrust bearing end axial position probe #2 (instrument manufacturer ID data[4])
- 3Y Input shaft coupling end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[4])
- 4X Input shaft coupling end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[4])
- 5Y Output shaft coupling end horizontal radial accelerometer 45° left of TDC[1] (instrument manufacturer ID data[4])
- 6X Output shaft coupling end horizontal radial accelerometer 45° right of TDC[1] (instrument manufacturer ID data[4])
- Φ1 Output shaft noncoupling end phase reference probe, 90° left of TDC[1] (instrument manufacturer ID data[4])
- R Radial bearing (description)
- T Thrust bearing (description)
- JB Junction box

NOTE 1 TDC indicates top dead center (6.1.5.2).

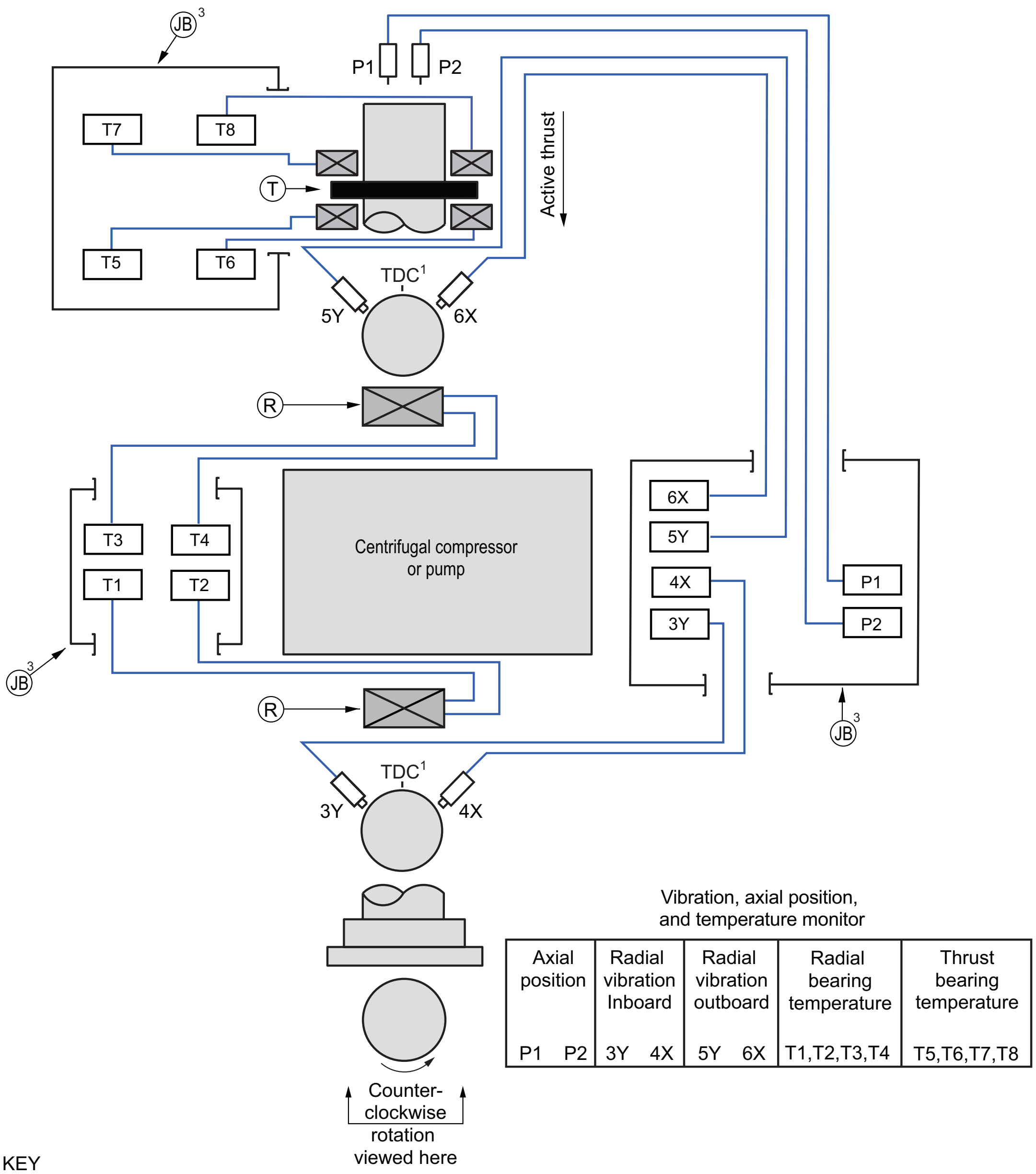
NOTE 2 For a single-helical gear, a pair of axial probes should be installed at each thrust-bearing end.

NOTE 3 Typical temperature sensors and monitors are shown in Figure H.3.

NOTE 4 Instrument manufacturer ID data includes vendor's model and part numbers.

NOTE 5 Labels inside the junction box represent the signal conditioning interface modules to which the sensors should interface.

Figure H.2—Typical System Arrangement for Double-helical Gear[2]

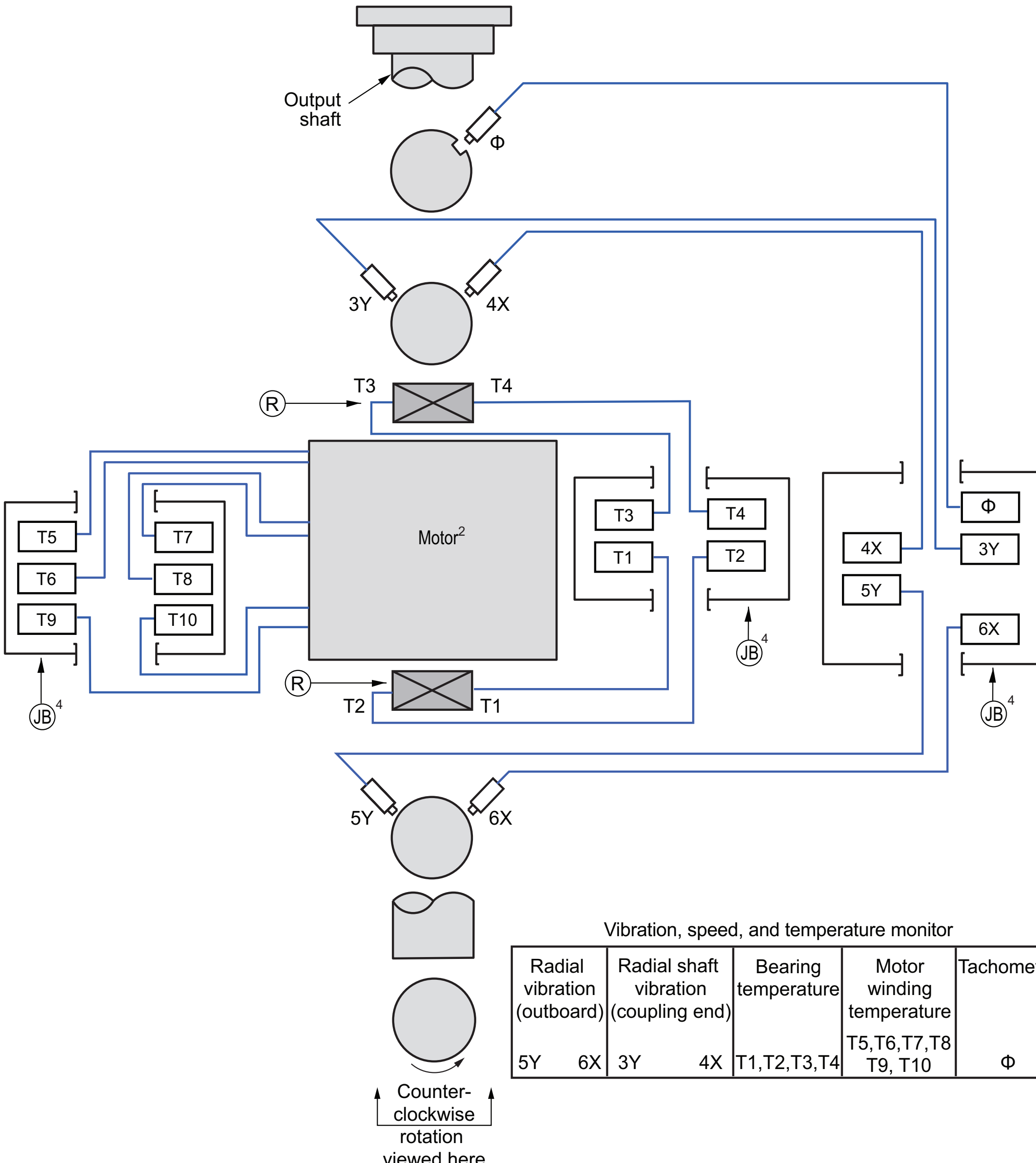


KEY

- P1 Axial position probe (instrument manufacturer ID data[2])
- P2 Axial position probe (instrument manufacturer ID data[2])
- 3Y Inboard end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[2])
- 4X Inboard end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[2])
- 5Y Outboard end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[2])
- 6X Outboard end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[2])
- R Radial bearing (description)
- T Thrust bearing (description)
- JB Junction box
- T1, T2 Coupling end bearing temperature
- T3, T4 Outboard end bearing temperature
- T5, T6 Active thrust bearing temperature
- T7, T8 Inactive thrust bearing temperature

NOTE 1 TDC indicates top dead center (6.1.5.2).
NOTE 2 Instrument manufacturer ID data includes vendor's model and part numbers.
NOTE 3 Labels inside the junction box represent the signal conditioning interface modules to which the sensors should interface.

Figure H.3—Typical System Arrangement for a Centrifugal Compressor or a Pump with Hydrodynamic Bearings



Vibration, speed, and temperature monitor

Radial vibration (outboard)		Radial shaft vibration (coupling end)		Bearing temperature	Motor winding temperature	Tachometer
5Y	6X	3Y	4X	T1,T2,T3,T4	T5,T6,T7,T8 T9, T10	Φ

KEY

- 3Y Inboard end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
- 4X Inboard end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
- 5Y Outboard end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
- 6X Outboard end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
- R Radial bearing (description)
- JB Junction box
- T1, T2 Outboard end bearing temperature
- T3, T4 Inboard end bearing temperature
- T5, T6 Motor winding temperature (phase A)
- T7, T8 Motor winding temperature (phase B)
- T9, T10 Motor winding temperature (phase C)
- Φ Phase reference transducer, 45° right of TDC[1] (instrument manufacturer ID data[3])

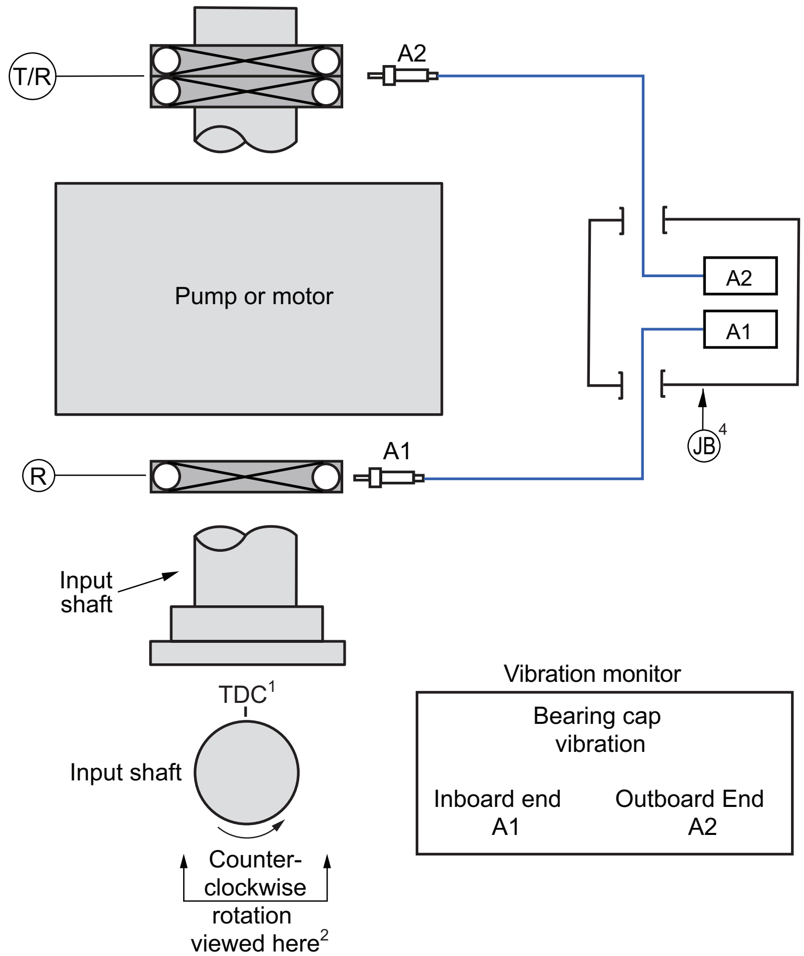
NOTE 1 TDC indicates top dead center (6.1.5.2).

NOTE 2 In most cases, probe configurations for generators will be the same as shown for the motor.

NOTE 3 Instrument manufacturer ID data includes vendor's model and part numbers.

NOTE 4 Labels inside the junction box represent the signal conditioning interface modules to which the sensors should interface.

Figure H.4—Typical System Arrangement for an Electric Motor with Sleeve Bearings



KEY

A1 Inboard end radial horizontal accelerometer 90° off TDC[1] (instrument manufacturer ID data[3])

A2 Outboard end radial horizontal accelerometer 90° off TDC[1] (instrument manufacturer ID data[3])

R Radial bearing (description)

T/R Thrust/Radial bearing (description)

JB Junction box

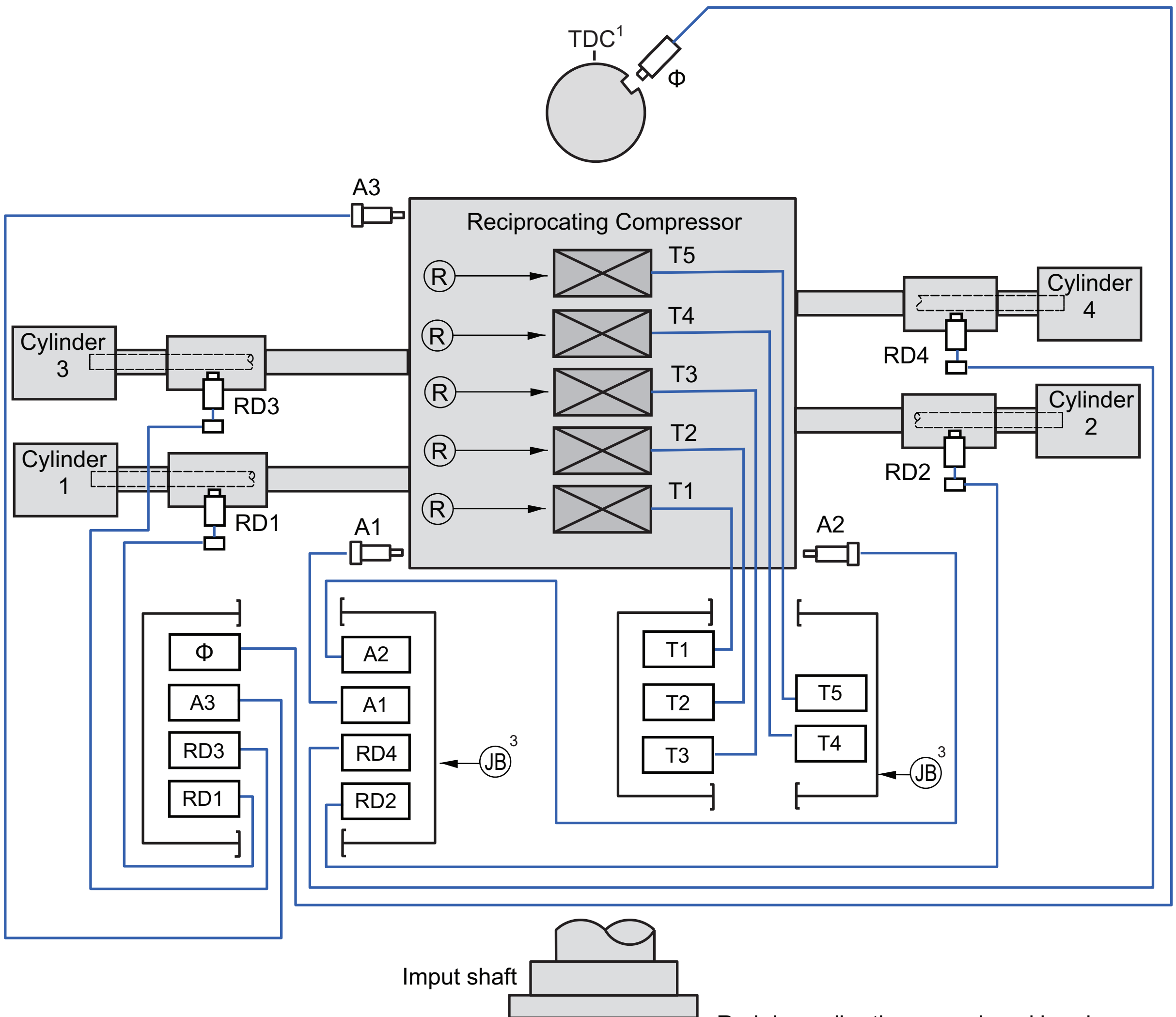
NOTE 1 TDC indicates top dead center (6.1.5.2).

NOTE 2 The same arrangement would be used for a motor with rolling element bearings but would be viewed from the outboard end.

NOTE 3 Instrument manufacturer ID data includes vendor's model and part numbers.

NOTE 4 Labels inside the junction box represent the signal conditioning interface modules to which the sensors should interface.

Figure H.5—Typical System Arrangement for a Pump or Motor with Rolling Element Bearings



Rod drop, vibration, speed, and bearing temperature monitor system

Piston rod drop channels	Casing vibration channels	Bearing temperature channels	Tachometer
RD1, RD2, RD3, RD4	A1, A2, A3	T1,T2,T3,T4,T5	Φ

KEY

Φ	Phase reference transducer
R	Radial bearing (description)
JB	Junction box
T1-T5	Main bearing temperatures
RD1-RD4	Rod drop probes (instrument manufacturer ID data[2])
A1, A2, A3	Casing Accelerometers

NOTE 1 TDC indicates top dead center (6.1.5.2).

NOTE 2 Instrument manufacturer ID data includes vendor's model and part numbers.

NOTE 3 Labels inside the junction box represent the signal conditioning interface modules to which the sensors should interface.

Figure H.6—Typical System Arrangement for a Reciprocating Compressor

Annex I
(informative)

Setpoint Multiplier Considerations

I.1 General

I.1.1 Setpoint multiplication is the function whereby selected channels in the monitor system have their alarm (alert) and shutdown (danger) setpoints elevated by some preset amount (usually an integer multiple such as 2 or 3).

I.1.2 Setpoint multiplication is usually invoked by an external contact closure (such as a turbine control system relay output). However, this command could also be invoked via a digital communication link on some MPS's.

I.1.3 This annex provides an explanation of why this feature may be required on some machine types, and it also offers guidance for the proper use of this feature.

NOTE Alarm setpoints can vary depending on the strategy and requirements of various users for machinery protection. In some cases, alarm levels are established very close to the mechanical clearance limits of the machine. In these cases, setpoint multiplication should not be specified because it will result in alarm levels that exceed these mechanical clearances and will not provide adequate machinery protection.

I.2 Fundamental Rotor Response

I.2.1 General

I.2.1.1 All rotating machinery exhibits characteristic resonances at certain excitation frequencies. The most common form of excitation is the rotor's own unbalance forces occurring at the rotational speed of the machine. This discussion assumes excitation caused by these unbalance forces.

I.2.1.2 When a machine's rotational speed coincides with one of its resonances (such as during start-up or shutdown), vibration can result that is far above the levels expected at rated running speeds.

I.2.1.3 Machinery designers are generally careful to account for these resonances in their rotor dynamic designs such that the machine does not operate at or near any resonances.

I.2.2 Types of Responses at Resonance Conditions

Vibratory response at resonance conditions can be lateral (i.e. radial vibration), axial, or torsional. This standard does not address either axial vibration or torsional vibration measurements as part of the MPS. Therefore, this discussion focuses only on the lateral or radial vibration response as measured by proximity probes or by casing transducers such as accelerometers. However, care should be taken to recognize and document resonance responses other than radial vibration because they can be just as damaging to the machine.

I.2.3 Operation Above the First Critical Speed

I.2.3.1 For machines that operate at rotational speeds above their first critical, it is necessary for the machine to pass through one or more resonances as it ramps up or ramps down. Figure I.1 shows a typical radial vibration amplitude response of a machine operating above its first critical but below its second critical. The first critical occurs at the speed designated as $\mathrm{rpm}_{\mathrm{critical}}$ in Figure I.1. The vibration amplitude at this rotational speed is shown as $\mathrm{Amplitude}_{\mathrm{critical}}$. While this figure shows only the response from a single measurement location on the machine, similar graphs can be constructed for each radial vibration measurement location.

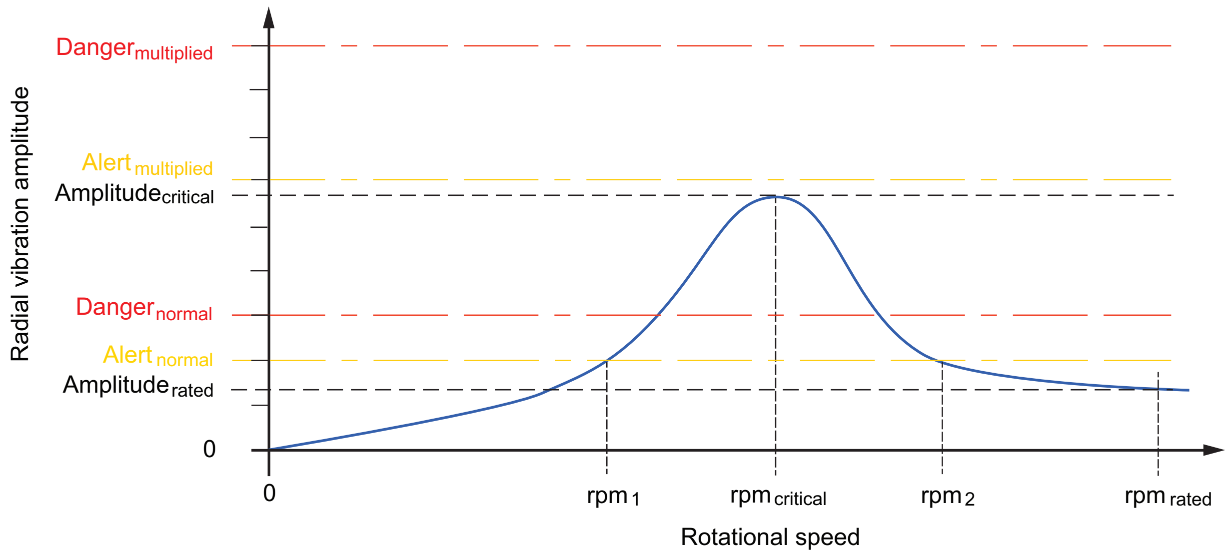


Figure I.1—Setpoint Multiplication Example

I.2.3.2 The machine's rated rotational speed is designated as $\mathrm{rpm}_{\mathrm{rated}}$ and the radial vibration amplitude occurring at this speed is designated as $\mathrm{Amplitude}_{\mathrm{rated}}$. At this rated running speed, the vibration amplitude $\mathrm{Amplitude}_{\mathrm{rated}}$ is less than the normal alert ($\mathrm{Amplitude}_{\mathrm{normal}}$) and danger ($\mathrm{Danger}_{\mathrm{normal}}$) setpoints.

I.3 Conditions Requiring Setpoint Multiplication

I.3.1 Notice that the machine in Figure I.1 experiences vibration amplitudes in excess of its normal alarm ($\mathrm{Alert}_{\mathrm{normal}}$) and shutdown ($\mathrm{Danger}_{\mathrm{normal}}$) setpoints when it passes through its first critical. If the machine remains in this speed region ($\mathrm{rpm}_1 \leq$ speed $\leq \mathrm{rpm}_2$) for a time Δt that exceeds the preset alarm delays for the channel, alarm (alert) or shutdown (danger) events will result. In the case of a danger event, this may actually result in the machine being shut down even though it was merely experiencing normal vibration responses as it passed through a resonance.

I.3.2 The condition defined in I.3.1 leads to the need for setpoint multiplication. As shown in Figure I.1, if the alarm ($\mathrm{Alert}_{\mathrm{normal}}$) and shutdown ($\mathrm{Danger}_{\mathrm{normal}}$) setpoints are multiplied by a factor of 3 while the machine is operating between rotational speeds rpm_1 and rpm_2, the machine can pass through its first critical without encountering spurious alarms and shutdowns. In this case, the alarm (alert) and shutdown (danger) setpoints are elevated temporarily to $A_{\mathrm{multtiplied}}$ and $D_{\mathrm{multiplied}}$, respectively. The setpoints return to their normal levels when the machine is outside this speed region.

I.3.3 Thus, setpoint multiplication is required when both the criteria below are met:

a) the machine experiences vibration amplitudes in excess of its danger or alert setpoints as it passes through a machine resonance and this results in unwanted machine shutdown or alarms;

b) the duration of this setpoint violation exceeds the preset alarm delay times.

I.4 Alarm Suppression or Bypass Considerations

The practice of bypassing or suppressing the MPS alarms while it passes through a resonance in lieu of using properly established setpoint multiplication functions is strongly discouraged. Setpoint multiplication merely elevates the alarms—it does not suppress them. This ensures that machinery protection is provided at all rotational speeds of the machine.

I.5 Proper Applications of Setpoint Multiplication

I.5.1 General

The proper application of the setpoint multiplication function can be divided into two basic considerations.

I.5.2 Proper Identification of Applicable Channels

Each radial vibration location will typically measure a different amplitude response. Thus, the machine's characteristic response at each radial vibration measurement location should be documented over the range of rotational speeds from zero to rated speed. This information should be used in determining which channels require setpoint multiplication. Only those channels that meet the criteria of I.3.3 a) and I.3.3 b) above should be fitted with setpoint multiplication functions.

I.5.3 Proper Selection of Setpoint Multipliers

The characteristic response for each measurement location documented in I.5.2 above should also be used to establish the appropriate multiplier. The multiplier should generally be chosen to be as small as possible while still elevating the alarm (alert) and shutdown (danger) setpoints to levels that are above the machine's characteristic response at resonance. Provisions for setpoint multiplication by 2 or 3 are required of MPS's complying with this standard (the example contained in Figure I.1 assumes an integer multiple of 3 as can be noted by the tic marks on the vertical axis). When multipliers in excess of 3 are required to accommodate the machine's response at resonance(s), this may be indicative of machinery that has unacceptably large amplification factors. The machinery manufacturer should be consulted.

I.6 Control System Interface Considerations

I.6.1 General

Typically, the machine control system will be capable of generating an output signal, such as a relay contact closure, that is wired to the MPS to invoke its setpoint multiplication function. There are three basic ways this is accomplished.

I.6.2 Absolute Speed Range Sensing

This method requires the machine control system to sense the rotational speed of the machine and activates an output any time the machine is operating at speeds between rpm_1 and rpm_2 (see Figure I.1).

I.6.3 Timer

This method can be used if the acceleration and deceleration rates of the machine are repeatable. In this case, a preset timer in the machine control system is triggered whenever the machine is accelerating through speed rpm_1 or decelerating through speed rpm_2. The machine control system simply invokes the setpoint multiplication output for a time equal to or greater than Δt (see I.3 for a discussion of Δt).

NOTE The duration Δt is dependent on the acceleration and deceleration rates governed by the machine control system. This paragraph should not be construed as permitting the machine to dwell indefinitely at or near its critical speed(s).

I.6.4 Manual Operation

This method does not rely on an automatic machinery control system. Instead, an operator manually invokes the setpoint multiplication in the MPS by a pushbutton or switch or timer as part of the machine start-up or shutdown procedure. However, this is rarely encountered because most machines are now fitted with automatic control systems capable of performing all start-up and shutdown control and sequencing without human intervention.

I.6.5 Best Practice Recommendations

The method described in I.6.2 above is encouraged as best practice when integrating the machine control system with the MPS. The manual method described in I.6.4 is least desirable because it relies on human intervention for proper machinery protection. It can result in false shutdowns or alarms if the setpoint multiplication function is not invoked. It can also lead to missed shutdowns or alarms if the setpoint multiplication function remains invoked even though the machine is operating outside the region between rpm_1 and rpm_2.

Annex J
(normative)

Electronic Overspeed Detection System Considerations

J.1 General

J.1.1 The standard employed for the rotating machine under consideration will generally specify the allowable momentary overspeed as a percent of rated operating speed. For example, API 612 requires the overspeed protection system to preclude the rotor from ever exceeding 127 % of the rated operating speed on mechanical drives and 121 % on generator drives.

J.1.2 The electronic ODS is only one component within the entire overspeed protection system (see Figure J.1). The performance of the entire system is not limited to items discussed in this standard. Other components that are critical in determining the response of the entire system may include, but are not limited to: interposing relays, solenoids, shutdown valve(s), nonreturn valves, steam and hydraulic piping, and the entrained energy within the rotating machine itself. Collectively, these components comprise the overspeed protection system.

J.2 System Response Time

This standard requires that the electronic ODS be able to detect an overspeed event and change the state of its output relays within 40 ms when provided with an input signal frequency of at least 300 Hz. However, this response time of the detection system alone does not guarantee that the complete overspeed protection system will be suitable for a particular application. Other system dynamics need to be considered. Proper engineering judgment and system design shall be used to ensure that the complete overspeed protection system functions properly and responds fast enough to preclude the rotor speed from exceeding the maximum allowable limit. Consult Annex O as an example of how to evaluate the total system response time.

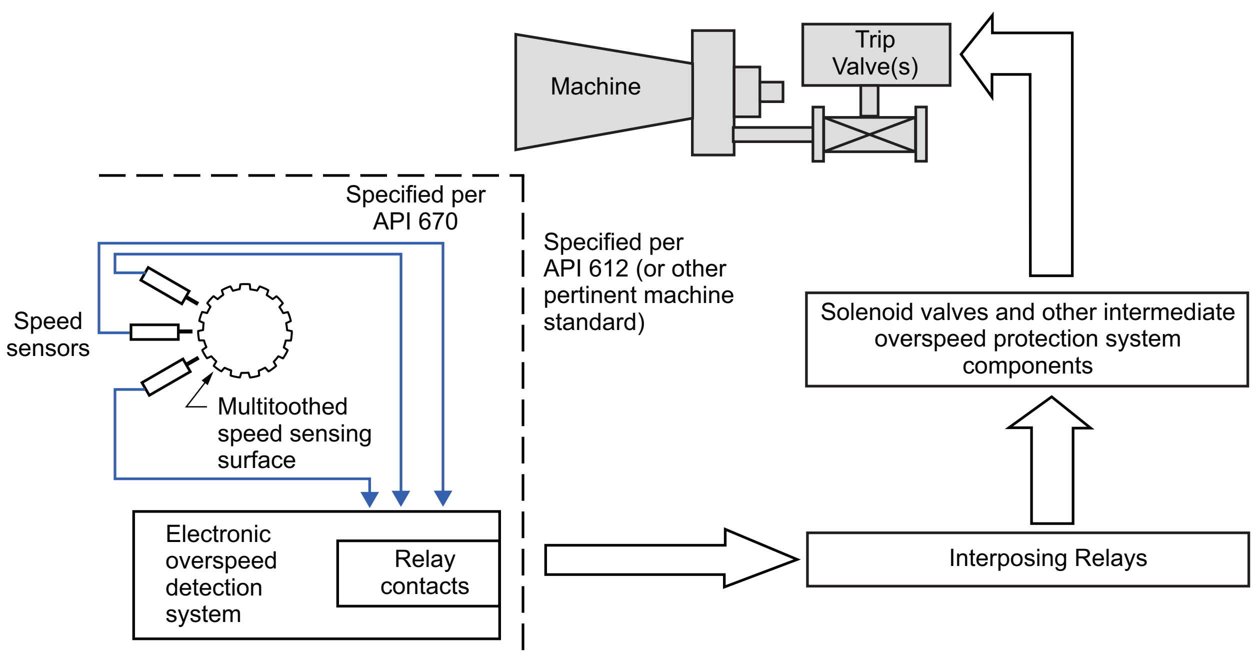
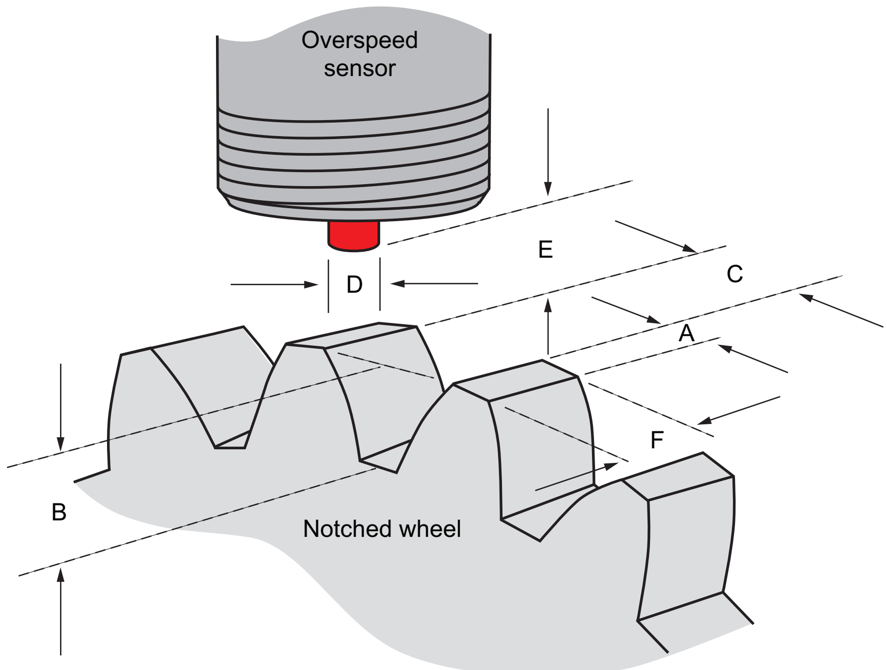


Figure J.1—Overspeed Protection System



Dimension	Description
A	Tooth length
B	Tooth depth
C	Notch length
D	Diameter of proximity probe tip or magnetic speed sensor pole piece
E	Gap
F	Tooth width

Figure J.2—Relevant Dimensions for Overspeed Sensor and Multitooth Speed Sensing Surface Application Considerations (See Table J.1)

J.3 General Considerations for Multitoothed Speed Sensing Surfaces

J.3.1 General

J.3.2 The speed sensing surface may be a gear, toothed wheel, evenly spaced holes in a shaft surface, or other such target that provides gap discontinuities for the speed sensors to observe. Characteristics of the sensing surface will need to be matched to the sensor type to ensure the input signal amplitude to the electronic ODS is within allowable minimum and maximum voltage limits. Figure J.2 shows the dimensions of the speed sensor and multitooth speed sensing surface that are relevant to application considerations.

J.3.3 When designing or installing a multitoothed speed sensing surface, care should be taken to ensure that differential axial movement will not cause the speed sensing surface to move outside the transducer's range. The machine may expand or contract because of thermal conditions and normal rotor axial float. Precautions can be taken to address the expansion and contraction characteristics. The speed sensing surface should be of suitable thickness or may be located in an area not subject to excessive axial expansion or contraction of the shaft or the surface to which the speed sensor is affixed.

J.3.4 Speed Sensing Surface for Magnetic Speed Sensors

J.3.4.1 When magnetic speed sensors are used, the optimum dimensions of the speed sensing surface are a function of the pole piece diameter (D). See Table J.1 for recommended dimensions when this arrangement is used. However, additional calculations are required to ensure optimum signal strength for the electronic ODS inputs. Some of these additional calculations include, but are not limited to, surface speed, gear pitch, air gap, and load. Consult the magnetic speed sensor manufacturer to ensure correct application guidelines are observed.

J.3.4.2 Installation considerations require a thorough understanding of the peak-to-peak vibration characteristics at the speed sensing location during both running speed and overspeed conditions. Magnetic speed sensors require a close gap, typically less than 0.51 mm (20 mil), for optimal operation. This may allow the observed speed sensing surface to contact the sensor during high radial vibration conditions, causing loss of signal and failure of the sensor. Applications in which the speed sensing surface is subject to high radial vibration amplitudes (particularly during an overspeed event) should consider the use of proximity probes as detailed in J.3.5 and J.3.6.

J.3.5 Nonprecision Speed Sensing Surface for Proximity Probes

A nonprecision speed sensing surface employs tooth depths that exceed the proximity probe's linear operating range (see Figure J.2). While proximity probes do not necessarily have to be used with a precision-machined speed sensing surface (see J.3.6), that arrangement is recommended to achieve the best possible diagnostic capabilities on the speed sensor inputs. When a nonprecision speed sensing surface is employed with proximity probe speed sensors, see Table J.2 for recommended dimensions.

J.3.6 Precision-machined Speed Sensing Surface for Proximity Probes

A precision-machined toothed wheel employs a precise tooth depth to keep a proximity probe system within its linear operating range at all times (see Figure J.3). This arrangement permits enhanced circuit fault detection and diagnostic capabilities beyond those achievable when speed sensors are used as detailed in J.3.1, J.3.4, and J.3.5. In addition, this arrangement is capable of providing an OK sensor indication while the machine is not running. See Table J.3 for recommended dimensions when using this arrangement.

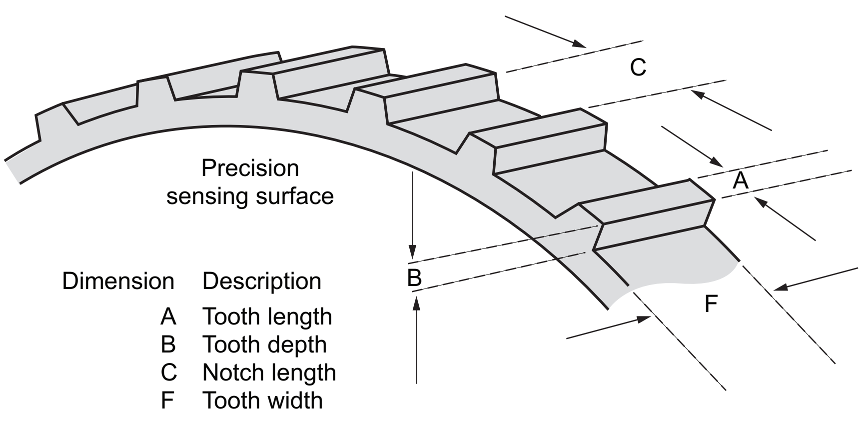


Figure J.3—Precision-machined Overspeed Sensing Surface (See Table J.3)

Table J.1—Recommended Dimensions for Speed Sensing Surface when Magnetic Speed Sensors Are Used

Dimension	Recommended
A (tooth length)	≥D
B (tooth depth)	≥C
C (notch length)	≥3D
D (diameter of pole piece)	Typically 4.749 mm (0.187 in.).
E (gap)	As close as possible. Typically 0.254 mm (10 mil) or less.
F (tooth width)	≥D

Table J.2—Recommended Dimensions for Nonprecision Speed Sensing Surface when Proximity Probe Speed Sensors Are Used (Note 1)

Dimension	Minimum	Nominal	Maximum
A (tooth length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
B (tooth depth)	2 mm	Unlimited	Unlimited
C (notch length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
E (gap)	0.5 mm	0.875 mm	1.25 mm
F (tooth width)	8 mm	Unlimited	Unlimited

Table J.3—Recommended Dimensions for Precision-machined Speed Sensing Surface when Proximity Probe Speed Sensors Are Used (See Note 1)

Dimension	Minimum	Nominal	Maximum
A (tooth length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
B (tooth depth) (Note 4)	1 mm	1 mm	1.3 mm
C (notch length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
E (gap) (Note 4)	0.5 mm	0.65 mm	0.8 mm
F (tooth width)	8 mm	Unlimited	Unlimited

NOTE 1 Table J.2 and Table J.3 assume the use of standard or standard-option proximity probes (see 5.1.1.2 and 5.1.1.3) with a linear range of at least 2.03 mm (80 mil). For applications where nonstandard probes are to be used, consult the machinery protection system vendor.

NOTE 2 Where an unlimited dimension is stated, the actual maximum limit will be determined by the overall diameter of the multitoothed speed sensing surface and the desired number of events-per-revolution.

NOTE 3 An unlimited tooth length/notch length is not intended to imply that a speed sensing surface with only a single discontinuity (i.e. tooth) is acceptable for overspeed applications. Such a design provides only a one-event-per-revolution signal and is rarely able to achieve the necessary response time required for proper machinery overspeed protection. Unlike a multitooth design, it requires multiple revolutions of the rotor to determine the change in rotor speed. The greater the number of events-per-revolution, the higher the resolution of the sampled speed signal.

NOTE 4 If dimension B + dimension E exceeds 1.8 mm (70.9 mil), the probe may indicate a NOT OK condition if the rotor stops with the probe observing a notch.

Annex K
(informative)

Surge Detection and Antisurge Control

K.1 General

K.1.1 Surge is a highly transient process that creates high stresses in compressor vanes and blades, creates higher than design stresses on diaphragms, damages internal seals, and causes high impact loads on thrust bearings of centrifugal and axial flow compressors. Axial compressors have free-standing blades, and a low number of isolated surge cycles can initiate cracks. Damage to centrifugal compressors usually results from repeated high energy surge cycles over a longer period of time. High internal temperatures caused by repeated surge cycles can also lead to damage.

K.1.2 Not all surge conditions result in damage. Some aerodynamic instability can occur within the compressor and not cause damage to the compressor components. Surge detection methods should therefore focus on detecting and taking action on high energy surge cycles and not on small, harmless flow instability. High energy surge cycles are usually characterized by full flow reversal while operating near the design envelope.

K.2 Distinctions of Surge Detection and Antisurge Control

K.2.1 To avoid damage caused by surge, an antisurge control system is used on all axial flow compressors and most centrifugal compressors. If an antisurge control system is adequately designed and maintained, machinery damage due to surge events are less likely to occur.

K.2.2 Because of compressor fouling, transmitter drift, or component failures, a compressor may experience a surge event (consisting of one or more surge cycles) even when equipped with adequate antisurge control. If an antisurge control system is unable to prevent surging, then a surge detection system can be used to independently detect the surge cycles and take action to avoid severe compressor damage. These detectors should use independent sensors and independent hardware to avoid common mode failures. If the antisurge control system incorporates redundant transmitters and redundant controllers, the surge detection function may be included in the antisurge control system. Generally, using a common flow measuring element with independent transmitters is acceptable.

K.3 Description of the Surge Phenomena and Introduction to Surge Control

K.3.1 The onset of surge can be understood by considering a compressor operating at a fixed speed with constant inlet conditions and a discharge throttle valve. For such a system, the normal relationship between the volumetric flow measurement (Q) and the discharge pressure (P_d) is a single curve, as shown in Figure K.1. At any given time, the values of those two variables define an operating point that will fall on that performance curve unless the compressor is surging.

K.3.2 Imagine that this system is operating at steady state with a flow and pressure corresponding to point A. If the discharge throttle valve were closed slightly, the downstream system resistance would effectively increase, the flow through the compressor would decrease, and the pressure at the compressor outlet would rise.

K.3.3 If we continue to close the valve in small steps, the compressor reaches point B where a further reduction in flow produces no increase in the final discharge pressure, as the operating point approaches the surge limit. Closing the valve further increases the discharge pressure above the maximum value that the compressor can sustain. At this point the flow of gas leaving the compressor has insufficient energy to enter the discharge volute. The forward flow regime through the compressor collapses, typically reversing in approximately 20 ms to 80 ms. The flow reversal through the machine and through the discharge valve causes the discharge pressure to rapidly drop and forward flow

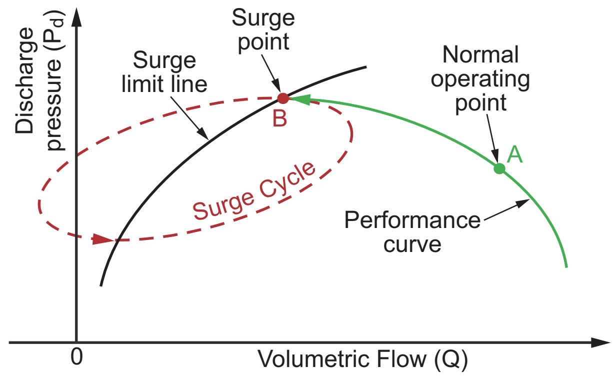


Figure K.1—Compressor Performance Limitations

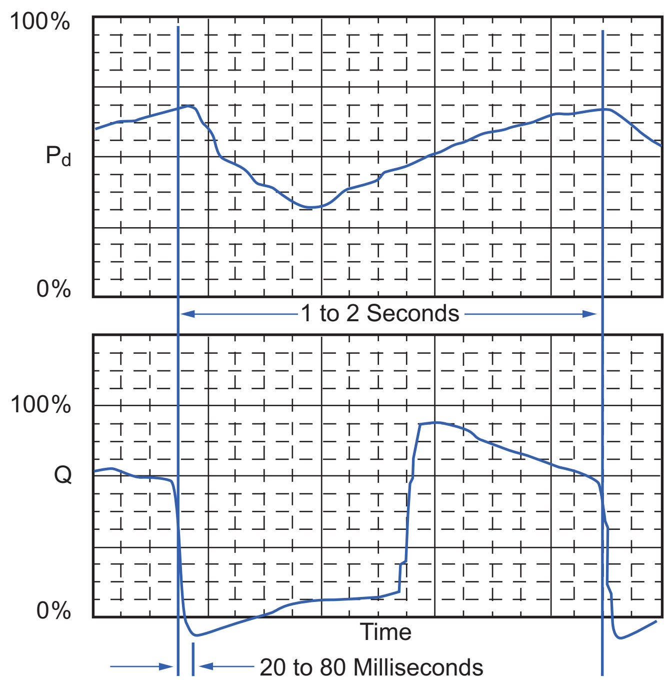


Figure K.2—Pressure and Flow Variations During a Typical Surge Cycle

is reestablished. This is a surge cycle. If flow is reestablished and the system resistance remains elevated, then the discharge pressure will rapidly reach the unstable point B again, and the surge cycle would repeat.

K.3.4 In the example in K.3.2 and K.3.3, the surge was caused by a closing discharge valve; however, anything that increases system resistance, such as fouling of intercoolers or changes in process characteristics, can lead to surge.

K.3.5 Figure K.2 shows these fluctuations as they might be measured during an actual compressor surge. As shown, a typical surge cycle will last only 1 to 2 seconds. Depending on the application, other variables (such as speed, suction pressure, discharge temperature) may also fluctuate rapidly. The occurrence of a surge can be inferred from a rapid change in any one or more of such variables.

K.3.6 Once induced, surge can continue indefinitely until the cause is removed. In the interim, the severe oscillations of flow and pressure create heavy thrust-bearing and impeller or blade loads, vibration, and rising gas temperatures. Because of the reverse flow, the hot gas flows to the suction and is reheated in the next compression cycle. This cycle greatly increases the gas temperature. This high temperature may exceed the design limits of the compressor materials or reduce internal clearances. If more than a few cycles occur, severe compressor damage can result.

K.3.7 To prevent or stop surge, measures should immediately be taken to increase the flow through the compressor, usually by opening a valve to recycle some of the flow to the compressor inlet or (for an air compressor) to blow-off some of it to the atmosphere.

K.3.8 A system that automatically takes action to prevent surge from occurring is an antisurge control system. These systems generally utilize sensors in the process (upstream and downstream of the compressor) and logic algorithms to determine the location of the operating point relative to the theoretical (or as tested) specific compressor surge limit line. If the operating point approaches the surge limit then the recycle or blow-off valves are opened to prevent reaching the predetermined surge point.

K.3.9 If the antisurge control system fails to prevent surge for any reason (e.g. faulty sensor, logic solver, stuck antisurge valve) then the surge detection system detects the actual surge cycles and takes independent action to prevent machine damage. Surge detection systems do not rely on determining the theoretical surge limit line or operating point locations, but instead only rely on detecting the system response to an actual surge cycle.

K.4 Considerations for Surge Detection on Centrifugal Compressors

K.4.1 Surge detection systems as defined in this annex have proven effective at reducing the risk and consequence of surge-related damage on axial compressors. Justification for surge detection systems on centrifugal compressors is application dependent. Applications that include some or all of the following risk factors may benefit from the addition of an effective surge detection system.

a) Applications where previous experience has proven the risk of surge-related damage to be unacceptable.

b) Centrifugal compressors with design features that can result in damage with a limited number of isolated surges, such as:

   i) very high pressures or pressure ratios,

   ii) very high speed,

   iii) very small internal operating clearances/tolerances,

   iv) low stability margins (long rotors),

   v) highly loaded thrust bearings.

c) If the probability of failure of the antisurge control system does not meet plant requirements for preventing machine damage.

d) If the consequence of surge-related compressor damage is unacceptable to the operator because of large production losses due to unplanned outage or performance deterioration.

e) Hazardous gas application [potential gas leaks (seal failure)].

f) Difficult location factors such as remote or unmanned operation.

K.4.2 Even if a specific surge detection system is not justified, all process plant designs that incorporate centrifugal compressors should consider the possible consequences of damage associated with compressor surge. As a minimum, this should include detection and alerting of such consequences as: gas leak detection; high or low excursions of process pressures or temperatures; abnormal rotor axial position; high bearing temperatures; or high motor currents, etc. On detection and annunciation of such conditions, the operator can take action to shut down and bring the compressor to a safe state.

K.5 Considerations for Surge Detection System Testing and Field Surge Detection Calibration

K.5.1 Surge Detection System Testing

K.5.1.1 The objective of testing the surge detection system is to validate sensor and logic solver component functionality. This usually includes a demonstration that the system will reliably detect a surge cycle and take the intended action(s).

K.5.1.2 The purpose of the surge detection system test is not intended to validate the surge control system or other compressor protective systems.

K.5.1.3 Testing the surge detection system does not necessarily expose the machine to surge, nor does it adequately identify the surge limit line location. It does test the functionality of the surge detection system and components based on the methods identified in this standard.

K.5.2 Field Surge Detection Calibration

K.5.2.1 If process variable rate-of-change methods of surge detection are used, then surge testing in the field should be used to calibrate the threshold levels that define a surge cycle on each unique system. Duplicate machines should be individually surge tested in the field to account for installation and manufacturing differences between duplicate machines.

K.5.2.2 All other methods that demonstrate acceptable surge detection without field surge testing should be proven by successful experience and require specific purchaser approval. The purchaser may agree to OEM-recommended settings for surge detection calibration based on design models, experience, and bench testing. In these cases, the machine may not need a surge test validation in the field.

K.5.2.3 Although the objectives are different, the surge detection field calibration can coincide with the calibration of the antisurge control and other systems.

K.5.2.4 The following are prerequisites for surge testing the compressor to calibrate the surge detection system:

a) all antisurge control system and surge detection system loop functions should be tested and functional;

b) all antisurge, vibration, and CMS's should be tested and functional;

c) all high-speed event recording and diagnostics systems should be operational and temporary instrumentation needed for surge testing available and installed.

K.5.2.5 Where possible, the antisurge control should be functionally checked and operational before starting surge testing. If antisurge controls are provided, then they are configured to allow a surge to occur by moving the antisurge setpoint or control line to approach surge, or by setting the setpoint or surge line slightly below the surge line, then closing the recycle or bypass valve manually to initiate the surge.

K.5.2.6 When surge is detected, measure and record the rate of change for the surge detection variables that will be used.

K.5.2.7 For rate-of-change surge detection methods, use the measured rate of change as the basis for setting the surge detection limits.

K.5.2.8 For threshold methods, user experience or vendor experience should be consulted in setting the limit.

Annex L
(informative)

Safety Integrity Level

L.1 Introduction

L.1.1 The introduction of the ANSI/ISA standard S84.00.01 (Safety Instrumented Systems for the Process Industries) in 1996, followed by IEC 61508 (Functional safety of electrical/electronic/programmable electronic safety-related systems) in 1998 and the IEC 61511 (Functional safety - safety instrumented systems for the process industry sector) in 2003 have been received in the industry. These standards apply to all processes and process equipment handling hazardous materials in the oil, gas and chemicals industries, including all sorts of rotating machinery.

L.1.2 This annex summarizes the basic methods of functional safety. It also addresses some sector specific standards which have been derived from the IEC 61508 base standards.

L.1.3 It has to be noted that each human health and environmental risk in any process environment should be evaluated individually and that the examples given in this annex are given for educational purposes only.

L.1.4 The methodologies are demonstrated through examples (SIS architectures) that represent possible system configurations and should not be interpreted as recommendations for system design. The user is cautioned to clearly understand the assumptions and data associated with the methodologies in this document before attempting to utilize the methods presented herein.

NOTE This text is mainly taken from ISA-TR84.00.02-2002, Part 3.

L.2 Scope

L.2.1 This annex defines Functional Safety in the field of machinery protection systems. It presents the basic process of implementing functional safety in this field. It demonstrates, using the risk graph method, how to determine a required safety integrity level per IEC 61511 and ISO 13849. Some recommendations for scaling factors for the risk graphs are also given.

L.2.2 The user is cautioned that many different methods to identify a SIL target and verify that the selected hardware and software meets the required safety level are available. This annex only demonstrates some basic functions and is not intended to limit the user's choice in which method to follow.

L.2.3 The user is also reminded that the vendor with unit responsibility should provide all information that allows the owner to operate and maintain the safety system to meet the required safety level.

L.2.4 Two examples are included for reference (see L.7.3 and L.7.4). The first example shows a control system architecture which does not meet the target safety level, the second does.

L.3 Standards and Codes References

The following standards and codes are referenced in the annex.

IEC 61508 [11], *Functional safety of electrical/electronic programmable electronic safety-related systems*

IEC 61511, *Functional safety—Safety instrumented systems for the process industry sector*

[11] International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.

IEC 62061, *Safety of machinery—Functional safety of safety-related electrical, electronic and programmable electronic control systems*

ANSI/ISA 84.00.01-2004 (IEC 61511 Mod) [12], *Functional safety: Application of Safety Instrumented Systems for the Process Industries*

ISA 91.00.01, *Identification of Emergency Shutdown Systems and Controls That Are Critical to Maintaining Safety in Process Industries*

ISA-TR84.00.02-2002, *Safety Instrumented Functions (SIF)-Safety Integrity Level (SIL), Evaluation Techniques Part 1: Introduction*

ISA-TR84.00.02-2002, *Safety Instrumented Functions (SIF)-Safety Integrity Level (SIL), Evaluation Techniques Part 2: Determining the SIL of a SIF via Simplified Equations*

ISA-TR84.00.02-2002, *Safety Instrumented Functions (SIF)-Safety Integrity Level (SIL), Evaluation Techniques Part 3: Determining the SIL of a SIF via Fault Tree Analysis*

ISA-TR84.00.02-2002, *Safety Instrumented Functions (SIF)-Safety Integrity Level (SIL), Evaluation Techniques Part 4: Determining the SIL of a SIF via Markov Analysis*

ISA-TR84.00.02-2002, *Safety Instrumented Functions (SIF)-Safety Integrity Level (SIL), Evaluation Techniques Part 5: Determining the* PFD_{avg} *of SIS Logic Solvers via Markov Analysis*

ISO 13849 [13], *Safety of machinery—Safety-related parts of control systems*

ISO 21789: 2009, *Gas turbine applications—Safety*

ISO 12100:2010, *Safety of machinery—General principles for design—Risk assessment and risk reduction*

ISO 13849/IEC 62061, *Guidance on the application of ISO 13849-1 and IEC 62061 in the design of safety-related control systems for machinery* (Joint IEC/TC44 and ISO/TC199 technical report)

VDMA Einheitsblatt 4315-1 [14], *Turbomachinery—Application of the principles of functional safety—Evaluation Part 1: General*

L.4 Standard Abbreviations

The following abbreviations are commonly used throughout the referenced standards for functional safety and this annex and are listed here for easy reference:

ALARP	as low as reasonably practical
ANSI	American National Standards Institute
Avg	average
DC	diagnostic coverage
FBD	functional block diagram

12 International Society of Automation, 67 T.W. Alexander Drive, Research Triangle Park, North Carolina, 22709, www.isa.org.
13 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.
14 Verband Deutscher Maschinen- und Anlagenbau e.V. (German Engineering Federation), Lyoner Strasse 18, 60528 Frankfurt, Germany, www.vdma.org.

FR	failure rate
HAZOP	hazard and operability study
HFT	hardware fault tolerance
HSE	health, safety, environment
IEC	international electrotechnical commission
IPL	independent protection layer
ISA	International Federation of the National Standardizing Associations
ISO	International Organization for Standardization
MPS	machinery protection system
MTBF	mean time between failure
MTTF	mean time to failure
OSHA	Occupational Safety and Health Administration
PCB	printed circuit board
PES	programmable electronic systems
PFD_{avg}	probability of failure on low demand
PFH	probability of failure on high demand (1/Hr)
PL	performance level
RBD	reliability block diagram
RFQ	request for quotation
SFF	safe fail fraction
SIF	safety instrumented function
SIL	safety integrity level
SIS	safety instrumented systems
SRP/CS	safety-related parts of control systems
SRS	safety requirement specification
SOV	solenoid operated valve
VDMA	Verband Deutscher Maschinen - und Anlagenbau e.V. (German Engineering Federation)

L.5 Basic Definition of Functional Safety

L.5.1 General

L.5.1.1 The Introduction of IEC 61508 provides a valuable exposure to the topic of Functional Safety and discussion of its basic features.

L.5.1.2 Safety strategies should consider not only the individual system components but also the integration of each system into a complete machinery package and how they apply to functional safety. While the international standards IEC 61508, 61511 and 62061 are concerned with electrical/electronic/programmable electronic (E/E/PE) safety-related systems only, it is recommended to apply functional safety methodology to non E/E/PES systems such as hydraulic, pneumatic and mechanical systems as well.

L.5.1.3 This annex provides guidance on the development of the safety requirements specification necessary to achieve the required functional safety for the machinery related safety systems. It provides further direction through examples to design suitable protection system architecture and verification methods to ensure the design is adequate.

NOTE Text mainly taken from the introduction of IEC 61508.

L.5.2 Functional Safety in Machinery Protection Systems

L.5.2.1 Process Safety is regulated in the USA by OSHA 29 CFR 1910.119. It directs the end user to follow current standards, codes and best industry practice. OSHA has recognized ANSI/ISA-S84.00.01-2004 (IEC 61511) as an example of best industry practice for Safety Instrumented Systems (SIS). Machinery Safety is regulated in Europe by the Machinery Directive 2006/42/EC.

L.5.2.2 The European Machinery Directive cites IEC 62061 and ISO 13849 as harmonized standards for machine safety systems. The user should note that IEC 62061/ISO 13849 does not address the industry in which the machine will be used and recommends that relevant industry standards should also apply when reviewing the system design. Therefore, the user purchasing rotating equipment originally designed in accordance with IEC 62061 will apply IEC 61511/ISA S84.00.01 methodologies when using that machine in the process industry to evaluate the OEM's machinery protection system.

L.5.2.3 Safety instrumented systems are mainly used to mitigate hazards to people and the environment. Machine hazards which may harm the environment are normally linked to hazards for people. The harm which can be done to people is typically more severe than environmental harm. For this reason, this annex deals with protection of people only. It should be noted that environmental hazards should also be considered in each specific risk assessment.

L.5.2.4 The process of functional safety is the same for human health and environmental protection. However, to limit economic losses, methods other than functional safety are typically applied. Refer to Annex M for further details on designing to mitigate economic losses.

L.5.2.5 Every machine which operates in the process industry imposes hazards to people and the environment. In a risk assessment, hazards are analyzed to determine a level of risk. In some cases, safety instrumented systems are put in place to mitigate that risk. Risk is determined by the severity of the consequence of the hazard and the frequency that the unwanted event is expected to occur. The risk assessment may include consideration of independent protection layers, if present.

L.5.2.6 During the risk assessment, each hazard's risk has to be determined and compared to the tolerable risk. This risk assessment is done under the assumption that the safety instrumented system under evaluation is not present. See IEC 61511, Figure 3 (Risk Reduction: General Concepts) for examples of risk reduction.

L.5.2.7 In IEC 61508/61511, functional safety classifies the necessary degree of risk reduction into four safety integrity levels: SIL 1, SIL 2, SIL 3, and SIL 4. A SIL 1 safety system provides the least amount of risk reduction, while a SIL 4 safety system provides the highest amount of risk reduction. The probability of failure on demand (PFD) is used to describe the probability of the safety system not responding to a potentially dangerous condition. PFD_{avg} is the average probability of failure on demand and is a function of the time interval for which the equipment is tested for faults. As can be seen from Table L.1, to reduce process risk by a factor of at least 10 or up to 100, a safety system of at least SIL 1 is required. To meet SIL 1, this safety system will have a PFD_{avg} no greater than 10-1. Risk reduction factors of more than 10,000 (SIL 4) are typically not seen in machinery applications. PFH is the equivalent probability of failure per hour.

L.5.2.8 The scope of the standards IEC 61508/61511/62061 is limited to electric systems (E/E/and PES) whereas the ISO 13849 includes mechanical, pneumatic and hydraulic systems as well. IEC 61508/61511/62061 use the term Safety Integrity Level (SIL) for the degree of risk reduction whereas ISO 13849 uses the term performance level (PL). The SIL evaluation per IEC is done mainly by quantitative methods (calculation), whereas the ISO 13849 allows a combined quantitative/qualitative approach. Details are given below.

Table L.1—Safety Integrity Levels and Probability of Failure

Safety Integrity Level SIL as per IEC 61508	Target Range Probability of Failure on Demand Average PFD_{avg}	Probability of Dangerous Failure per Hour PFH_d	Risk Reduction Factor
1	10^{-1} to 10^{-2}	10^{-5} to 10^{-6}	10 to 100
2	10^{-2} to 10^{-3}	10^{-6} to 10^{-7}	100 to 1,000
3	10^{-3} to 10^{-4}	10^{-7} to 10^{-8}	1,000 to 10,000

L.5.2.9 The higher the safety integrity level (SIL), the higher the requirements for the safety instrumented system. The following paragraphs describe these requirements in more detail.

a) The standards for functional safety differentiate between high demand mode and low demand mode. These modes are defined as follows.

   1) Low Demand Mode—Where the frequency of demands for operation made on a safety related system is no greater than one per year.

   2) High Demand Or Continuous Mode—where the frequency of demands for operation made on a safety-related system is greater than one per year.

b) Different evaluation procedures apply to these two modes. Some standards for high demand mode do not consider proof tests but give detailed instructions for diagnostic tests.

NOTE In most cases, either one of the evaluation procedures provides more or less similar results if the same risk parameters are used. If a SIS responds one or more times per years, the procedures for high demand mode may be used, even if the response of the system is initiated by test.

L.6 Process of Functional Safety

L.6.1 General

A life-cycle approach to Safety Instrumented systems has been adopted by standards such as ANSI/ISA 84.00.04 and IEC 61511. See IEC 615111, Figure 8 (Safety Life Cycle Phases) for the multiple stages of the SIS life-cycle. Two evaluation examples are given using risk graph assessment tool and SIL verification using PFD_{avg} calculation with reliability block diagrams. These examples are presented for the sake of education, noting that there are equally acceptable techniques available and that the user should be qualified in the use of these techniques..

L.6.2 Process Hazard Analysis and Risk Assessment

L.6.2.1 General

L.6.2.1.1 After the conceptual design has been completed, a Hazard Analysis and Risk Assessment should be scheduled. During this risk assessment, all hazards and risks to personnel or the environment are analyzed individually. The actual risk that is seen if no MPS exists is compared with the tolerable risk. If the actual risk is lower than the tolerable risk, the MPS does not need to be considered as a SIS.

L.6.2.1.2 If the actual risk (without a MPS) for personnel or environment exceeds the tolerable risk, risk reduction methods should be enforced which typically includes the installation of a MPS which functions as a SIS. The necessary degree of risk reduction should be determined in the risk assessment.

L.6.2.1.3 There are four levels of risk reduction specified in IEC 61508, 61511 and 62061, and five levels in ISO 13849. These levels are called Safety Integrity Level (SIL) in the IEC standards and Performance Level (PL) in ISO 13849.

L.6.2.1.4 The relationship between risk reduction factors and SIL/PL can be seen in Table L.2.

Table L.2—Performance Level as per ISO 13849 and Safety Integrity Level as per IEC 61508/61511

Performance Level as per ISO 13849	Safety Integrity Level as per IEC 61508
A	None
B	1
C	1
D	2
E	3
NOTE Details can be found in ISO 13849-1.	

L.6.2.2 Target SIL/PL

Different methods for determination of the required Safety Integrity Level are available. Available options are the risk graph as per L.6.2.1.1, LOPA (layers of protection analysis) and the risk matrix. Other methods are used as well.

L.6.2.3 Risk Graph of IEC 61511

L.6.2.3.1 General

L.6.2.3.1.1 A common risk assessment method among several available is the risk graph. The referenced standards show different risk graphs for personnel and environmental protection. This annex limits its consideration to personnel protection. The risk graph shown in Figure L.1 is specifically adapted to the requirements of turbomachinery. Details can be found in IEC 61511 and VDMA 4315-1.

L.6.2.3.1.2 The risk graph is used to determine the required SIL for the safety function from the four parameters:

a) severity (S) of the unwanted event;

b) frequency (F) of the unwanted event and exposure time to the unwanted event,

c) possibility to avoid (AV) the impact of the unwanted event,

d) probability of the occurrence (W) of the unwanted event.

An example on how to use the risk graph is given in L.8.4.1

L.6.2.3.2 Severity or Consequence of Risk—Parameter S

The range of the parameters of the risk graph above is defined in Table L.3.

L.6.2.3.3 Probability of Presence in the Hazardous Zone—Parameter F

Parameter F is the probability that a person is located in the hazardous area at the time when the hazardous event can occur. It encompasses the frequency of, and exposure time in, the hazardous zone (as per ISO 12100:2010 Chapter 5.5.2.3.2, Occurrence of hazardous events) (see Table L.4).

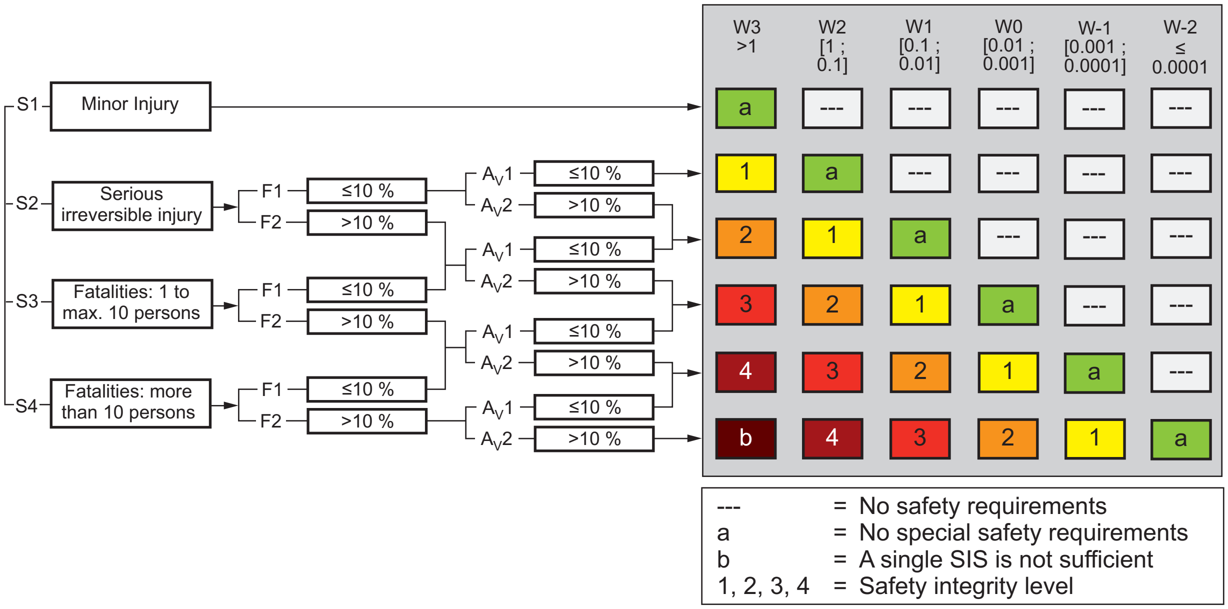


Figure L.1—Risk Graph as per VDMA 4315

Table L.3—Definition of the Range of the Parameter Severity, S

Severity or Consequence of Risk—S			
Parameter	**Definition**	**Severity-based Tolerable Accident Rate**	**Comments**
S1	Minor injury	1/100 years	Reversible injury: — first aid required — medical care required
S2	Serious or permanent injury to one or more persons	1/1,000 years	Reversible injury: — broken limbs Irreversible injury: — loss of a finger — loss of eye or arm The death of one person will be considered in this category as a consequence of serious injury
S3	Death of 1 to 10 persons	1/10,000 years	Immediate death of a person
S4	Death of more than 10 persons	1/100,000 years	Highest risk relevant to turbomachinery

Table L.4—Definition of the Range of the Parameter Probability of Presence in the Hazardous Zone—F

Probability of Presence in the Hazardous Zone—F		
Parameter	**Definition**	**Comments**
F1	≤10 %	The probability of the presence of a person in the hazardous area is ≤10 % for all possible events.
F2	>10 %	The probability of the presence of a person in the hazardous area is >10 %. Applies typically for hazards spread over a large area. (e.g. events where parts of the rotor can exit the machine). All events that will only be detected if a person enters the hazardous area have to be considered with F > 10 %. EXAMPLE Cutting jet from a high pressure system.

L.6.2.3.4 Unavoidability Under Consideration of Vulnerability—Parameter AV

L.6.2.3.4.1 General

Even if an event happens and a person is in the hazardous area, there is still a probability that the person(s) is not exposed to injury based on the following two parameters A and V.

L.6.2.3.4.2 Parameter A: Unavoidability

When a hazardous event occurs, and a person is in the hazardous area, the person may not be able to avoid injury through his/her own actions (e.g. escaping). Parameter A (see Table L.5) is the probability that the person cannot avoid injury by his/her own action.

NOTE IEC 61508/61511 uses parameter P (probability to avoid) which is the compliment of A.

L.6.2.3.4.3 Parameter V: Vulnerability

When a hazardous event occurs, and a person is in the hazardous area, and the person is unable to avoid injury through his own actions, it is still possible for the person to remain injured due to circumstances outside of his control. This is known as Vulnerability (see Table L.5).

EXAMPLE 1 If the vicinity of the machine is flooded with gas or steam, every person in the hazardous zone will be affected; the vulnerability would approach 1.

EXAMPLE 2 If the event is caused by a piece of material leaving the shaft, the likelihood of a person in the hazardous area being injured is less than in example 1, and the vulnerability will be less than 1.

From the two parameters A and V, the unavoidability AV (see Table L.6) can be calculated per the formula

$$AV = A \times V$$

Table L.5—Definition of Vulnerability V and Unavoidability A

Parameter	Definition	Character	Range
V	Vulnerability	Probability	[0…1]
A	Unavoidability	Probability	[0…1]
P	Parameter P: avoidability or probability to avoid the hazardous event	Probability	[1…0]
AV	Unavoidability considering the vulnerability	Probability	[0…1]

Table L.6—Definition of the Range of the Parameter AV (Unavoidability Considering the Vulnerability)

Unavoidability AV Under Consideration of Vulnerability—AV = A × V		
Parameter	**Definition**	**Comments**
AV1	≤10 %	Probability ≤10 % that a hazardous event with occupied hazardous zone will lead to damage
AV2	>10 %	Probability > 10 % that a hazardous event with occupied hazardous zone will lead to damage

L.6.2.3.4.4 Probability of the Occurrence of the Unwanted Event—Parameter W

Parameter W is the number of hazardous events per time unit (e.g. "per year" or "per hour"). Its purpose is to estimate the frequency of the unwanted occurrence taking place without the addition of any safety-related systems. The assumption that the unwanted event may occur does not necessarily mean that the event actually happens.

Table L.7—Definition of the Range of the Parameter W (Probability of the Occurrence of the Unwanted Event)

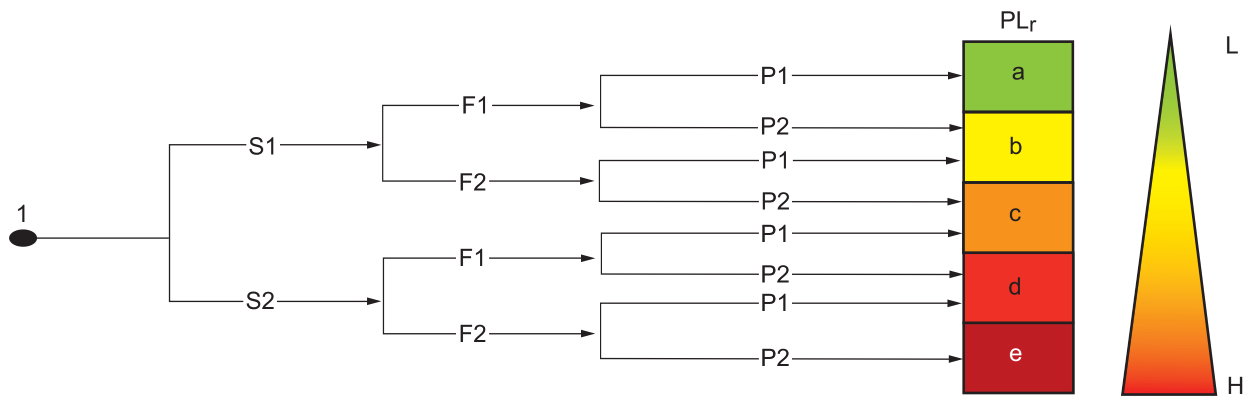
Probability of the Occurrence of the Unwanted Event—W		
Parameter	**Definition**	**Comments**
W3	>1 per year	
W2	>1 per 10 year ≤1 per year	
W1	>1 per 100 years ≤1 per 10 years	
W0	>1 per 1,000 years ≤1 per 100 years	W0, W-1, and W-2 have been introduced because hazards exist whose probabilities of occurrence are so small that little or no risk reduction is necessary. (For example, crack of a shaft after material embrittlement caused by excessive temperature after total failure of lube oil supply.)
W-1	>1 per 10,000 years ≤1 per 1,000 years	
W-2	≤1 per 10,000 years	

L.6.2.4 Risk Graph of ISO 13849

L.6.2.4.1 The risk graph of ISO 13849 (see Figure L.2) looks very similar to the IEC risk graph. It uses the same input parameters; however, a degradation of the risk reduction in relation to the probability of the occurrence of the unwanted event (parameter W) does not exist. The parameter P (possibility of avoiding hazard or limiting harm) is used instead of parameter AV.

NOTE An example of a PL evaluation per ISO 13849 is given in L.8.5.

L.6.2.4.2 ISO 13849 ignores the probability of the unwanted occurrence (W) and assumes it is high. However in turbomachinery applications, this probability is typically low. As per Table L-2 (taken from ISO 13849), a direct relationship between SIL and PL is given. For this reason, it is acceptable to use the risk graph (or any other method) from IEC 61508/61511 and use the evaluation method of ISO 13849, or vice-versa.



Key
1 Starting point for evaluation of safety function's contribution to risk reduction
L Low contribution to risk reduction
H High contribution to risk reduction
PL_r Required performance level

Risk parameters:
S Severity of injury
 S1 Slight (normally reversible injury)
 S2 Serious (normally irreversible injury or death)
F Frequency and/or exposure to hazard
 F1 Seldom-to-less-often and/or exposure time is short
 F2 Frquent-to-continuous and/or exposure time is long
P Possibility of avoiding hazard or limiting harm
 P1 Possible under specific conditions
 P2 Scarcely possible

Figure L.2—Risk Graph as per ISO 13849

L.6.3 Risk Assessment by Other Methods

There are a number of other methods available for risk assessment, such as LOPA (layer of protection analysis) as per IEC 61511-3 Annex F, or the Risk Matrix as per IEC 61511-3 Annex C. Details of these methods can be found in their respective standards.

L.6.4 Safety Requirement Specification

The next step in the process of functional safety is to develop a safety requirement specification (SRS). This describes all aspects of the required safety system including the test procedure for the validation test along with the acceptance criteria. Details are given in the respective standards, e.g. IEC 61511 Part 1 and 2.

L.6.5 Selection of Design and Architecture

L.6.5.1 The design process starts with the development of a system function block diagram. This is converted into a reliability block diagram by deleting all those components which are not safety relevant. Among others, the fault tree analysis as per ISA-TR84.00.02-2002 - Part 3 is an appropriate method.

L.6.5.2 The basic parameters for functional safety are:

a) probability of failure on demand (PFD_{avg}),

b) safe failure fraction (SFF),

c) hardware fault tolerance (HFT),

d) proof test interval (TI).

Each one of these parameters has to meet SIL/PL-dependent minimum values.

L.6.5.3 If the system verification shows that the actual achieved SIL/PL is lower than the required one, any or several of the above parameters should be improved and the Safety Requirement Specification has to be changed accordingly.

L.6.6 SIL/PL Evaluation

L.6.6.1 After the SIS has been designed, the SIS should be evaluated to prove that the selected architecture along with the properties of the selected components meets the requirements stated in the safety requirement specification (SRS). There are different methods available for SIL evaluation. The most common method for complex systems is a SIL verification calculation, using different safety-specific parameters which should be made available from the component vendor or be taken from industry-accepted data bases. The basics for these calculations are given in IEC 61508 Part 6. In some applications, a method with simplified equations as per ISA-TR84.00.02-2002 - Part 2 may be used. Care should be taken that the simplifications are acceptable for the system under review.

L.6.6.2 Complex systems such as ones using programmable logic solvers should be evaluated thoroughly by either using detailed equations or a Markov analysis similar to the method described in ISA-TR84.00.02-2002 - Part 5.

L.6.6.3 Many software packages are available to facilitate the detailed SIL verification calculations. These software packages typically use approximation techniques for obtaining the results. As with any software tool, the user is cautioned to understand the equations, mathematics, and any simplifying assumptions, restrictions, or limitations.

NOTE Above taken from ISA-TR84.00.02-2002, Part 3.

L.6.6.4 The selected SIS has to meet several conditions to be allowable in a distinctive SIL application:

a) The Probability of Failure on Demand (PFD_{avg}) of the entire loop should be lower than what is required for the SIL/PL. The higher the SIL, the lower the acceptable PFD_{avg}.

b) For higher SIL, system redundancy is required. This is defined by the Hardware Fault Tolerance (HFT).

c) Safe failure fraction (SFF) describes the fraction of safe and dangerous detected failures compared to all possible failures. The higher the SIL, the higher the required SFF. A lower number in SFF can be compensated by a higher HFT, or vice- versa.

d) Proof test interval. during a proof test, the full functionality of the SIS is verified. After a proof test, all tested components of the SIS are in as-new condition, or as close as possible to new.

L.6.6.5 If redundancy is used to improve the functional safety, care should be taken regarding common-cause failures. These are typically the most dominant factors during the SIL/PL evaluation. The probability of common-cause failures is described by the factor *ß*.

L.6.6.6 ISO 13849 uses a slightly different semi-quantitative approach. The parameters are as follows.

a) Mean Time To Fail to dangerous condition ($MTTF_d$).

b) Diagnostic Coverage (DC) is the ratio of detected dangerous failures in relation to the total number of dangerous failures (Table L.10). These are clustered into three groups (low, medium, high).

c) The system architecture of the SIS is clustered into 5 categories (B, 1, 2, 3, and 4). They differ in the diagnostic capabilities. Categories B and 1 have no diagnostics; category 4 is fully redundant with extended checks.

L.6.6.7 Figure L.3 indicates which combination of parameters is acceptable for a given PL. The higher the required risk reduction, the stronger the requirements on $MTTF_d$, DC, and system architecture (category).

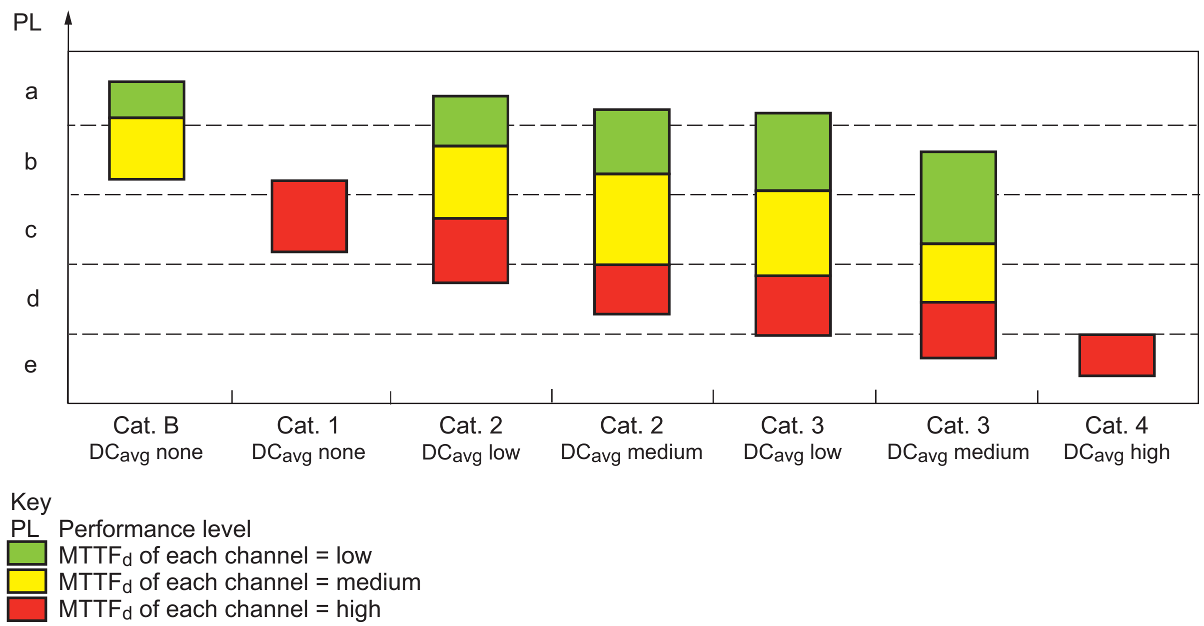


Figure L.3—Relationship Between Categories, DC_{avg}, $MTTF_d$ of Each Channel, and PL

L.6.6.8 If the achieved risk reduction factor exceeds the necessary reduction factor, the SIS may be built. If the actual risk reduction factor is lower than the required one, the system architecture and/or the component selection should be reviewed. All decided changes should to be incorporated into the SRS, and the SIL/PL evaluation process has to start again.

L.6.6.9 If the selected architecture cannot be found in the standard, the closest available standard with a lower degree of safety should be selected.

L.6.7 Verification and Validation

L.6.7.1 After each process step, the SIS should be verified against the safety requirement specification. Finally, the SIS should to be tested as per the test plan and test criteria given with the safety requirement specification. If the system cannot meet the requirements, the process of functional safety shall start from the beginning with an SRS that reflects the changes.

L.6.7.2 Select components matching the blocks in FBD and RBD:

a) list the available components;

b) delete those components from the list for which the equipment vendor cannot certify the suitability for the required SIL/PL;

c) if the required SIL is greater than 2, discard entries for which SIL is not certified by an organization independent of the vendor. Preferably the certificate should have been issued by a recognized certifying body;

d) have the selected vendors provide the following information concerning their products:

— diagnostic coverage (DC);

— safe failure fraction (SFF);

— probability of failure on demand (PFD) and probability of failure per hour (PFH);

— mean time to fail to dangerous state ($MTTF_{dangerous}$)

— mean time between failures (MTBF)

L.7 Responsibilities

L.7.1 End User Responsibilities

L.7.1.1 The end user has the ultimate responsibility for the safety of the plant. In his risk assessment and SIL/PL evaluation, the end user should follow IEC 61508, IEC 61511, and ANSI/ISA-S84 respectively.

L.7.1.2 The RFQ should indicate any minimum architectural requirements (e.g. one-out-of-one, two-out-of-three). It is recommended the end user conduct a risk analysis to determine the required degree of risk reduction for each protection loop. This risk analysis should be done in conjunction with the machine vendor as part of their HAZOP and SIL reviews.

L.7.1.3 The RFQ should also indicate the shortest acceptable proof test interval for those tests which affect the process. Partial stroke tests or other proof tests which have minor or no effect on the process may be performed more frequently.

L.7.1.4 The end user will perform a SIL/PL evaluation based on the data provided by each vendor to verify that the entire loops meets all functional safety requirements.

L.7.2 Machine Vendor

L.7.2.1 Machinery safety is regulated in Europe by the Machinery Directive 2006/42/EC.

L.7.2.2 Machine protection standards such as ISO13849 (PL) and IEC 62061 (SIL) as well as IEC 61508 and 61511 are used by the European Community (EC) machinery vendors to assess fundamental machinery safety.

L.7.2.3 Machine manufacturers in the USA follow ANSI/ISA-84.00.01, IEC 62061, as well as IEC 61508 and 61511 for machinery safety assessment upon end user request.

L.7.2.4 Oil, gas and chemical industry specialized machine manufacturers follow API 670 and other 600-series standards. These standards are based on industry best practices.

L.7.2.5 Based on these standards, the machinery vendor has to perform his own risk assessment which is a prerequisite for supplying a safe machine.

L.7.3 Equipment Vendor Responsibilities

L.7.3.1 The equipment vendor provides all necessary data that are required by end user and machine vendor to perform their risk assessment and SIL/PL evaluation. These are (amongst others):

a) probability of failure on demand for each subsystem (PFD_{avg}; PFH)

b) proof test interval used for data of L.7.3.1.a)

c) hardware fault tolerance (HFT)

d) safe failure fraction (SFF)

e) diagnostic coverage (DC)

f) mean time to fail ($MTTF_{Dangerous}$)

g) mean time to repair (MTTR)

L.7.3.2 If the risk analysis of the end user and the machine vendor comes up with different results for the required SIL/PL, then the highest SIL/PL requirement will govern.

L.8 Examples

L.8.1 General

The intention of this section is to provide a basic overview of functional safety principles rather than a user guideline for specific applications. The following examples are generic rather than specific. Two protection loops (Figure L.4 and Figure L.5) will each be evaluated and assessed using IEC 61511 and ISO 13849 to compare and contrast the techniques of each standard.

L.8.1.1 Typical Protection Loop with Single Solenoid Valve

Figure L.4 shows a typical protection loop, consisting of sensor, signal conditioner, monitor, logic solver, solenoid valve, and stop valve. The loop illustrates a one-out-of-one architecture with one sensor per plane and a simplex logic solver with a single solenoid valve. It can represent a shaft vibration loop, a single-channel axial displacement loop, a temperature loop with local temperature transmitter, or even a single-channel overspeed loop.

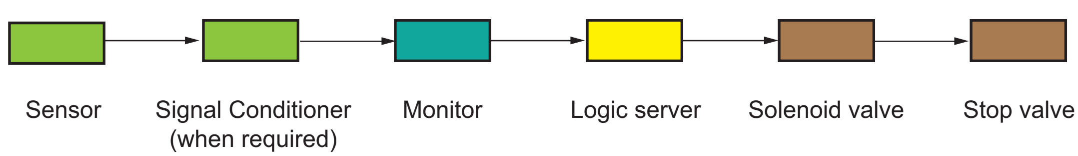


Figure L.4—Functional Block Diagram of Typical Protection Loop with a Single Solenoid Valve

L.8.1.2 Typical Protection Loop with Dual Solenoid Valve

Figure L.5 illustrates the same loop as Figure L.4 except with redundant solenoid valves.

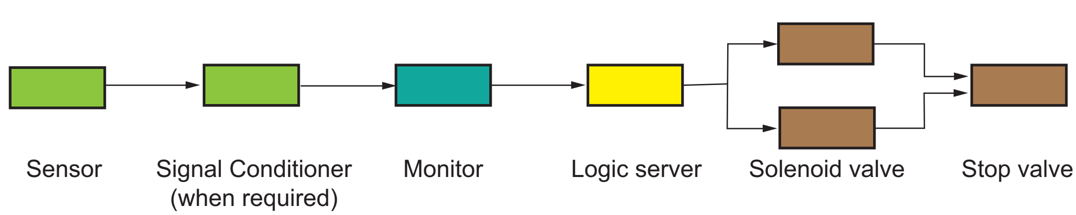


Figure L.5—Functional Block Diagram of Typical Protection Loop with a Dual Solenoid Valve

L.8.2 Example 1A—Loop Evaluation Using IEC 61511

L.8.2.1 Establish SIL Requirement Using Risk Graph of IEC 61511/VDMA 4315

L.8.2.1.1 Example 1A illustrates a risk assessment of the loop in Figure L-6 made using the risk graph of Figure L-3. The unwanted event, for example, is serious personnel injury. Assume the following parameters have been established.

a) The severity is S2.

b) The frequency of exposure time is assumed to be more than 10 % (for more than 10 % of the total operation time, a person is located in an area where the unwanted event may harm them), thus F = F2.

c) The probability that a hazardous event will lead to harm depends largely on how the event develops. As this can not be fully determined, a conservative assumption AV2 is made (the probability that the event may harm a person is higher than 10 %).

d) It is assumed that such an event may happen between once per year and once in 10 years. W = W2.

Therefore, using Figure L-3 and the above assumptions, SIL 2 is identified for this risk.

L.8.2.1.2 If the machine room is occupied only occasionally (less than 10 % of the total operation time), F can be selected to F1. This leads to SIL 1. The same applies if the probability that the unwanted event happens is less than once in ten years (W = W1).

L.8.2.2 Evaluate Loop SIL Using IEC 61511

L.8.2.2.1 Data for PDF Calculation

For the loop in Figure L.4, the equipment vendor provided following data.

a) Input system:

— PFD_{avg} per probe and transducer PFD_{avg} = 2.56E-4,

— safe failure fraction, SFF = 0.65,

— Type A components (noncomplex).

b) Logic solver:

— PFD_{avg} for the monitoring system PFD_{avg} = 1.58E-3,

— PFD_{avg} for logic solver PFD_{avg} = 1.70E-4,

— safe failure fraction, SFF = 0.95,

— Type B components (complex).

c) Output subsystem:

— PFD_{avg} for trip solenoid valve PFD_{avg} = 8.72E-3,

— PFD_{avg} for stop valve PFD_{avg} = 3.75E-3,

— safe failure fraction, SFF = 0.62,

— Type A components (noncomplex).

d) Common data for all parts:

— hardware fault tolerance, HFT = 0,

— proof test interval, TI = 2 years,

— mean time to repair, MTTR = 8 h.

L.8.2.3 Calculation of Probability of Dangerous Failure of the Loop

The PFD_{avg} calculation provides PFD_{avg} = 1.45E-2 for the complete safety loop. This is summarized in Table L.8.

This figure is higher than the acceptable 1E-2 for SIL 2 (see Table L.1). Consequently, this system may be used as SIL 1 only.

Table L.8—Table of Calculated PFD_{avg} for Example of L.7.2.2

PFD_{avg}	Device or Component
2.56E-4	Sensor and Signal Conditioner
1.58E-3	Monitor
1.70E-4	Logic Solver
8.72E-3	Solenoid Valve
3.75E-3	Stop Valve
1.45E-2	Example 1A (Overall Value)

L.8.2.4 Architectural Constraints of the Loop

L.8.2.4.1 Input Subsystem

The sensor and signal conditioner are both Type A components (noncomplex), so the architectural constraints according to IEC 61508-2, Table 2 allow a maximum rating of SIL 2 because SFF > 60 % at HFT = 0.

L.8.2.4.2 Logic Solver Subsystem

Monitor and logic solver are both Type B components (complex), so their architecture is evaluated according to IEC 61508-2, Table 3. SFF = 95 % and HFT = 0 allow a maximum rating of SIL 2.

L.8.2.4.3 Output Subsystem

Solenoid valve and stop valve are noncomplex Type A components. SFF = 62 % and HFT = 0 allow a maximum rating of SIL 2.

L.8.2.5 Results of the Loop Evaluation per IEC 61511

The architectural constraints (SFF and HFT) for all subsystems would allow up to SIL 2. However, the probability of failure (PFD_{avg}) for the complete safety loop restricts the safety function to a maximum rating of SIL 1. The trip solenoid is the weakest item in the loop, (i.e. highest PFD_{avg}) and therefore an improvement can be made by putting two solenoids in parallel. This is discussed further in Example 1B (L.8.3).

NOTE There are different measures available to increase the degree of risk reduction, e.g. shorten the proof test interval, select components with lower probability to fail, or install redundancy.

L.8.3 Example 1B—Loop Evaluation Using ISO 13849

L.8.3.1 Establish PL Requirements Using Risk Graph of ISO 13849

L.8.3.1.1 With the same risk assessment as for the IEC risk graph (L.6.2.3), the ISO parameters are selected for S2, F2 and P2. The corresponding ISO risk graph is found in L.6.2.4. For the example under consideration, the required performance level is PL_re. PL_re is equivalent to SIL 3.

L.8.3.1.2 ISO 13849 ignores the probability of occurrence of the unwanted event (W). However, for a high probability event (W = W3), both the risk graphs of both standards give the same required performance (protection) level (SIL 3 and PL_re).

L.8.3.2 Evaluate Loop Using ISO 13849

L.8.3.2.1 Architectural Constraints of the Loop

L.8.3.2.1.1 The architecture of Figure L-6 (a simplex protection loop without any automated checking of the safety function) fits in Category 1 per Figure L-5. Per Figure L-4, PLr e requires Figure L-5 architecture Category 3 (full redundancy where HFT = 1 with diagnostic tests) and a high value of MTTF, i.e. > 30 years. The DC may be medium or high.

L.8.3.2.1.2 If the location of the machinery is occupied less than 10 % of the time, F = F1 and the required performance level is PL_rd. Per Figure L-5, this performance level requires either Category 2 with high MTTF or Category 3 with medium to high MTTF. The DC should be low to medium.

L.8.3.3 PL Evaluation as per ISO 13849

Using the previous information and the additional equipment vendor data:

a) $MTTF_d$ per sensor and signal conditioner MTTF = 39.6 years,

b) $MTTF_d$ per the monitor and logic solver MTTF = 19.5 years,

c) $MTTF_d$ per trip solenoid MTTF = 20 years.

The resulting total loop MTTF is 7.9 years low.

The requirements are not met.

The resulting total loop MTTF is 7.9 years while the required MTTF (Table L.9) needs to be more than 10 years for medium denotation. The requirements are not met. If the loop does not meet architectural requirements and the requirement for medium to high MTTF, then the selected SIS is not suitable to be used as a PL_rd or PL_re loop. In order to meet the MTTF, the architecture or the component selection should be revised. The SRS should also be revised and the PL_r evaluation repeated.

Table L.9—Mean Time to Dangerous Failure of Each Channel ($MTTF_d$)

$MTTF_d$	
Denotation of Each Channel	**Range of Each Channel**
Low	3 years ≤ $MTTF_d$ < 10 years
Medium	10 years ≤ $MTTF_d$ < 30 years
High	30 years ≤ $MTTF_d$ ≤ 100 years

NOTE 1 The choice of the $MTTF_d$ ranges of each channel is based on failure rates found in the field as state-of-the-art, forming a kind of logarithmic scale fitting to the logarithmic PL scale. An $MTTF_d$ value of each channel less than three years is not expected to be found for real SRP/CS since this would mean that after one year about 30 % of all systems on the market will fail and will need to be replaced. An $MTTF_d$ value of each channel greater than 100 years is not acceptable because SRP/CS for high risks should not depend on the reliability of components alone. To reinforce the SRP/CS against systematic and random failure, additional means such as redundancy and testing should be required. To be practicable, the number of ranges was restricted to three. The limitation of $MTTF_d$ of each channel value to a maximum of 100 years refers to the single channel of the SRP/CS that carries out the safety function. Higher $MTTF_d$ values can be used for single components (see Table D.1 in ISO 13849).

NOTE 2 The indicated borders of this table are assumed within an accuracy of 5 %.

Table L.10—Diagnostic Coverage (DC)

DC	
Denotation	**Range of Each Channel**
None	DC < 60 %
Low	60 % ≤ DC < 90 %
Medium	90 % ≤ DC < 99 %
High	99 % ≤ DC

NOTE 1 For SRP/CS consisting of several parts, an average value DC_{avg} for DC is used in Figure 5, Section 6, and E.2 of ISO 13849.

NOTE 2 The choice of the DC ranges is based on key values 60 %, 90 %, and 99 % also established in other standards (e.g. IEC 61508) dealing with DC of tests. Investigations show that (1 – DC) rather than DC itself is a characteristic measure for the effectiveness of the test. (1 – DC) for the key values 60 %, 90 %, and 99 % forms a kind of logarithmic scale fitting to the logarithmic PL scale. A DC value less than 60 % has only slight effect on the reliability of the tested system and is therefore called “none.” A DC value greater than 99 % for complex systems is very hard to achieve. To be practicable, the number of ranges was restricted to four. The indicated borders of this table are assumed within an accuracy of 5 %.

L.8.4 Example 2A—Loop Evaluation Using IEC 61508, 61511, 62061

L.8.4.1 The risk assessment for the loop (Figure L.4) shown in example 1 results in a required SIL 2 if the machinery location is frequently occupied by persons. The impact of adding a parallel solenoid valve (Figure L.5) is demonstrated in Example 2.

L.8.4.2 Using the same equipment vendor-provided data (L.8.2.2.1) used in example 1 for the calculation of the PFD_{avg} for the loop in Figure L.5, a common cause factor *ß* = 0.05 (typical value) is estimated. This gives a PFD_{avg} of 6.27E-3 (Table L.11) for the loop with two parallel solenoids. This is below the required value of 1E-2; therefore the arrangement meets the required SIL 2.

L.8.4.3 Since the architectural constraints of example 1A already met the requirements of SIL 2, the higher fault tolerance in example 2A with parallel solenoids will only improve on it. Therefore, the requirements of functional safety are met.

Table L.11—Table of Calculated PFD_{avg} for Example in L.8.4

PFD_{avg}	**Device or Component**
2.56E-4	Sensor and Signal Conditioner
1.58E-3	Monitor
1.70E-4	Logic Folver
5.12E-4	Solenoid Valve, One-out-of-two Fault Tolerant
3.75E-3	Stop Valve
6.27E-3	Example 2A (Overall Value)

L.8.5 Example 2B - Loop Evaluation using ISO 13849

As already explained in L.8.3.2.1.1, a PL_re loop should have full redundancy (HFT = 1). For PL_rd, a single loop architecture with self-diagnostic feature may be used (Category 2), if MTTF is above 10 years (medium). The parallel arrangement of the two solenoid valves increases the MTTF to 12.65 which is medium. This loop meets the requirements of PL_rd.

L.8.6 Proof by Reverse Consideration

L.8.6.1 The process of functional safety requires making several assumptions in regard to the consequences of an unwanted event and in regard to the probability that an unwanted event happens. It is often very difficult to determine the probability of the occurrence of the unwanted event without a MPS present (parameter W). Field experience-based data always have a MPS in place.

NOTE Risk analyses require information on how often an event happens without a protection system in place. In practice, however, all real installations are equipped with protection systems. Thus, all field-experienced based data (from events that happened) reflect installations which have a MPS in place. Overspeed analyses for example, need to estimate a figure of how often an overspeed trip event with harm to people or environment will occur if an overspeed trip system is not installed. Such an estimate is not known since all turbines in the field have an overspeed trip system installed and all experience-based data refers to installations with a MPS in place. Further, if we count how often the MPS was activated, we will get incorrect estimates as not each event which made the MPS respond would have resulted in an accident.

L.8.6.2 At the end of a complex calculation process, it is good engineering practice to check whether the result is in line with field experience. This check can be used if the MPSs in use are of similar or lesser quality than those specified.

L.8.6.3 The probability of occurrence of the unwanted event W (Table L.7), multiplied by the risk reduction factor, which is determined by the SIL (Table L.1), gives the remaining probability that the unwanted event occurs even with the safety system in place. It is recommended to compare this remaining probability with actual statistics from machines in operation.

L.8.6.4 An example of the reverse consideration follows.

L.8.6.4.1 The risk analysis for shaft vibration is typically classified as W1 which assumes that the unwanted event (risk of harm to a person if shaft vibration trip is not present) occurs less than once in 10 years.

L.8.6.4.2 The MPSs commonly in use are certified for SIL 1 which is equivalent to a risk reduction factor of 10 to 100 which allows that the safety function fails to stop the machine once in 10 to one of 100 cases (refer to Table L.1).

L.8.6.4.3 A machine that is protected by a MPS (per the above data) may be exposed to an unwanted event (injury or death of person) in one in 100 up to one in 1,000 years, even with the MPS in place.

L.8.6.4.4 The actual field experience with current installations shows that there is not more than one event (personal injury due to missed vibration trip) in 1000 years.

L.8.6.4.5 Therefore, this proves that the selected degree of risk reduction is adequate.

Annex M
(informative)

Considerations Regarding Spurious Shutdowns and the Use of Functional Safety Methodology to Reduce Economic Losses

M.1 General

M.1.1 Functional safety is a mandatory requirement for health to personnel and the environment.

M.1.2 Annex L provides an overview to the concept of functional safety and SILs as they pertain to MPS's in regard to personnel and environmental protection. It assumes that a particular SIF is designated purely or primarily for safety-related reasons. In contrast, this annex discusses the voluntary application of SIL ratings and other methods to MPS's in order to reduce risk of economic losses.

M.1.3 Economic losses may result from following the following situations.

M.1.3.1 The protection system should have brought the unit into a safe state but failed to do so. This is called a missed shutdown.

M.1.3.2 The protection system brought the unit into the safe state without the necessity to do so. This is called a spurious shutdown.

M.1.4 Functional safety employs the concept of SIL as a way of reducing safety-related risk exposure. As such, it is not typically concerned with spurious shutdowns but rather with missed shutdowns as missed shutdowns may mean the machine progresses unprotected to catastrophic failure and associated HSE-related consequences.

M.1.5 Functional safety methodology is not to reduce the risks of economic losses due to lost production. It typically fails to include spurious shutdowns that may be caused by protective equipment.

M.1.6 ISA TR84.00.02-2002, Part 1 defines the false shutdown, nuisance shutdown, or spurious shutdown rate. ISA TR84.00.02-2002, Part 2 describes a procedure to reduce the number of spurious shutdowns to an acceptable level.

M.1.7 Minimizing spurious shutdowns requires fault tolerant systems and measures for avoidance.

M.1.8 This annex recommends some practices to reduce the risk of economic losses.

M.1.9 The following principles are widely used for this purpose.

a) Apply the methods of functional safety to those risks that can cause severe equipment damage to rotors or bearings.

b) Introduce redundancy to make MPS's fault tolerant (e.g. by the use of m-out-of-n voting).

c) Introduce diagnostics to get advanced (early) warning of developing system faults.

M.1.10 The methods of functional safety may also be used to reduce the risk of economic losses due to equipment damage (e.g. bearings, rotors, seals).

M.2 Reduction of Economic Losses Caused by Missed Shutdowns

M.2.1 Regardless of whether there are HSE-related consequences associated with a machinery failure, there will almost always be economic consequences for the classes of machinery addressed by an API 670 protection system. Such economic consequences include, but are not limited to, machinery repair costs and/or lost-production costs.

M.2.2 When large enough, these costs can prompt end users to specify additional measures beyond the requirements in regard to HSE.

M.2.3 In such cases, the end user may specify a particular SIL rating not because they are required to do so by safety-related laws or regulations but rather as an entirely voluntary method of mitigating exposure to economic risk.

M.2.4 The purchaser should either perform his/her own analysis and specify the required SIL for each individual protection loop. Alternatively, he/she may give the machine vendor a suitable calibration chart, risk matrix, or risk graph to receive their recommendations.

M.2.5 All steps of the risk reduction procedure should follow Annex L.

NOTE The application of the methods of functional safety on equipment damage is only required if expressively specified by the purchaser.

M.3 Reduction of Economic Losses Caused by Spurious Shutdowns

M.3.1 General

M.3.1.1 When the design of a system is focused purely on lowering the probability of missed shutdowns, it may have the undesirable effect of increasing the probability of spurious shutdowns.

NOTE HFT is an important parameter for functional safety. The HFT parameter defines how many loops in parallel need to initiate the safety function in a one-out-of-m voting.

M.3.1.2 The common method to avoid these shutdowns is the introduction of fault tolerance.

M.3.1.3 If functional safety requires HFT = x, $m = x + 1$ loops need to vote in a one-out-of-m system. If any of the loops detects a dangerous situation, the system goes to the safe state.

NOTE A simplex one channel loop has a HFT of 0.

M.3.1.4 A fault tolerant system consists of $n = m + 1$ (or more) parallel elements. This architecture allows the design of a fault tolerant two(or more)-out-of-n architecture. This system takes the safe state only if at least two parallel loops have detected an unsafe condition (unwanted event or unsafe failure).

M.3.1.5 Below is some general information on voting schemes.

M.3.2 1-out-of-n Voting

Consider a system with n sensors where any single sensor can shutdown the machine (logical OR voting). In such a "one-out-of-n" voting structure, the probability of a missed shutdown could be made arbitrarily low by simply introducing more sensors (increasing n). However, the probability of a spurious shutdown increases with each sensor added because the sensor itself may fail and falsely indicate a machinery problem when no problem actually exists. The larger the number of sensors, the more likely that any one sensor will fail in a manner that falsely indicates a machinery problem.

M.3.3 *n*-out-of-*n* Voting

By changing the voting logic from OR to AND, an "*n*-out-of-*n*" system results. In such a system, the probability of spurious shutdowns can be made arbitrarily low by simply introducing more and more sensors. The likelihood that all *n* sensors will fail and simultaneously give a so-called "false positive" indication becomes lower with each incremental sensor addition. Conversely, the probability of a missed shutdown increases with each sensor added because the sensor itself may fail and disable the protection provided by the whole assembly on this configuration.

M.3.4 Minimizing Both Missed and Spurious Shutdowns

In practice, end users are typically concerned with minimizing both missed shutdowns and spurious shutdowns as each may have associated economic related consequences. *m*(good)-out-of-*n*(total) voting strategies such as two-out-of-three or two-out-of-four are commonly employed to balance the probabilities of spurious shutdowns against those of missed shutdowns. In those schemes, the failure of n-m sensors can be tolerated without decreasing the functional protection specified. The voting of a majority of sensors m can be trusted to most likely represent the correct status of the sensors.

M.3.5 Appropriate Expertise

To achieve the proper level of reliability with respect to both missed shutdowns and spurious shutdowns, an individual skilled in functional safety concepts, the design of SIS's, and the calculations involved in determining SILs should be consulted. Such expertise may exist in the end user's organization, in the machinery or MPS vendor's organization, in the purchaser's organization, or in a third party specializing in SIS engineering consultation.

NOTE See M.5.

M.4 Reduction of Economic Losses by Preventive Diagnostics

M.4.1 A further method to reduce the risk of economic losses is the use of monitoring and diagnostic processes that diagnose the condition of the protection system and generate a prewarning if any monitored parameter has left the nominal working range. Such a prewarning allows the operator to service the protection system under convenient circumstances.

EXAMPLE 1 On speed sensing systems using eddy current probes, the gap between gear wheel and probe can be monitored continuously for high or low gap, with alarms generated once thresholds are exceeded.

EXAMPLE 2 The temperature of the PCB or important components on the PCB can be monitored and an alarm generated if the temperature exceeds the acceptable level.

EXAMPLE 3 Current consumption of sensors or electronic components can be monitored and alarmed if too high or too low.

M.4.2 The machinery system operations manual should advise what to do once an alarm occurs.

M.5 Combining Fault Tolerance with Functional Safety for Safety Loops

M.5.1 Fault tolerance with *m*-out-of-*n* voting systems above or beyond the requirements of functional safety can reduce the rate of spurious shutdowns. This is voluntary whereas functional safety in regard to protection of personnel and the environment is mandatory. Therefore, any system architecture that has been selected to reduce economic losses has to be checked against the SRS for compliance with the methods of functional safety.

M.5.2 Figure M.1 describes the process below. Any architectural requirement has to be considered a prerequisite to the process of functional safety. Once the SRS is finished, no design changes to the protection system are acceptable, as far as HSE is concerned.

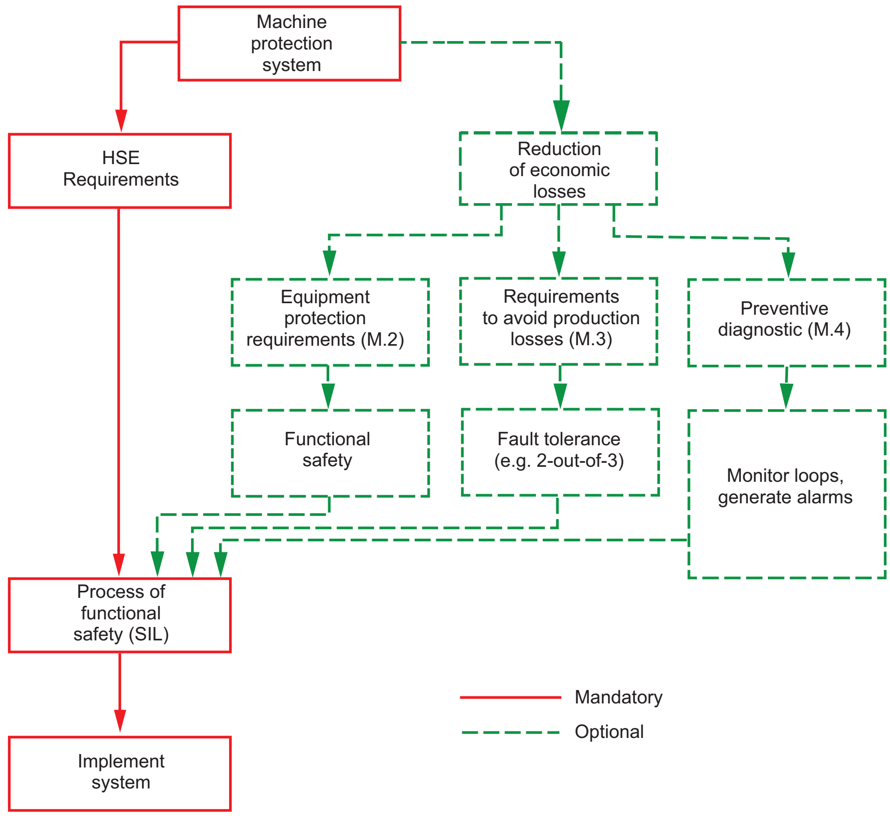


Figure M.1—Process Block Diagram

Annex N
(informative)

Condition Monitoring

N.1 General

This annex discusses the function and requirements of machinery CMS's and offers recommendations for monitoring methods, intervals, parameters to be measured and evaluated, and data to be recorded.

Caution—The function of a MPS as outlined in the normative sections of this standard shall not be compromised or impeded in any way by the implementation, function, or malfunction of a CMS.

N.2 Scope

While the normative sections of this standard specifically define a MPS, this informative annex is tutorial in nature and suggests common functionality in (and recommended application of) CMS's. For the purpose of this discussion, a CMS is considered distinct and separate from a MPS. While it is recognized that these systems are frequently installed together and, may even be tightly integrated with one another, irrespective of the architecture, the recommendations offered in this informative annex do not in any way supersede or eliminate the requirements of the normative sections of this standard. The functionality described in this annex may build upon the underlying protection system capabilities, but should be construed as augmenting, rather than relaxing, the requirements specified elsewhere in this standard.

N.3 Data Sources

N.3.1 CMS's may be employed to monitor the health of many types of assets in a plant or enterprise and are not limited to assets already fitted with a MPS. Their function is to detect and identify a fault before it could potentially lead to a shutdown. This may require additional data sources beyond those typically available in a MPS.

N.3.2 In general, the inputs to a CMS may be categorized as follows.

a) Signals from vibration or temperature sensors installed as part of a MPS conforming to this standard.

b) Signals from additional sensors mounted on machinery fitted with a MPS but that do not provide input to the protection system.

c) Signals from vibration, temperature, pressure, or other types of sensors mounted on machinery not fitted with a MPS conforming to this standard.

d) Data passed from process control and automation systems. These data are typically measures of attributes that pertain to the process in which the machine contributes. Examples include flows, gram molecular weight, fluid temperature, suction and discharge pressures, etc. This data is typically valuable because it describes the process conditions acting on and in the machine. It is also valuable for thermodynamic performance calculations that may augment the mechanical and rotordynamic measurements available from the machine.

e) Manually gathered data such as oil analysis data, additional machinery vibration data, thermographic data, and others.

N.4 Approach

This annex outlines the recommended steps to implement a monitoring program. The major steps include the following.

a) Define the intended use and anticipated value of the system. This is an often overlooked aspect of the requirements identification process but perhaps the most critical. For example, if the purpose of the system is to reduce maintenance costs through the application of predictive maintenance techniques, then a very different system/program/process might suffice than if the requirement is to minimize downtime by detecting faults before they can impact machine performance.

b) Identify the potential equipment faults that could be detected by monitoring and the symptoms that would be produced by these faults.

c) Determine the analysis techniques that are appropriate to the faults that are being monitored.

d) Establish the monitoring program to detect equipment deterioration or equipment faults early enough to prevent functional failure of the equipment.

e) Apply the evaluation criteria for each piece of equipment.

N.5 Differentiation of Machinery Protection and Condition Monitoring

Caution—The implementation of a CMS should not in any way compromise or interfere with the function of machinery protection as outlined in the normative section of this standard.

N.5.1 Table N.1, extracted from the definition section of the normative specification, illustrates the fundamental difference between machine protection and CMS's. The balance of this section is intended to provide a further discussion regarding the consequential differences between a MPS as specified in the normative section of this document and a CMS as described in this informative annex.

Table N.1—MPS and CMS Objectives and Goals

	Machine Protection System	Condition Monitoring System
Objective	Senses, measures, monitors, and displays machine parameters indicative of its operating condition. When a parameter exceeds predefined limits, indicating an abnormal condition, the system will communicate the event to operators and/or a shutdown system.	Measures and trends specified machine and process parameters. Provides alarming, presentation, and analysis tools for the detection and identification of developing faults. Allows for the continued monitoring of a detected fault to determine its propagation and severity. May also be used to manage the operating conditions of the machine to reduce stress from a developing fault. Can, in some cases, reduce the rate at which a fault propagates to minimize additional damage thus extending the time before necessary repairs.
Goal	The goal of the system is to prevent injury to personnel and to prevent or mitigate damage to the machine or harm to the environment.	The goal of a condition monitoring system is to maximize availability by obtaining an insight into the operating condition of the equipment monitored, by being able to better predict when equipment will need to be repaired or replaced, and finally by optimizing repair and turnaround schedules.

N.5.2 Table N.2 identifies the difference between this annex and the normative main body of this standard.

N.5.3 As Table N.2 suggests, there are obvious differences between protection and condition monitoring systems. Besides the objectives and goals of the systems, these differences include the type of data processed, the ability to

Table N.2—MPS and CMS Content Comparison

	Main Body	Condition Monitoring Annex
Use	Normative specification	Informative text
Content	Mandatory specifications detailing the physical, functional, performance, and reliability characteristics of the protection system from sensor to monitor to user interface. Addresses the measurement and monitoring requirements for vibration, speed, thrust and bearing temperature, overspeed protection, and surge.	Recommended guidelines and information useful in the selection and application of a condition monitoring system. Addresses the evaluation and use of existing sensors, common and advanced diagnostic techniques, alarming strategies, and use of additional measurement technologies such as oil analysis and infrared thermography.

store, retrieve and analyze historical data, and the types of data gathered. Differences also include how the data is presented and the tools available for users to apply in processing or presenting the data.

N.5.4 In short, a protection system fulfills a specific task, while a CMS is a computerized data acquisition and analysis tool that can be applied to a broad range of applications.

N.5.5 Aside from the above there remain similarities. Both types of systems share many of the same types of sensors and the same types of signal processing capabilities. But nevertheless there are areas of difference that are significant and should be understood so as to minimize confusion when purchasers specify, compare or assess these systems.

N.6 Consequence of Failure

N.6.1 General

N.6.1.1 One of the most defining differences between a MPS and a CMS is the consequence of failure. For a MPS, the failure to perform its function could lead to catastrophic results such as death or injury to personnel, severe damage or destruction of assets, and unacceptable harm to the environment. In contrast, the failure of a CMS, as discussed in this informative annex, would lead to the momentary loss of information that might impact future maintenance planning and/or forewarn of machine problems prior to the activation of the protection system. For more advanced applications, it could potentially also lead to an unexpected production stoppage.

NOTE The application of a CMS where its failure could impact safety or the environment is excluded from this annex.

N.6.1.2 Because of the consequences of failure for a MPS, the normative section of this standard specifies degrees of system completeness, reliability, and responsiveness that go well beyond what is required for general condition monitoring. Each of these characteristics is addressed in the following sections.

N.6.2 Responsiveness

N.6.2.1 The responsiveness of a MPS (i.e. how quickly it detects and reacts to an event) is specifically defined in this standard. This is necessary for the system to fulfill its mission. No equivalent standard exists for CMS's.

N.6.2.2 While a CMS may be designed to measure rapidly or even continuously, such as for transient monitoring, and it may provide alerts based on these measurements, no specific performance requirements for a CMS are outlined within this document.

NOTE "Performance" as defined in this standard specifically refers to the responsiveness of a system. When evaluating a CMS, there may be other aspects of performance that are not addressed here.

N.6.3 Reliability

N.6.3.1 The reliability of a MPS (i.e. assure that it functions continuously to provide protection monitoring) is specifically defined in this standard. No equivalent standard exists for CMS's. It should be noted therefore that reliability of available options for condition monitoring spans a much broader range.

N.6.3.2 The simplest products may be based on conventional PC's and commercial grade components, while hardened system may incorporate industrial-grade components that approach the stringent level required for MPS's.

N.6.3.3 It remains the responsibility of the purchaser to match the level of reliability and/or accuracy to their application. For example, if the main purpose of a CMS is to provide advance warning about developing faults, it may be feasible to accept a lower level of reliability than if it is integrated directly into a control system (e.g. efficiency measurements, cavitation monitoring). If the availability of information from the system to manage an abnormal or upset situation is critical, a higher level of reliability may also be required.

N.6.4 Completeness

N.6.4.1 The completeness of a protection system (i.e. inclusion of all elements required to provide protection) is specifically defined in this standard. No equivalent standard exists for CMS's. It remains the responsibility of the purchaser to identify all of the components required by their application.

N.6.4.2 A CMS may have common inputs or even components with a MPS. This approach frequently provides a cost-effective method to obtain more detailed information about machine condition. As noted at the beginning of this annex, the implementation of a CMS shall not in any way compromise or interfere with the function of machinery protection as outlined in the normative section of this standard.

N.7 Critical vs Special-purpose Equipment

N.7.1 Criticality in Respect to Machinery Protection

N.7.1.1 The API 670 MPS standard is usually considered to be for "critical" equipment because its application is sometimes limited to those pieces of equipment that are considered the most important for minimizing disruptions to plant processes or where at least minimizing and/or mitigating the damage when problems do occur is essential.

N.7.1.2 The terms that are sometimes interchanged with critical versus noncritical are general purpose versus special purpose.

N.7.1.3 *General-purpose Application*—An application that is usually spared, is relatively small in size, or is in noncritical service.

N.7.1.4 *Special-purpose Application*—An application for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no installed spare equipment.

N.7.1.5 There are times when a machine, which would normally be considered general purpose, is treated as special purpose from a machinery protection standpoint. This normally happens when a machine failure could cause a safety and/or environmental event. An example is a spared pump handling a flammable or toxic fluid. A failure can result in a fire and environmental release with large impact. This also figures into the type of condition monitoring approach required.

N.7.1.6 In the end, it is the owners and users who should determine which services and pieces of equipment are considered critical because it is they who will assume responsibility for all losses.

N.7.2 Criticality in Respect to Condition Monitoring

N.7.2.1 Overall in a plant process, “why” and ”where” to implement condition monitoring is best established by a maintenance strategy review, typically employing reliability centered maintenance or similar techniques.

N.7.2.2 When implementing condition monitoring, we can speak of levels of priority as they relate to the methodology and/or frequency of collecting and storing data.

N.7.2.3 Suggested levels and an explanation of their meanings are shown below.

a) High priority—continuous on-line system (continuous—e.g. update rate measured in seconds).

b) Medium priority—unmanned scanning system (scanning systems will typically store a reading every few hours or better. Data is retrieved in an unmanned collection mode).

c) Low priority—walk around manual system (typically collected once per week or once per month; emphasis here is that the data is collected manually).

N.7.2.4 These priority levels can further be broken down based upon triggering methodologies for collection and storage. For example, although a continuous on-line monitoring system may be scanning sensors almost instantaneously, the data may not be stored unless triggered to do so by a change in amplitude of one or more signals. Similarly, although a scanning system may be configured to collect and store data hourly, it is possible to configure a trigger to “wake” the system based upon a change of state and collect data more frequently.

N.7.2.5 Again, the owners and users should determine which methodologies and strategies should be used to best maintain the integrity and efficiency of their processes. Although it may not be necessary to monitor the efficiency of a process in order to ensure its safety, it may be prudent to do so in order to minimize energy requirements and maximize profitability.

N.8 Aspects of Condition Monitoring

N.8.1 General

There are four distinct aspects to condition monitoring.

N.8.2 Protection Systems

N.8.2.1 Protection systems are applied when the process or machinery are deemed critical in nature and require on-line supervision (see **monitor system** definition 3.1.113).

N.8.2.2 As stated in Table N.1, a protection system is described in the normative section of this document; however, it is common to use the data from a protection system as the basis for a CMS.

N.8.3 Predictive Maintenance

N.8.3.1 Prediction, as applied to predictive maintenance, is the most common reason for implementing condition monitoring programs or systems. The concept is to base maintenance decisions, and in some cases, operating decisions, on the (measured) condition of the machine.

N.8.3.2 By trending information over time, we can attempt to discover the degradation rates of various components and thereby predict the remaining life of that piece of equipment. Or perhaps more realistically, to intelligently predict if we can make it to the next scheduled overhaul and eliminate the need for an unscheduled shutdown.

N.8.3.3 A key aspect of this motivation is the consideration of the value to the process of the CMS. In many cases the reason for the system is not to reduce maintenance but rather to help in assuring that production can be maintained or that production goals can be met. By arming operators and management with better knowledge of the health of the critical assets in a process, better, more accurate production planning can be achieved.

N.8.4 Optimization

CMS's applied to monitor the performance of a machine and/or process can be used to aid in optimizing the operating parameters (environment) of an asset to maximize one or more aspects of its function (throughput, power consumption, etc.). They can also assist in evaluating whether it might be more cost effective to replace a unit with a newer, more efficient model, even if the existing unit is not showing signs of wear. Correlating process data with machine condition data is a very powerful machinery life management tool and needs to be considered as a part of any CMS.

N.8.5 Preventative Maintenance

N.8.5.1 Prevention can be applied as a system, a process or procedure, or a program. The concept of prevention is to eliminate, or control, the source of a potential problem before one develops. The most common example of this is a preventative maintenance program, where parts that normally wear are replaced on a schedule so as to prevent them from wearing to the point that the machine's health or performance is affected. But the concept of prevention can be applied to more than maintenance, particularly with respect to managing the operating environment of a machine. In some cases, condition monitoring can reduce the need for preventative maintenance.

N.8.5.2 Life reducing conditions/events can impact a machine because of its operating environment. When the right data is presented to the operator in the right format, action can be taken to return the environment to normal and eliminate the high stress on the machine extending its life. A good example is a spared pump. An operator may run both pumps to handle a peak flow condition. When flow is reduced both pumps cavitate, thus reducing life. If the operator is fed this data, one pump would be turned off, eliminating the problem.

N.9 Static versus Dynamic Data

N.9.1 When discussing data associated with condition monitoring, a good initial separation is static versus dynamic. With a radial displacement probe, the static portion can be classified as an overall amplitude or with filtering and a speed reference can be broken into a filtered amplitude and phase, typically 1X, 2X, etc. If the dynamic portion of the data is also captured, additional information can be displayed in the form of time waveforms, orbits, spectrum, and many others. This differentiation is also applicable for velocity probes, accelerometers, load cells, microphones, strain gauges, and dynamic pressure transducers.

N.9.2 Static data is data that describes the quantitative characteristics of the measured parameter. Static data can also include quantitative values describing the conditions under which the parameter was measured. For predictive maintenance purposes, static data is typically presented in various forms of trend plots and displays/lists of current values. Examples of static data include vibration amplitude, phase lag angle, frequency, average shaft position, shaft rotative speed, time, date, monitor alarm, and OK status. The static portion of a radial proximity probe should include the shaft position information, which is in the gap voltage. The combination of "X" and "Y" shaft position information produces the shaft centerline plot.

N.9.3 Dynamic data is data (steady state or transient) that contain the part of the transducer signal representing the dynamic (e.g. vibration) characteristics of the measured variable. Typical dynamic data presentations include orbit, timebase waveform, spectrum, polar, Bode, cascade, and waterfall plots. From this data, it is possible to derive static data signal parameters, such as amplitude, frequency filtered amplitude, and phase lag angle.

N.9.4 For most process data, only a static component is available. Typical examples of static data are temperatures, pressures, flows, valve positions, etc.

N.10 Machine Faults

N.10.1 Introduction

N.10.1.1 The following graphs and illustrations highlight some of the more common faults found on rotating equipment along with their typical symptoms and plots used by analysts to diagnose them. Please note that the included plots are purposely in different styles and formats so that our users are exposed to different presentation styles. For example, frequency plots can be displayed with Hertz, cycles per minute (cpm), or orders as the x-axis without changing the validity of the plot.

N.10.1.2 The following is not intended to be a comprehensive list of faults or fault indicators. When developing a program, users should also consult other sources of fault detection and diagnostic techniques appropriate to their specific machines and application. They should also consider their corporate capabilities, procedures, and standards.

N.10.2 Data Display with No Faults

N.10.2.1 The orbit and order spectrum in Figure N.1 are a case with only forward 1X data and no malfunction present.

N.10.2.2 The plots in Figure N.2, Figure N.3, Figure N.4, and Figure N.5 illustrate examples of waterfalls and cascades, with the x-axis configured for either frequency or orders .

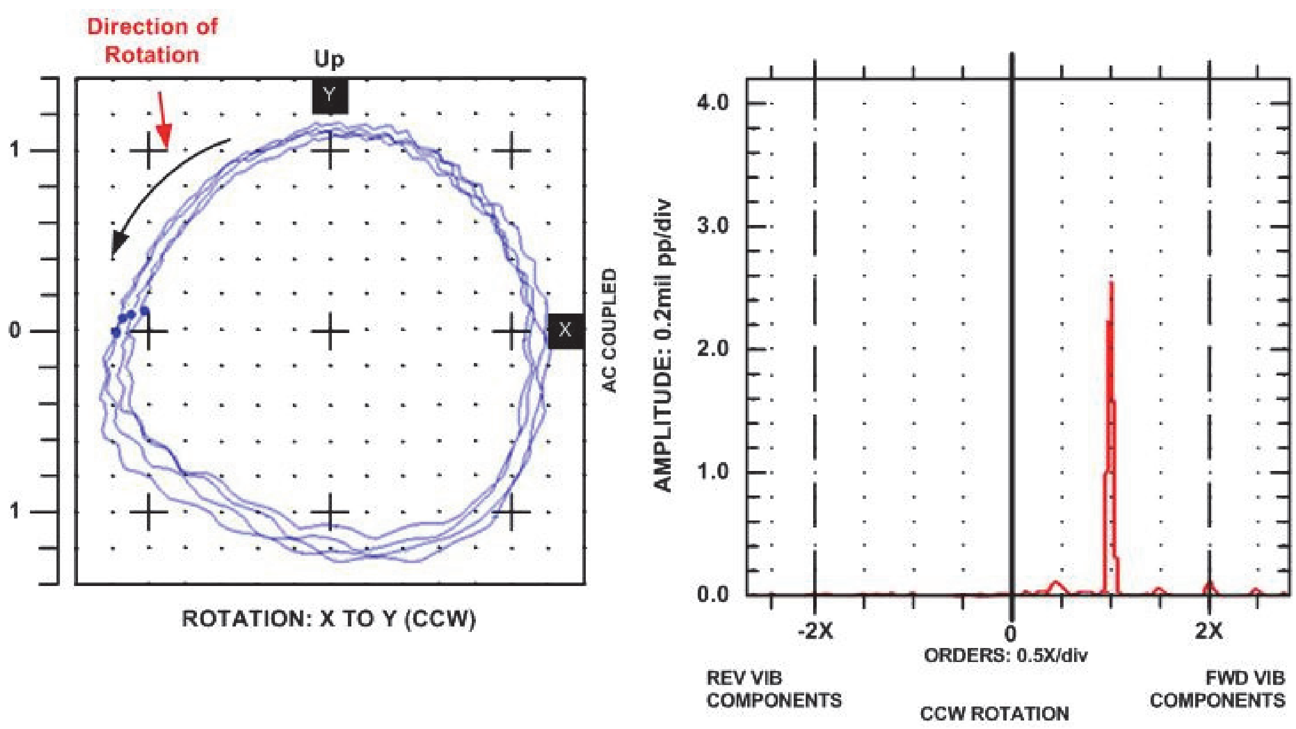


Figure N.1—Orbit Plot and Order Spectrum

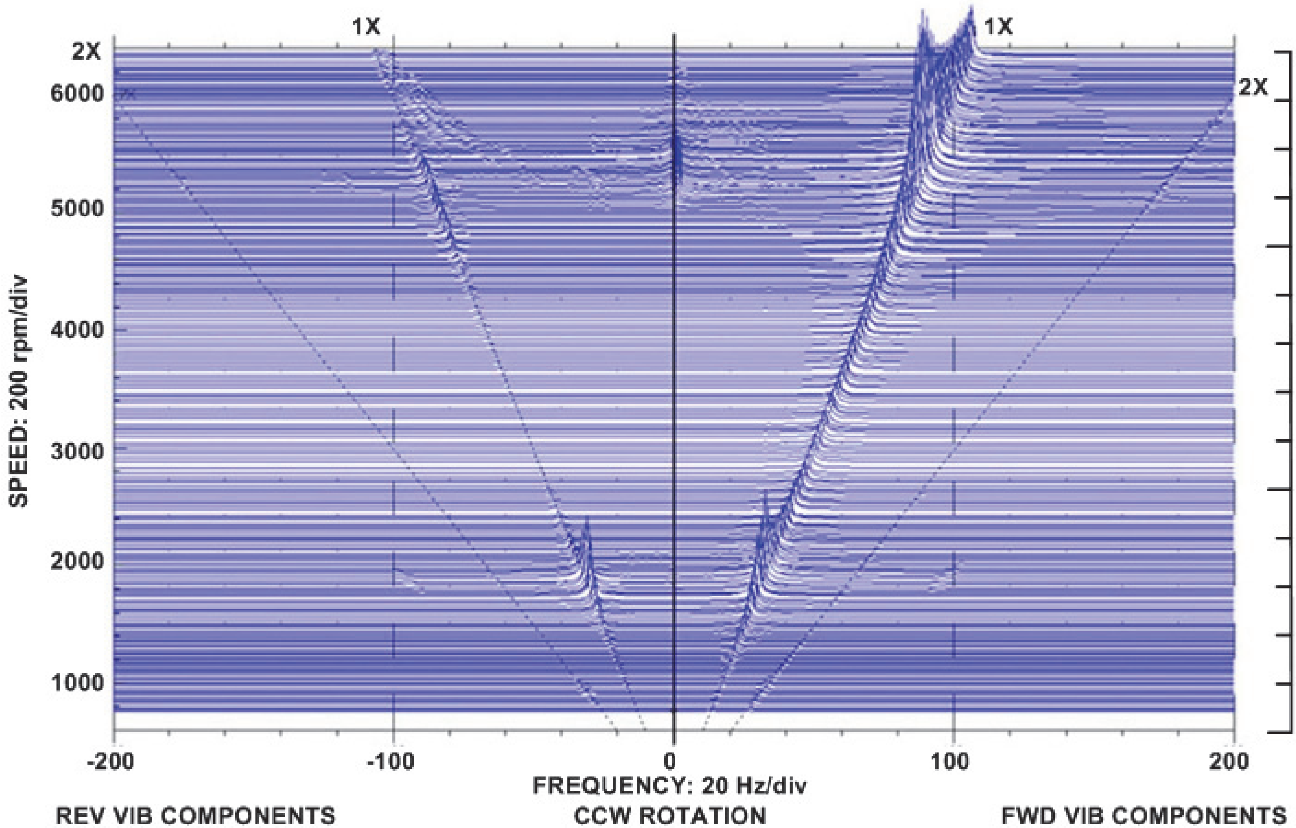
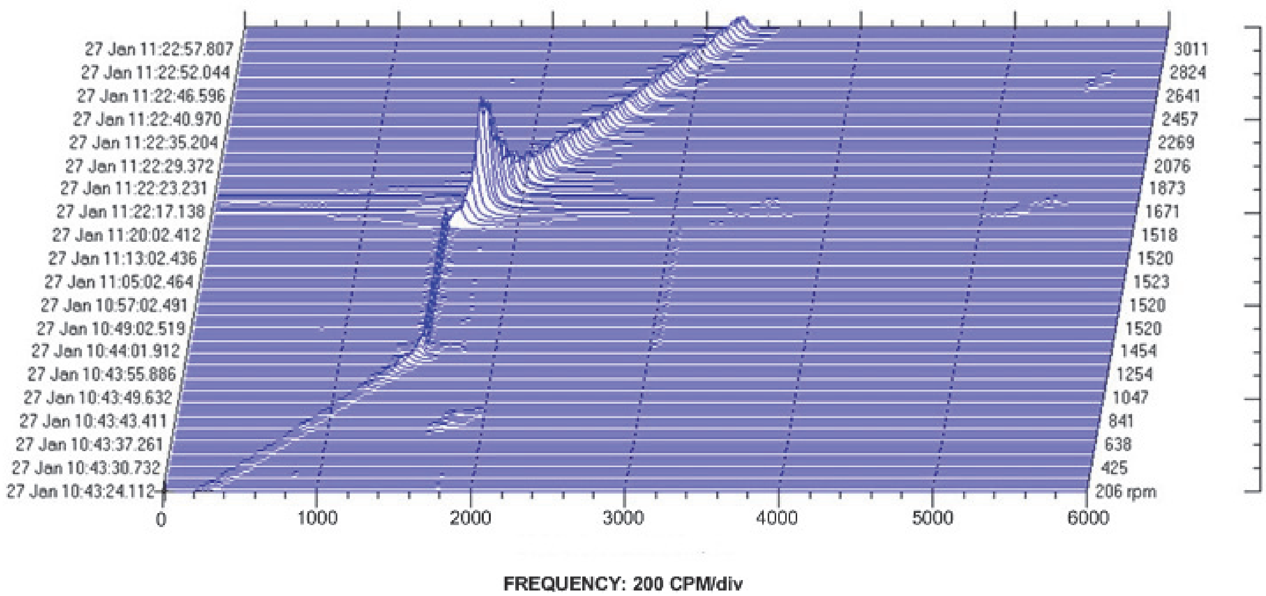


Figure N.2—Case Plot with x-axis Configured for Frequency



NOTE Machine start-up showing operation at a constant speed for a period of time during the start-up. This is typical of the "Heat Soaking" or Thermal Equilibrium Phase of a start-up. (The delta time format of the waterfall plot allows you to view the "Heat Soak" while running at a constant speed.)

Figure N.3—Waterfall Plot with Half Spectrum and x-axis Configured for Frequency

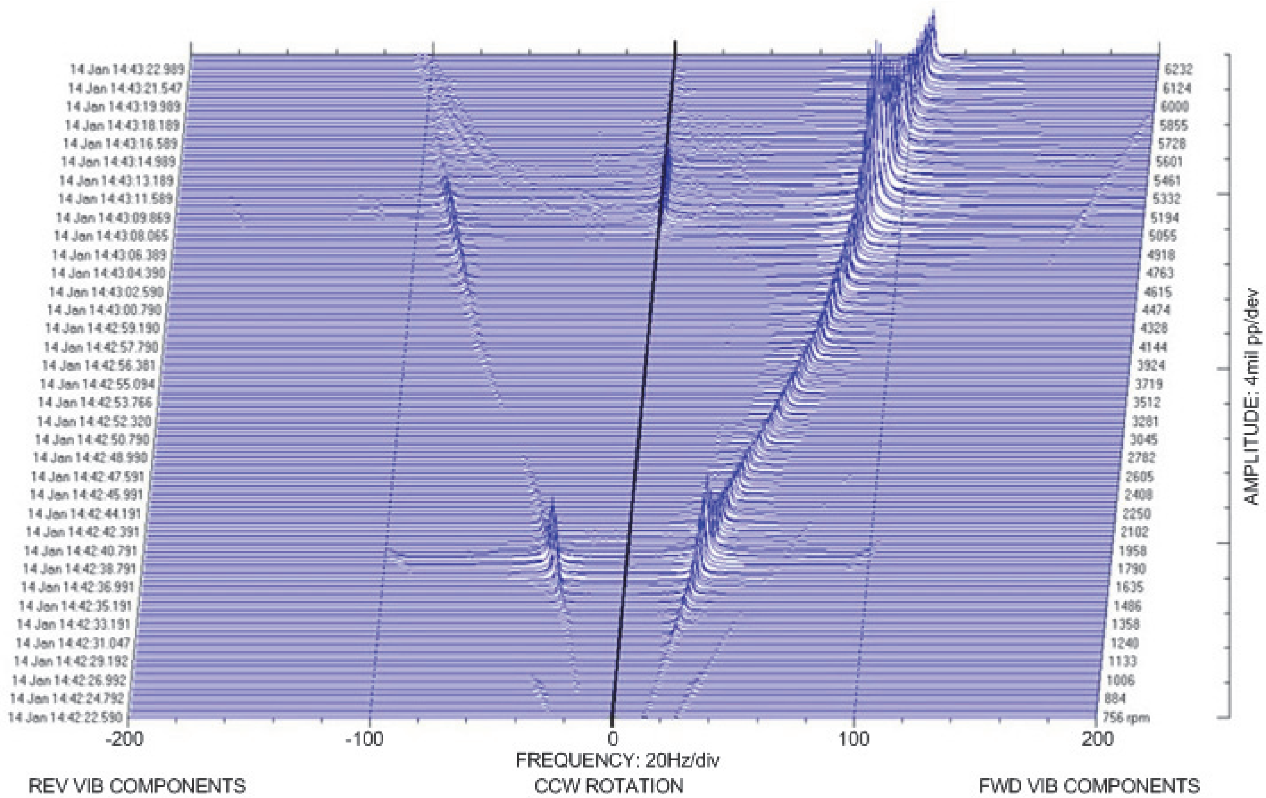


Figure N.4—Waterfall Plot with x-axis Configured for Frequency

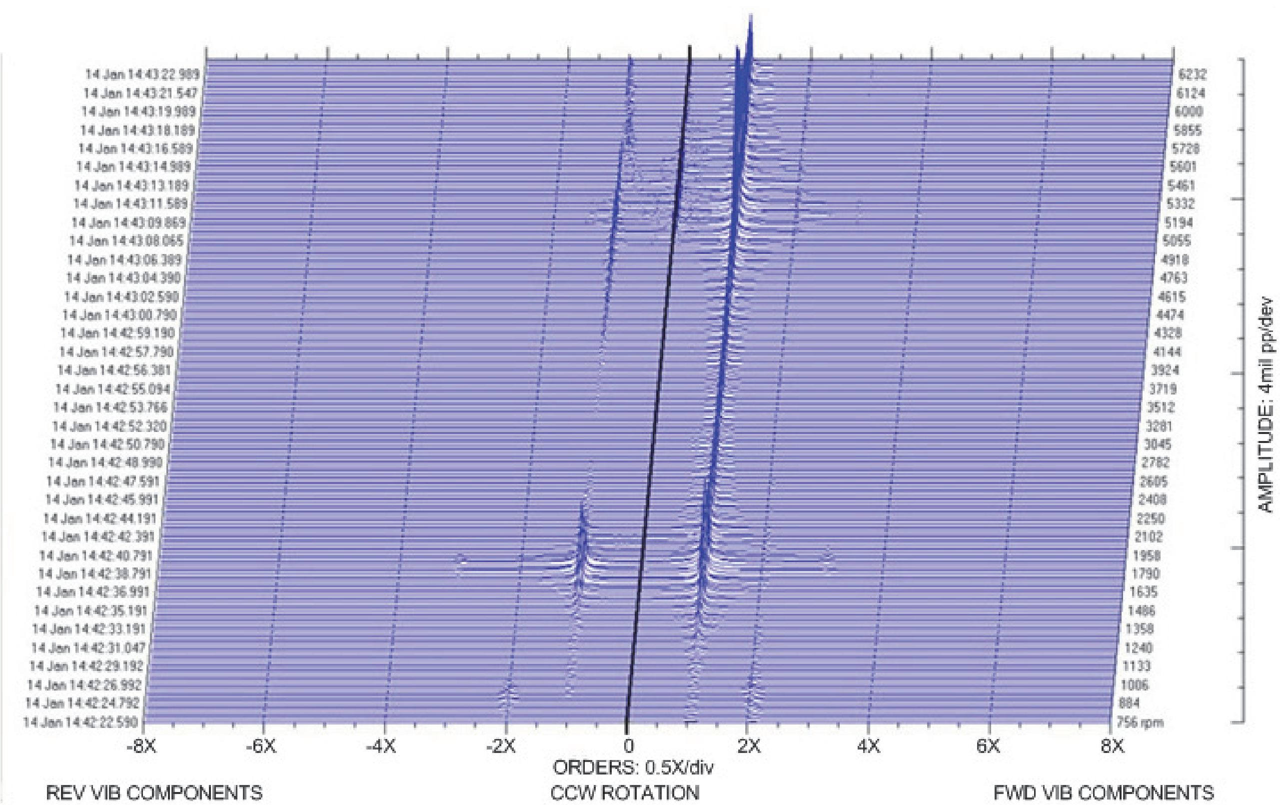


Figure N.5—Waterfall Plot with Full Spectrum and x-axis Configured for Orders

N.11 Faults

N.11.1 General

When diagnosing any fault it is recommended that the analyst ensure that all operating parameters are within the normal ranges. Something as simple as a lube oil supply temperature being out of range can change the oil viscosity and therefore cause a change in the vibration signal. Running machinery at or near a resonance frequency can cause the overall amplitude to increase drastically.

N.11.2 Unbalance

Unbalance occurs on a rotor when there is a heavy spot (see Figure N.6). This can either be caused by the addition of mass (e.g. material build-up on a fan) or by the loss of mass (e.g. tip breaks off of a fan blade). It is characterized by a strong 1X vibration in the radial direction. Because it is a radial force, the amplitude should be roughly equivalent in both the horizontal and vertical directions. If there is a large discrepancy between these values, then there is suspicion of a resonance on the machine as well.

NOTE Imbalance on an overhung rotor can also generate a strong 1X amplitude in the axial direction.

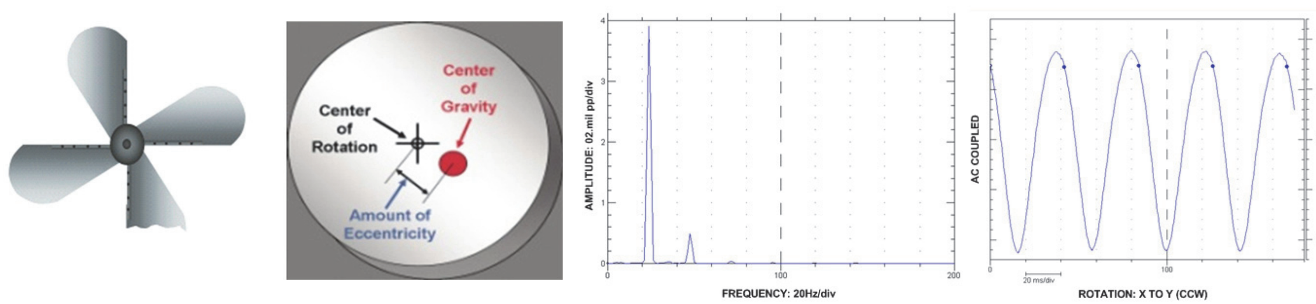


Figure N.6—Example of Broken Fan Blade Causing Unbalance Condition. Diagram Shows the Heavy Spot. The Spectrum Indicates High 1X Peak and the Waveform Resembles a Sine Wave.

N.11.3 Misalignment

Misalignment occurs when the shaft centerlines of two coupled shafts are not colinear. It can consist of an offset misalignment, Figure N.7, as well angular misalignment, Figure N.8. Offset misalignment generates a high 2X peak in the radial direction, Figure N.9, while angular misalignment generates a high 1X peak in the axial direction.

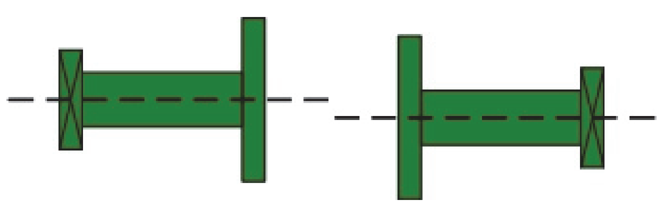


Figure N.7—Offset Misalignment

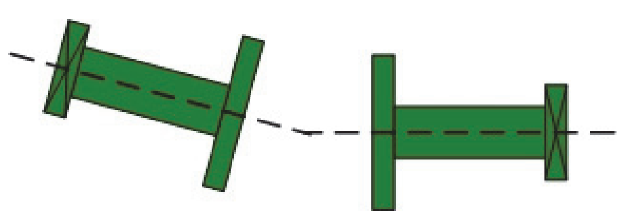


Figure N.8—Angular Misalignment

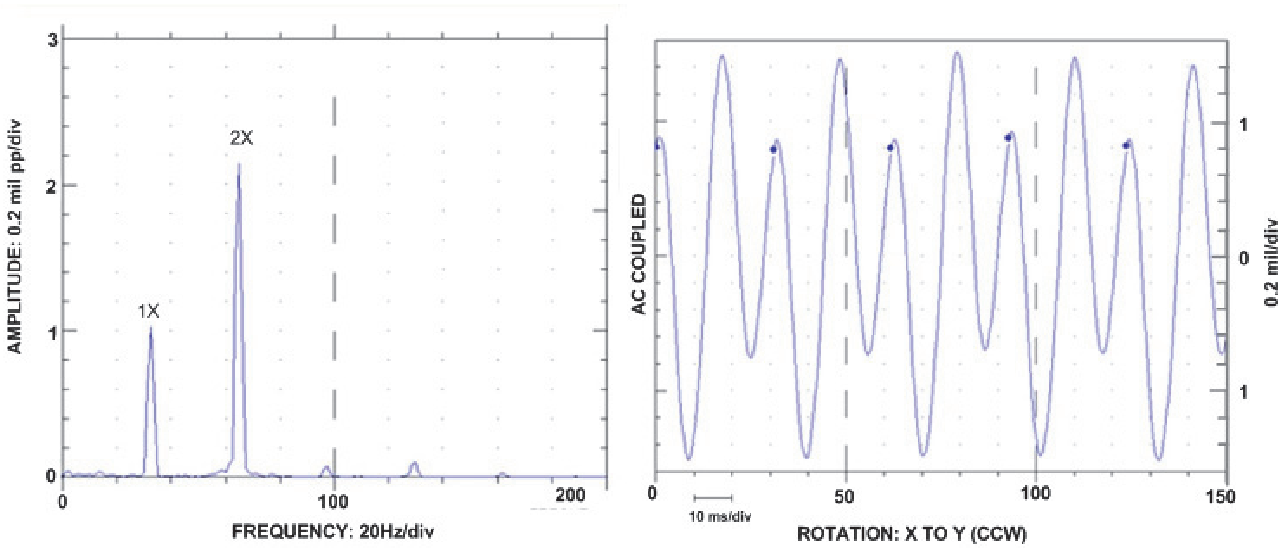


Figure N.9—Offset Misalignment Spectrum Shows 1X with Larger 2X Peak. Offset Misalignment Waveform Shows Two Peaks per Revolution.

N.11.4 Looseness

Looseness (see Figure N.10) increases on a machine whenever the clearance tolerances are exceeded (e.g. due either to wear or maladjustment) or when the supports of the machine are loose or damaged (e.g. cracked foot).

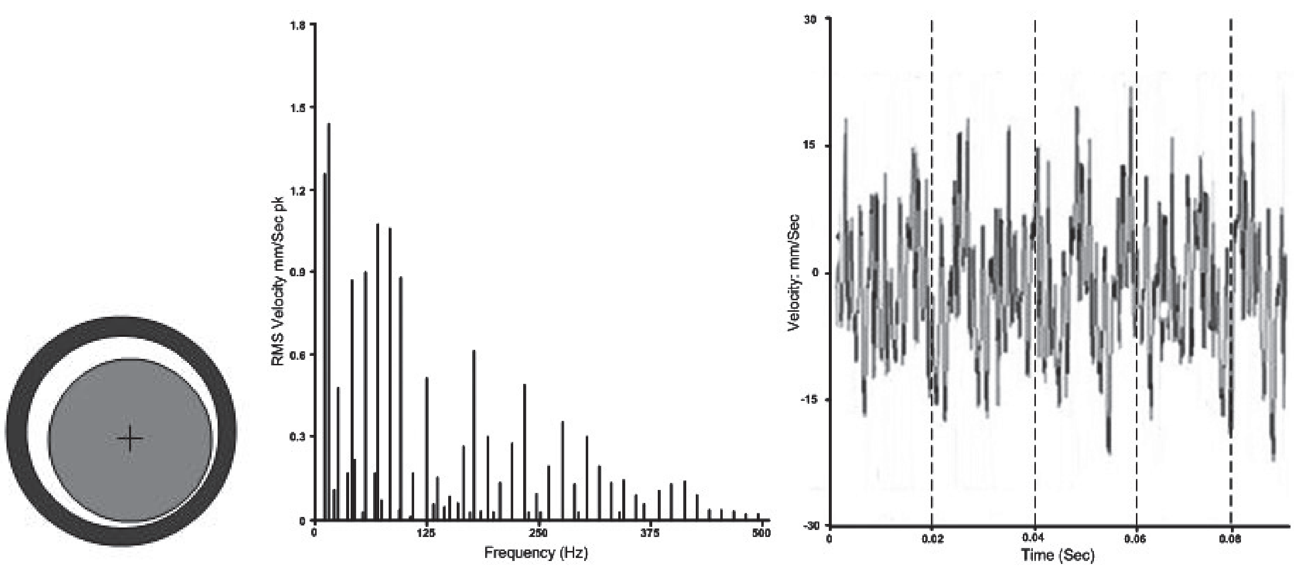


Figure N.10—Looseness Can Be Caused by Excessive Clearance in a Bearing. The Looseness Spectrum Shows Many Harmonics of 1X. Looseness Waveform Shows Random Peaks—No Pattern.

N.11.5 Rotor Rub

A rotor rub (see Figure N.11 and Figure N.12) can result because of various causes such as rotor bow or unbalance.

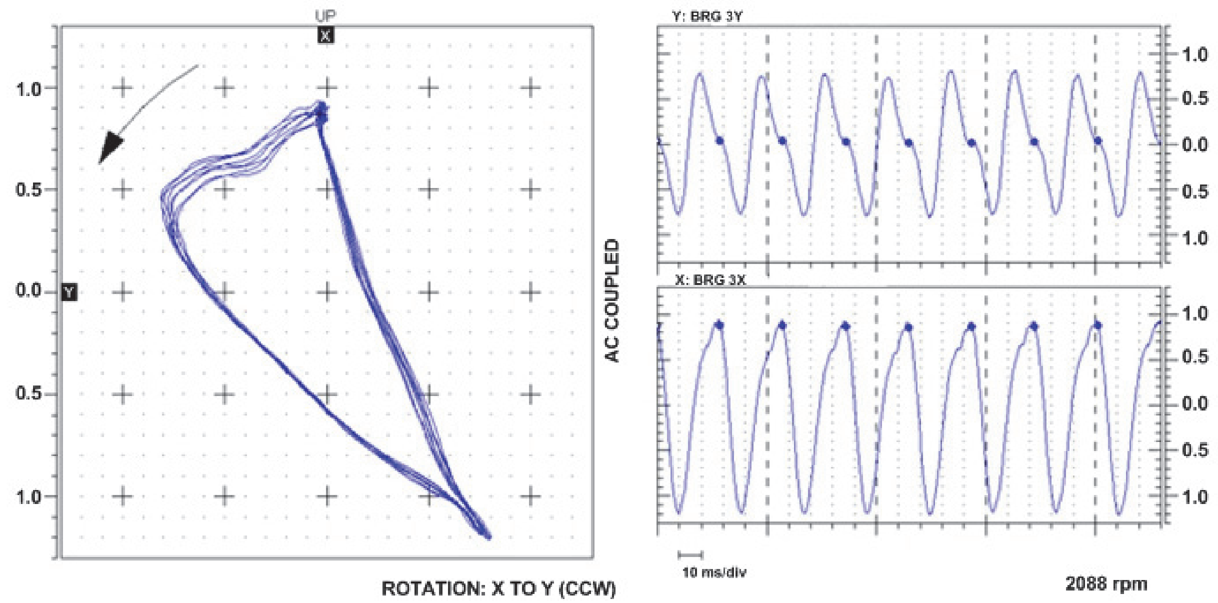


Figure N.11—Orbit and Time Waveform Plot of a Rub on a Motor

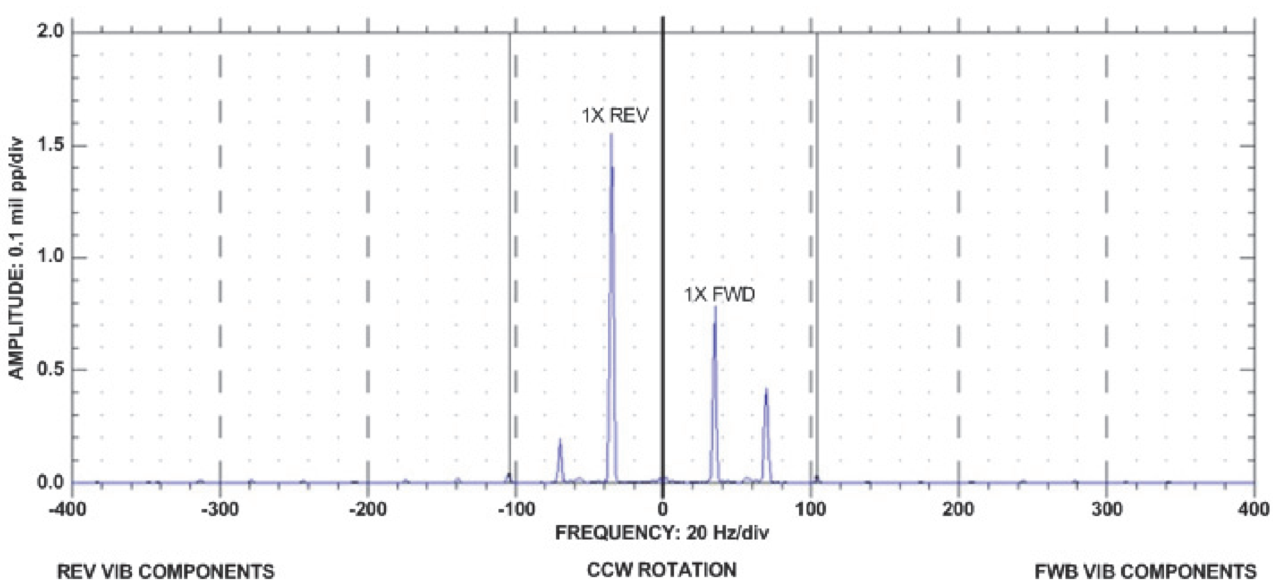


Figure N.12—Full Spectrum Plot of a Rub on a Motor

N.11.6 Antifriction Bearing

N.11.6.1 Antifriction bearings, also known as roller element bearings, generate many different fault frequencies because of their complex design. Examples of antifriction bearings are shown in Figure N.13.

N.11.6.2 Specialized techniques for rolling element bearing monitoring are available from most vendors.

Figure N.13—Antifriction Bearings

N.11.6.3 Specifically, there are four distinct fault frequencies. One associated with the cage, one with the rolling element, one with the outer race, and one with the inner race. Outer race defects are most commonly seen, although all of the defects types occur and can be identified in the vibration data. In the case of an outer race defect, as each rolling element passes over the defect, it creates an impact that literally “rings” the bearing like a bell at its characteristic resonant frequency. If the internal geometry and the turning speed of the bearing are known, it is possible to calculate the outer race frequency exactly. The following sections outline how to calculate the fault frequency for each component based the following definitions:

PD	pitch diameter; the diameter of the circle along which the centers of the balls or rollers move
BD	ball diameter
ϕ	contact angle of the balls or rollers
FTF (K)	cage frequency relative to cup or fundamental train frequency
BPFI	ball pass frequency on the inner race
BPFO	ball pass frequency on the outer race
BSF (R)	roller spin frequency or roller speed relative to cage
rpm	revolutions per minute
S	speed, revolutions per second

N.11.7 Cage Defect (FTF)

The cage frequency (see Figure N.14) is also referred to as the “fundamental train frequency,” which is where the abbreviation for this value is derived. It is calculated as follows:

$$\mathrm{FTF} = \frac{S}{2}\left(1 - \frac{\mathrm{BD}}{\mathrm{PD}}\cos\phi\right) \quad \text{(N.1)}$$

NOTE The formula shown is for a bearing with a stationary outer race. If the inner race is stationary, then it causes a change in sign.

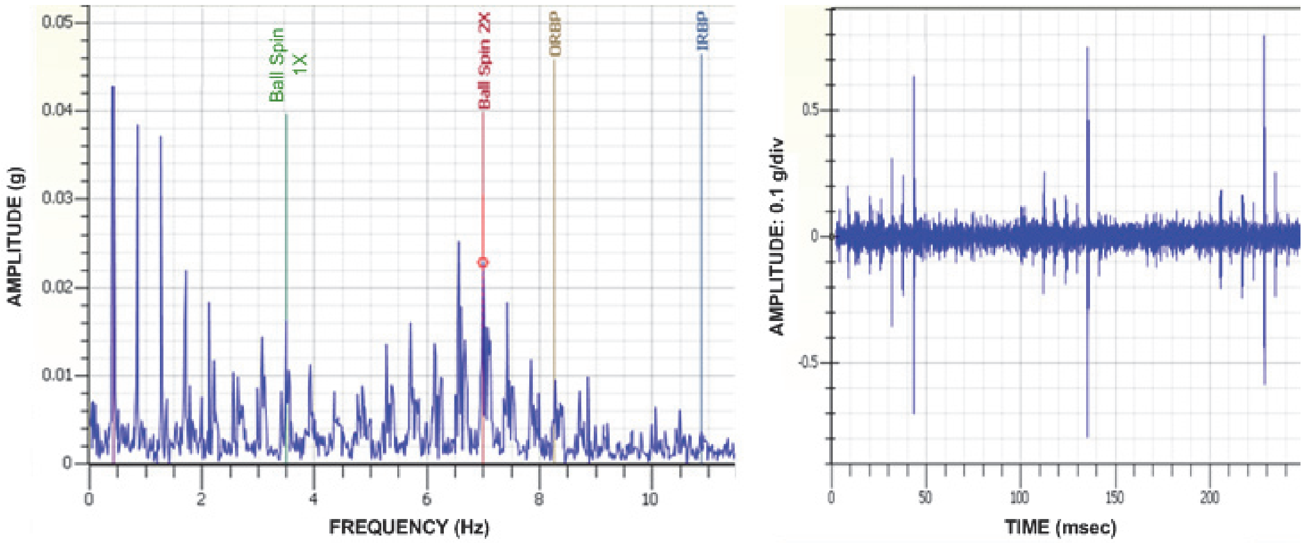


Figure N.14—Spectrum (left) Shows Cage Defect Frequency The Waveform (right) Has a Clear Impacting Pattern

N.11.8 Rolling Element Defect (BSF)

The defect frequency for the rolling element is referred to as the "ball spin frequency." It is calculated as follows:

$$\mathrm{BSF} = \frac{\mathrm{PD}}{2 \times \mathrm{BD}} S\left[1 - \left(\frac{\mathrm{BD}}{\mathrm{PD}}\right)^2 \cos^2 \phi\right] \tag{N.2}$$

N.11.9 Outer Race Defect (BPFO)

The outer race defect frequency is referred to as the "ball pass frequency on the outer race." It is one of the most common faults found because the outer race is typically stationary, and therefore the loading always occurs in the same area leading to accelerated wear. Outer race defects are typically characterized by a series of harmonics of the BPFO, which are often more dominant than the fault frequency itself. The formula for the frequency is:

$$\mathrm{BPFO} = \frac{\mathrm{NB}}{2} S\left(1 - \frac{\mathrm{BD}}{\mathrm{PD}} \cos \phi\right) \tag{N.3}$$

N.11.10 Inner Race Defect (BPFI)

N.11.10.1 The inner race defect frequency is referred to as the "ball pass frequency on the inner race." It can be difficult to detect the defect because the vibration signal shall pass through so many different materials before it reaches the casing where the sensor is placed. The high frequency signals generated by this defect type can be quickly attenuated. Special measurement techniques are frequently required to identify this defect before it leads to a machine failure. Inner race defects are typically characterized by a series of harmonics of the BPFI, which are often more dominant than the fault frequency itself. Typically, sidebands of shaft speed are present around the harmonics of the BPFI.

N.11.10.2 For most well-balanced machines, the load on a bearing is generally steady (i.e. it is constant in magnitude and acts in the same direction relative to the outer race). An inner race defect will rotate with the shaft and pass through the load zone once per revolution. While the defect is in the load zone, impact vibration at BPFI occurs as the balls pass over the defect. The result is an amplitude modulated waveform like that shown in Figure N.15. The

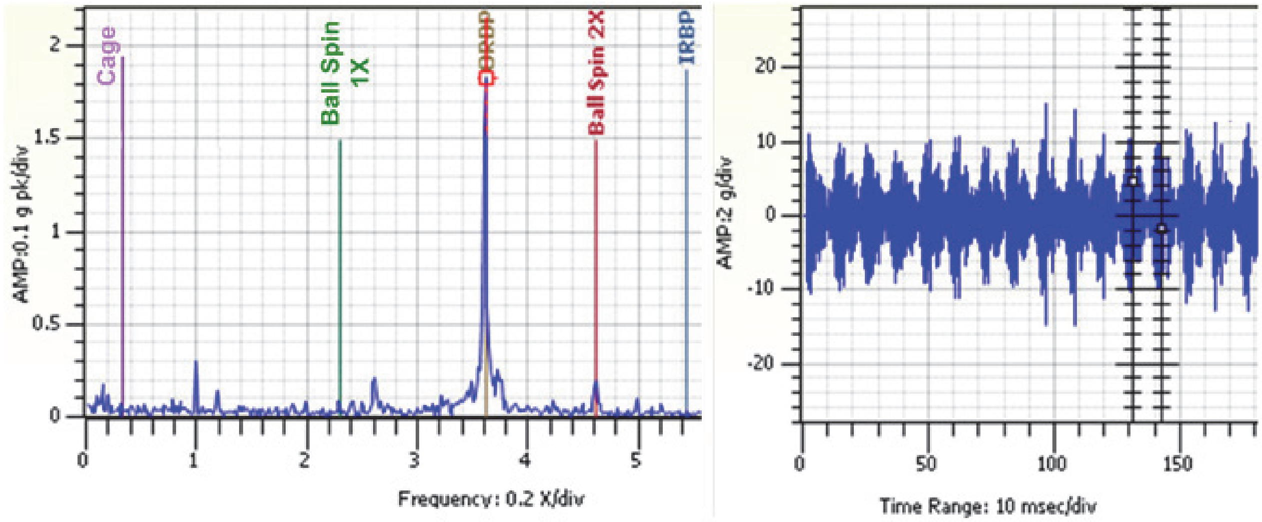


Figure N.15—Spectrum (left) Plot of Outer Race Defect Generates Spiked Peaks at Harmonics of BPFO The Waveform (right) Shows a High Number of Impacts Closely Spaced Together.

waveform appears to have “pulses” in it—short periods of high frequency vibration occurring once each revolution. As a result of the FFT process, this modulation of the bearing vibration by the running speed will produce a spectrum with running speed sidebands around the multiples of BPFI.

The formula to calculate the BPFI fault frequency is:

$$\mathrm{BPFI} = \frac{\mathrm{NB}}{2} S\left(1 + \frac{\mathrm{BD}}{\mathrm{PD}} \cos\phi\right) \quad \text{(N.4)}$$

N.11.11 Waveform Analysis

N.11.11.1 Much of the diagnostic activity involved in condition monitoring is focused on spectrum analysis (see Figure N.16). It is important, however, not to overlook the available information in the time waveform. The time waveform not only provides confirmation of the data in the spectrum but may also contain information that is not visible in the spectrum and that may be critical for an accurate and complete diagnosis. The waveform can also show instrumentation problems (such as clipping) that will result in spectrum errors.

N.11.11.2 The graphs below (see Figure N.17) show the progression of a bearing outer race defect as visible in the waveform. Putting these plots side by side using the same scaling, it is clear even to a novice that level of impacting as increased dramatically. A trend of the peak-peak waveform amplitude is shown on the far right. Notice how the amplitude returns to normal levels after bearing replacement.

N.11.12 Gear Defect

Gearboxes (see Figure N.18) are among the noisiest and most complex pieces of equipment to diagnose. Each time that a tooth on one gearwheel mates up with a tooth on the other gearwheel, it generates an impact. Given the large number of teeth on gearwheels, there can be hundreds of impacts occurring in a single shaft rotation—especially on a multistage gearbox such as the one shown below. The “gear mesh (GM)” frequency (see Figure N.19, Figure N.20, and Figure N.21)is equal to the turning speed of a shaft multiplied by the number of teeth on the gear wheel attached to that shaft. Vibration measurements will normally have high amplitude, so it is necessary to look in the spectrum (or waveform) for specific information about the nature of the vibration in order to diagnose a gear fault (see Figure N.22 and Figure N.23). The high peaks in the spectrum shown below are the 1X and 2X of the gear mesh frequency (see Figure N.19, Figure N.20, and Figure N.21).

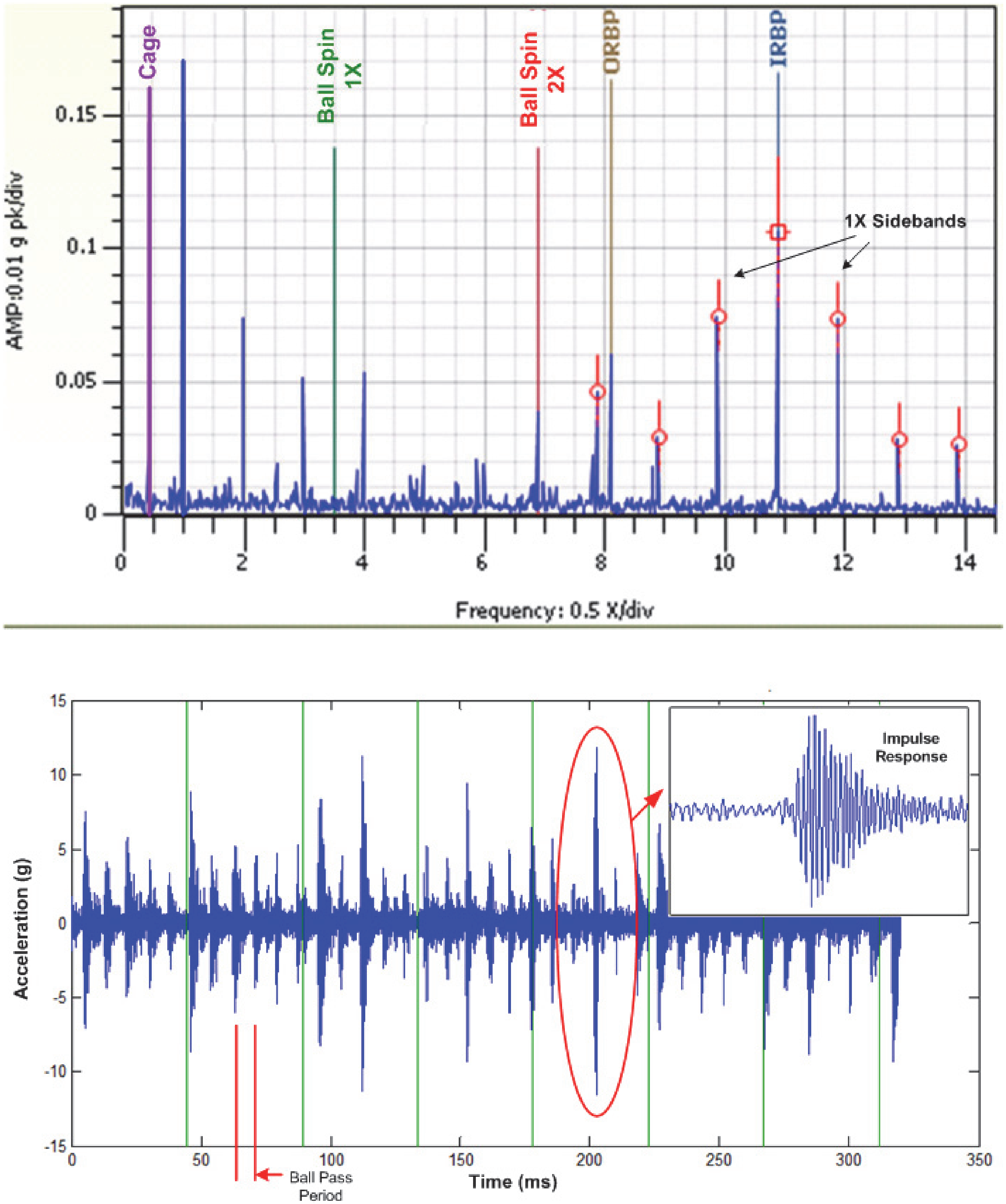


Figure N.16—The Spectrum (top) Shows High Frequency Peaks Typically Surrounded by Sidebands The Waveform (bottom) Shows Repeating Peaks with a Modulated Amplitude.

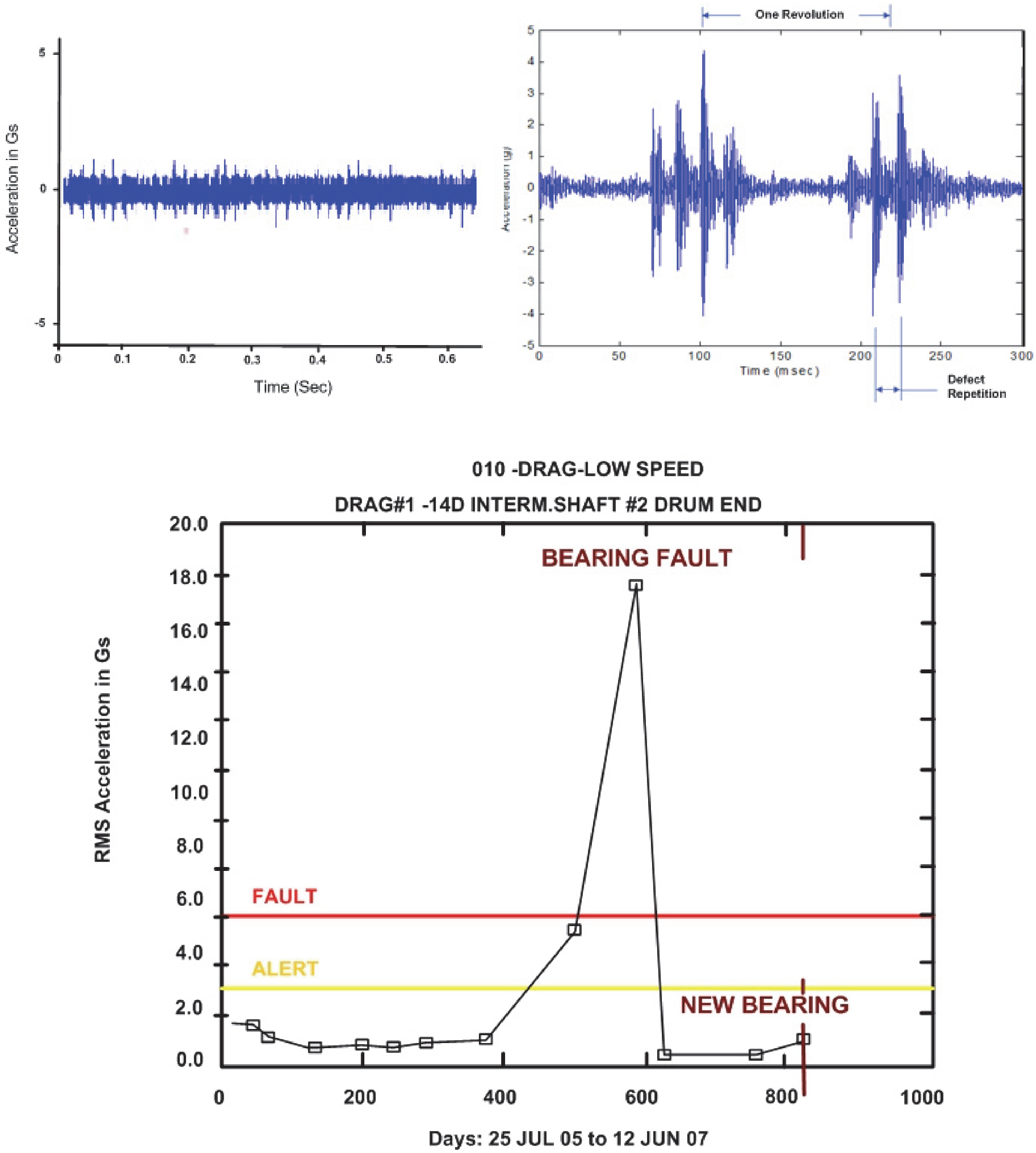


**Figure N.17—The First Waveform (upper left) is of Early Stage Defect
The Second Waveform (upper right) is of an Advanced Stage Defect
The Third Plot (bottom) is the Trend of Waveform Amplitude.**

Figure N.18—Typical Multistage Gearbox

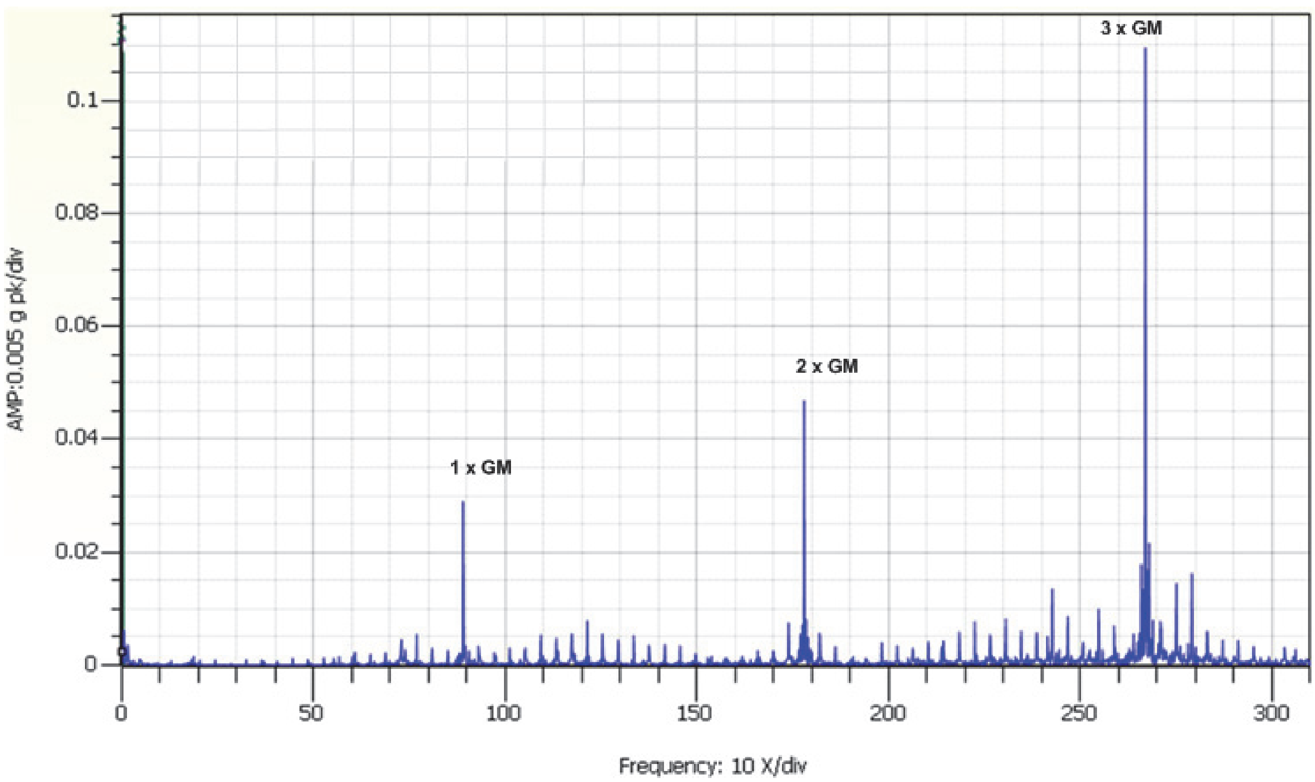


Figure N.19—Spectrum Showing 1X and 2X of Gear Mesh Frequency

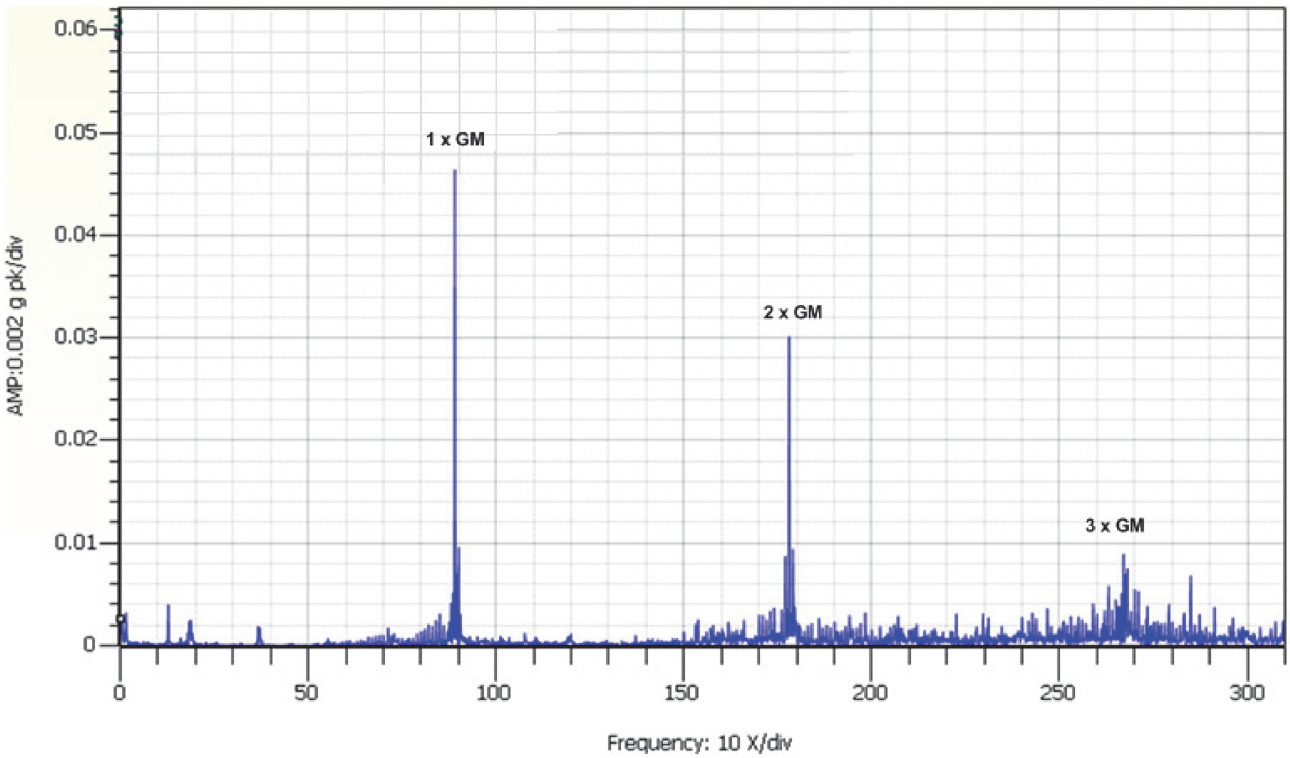


Figure N.20—Early Stage Gear Wear Showing 1X, 2X, and 3X of Gear Mesh Frequency

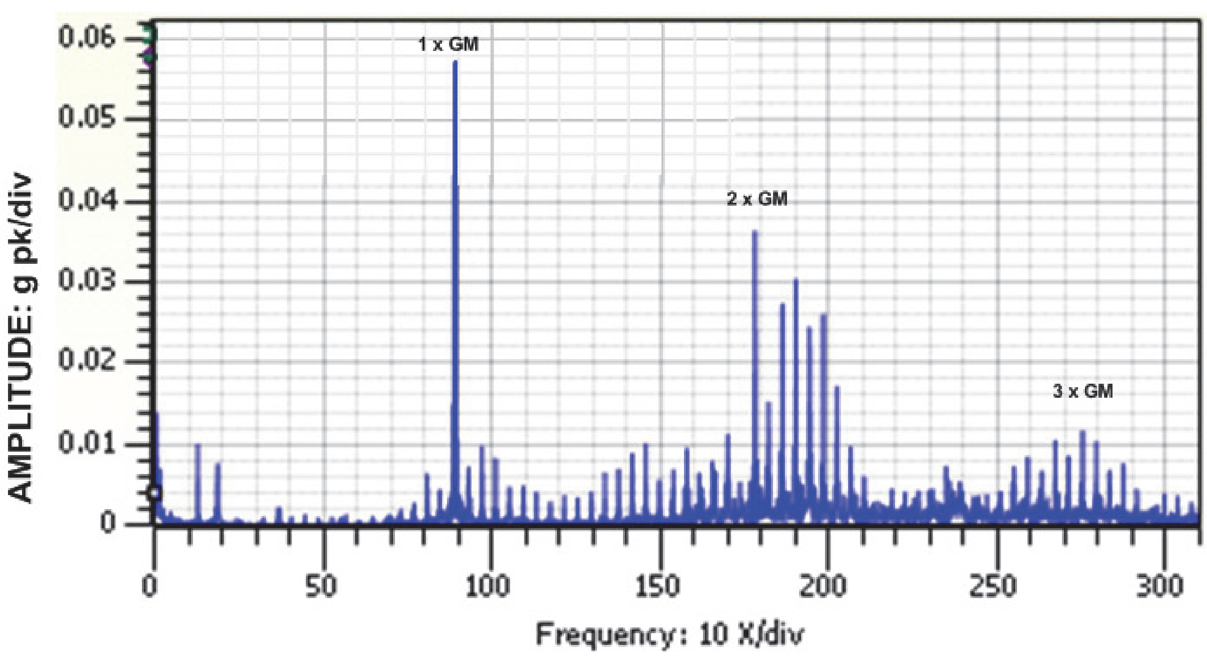


Figure N.21—Late Stage Gear Wear Showing Sidebands Around Gear Mesh

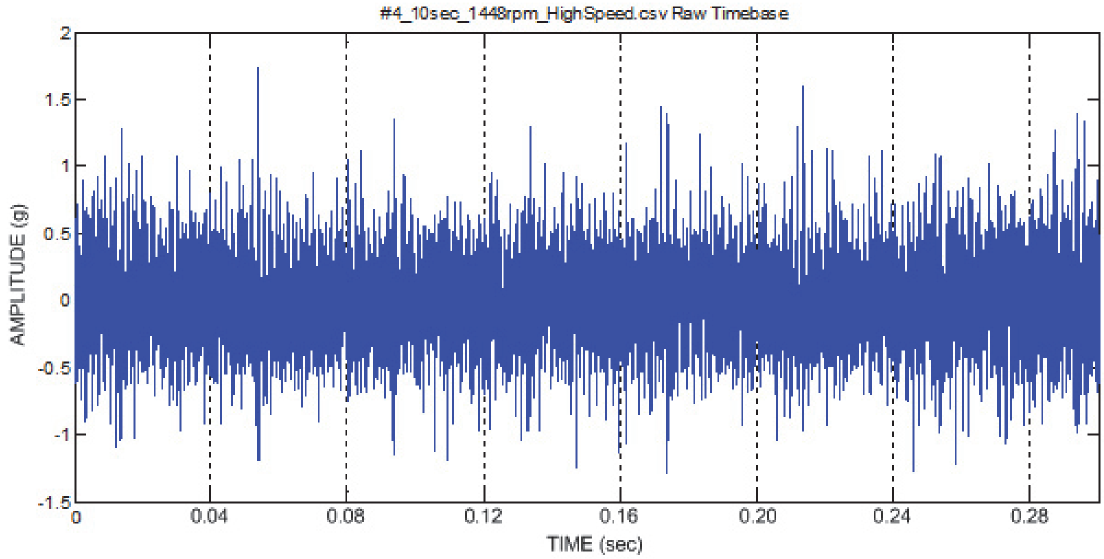


Figure N.22—Waveform Showing Amplitude Modulation of Impacts

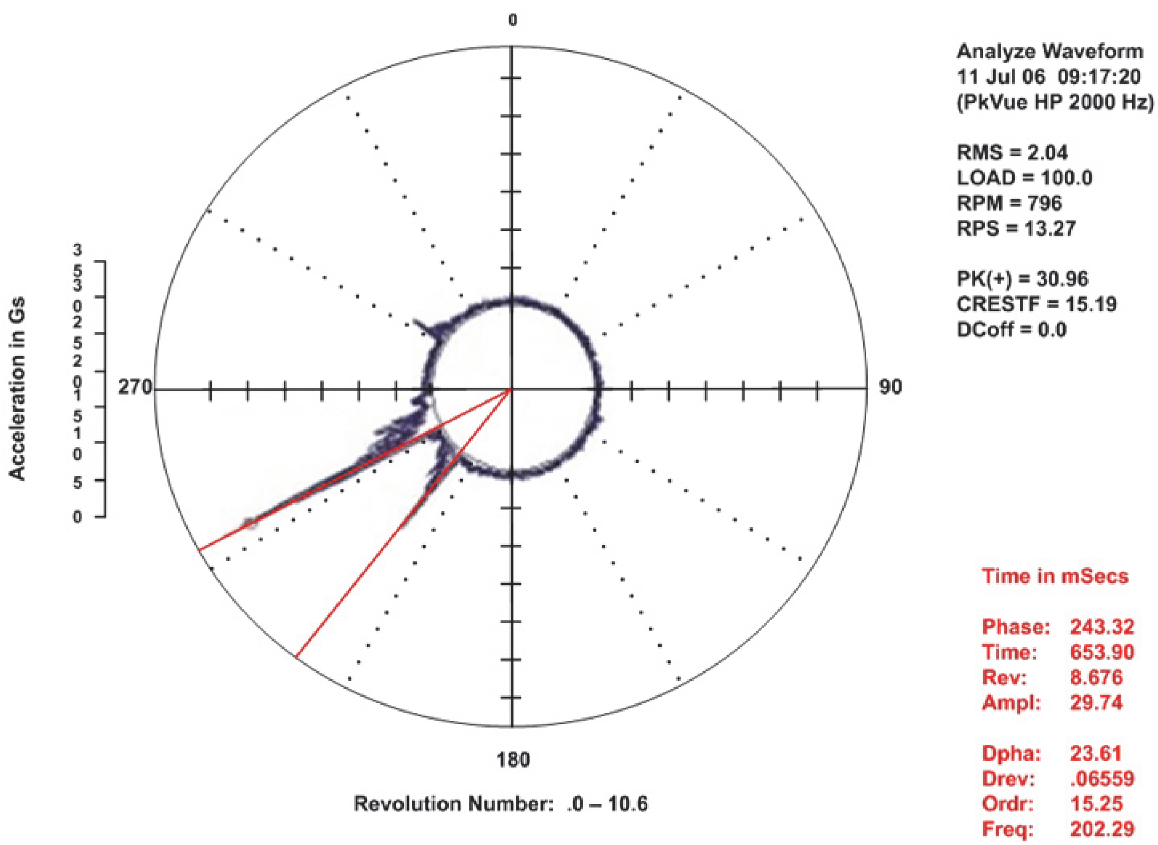


Figure N.23—Circle Plot of the Waveform Reveals the Number and Location of Broken Teeth

N.12 Fluid-induced Instabilities

N.12.1 General

N.12.1.1 Fluid-induced instabilities are caused by fluid forces acting on the rotor and can result in undesirable (often destructive) levels of vibration. Fluids may be liquids or gases. Typical source locations of fluid-induced instabilities are within the support bearings or seals. Oil lubricated bearings are designed as a hydrodynamic bearing. It forms a hydrodynamic wedge of oil that lubricates the surfaces and supports the weight of the rotor. The rotation of the rotor causes circumferential rotation of the oil within the bearing. Two boundary conditions exist. The oil wedge surface that is in contact with the shaft surface has an angular velocity equal to rotor speed. The oil wedge (see Figure N.24) surface that is in contact with the bearing surface has an angular velocity equal to zero. Therefore, the average circumferential velocity of the oil is 50 % of rotor speed. Because of viscous friction and shearing effects, the actual average circumferential velocity of the oil is less than 50 % of rotor speed (typically 35 % to 48 %). The fluid forces of the oil acting on the rotor can be categorized as two fundamental forces: a fluid film radial force and a tangential fluid film force due to rotation and circumferential velocity. A complete mathematical treatise of these forces and bearing stiffness profiles is beyond the scope of this document.

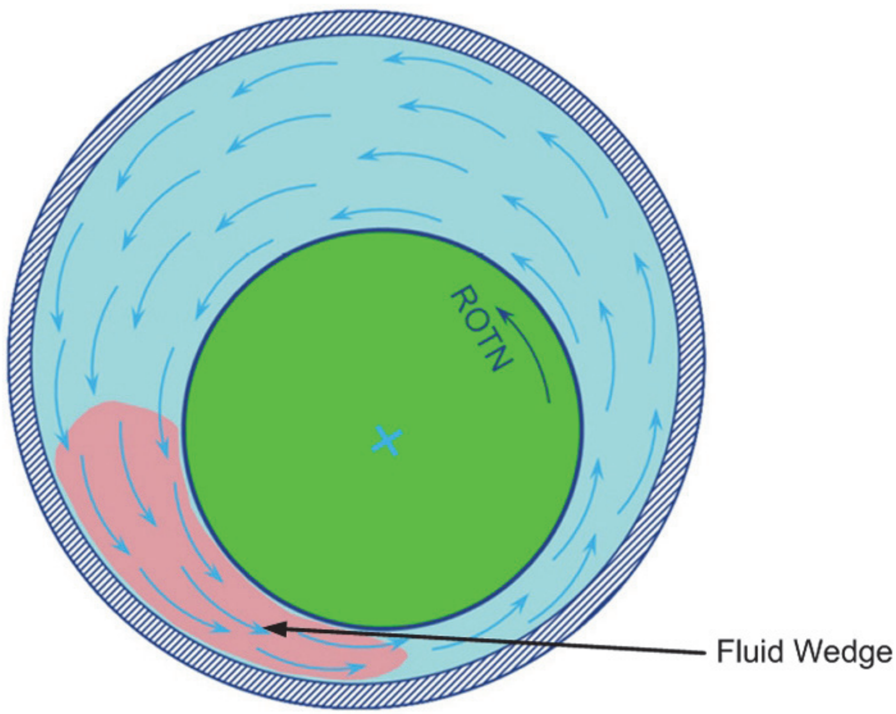


Figure N.24—Fluid Wedge Illustration

N.12.1.2 Use an orbit or orbit/timebase presentation to corroborate the existence of a fluid-induced instability.The most definitive signal characteristics of a fluid-induced instability are high amplitude, subsynchronous frequency, circular (or nearly circular) orbits with forward precession and a low eccentricity ratio.

N.12.2 Oil Whirl

N.12.2.1 Oil whirl is an instability that causes subsynchronous vibration in a journal bearing (see Figure N.25). The vibration frequency is determined by the average circumferential velocity of the oil within the hydrodynamic wedge. This typically occurs at 38 % to 48 % of rotor rotational speed. The shaft orbit will be circular and forward precession. This further differentiates fluid-induced instabilities from other malfunctions that produce subsynchronous vibrations. A significant identifier of oil whirl is that the subsynchronous vibration frequency will track the shaft rotational speed at

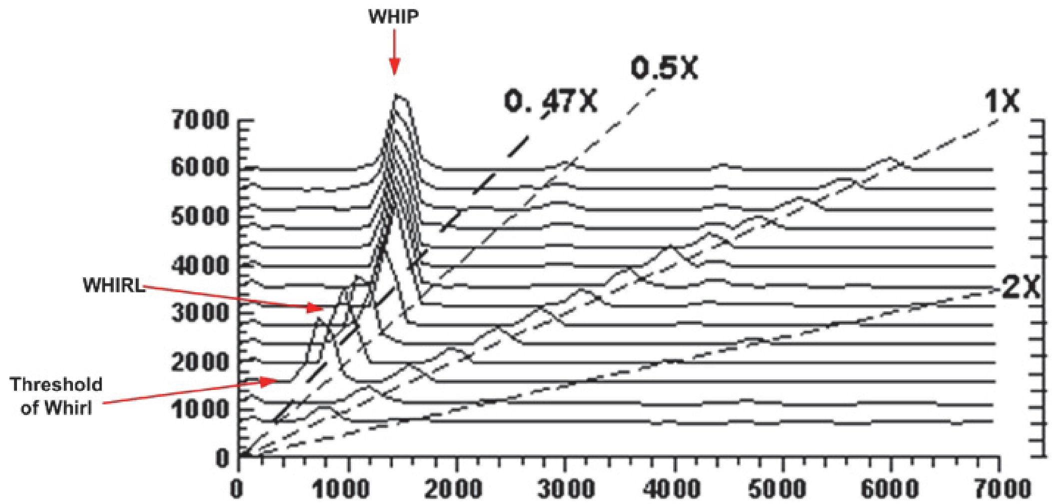


Figure N.25—Waterfall Representation of Whirl and Whip Phenomenon

a fixed percentage through changes in shaft speed. Oil whirl can be caused by numerous conditions (see Figure N.26 and Figure N.27). Some of those conditions are lightly loaded bearings or excessive bearing clearance. Bearing unloading can be induced by preload forces such as shaft misalignment. Oil damping properties are a function of the oil viscosity and temperature. Increases in damping will reduce the subsynchronous vibration levels. Often a change in the bearing design to a multilobe design, oil pressure dam design, or tilting pad bearing (in increasing order of complexity and cost) will eliminate the problem.

N.12.2.2 In this case, as with most others, the first step in resolving the instability may be to verify that all operating parameters are within the normal ranges. Something as simple as lube oil supply temperature being out of range can affect the oil viscosity and therefore cause the instability.

N.12.2.3 Figure N.28 is another case of oil whirl, displaying both an orbit and a full spectrum. All forward vibration, round orbit, large subsynch is close to $^1/_2$X (0.47X). Conventional half spectrum would only show frequency content on the right side of the spectrum plot. Frequency domain data would look very similar to a that of a rub; however, with full spectrum, you can easily see the vibration content is all forward differentiating easily from a rub condition.

N.12.3 Oil Whip

Oil whip (see Figure N.29) occurs when the oil whirl frequency coincides with the rotor natural frequency (= N_{c1}) and re-excites the rotor natural frequency. The shaft orbit will be circular with forward precession and may take up the full bearing clearance. This further differentiates fluid-induced instabilities from other malfunctions that produce subsynchronous vibrations. Typically, this only happens when N_{c1} is lower than operating speed (50 % or less of 1X). The interaction of the two resonant frequencies is known as a “self-excited system.” The oil whip frequency will remain constant at the rotor natural frequency when the rotor speed changes. This can be a very destructive vibratory force. The amplitude can quickly utilize all of the bearing clearance, and a shut down, voluntary or otherwise, is often inevitable. Similar to oil whirl, the solution to eliminate oil whip is ensuring that the bearing has the correct bearing clearances, bearing loading, and eccentricity ratio.

N.12.4 Resonance

N.12.4.1 All structures, including machinery, machine components, piping, and foundations have a series of natural (resonant) frequencies. The resonant frequency(s) of a rotor system is determined by the rotor mass (M) and the

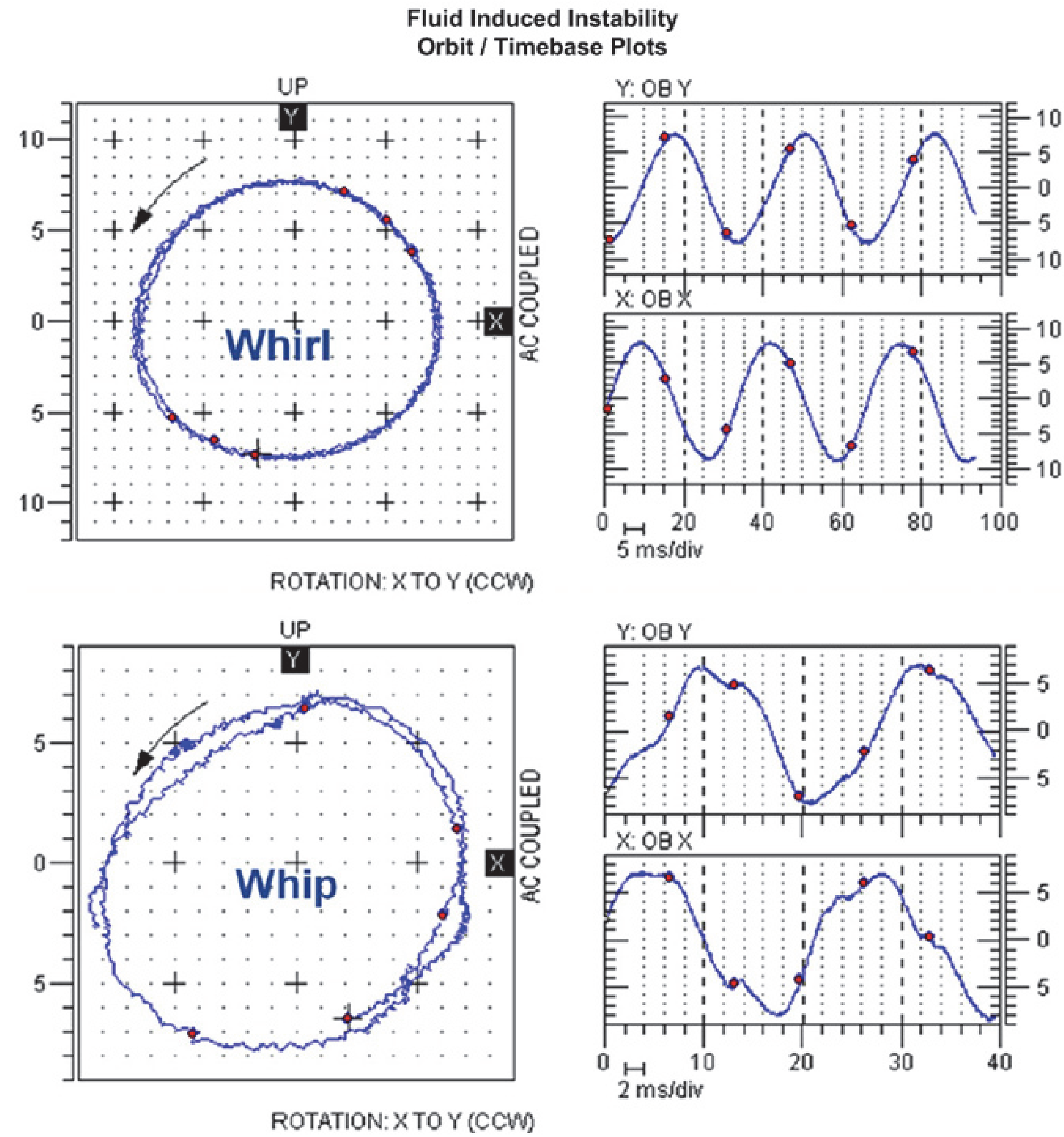


Figure N.26—Orbit and Time Waveform Representation of Whirl and Whip Phenomenon

stiffness properties of the machine elements. Total system stiffness (K) is determined by the material properties of the rotor elements and the dynamic stiffness properties of the bearings and seals.

The resonant frequency (radians per second) is defined as:

$$\omega = \left[\frac{K}{M}\right]^{0.5} \tag{N.5}$$

In terms of rpm,

$$\text{rpm} = \omega \times 9.55 \tag{N.6}$$

N.12.4.2 Forces acting on the rotor system may be impact (rubs) or periodic forces, such as mass unbalance. All rotors will have a certain amount of residual mass unbalance. Since unbalance yields a centrifugal force, the

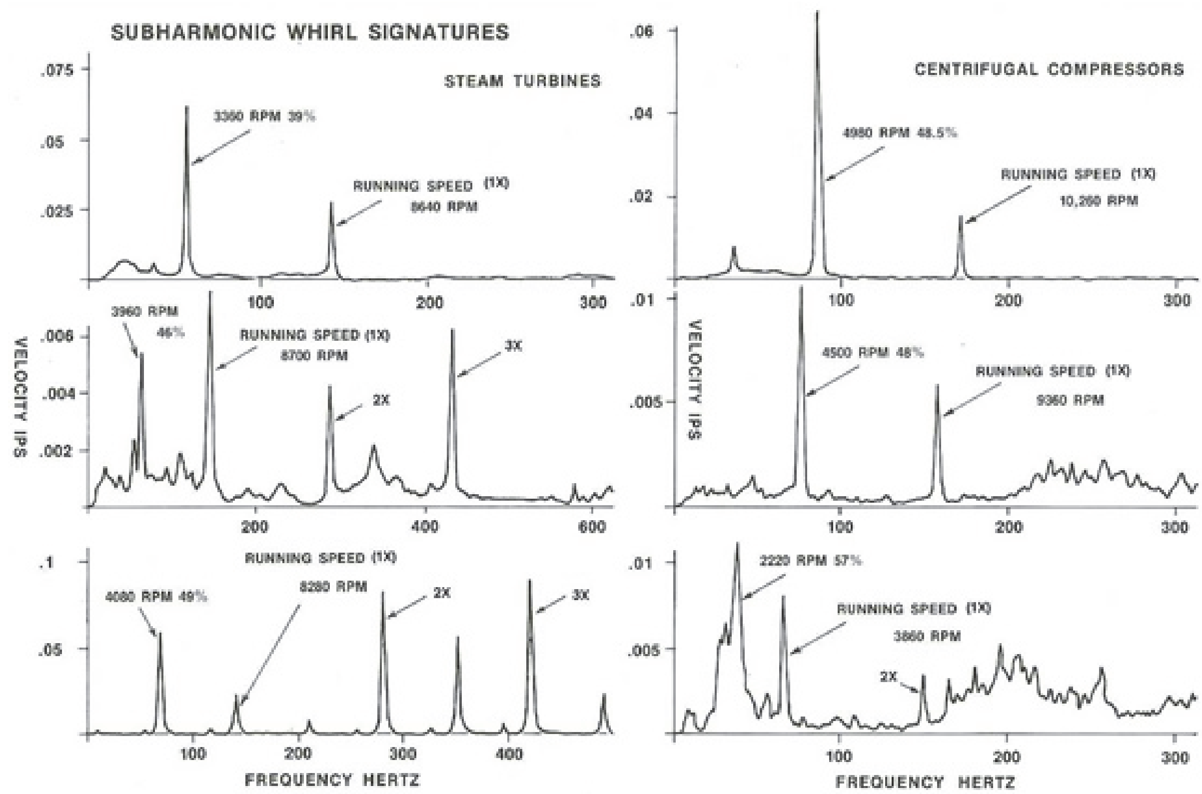


Figure N.27—Examples of Oil Whirl Frequency Spectrums

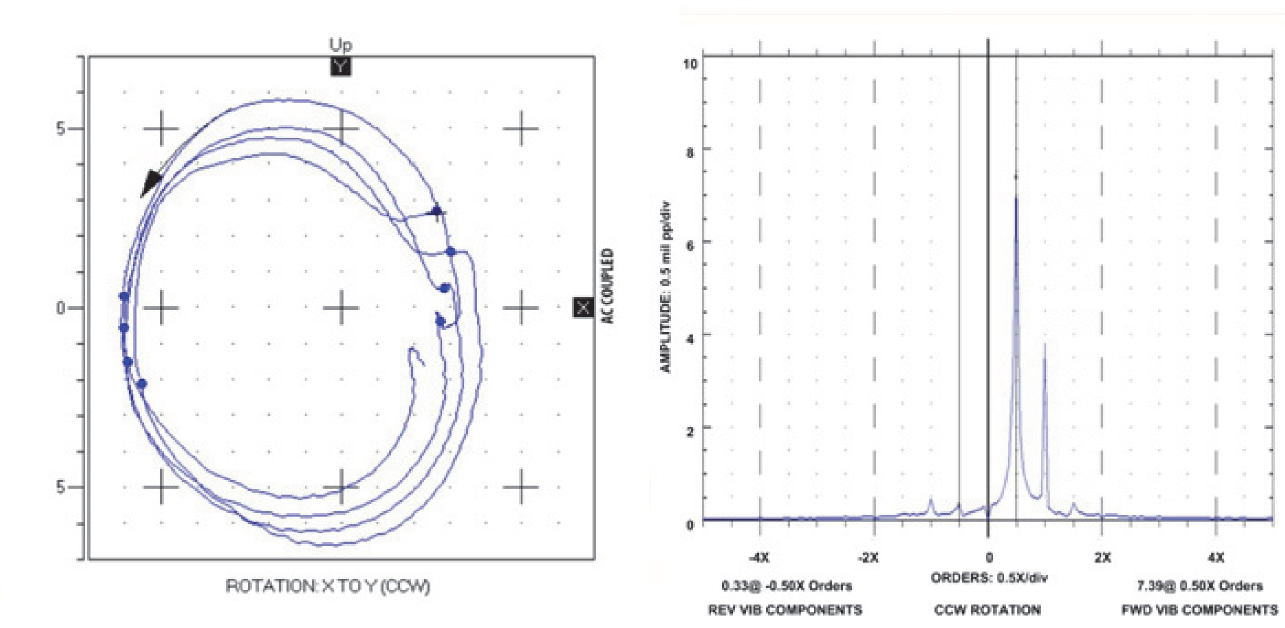


Figure N.28—Examples of Oil Whirl Orbit and Frequency Spectrum

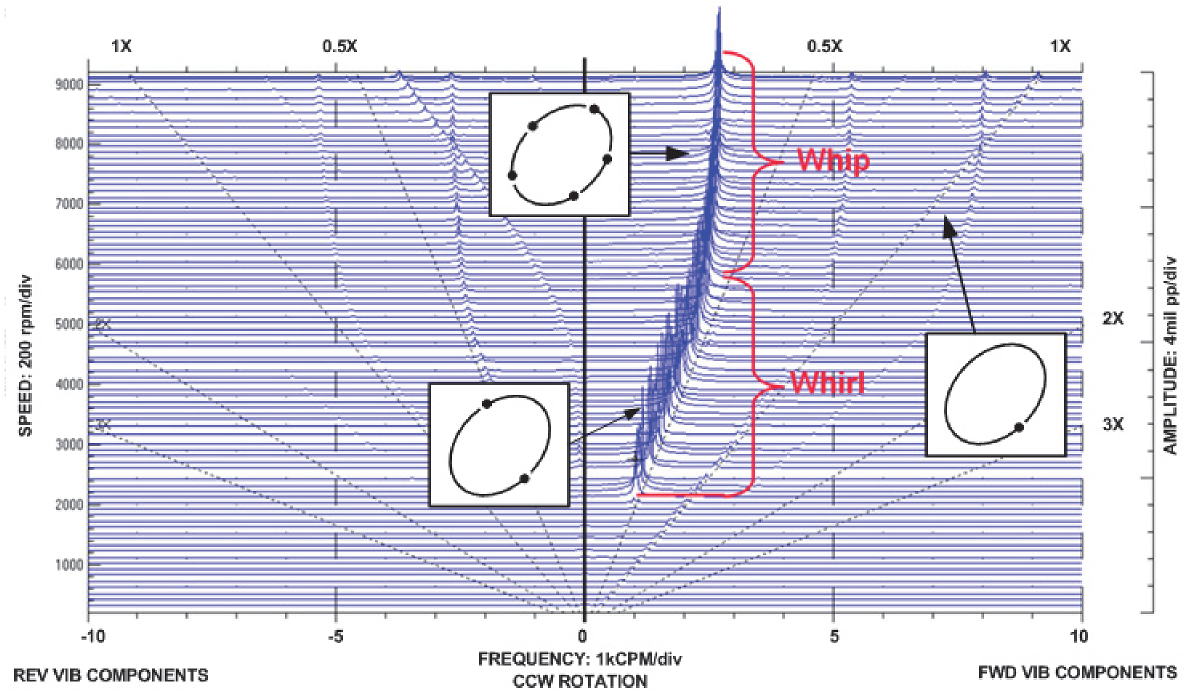


Figure N.29—Waterfall Plot with Orbits Displaying Oil Whirl and Oil Whip

frequency of the unbalance force is equal to rotor speed (1X). If the rotor speed is equal to the resonant frequency of the system, unbalance forces will excite the natural resonance. This may cause an increase in the vibration amplitude. The magnitude of the vibration level at resonance is determined by the unbalance force and the system damping properties (see API 684).

N.12.4.3 Many machines operate at speeds above the first resonance, and some machines operate above the second resonance. Therefore, during start-ups and shutdowns, the resonant frequency will be excited by the rotor speed and unbalance forces. The transient response of a machine is typically displayed as a Bode plot or polar plot.

N.12.4.4 Rotor systems are precision balanced to minimize the unbalances forces. Bearings and seals are designed to optimize their damping properties and minimize the rotor vibration levels at resonance. Poorly balanced machines or inadequate damping may allow for potentially destructive levels of vibration at the resonant frequencies

N.12.4.5 In addition, API has developed standards that define the required margin of separation of the operating speed of the machine (and harmonics) from the resonant frequencies. Review API 684 for further information.

N.12.4.6 When excitation is present at a natural frequency (see Figure N.30 and Figure N. 31), the resulting high amplitude can quickly cause fatigue failure. Turbine blade failures, caused by excitation at a natural frequency by flow discontinuities from upstream nozzles or stationary blades, have been experienced. The amplitude of the excited resonance vibration on machinery is a factor of the amount of damping. It is important to note that the excitation of a resonant frequency or critical speed of a rotor do not occur only at one frequency. It is normally more of a bell-shaped curve for the vibration amplitude around the resonance frequency. The shape of this frequency range is related to the damping and dynamic stiffness properties.

N.12.5 Pump Cavitation

N.12.5.1 Cavitation in a liquid handling pump occurs when the static pressure drops below the vapor pressure of the liquid. Vapor pockets are formed in the liquid. The vapor pressure level is determined by the specific liquid and the

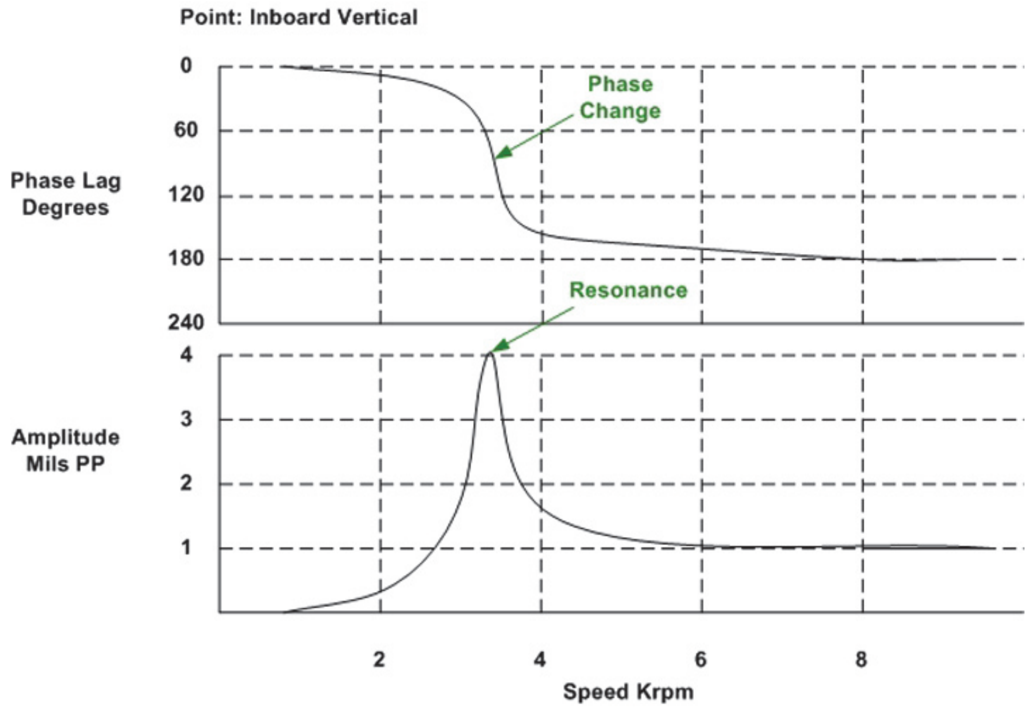


Figure N.30—Bode Plot showing Resonant Frequency

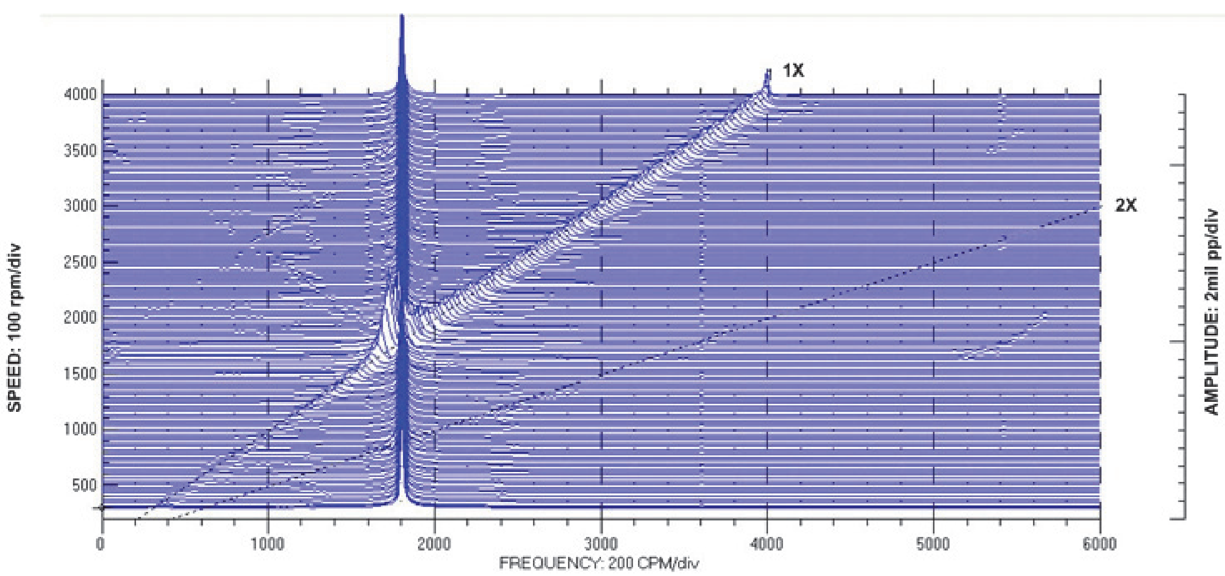


Figure N.31—Cascade Plot of a Start-up. A Structural Resonance is Present in the Data as Well as the Normal 1X Vibration. When Machine Speed Becomes Equal to the Resonant Frequency, a Large Increase in Amplitude Occurs.

liquid temperature. Therefore, pumps are designed and specified to maintain the required static pressure to eliminate cavitation occurrences. The parameter specified is the net positive suction head (NPSH3) requirement. The recent change in API 610 changed NPSH to NPSH3. The reason is that the NPSH required test determines the actual NPSH required at a 3 % head drop. Normally, curves are developed at constant flow by reducing the net positive suction head available (NPSHA) to a point where the head curves break away from that developed with sufficient NPSHA by at least 3 %.

N.12.5.2 Properly designed pumping systems, operating at their best efficiency point, will not experience cavitation events. However, pump operation at flow rates well above the design flow may experience cavitation. If vapor pockets are formed, and the static pressure increases, the vapor pockets will collapse or implode. If the vapor pockets are formed close to the impeller blading, the violent collapse of the vacuum bubbles can cause local pressure changes up to 15,000 psi, leading to contact fatigue damage to the impeller.

N.12.5.3 Cavitation can cause vibration at high frequencies (see Figure N.32). The vibration has random frequencies and amplitudes. These are grouped in a frequency range, typically from 15 to 35 times shaft speed, but may vary according to the size and volume of the pump. Cavitation is commonly referred to as sounding like the pump is pumping gravel. Many methods can be used to decrease the cavitation occurrences. These methods are typically reducing flow rates, increasing the NPSHA, or changing the product temperature.

N.12.5.4 Cavitation is caused by the implosion of vapor pockets or bubbles in the product. The vapor pockets or bubbles normally occur because of the product reaching its vapor pressure at the low pressure area at the eye of the impeller. The increased pressure created as the product travels through the impeller causes the vapor bubbles to implode. This violent collapse of the vapor bubbles can cause fatigue damage to the impeller, casing, housing, and fixed internal guide vanes. If very small vapor pockets are formed, the time rate of implosion is very rapid and very high frequency vibration (10 kHz to 12 kHz) can be detected. It is not uncommon to see impellers that have multiple holes caused by the cavitation.

N.12.5.5 Since the vibration caused by cavitation is random in frequency and amplitude, it will appear as “noise” in the spectrum. Using high-resolution spectra or a large number of averages will reduce the noise present in the spectra and can hide the noise associated with cavitation. When cavitation is suspected, it is often useful to view spectral data “real time” without spectral averaging, using only 200 or 400 lines of resolution (see Figure N.33).

N.12.6 AC Electric Motor Faults

N.12.6.1 Stator defects will generate a high vibration at 2X line frequency. They do not necessarily generate pole pass frequency sidebands since they originate within the stator and are not modulated by either running speed or slip frequency. Stator faults include stator eccentricity (uneven stationary air gap), shorted laminations, or loose iron. High frequency resolution should be employed to differentiate between running speed harmonics and 2X line frequency.

N.12.6.2 An eccentric rotor defect (uneven rotating air gap) will generate a high vibration at 2X line frequency accompanied by sidebands spaced at pole pass frequencies (F_p = number of poles times slip frequency).

N.12.6.3 Rotor bar defects (broken or cracked rotor bars) will generate pole pass frequency sidebands around the 1X running speed. Indications of pole pass frequency sidebands could also be present at higher running speed harmonics (2X, 3X, and 4X rpm).

N.13 Continuously Scanned Vibration Data System Recommendations

N.13.1 Introduction

The purpose of this section is to present recommendations for a digital analysis system for vibration data analysis and display. The listed data acquisition capability, used to perform the necessary analysis, is reflective of a computer-based digital analysis system. Some of the support functions (signal conditioning, filtering, etc.) can be done with analog equipment.

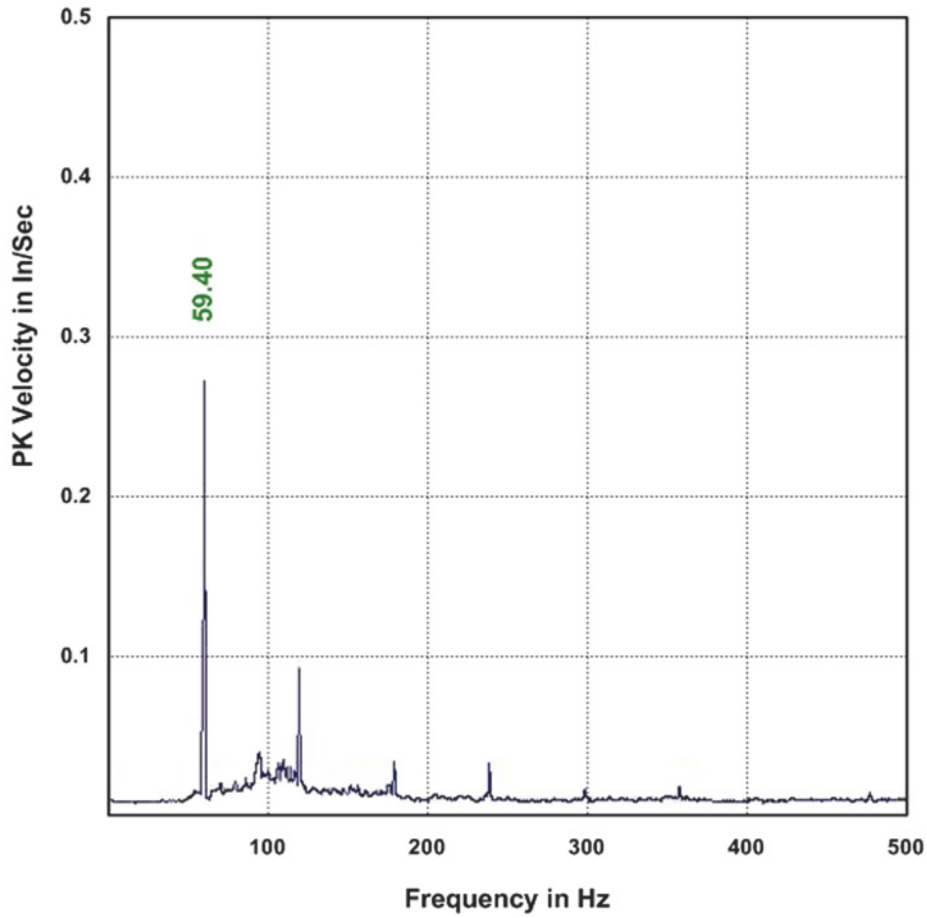


Figure N.32—Frequency Spectrum of Cavitation Fault

N.13.2 Data Acquisition for Dynamic Signals

N.13.2.1 Data acquisition refers to the process of digitally sampling an analog dynamic signal. The system needs to be able to support data acquisition for each of the data collection modes described in this section. The following data acquisition specifications are recommended to provide suitable data for the analysis functions listed.

N.13.2.2 General recommendations are as follows:

a) over range detection/indication is useful;

b) A/D as required to meet the accuracy requirements, typically a minimum of 16-bit for new equipment;

c) dynamic range—minimum 80 dB (typical);

d) magnitude accuracy—<0.1 % of full-scale range.

N.13.2.3 Spectra sampling requirements are as follows.

a) *Resolution*—The resolution of the spectrum increases with the number of spectral lines used. This means the more spectral lines, the more information the spectrum contains. However, if more spectral lines are used, it takes longer to measure and more memory is used to store the spectrum. High resolution measurements are

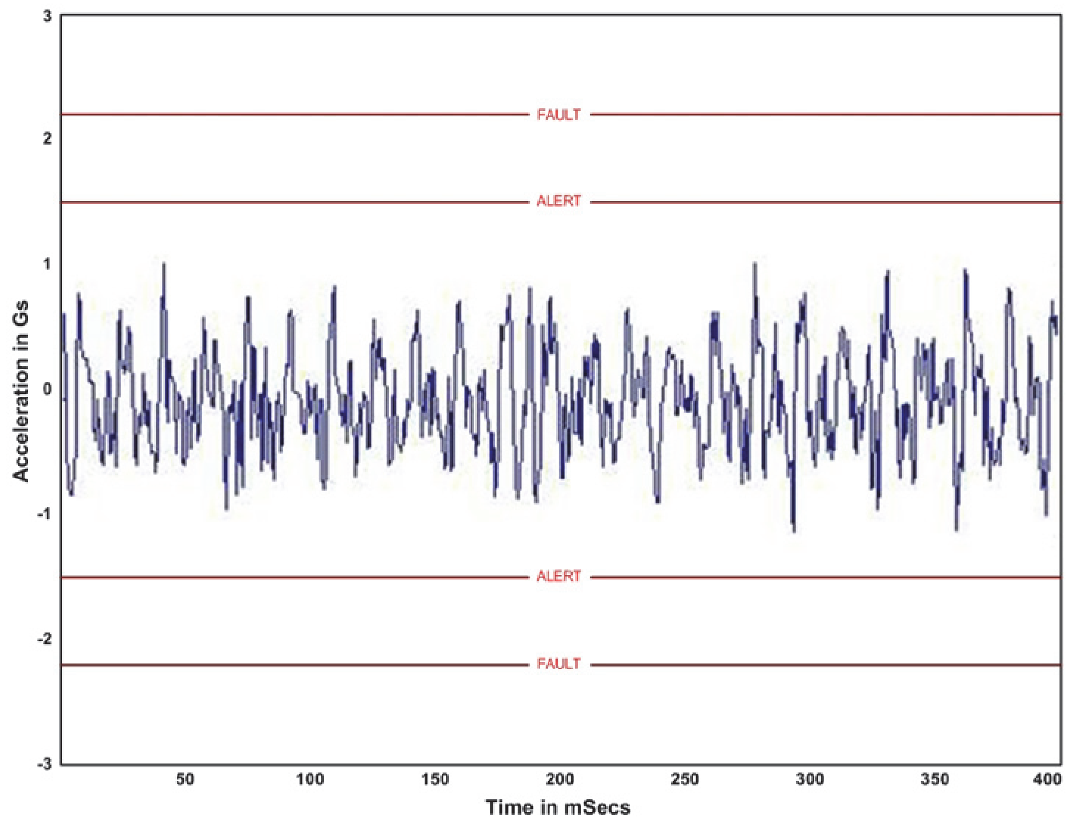


Figure N.33—Time Waveform of Cavitation Fault

appropriate for applications when it is necessary to distinguish between two closely spaced vibration frequencies (i.e. motor slip frequencies) or when the F_{max} is very large. For coast-up, coastdown recordings, a setting of 400 spectral lines is typically adequate. Additionally, a minimum of 800 spectral lines or higher is recommended for spectra measurements.

b) *Frequency Range* (F_{max})—F_{max} is the maximum frequency displayed on the spectrum. Or more specifically the frequency range, starting from zero, over which vibration amplitudes are displayed. In general, the higher the operating speed of a machine, the higher the F_{max} needs to be to capture all crucial information.

c) Runout compensation for synchronously sampled data should be provided.

d) F_{max} for proximity probes is typically set at 5 to 10 times shaft speed to provide good resolution of data for detection of common shaft related problems like unbalance, misalignment, excessive bearing clearance, oil whirl, oil whip, etc. In certain cases, it may be useful to display higher orders to detect high frequency phenomena like high-energy vane passage frequency in a pump or gear mesh frequencies in a gear unit.

N.13.2.4 Proximity probe systems have bandwidth capability in excess of 5 kHz and are capable of providing data in higher frequency regions when malfunction energy levels are high. It should be noted that vibration displacement amplitudes in these higher frequency regions tend to be low. Setting a high F_{max} on all points to ensure capturing high frequency problems on a few points has the effect of the frequency content for common shaft related problems "crowding" the left corner in the spectrum. This can result in difficulties detecting and diagnosing such lower frequency problems.

N.13.2.5 *Hanning Window*—Waveform data is processed by FFT to create a spectral plot. To prevent the spectral lines from bleeding into each other, the data is usually modified by a Hanning window function.

N.13.2.6 *Anti-aliasing Filters*—Aliasing is an effect that results in erroneous measurements when the frequency of the signal being sampled is more than 0.5 times the sampling rate. An anti-aliasing filter is recommended to eliminate these errors except in situations where the presence of an anti-alias filter would produce significant phase distortion at the frequencies of interest.

N.13.2.7 *Averaging*—Recommended method for standard vibration measurements is linear averaging with six averages.

N.13.2.8 Averaging is used to remove noise from a measurement. However, there are two types of noise to consider.

a) *Mechanical Noise*—This is actual measured "noise" where the vibration is caused by nonrepetitive (asynchronous) events such as steam or fluid flow or pressure oscillations. Users may or may not want to observe noise from these sources.

b) *Electrical Noise*—This is noise added to the system by the various electronic components. Its contribution to the measurement is quantified by the system's full-scale dynamic range (dBfs). In general, the greater the dBfs the less "unreal" noise is added to the system.

N.13.2.9 When vibration data is measured, several spectra are usually measured and then averaged to produce an average spectrum. The averaging process minimizes the effect of random variations or noise spikes that are inherent to vibration signals. The larger the number of spectra used for averaging, the more noise spikes in vibration signals are reduced, and the more accurately true spectral peaks are represented. However, the larger the number of averages, the more data needs to be collected, and therefore the longer it takes to obtain the average spectrum.

a) *Linear Averaging*—Six averages are recommended to remove random vibration without excessively prolonging data collection time. Linear averaging takes a straight average of a predefined number of samples (e.g. adding together six measurements and then dividing by six).

b) *Exponential Averaging*—Exponential averaging is done continuously, and it gives additional weight to the most recent events while continuously diminishing the impact of older measurements. It is recommended for situations where the machine condition is changing gradually.

c) *Peak Hold Averaging*—Peak hold averaging retains the highest—or peak—value measured for each frequency. This technique is frequently applied where the machine state is rapidly changing, such as a start-up or coastdown.

d) *Negative Averaging*—Negative averaging is a special technique that can be used to isolate vibration from a specific source by subtracting one measurement from another. It is frequently used when there are multiple machines with identical turning speeds to determine which one is the source of a fault vibration. It can also be applied to check the resonant frequency of a machine while the machine is in operation.

N.13.2.10 *Overlap*—Data overlap allows for faster data collection and is consistent with adequate data averaging. Data overlap controls the amount (%) that each new average overlaps the previous average when taking a measurement. This decreases the time required to collect data.

N.13.2.11 Overlapping data is a means of reusing a percentage of previously measured data to generate a new spectrum. The higher the overlap percentage, the less newly acquired data is needed to generate a spectrum and thus the faster the spectrum can be collected. This value ranges from 0 % (no overlap) to 99 %. The advantage of a higher amount of data overlap is the speed at which spectral data can be generated by the system. This should be balanced by the fact that too high of data overlap can cause "smearing" of the data. Also, a high percentage of data overlap lessens the impact of the filtering done by data averaging.

N.13.2.12 Typical data overlap is 50 %, 66 %, or 75 %, but it can vary based on the user's needs and the architecture of the system.

N.13.2.13 *Sample Rate*—For standard vibration measurements, the sample rate is automatically determined through the selection of the frequency range and the resolution.

N.13.2.14 *Peak Impact Detection*—Gearbox and rolling element bearing faults generate characteristic impact signals that are frequently not visible in a typical FFT measurement. Instead of using a typical FFT measurement, other parameters such as enveloping may be used to analyze the fault.

N.14 Waveform Sampling Recommendations

N.14.1 The system should be capable of both synchronous and asynchronous sampling.

N.14.2 Synchronous sampling should have the following:

a) at least 100 sample points per revolution at full speed;

b) at least 8 revolution sample length;

c) no anti-aliasing filters;

d) X and Y probes simultaneously sampled with phase reference;

e) option to time synchronous average waveforms with at least 16 averages unless system does not need averaging;

f) band-pass filtering available for $^1/_2$X, 1X, 2X, and 3X shaft speed and low-pass filtering with corners available for 1X, 2X, and 3X shaft speed. Caution should be taken to ensure no unwanted phase shifting of the data, as shifting can be caused by filters;

g) full spectrum plots presenting forward and reverse components are valuable, this presents orbit shape and component relationship in the frequency domain.

N.14.3 Asynchronous sampling should have at least 2048 sample points (block size).

N.15 System Accuracy and Calibration

N.15.1 With respect to accuracy the system is comprised of three main components: the transducer system, the measurement system, and the computer system. The accuracy of the transducer system and measurement system should be considered together, while the accuracy of the monitoring system should be considered separately.

N.15.2 Because the monitoring system is a digital device, consideration of its accuracy is a very different problem from that of the sensors and measurement systems. Accuracy in digital systems is a function of the method of data representation, specifically the format of the data stored, such as integer or floating point. The monitoring system should not degrade the accuracy of the data acquired from the transducer and measurement system such that the resulting accuracy is less than as specified in Table 1.

N.15.3 Several different floating point representations (formats) have evolved over the years. However, the most common format is defined by the IEEE 754-1985 standard. To minimize the complexity of moving data between systems the monitoring system should use the IEEE 754-1985 format.

N.15.4 Absolute phase accuracy should be quantified for both steady state and transient shaft speed. Phase accuracy should be known over the range of operating speeds from low to high.

N.16 Data Analysis and Display

N.16.1 General

As a minimum the following analysis and display functions should be provided.

N.16.2 General Recommendations

The following are general recommendations.

a) Cursor readout ability for all plots.

b) Manual and auto scaling for all plots.

N.16.3 Amplitude and Phase Recommendations

The following are amplitude and phrase recommendations.

a) Overall amplitudes should be measured and expressed as acceleration, velocity, or displacement.

b) As a minimum, users should monitor and trend the overall magnitude and the 1X and 2X magnitude values.

c) If a reference is available then the 1X and 2X phase values should also be monitored and trended.

d) Monitor and trend other values as appropriate for the machine.

N.16.4 Alarm Capabilities Recommendations

N.16.4.1 While it is not necessary to alarm in the machinery protection system on every value measured, it is often desirable to alarm on such measurement in the CMS. The alarms in the CMS and resulting actions desired should be considered and documented prior to installation. In most cases the vendor, vendor's representative, machine OEM, the facility or corporate predictive maintenance personnel, or other knowledgeable persons with respect to machinery monitoring techniques and the selected monitoring system should be consulted to assist in the proper definition of the alarms.

N.16.4.2 At minimum the analysis system should provide the following alarming capabilities.

a) Two level alarms with the following operators:

   i) greater than,

   ii) less than,

   iii) inside range,

   iv) outside range.

b) Acceptance region alarms for vector measurements.

c) Rate of change alarms.

d) Alarms should be assignable to any measured value.

e) Alarm annunciation capabilities should include:

  i) on-screen indication,

  ii) audible indication,

  iii) automatic reporting,

  iv) remote notification via email or other communication.

N.16.4.3 Frequency Domain Analysis

The following minimum frequency domain plotting capabilities should be provided:

a) frequency spectra in which linear amplitudes, accelerations, velocities, or displacements are plotted versus linear frequency expressed as cycles per second (Hz), cpm, or orders;

b) waterfall plots with at least 50 spectra plotted versus time;

c) cascade plots with at least 50 spectra plotted versus speed.

N.16.4.4 Time Waveform Analysis

The following minimum time domain plotting capabilities should be provided:

a) time waveform plots of unfiltered data;

b) time waveform plots of time synchronous averaged data;

c) orbit plots of unfiltered data;

d) orbit plots of synchronous (1X, 2X) or running speed data;

e) time synchronous averaged orbit plots;

f) runout compensation capabilities for synchronously sampled data (i.e. slow-roll compensation, thermal bow, etc.).

N.16.4.5 Critical Speed Analysis

When monitoring turbo machinery operating above the machine's first critical speed the following minimum transient data plotting capabilities should be provided:

a) Bode plot for speed-transient data;

b) polar plots for speed-transient data;

c) shaft centerline plots, polar plot of shaft centerline position within bearing;

d) gap voltage plots.

N.16.4.6 Trend Analysis

The system should be able to display any measured parameter as a function of time in a Cartesian plot.

N.17 Data Storage

N.17.1 Basic Data Storage for Normal Operation

N.17.1.1 For an online system, data being monitored should be captured and stored on an exception basis, for example whenever an alarm condition occurs or when the parameter value changes by more than a pre-defined amount. There should also be an option to store data on a time basis, for example, once per hour, once per day, once per week. Stored data should be retained in the database for at least 24 months. Vibration-related data should include, when available:

a) overall amplitude,

b) running speed amplitude and phase,

c) twice-running speed amplitude and phase,

d) gap voltage, and

e) speed.

N.17.1.2 Additional measures that are key condition or fault indicators for each specific machine should also be saved. Non-vibration-related data should include bearing temperatures, flows, and pressures.

N.17.2 Detailed Data Storage for Normal Operation

The system should provide storage of the following data at a minimal interval of at least once per day:

a) time waveforms with phase reference,

b) time synchronous waveforms,

c) averaged spectra (eight averages).

N.17.3 Data Storage for Start-up/Coastdown

When monitoring turbo machinery operating above the machine's first critical speed the system should collect and store the vibration-related data as specified in N.19.3 on coastdown and start-up at a rate of every 50 rpm or less. Additionally, one set of data, as specified in N.19.4.4 should be obtained once the machine has reached operating speed.

N.17.4 Data Storage for Known Machine Problem

The system should provide the capability to change the interval for the data collected in N.19.3 and N.19.4.4 for start-up or troubled machine monitoring.

N.17.5 Monitoring and Data Storage, Online Systems

N.17.5.1 Definition

Data storage and monitoring should be separate functions. If machine monitoring is separate from data storage, it is possible to more thoroughly monitor a machine while minimizing data storage by storing data only when exceptions occur. Storage of data should be possible both on exception and on a user-defined time basis.

N.17.5.2 Static Values

It is recommended that monitoring of static values such as overall vibration, DC gap voltage, thrust, and temperature should be at least once per second. Storage should be both by exception and on a user-defined time basis.

N.17.5.3 Dynamic Data

Dynamic data such as waveform and spectral data for long-term condition monitoring and maintenance planning should be monitored at least once per hour. Storage of waveform and spectral data should be possible both on exception and on a time basis. In addition the system should be capable of performing analysis on the waveform and spectrum such as energy in a frequency range, nX energy, nonsynchronous energy, waveform shape analysis, relative synchronous harmonics for the purpose of automatic analysis of user specified analysis types and automatic alarming on these analysis types. Dynamic data collection configuration should be capable of being tailored for process conditions. That is, analysis should be adaptable depending on machine speed, or other events.

N.17.5.4 Transient

N.17.5.4.1 When monitoring turbo machinery operating above the machine's first critical speed, the monitoring system should provide transient data capture and analysis capabilities. At minimum, the system should provide the following capabilities. For transient monitoring, it should be possible to monitor and store data across all monitored channels continuously during machine start-up and coastdown.

N.17.5.4.2 *Transient Data Extraction*—When transient data is captured in a field device a capability should be provided for the user to execute an "on-demand" upload of any stored data. Users should also be able to schedule periodic interrogation of the device with subsequent automatic upload of data.

N.17.5.4.3 *Transient Data Archive*—Transient stored data should be capable of being archived and used as reference data. For example, recall transient archived waveform, drag and drop on live or stored waveform for plot comparison.

N.17.5.4.4 *Transient Data Viewing*—Transient data that has been archived should be capable of being viewed for the purpose of reviewing a start-up, coastdown or anomaly that occurred during normal production state operation. Transient data that is archived should be capable of being displayed in the plots described in N.17.5.5.

N.17.5.5 Continuous Display of Dynamic Signals

N.17.5.5.1 Online systems should be capable of live or near real-time mode, displaying the following plots with typical refresh rate of at least once per second at 3000 rpm and above. Live mode shall not impact normal data collection, data storage, or transient data capture. The plots are as follows:

a) waveform,

b) spectrum,

c) orbit,

d) shaft centerline,

e) cascade,

f) waterfall,

g) Nyquist,

h) Bode.

N.17.5.5.2 Plot options should include filtering orbits and Bode plots, setting offset and specifying clearance for shaft centerline, defining acceptance regions on Nyquist plots, waveform runout subtraction and vector runout subtraction shall be capable of being stored, recalled and applied to plots.

N.17.5.6 Portable Analyzers

For a portable system, it should be capable of displaying the following plots from the manually collected data:

a) waveform,

b) spectrum,

c) orbit.

N.17.5.7 Storage and Printing

The system should be capable of printing the display on demand or saving the display data to disk.

N.17.6 Remote Access

N.17.6.1 Remote access can mean different things to different people and as such needs to be clarified for all parties to have a full understanding.

N.17.6.2 Remote connectivity can come from either a company Intranet or directly from the Internet. The important difference is where the security layer is located.

N.17.6.3 With a company Intranet, the trusted employee typically already has access to their local area network (LAN) and Intranet and only needs to be able to access the condition monitoring platform from within its secure confines. Monitoring systems are typically already connected to the company LAN, so no special wiring and connections are required. Access rights for the employee are the same regardless of whether they are logged in from their office, their home, or from a hotel room or conference room half a world away. Consultants, equipment OEMs, and others are typically excluded from this type access in order to protect company proprietary information, but this presents a barrier when sharing data in order to resolve equipment concerns.

N.17.6.4 Access to a condition monitoring platform directly from the Internet poses additional security and connection challenges but allows access to anyone with the proper logons and security passwords. This type system offers more flexibility but often at a higher cost.

N.17.6.5 Most modern monitoring systems include capabilities for remotely accessing the system to perform system maintenance, to adjust monitoring parameters, and to review data. As such capabilities can significantly improve the usability, and therefore value, of a monitoring system, they should be provided whenever possible.

N.17.6.6 Users should coordinate with the facilities or corporate information technologies (IT) departments (or equivalent) to insure the following.

a) The added data traffic will not adversely affect the performance of the facility or corporate networks. This is particularly important when sharing networks used for plant or machine control. Note that the system vendor should be able to help estimate the network load that the system could add for any given configuration.

b) The security of the system, facility, and corporation is not compromised. Appropriate systems and safeguards should be put in place to insure against unauthorized access to the system.

N.17.6.7 Access to the system should be protected to ensure that only authorized users have access. In addition the system should provide levels of access that allow different users different levels of access, such as “view only” or “administrator.”

N.18 Portable Vibration Data System Recommendations

N.18.1 Introduction

N.18.1.1 While an online system is recognized as the most effective method for condition monitoring, the cost of implementation may not always be justifiable. In these situations, it is still possible to provide a significant level of added diagnostic capability with a portable vibration analyzer.

N.18.1.2 Even for machines that are instrumented with an online system, the portable analyzer can still serve as a separate monitoring system to ensure that problems with the machine are not missed because of deficiencies in the installed monitoring system.

N.18.2 Analyzer Specifications

A portable analyzer should be capable of collecting predefined measurements (e.g. route data) as well as data that can be defined by the end user in the field. It should feature a large enough display for the end user to be able to review the data in the field and identify characteristics of the vibration spectrum and/or waveform.

N.18.3 Standard Measurement Capabilities

The standard measurement capabilities of the portable analyzer should match those outlined for online systems.

N.18.4 Extended Resolution

For detailed analysis, the ability to collect a spectrum with up to 12,800 lines of resolution or zoom is recommended for the portable analyzer. The objective is to have sufficient resolution (Hertz/line) to clearly separate frequency content that may be very close together. Zoom allows enhanced resolution just in the frequency ranges needed without adversely impacting data collection.

N.18.5 Extended F_{max}

For analysis of gearboxes, it is recommended to have an analyzer that can measure up to 4X the gear mesh frequency.

N.18.6 Extended Time Waveform

The portable analyzer should be capable of collecting and storing an extended time waveform with an F_{max} of 2000 Hz and a duration of at least 60 minutes to capture data from transient events such as start-up, coastdown, or process induced vibrations.

N.18.7 Extended Diagnostics

The portable analyzer should be capable of performing cross channel measurements such as cross channel phase, coherence, and the frequency transfer function.

N.18.8 Portable Data Collector Sensor Mounting Recommendations

The following are portable data collector sensor mounting recommendations (see Table N.3 and Figure N.34).

a) Keep magnet bottom (feet) clean to avoid rocking and insufficient contact with the machine surface.

b) Use caution when mounting hand held probes on magnets because of possible cantilever action.

c) Use as light a weight of cable as feasible. The heavier and stiffer the cable, the greater likelihood of cantilever action.

Table N.3—Probe Mount Frequency Ranges

Linear Response Summary	
Sensor Mounting Mechanism	**Linear Range [a]** Hz
Handheld	550
Two pole magnet	1100
Two pole magnet with coupling fluid	3325
Quick connect (1/4 turn)	2550
Rare earth magnet with mounting pad	1600
Rare earth magnet with mounting pad and coupling fluid	5000

[a] Using a 5 kHz response range accelerometer (±10 %).

N.18.9 Route Measurements

The portable analyzer should support route measurements that have been predefined using a companion software. Sections N.18.1.10 to N.18.1.21 pertain to the analyzer being operated in route mode.

N.18.10 Trend Parameters

The portable analyzer working should support the definition of trend parameters (e.g. fixed frequency band, variable frequency band) such that the value of each trend parameter is collected and store each time the point is measured. This data can then be uploaded to the companion software for trending and analysis.

N.18.11 Support for Variable Speed Equipment

The portable analyzer should have the ability to measure and record the shaft speed during or directly prior to the time of the vibration measurement. Furthermore, it should be able to adjust collection parameters as well as trend parameter definitions based on the measured shaft speed.

N.18.12 Support for Variable Load Equipment

The portable analyzer should have the ability to measure and/or record the load on the machine during or directly prior to the time of the vibration measurement.

N.18.13 Multipoint Measurements

The portable analyzer should support the ability to initiate multiple measurements at two adjacent sensors including, but not limited to the following: overall levels, standard spectrum, standard waveforms, specially processed spectrum and waveform (e.g. enveloping/demodulation), trend parameters, and orbit data.

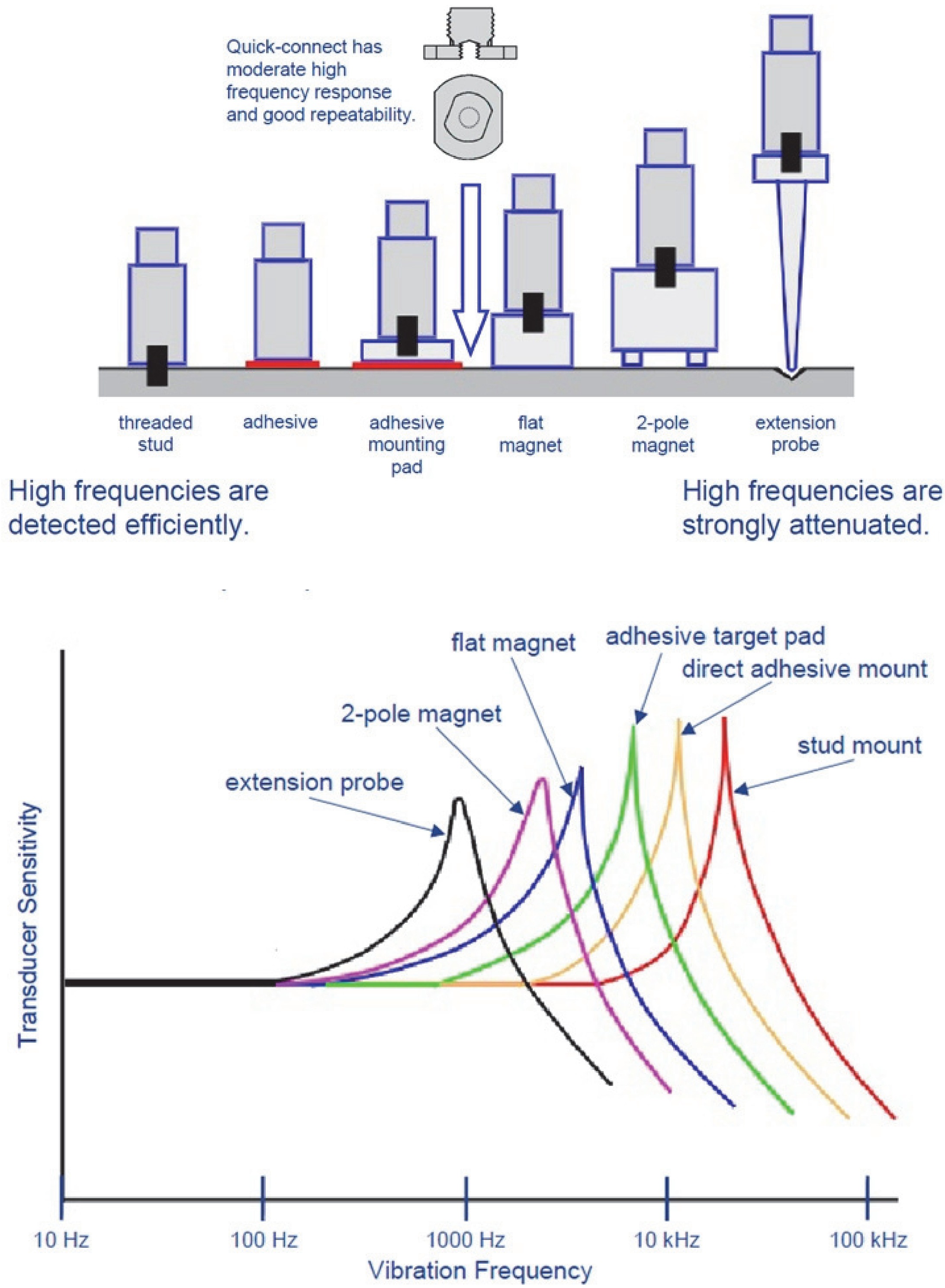


Figure N.34—Probe Mount Frequency Ranges

N.18.14 Display

The portable analyzer should have a display that is capable of plotting a 400-line spectrum with no loss of data. It is also recommended to have a split display function that makes it possible to view the spectrum and the waveform at the same time.

N.18.15 Monitoring Interval

Periodic monitoring is recommended at least every 30 days with shorter intervals recommended for highly critical equipment or for troubled machines with rapid failure modes. If vibration, thrust position, or bearing temperature are unusual, over the alarm value, or a deteriorating trend is seen, it is recommended to perform an evaluation and perform monitoring as required. As a minimum, the following data should be reviewed:

a) current alarms;

b) alarms received since last review;

c) trend of gap voltage; note any changes over 0.5 V;

d) trend of the overall amplitude for each vibration sensor;

e) trend of the 1X and 2X amplitude and phase for each vibration sensor;

f) trend of the bearing temperatures.

N.18.16 Vibration Data Monitor Points

Vibration data monitor points should include a vertical and horizontal reading for each bearing. An axial reading should be taken for each machine.

N.18.17 Data Types

In addition to measuring vibration data, it is recommended to record the following process data within 1 hour of the collection of the machine condition data—preferably at steady state conditions:

a) system load or power level;

b) system temperature;

c) system pressure, if applicable;

d) days online.

N.18.18 Data Upload

It should be possible to upload all collected back to a companion software.

N.18.19 Database

A long-term trending database should be maintained. This archive should be easily available as required to monitor for long-term changes in machine condition, to provide an archive of past machine problems, and to provide for statistical and other specialized analysis.

N.18.20 Data Display

In conjunction with a companion software, it should be possible to generate the same displays from portable data as outlined for online data.

N.19 Vibration, Axial Position, and Bearing Temperature Diagnostics

N.19.1 Introduction

The effective use of the installed monitoring system is crucial to an effective monitoring program. Alarms should be set properly, periodic review of the data should be performed, and an effective plan for responding to an alarm should be in place.

N.19.2 Post Maintenance Monitoring

After every machine maintenance, the monitoring specified in N.19.3 should be performed to verify the condition of the machine and to establish new baseline data.

N.19.3 Machine Start-up Monitoring Procedure

When transient data capture is available and appropriate, the following should be performed.

a) Set up to record the first 20 minutes on a transient data acquisition system. If any unusual vibrations were seen during the run, the data should be analyzed for the cause of the vibration.

b) Inspect the orbit and spectra of the X and Y probes for significant changes.

c) Monitor the 1X amplitude and phase.

d) Examine the 1X and 2X vector trends and polar plots of all probes for any unusual changes. For example, the following may indicate an unusual change:

   i) an amplitude increasing at a rate of 1 mil (25 μm) in 5 min,

   ii) an amplitude increase or decrease of 1 mil (25 μm),

   iii) an increase in 2X amplitude of 50 % when above 0.5 mils (15 μm),

   iv) an increase in 2X amplitude of 1 mil (25 μm),

   v) a change in the phase of the 1X or 2X of 30°.

e) If vibration, thrust position, or bearing temperature are unusual, over the alarm value, or a significant trend is seen, perform an evaluation in accordance with N.19.5.3.1 and perform monitoring in accordance with N.19.5.2 as required.

f) Whenever any spectrum or orbit shows a significant change, make a long-term storage media copy of the filtered and unfiltered orbit, time synchronous average orbit, and the spectra.

g) Make long-term storage media copies of the data listed below from the installed computer system. Data should cover the period from before start-up to establishment of baseline. Long-term storage media may be paper copies, disk files (floppy, hard drive, optical, etc.), or other retrievable records:

   i) overall vibration amplitude trend plots,

ii) thrust position trend plots,

iii) bearing temperature trend plot,

iv) 1X amplitude and phase trend plots,

v) 1X acceptance region plots,

vi) 2X amplitude and phase trend plots,

vii) 2X acceptance region plots,

viii) waterfall plots as a function of delta time,

ix) gap voltage trend plots.

h) After at least seven days of stable operation, take baseline data per N.19.4.

N.19.4 Baseline

N.19.4.1 New Baseline

A new baseline should be established for the machine after every outage where maintenance work is performed on the machines.

N.19.4.2 Time Elapse Before Collecting Baseline

Baseline data should be collected immediately after start-up in order to not lose data or a reference point, in the event of a problem. Start-ups can result in unit shutdowns or equipment operation outside desired conditions. A second set or conditional baseline can be collected after the equipment and process is stable.

N.19.4.3 Verify Machine Condition

The condition of the machines should be evaluated to be acceptable before accepting the baseline data.

N.19.4.4 Baseline Data

The following baseline data should be stored for each machine:

a) unfiltered orbit and waveform,

b) spectra,

c) filtered orbit and waveform,

d) time synchronous orbits and waveform,

e) acceptance region plot of the 1X rpm and 2X rpm component for each sensor,

f) process data at time of acquiring new baseline data,

g) analog monitor front panel readings,

h) current value displays of overall amplitude and gap voltage as applicable for each sensor,

i) current alarm settings,

j) slow-roll runout data (phase and amplitude).

N.19.4.5 Baseline Data Archive

The baseline data should be maintained for the life of the machine.

N.19.5 Periodic Monitoring

N.19.5.1 Intent of Period Monitoring

The intent of periodic monitoring is as follows:

a) provide a separate monitoring system and method to ensure that problems with the machine are not missed because of deficiencies in the installed (protection) monitoring system;

b) provide long-term trend data offline from the monitoring system;

c) ensure that a qualified person periodically reviews the machine condition.

N.19.5.2 Frequency of Periodic Monitoring

Periodic monitoring should be performed on a regular schedule, based upon the condition and criticality of the equipment. For example, for monitoring of a pump that has an installed spare and no known problems, monthly samples may be sufficient. If the installed spare is removed from service, you may want to increase the sampling frequency to once every two weeks. If a problem is suspected on that pump, you may want to increase the sampling to weekly or even more often.

N.19.5.3 Abnormal Readings

N.19.5.3.1 If vibration, thrust position, or bearing temperature are unusual, over the alarm value, or a significant trend is seen, perform an evaluation. As a minimum, the following data should be reviewed:

a) current alarms;

b) alarms received since last review;

c) trend of gap voltage; note any changes over 2 V;

d) trend of the overall amplitude for each vibration sensor;

e) trend of the 1X and 2X amplitude and phase for each vibration sensor;

f) trend of the bearing temperatures.

N.19.5.3.2 It is recommended that a baseline be taken for each sensor under normal operating conditions for comparison with future data.

N.19.5.3.3 A long-term trending database should be maintained separately from the installed monitoring system. This archive should be easily available as required to monitor for long-term changes in machine condition, to provide an archive of past machine problems, and to provide for statistical and other specialized analysis.

N.19.5.3.4 At an interval to ensure no data loss and the usefulness of the long-term trending database, transfer the historical files from the monitoring system to the long-term trending and archiving database.

N.19.5.3.5 Record the following process data within 1 hour (at steady state conditions if possible) of the collection of the machine condition data:

a) date/time of monitoring;

b) number of alarms in period;

c) number of system events in period;

d) machine load;

e) all bearing and any other machine or system temperatures;

f) all other machine process data that is available to the system;

g) days online.

N.19.5.3.6 If the facility has a computerized vibration monitoring program using portable data collectors, data from each channel should be taken with that system for long-term trending and off-line analysis.

N.19.5.3.7 Obtain a long-term storage media copy of the alarm list since the last time this procedure was performed.

N.19.6 Pre-outage Coastdown

When transient data capture is available and appropriate, before each outage during the normal machine coastdown, record the data. Examine data for any unusual patterns. Determine coastdown time and compare to normal. Note orbit shape during coastdown for any unusual patterns.

N.19.7 Enhanced Monitoring of a Troubled Machine

If unusual vibration or a trend in vibration, thrust position, or bearing temperature is detected, an enhanced monitoring program should be implemented until the problem is corrected or the machine is shut down. The enhanced monitoring program should include, as applicable, additional instrumentation (tape recorders, oscilloscopes, spectrum analyzers, etc.) and continuous or intermittent attendance by qualified analysis personnel. The interval of the monitoring and data storage should be based on the severity, rate of change, and the result of the analysis and diagnostics.

N.20 Alarm Settings

N.20.1 General

N.20.1.1 A fundamental difference between a CMS and a MPS is the intent and application of alarms.

N.20.1.2 MPSs monitor critical parameters that indicate the gross condition of the machine, typically balance. Its alarms are intended to annunciate a severe problem that, if left unattended, could result in damage to, or failure of the machine.

N.20.1.3 The intent of a CMS's alarms is to signal the presence, severity and/or propagation of specific faults and operating conditions. CMSs will usually monitor the same parameters that a MPS does but will also monitor many additional parameters that may indicate the presence of a fault or a condition that could promote the development of faults, and/or they may signal degraded machine performance.

N.20.1.4 Because the purpose of its alarms are different, the considerations of alarming with respect to the parameters to be alarmed, and the levels to assign those alarms, are very different from that of a MPS. Of course, for the typical protection parameters such as the overall vibration level, the determination of the alarm levels will follow that of the MPS, although perhaps a bit more conservatively.

N.20.1.5 When determining the alarm levels to apply in a CMS, users should first consider what parameters should be made, what they mean, and what level or change in level should warrant further attention from operators or maintenance personnel. Procedures should then be created that state the required actions of operators and maintenance personnel in response to any alarm that may occur.

N.20.2 Parameters to Alarm On

The specific parameters that should be selected and alarmed on will depend on the type of machine monitored, and to some extent on the capabilities of the monitoring system. However, as a general rule, systems should always monitor and alarm on parameters that are indicative of:

a) mechanical faults,

b) electrical faults,

c) structural faults.

N.20.3 Alarm Limits

For each alarm the Alert and Danger limits should be determined based on standards or OEM specifications. Where neither of these applies, which is the case for most fault indicators, users should consider limits based on the normal levels of each parameter while ensuring that the limits are set such that routine operations will not cause a shutdown. Further guidance for setting limits can be provided by your CMS vendor, staff technicians and engineers who are experienced in vibration monitoring, historical data on the monitored machine, on expert consultants, and other sources.

NOTE Setting limits too near to levels achieved during normal operation could result in nuisance alarms that, over time, may cause a loss of confidence in the system.

N.20.4 Alarm Response

N.20.4.1 Depending on the capabilities of the monitoring system, individual alarms may or may not be annunciated directly to operators. Users should consider each alarm and choose the appropriate notification process for each.

N.20.4.2 When any alarm is annunciated directly to operators, specific instructions should be provided that guide subsequent operator actions.

N.20.4.3 When alarms are not annunciated directly to operators, maintenance or engineering staff responsible for responding to the alarm should be available to acknowledge the alarm within a reasonable period for Alert alarms and immediately for Danger alarms.

N.20.4.4 The key requirement is that if alarms are applied, the user should ensure that operators, maintenance and engineering staff are properly trained and processes put in place to ensure that alarms are managed appropriately regardless of when they may occur.

N.21 Analysis and Diagnostics

N.21.1 Introduction

N.21.1.1 The accurate diagnosis of equipment condition is essential to maintaining operability, reducing plant down time, and increasing productivity. Diagnostics based on the analysis and interpretation of vibration data in conjunction with other equipment parameters such as flow, temperature, and pressure indicate the earliest signs of equipment degradation. Someone experienced in vibration analysis techniques should perform analysis and interpretation of vibration data.

N.21.1.2 The intent of this section is to list the types of data and the methodology used to diagnose equipment condition. This section is not intended to take the place of established plant procedures or to delineate certain analysis methods but rather to provide guidance where plant procedures do not exist or could be improved.

N.21.2 Data Types

Data collected for analysis should include the following:

a) routine steady state data,

b) data collected based on an alarm condition,

c) data collected during transient conditions.

N.21.3 Analysis Methods

The data collected should be analyzed using the following methods:

a) overall vibration (amplitude trends);

b) vibration orbit (form, precession, magnitude, and trends);

c) vibration spectra (harmonic content, amplitude, trends, and phase);

d) acceptance region deviations;

e) 1X and 2X vector analysis;

f) shaft position trends;

g) process data (deviations from normal values versus plant conditions and trends);

h) machine geometry;

i) maintenance history;

j) history of similar events on similar machines.

N.21.4 Data Analysis

An analysis is the process of reviewing the data collected as specified by this standard on a machine to determine equipment condition and diagnose equipment problems. A typical analysis would include the following:

a) comparing current vibration, process, and equipment parameters to baseline and determining any differences;

b) determining if any trends are present or are developing;

c) reviewing equipment history for similar occurrences;

d) reviewing the equipment history of like machines for similar occurrences;

e) determining significant symptoms;

f) determining probable causes of the symptoms (i.e. determining possible equipment faults, process changes, or plant conditions that could produce the observed responses);

g) evaluating the probable condition of the machine and assessing the severity.

N.22 Additional Technologies

N.22.1 General

The technologies described in this section should be used in conjunction with vibration analysis to determine the condition of machines. While one technology alone may convey some evidence of a fault condition, the inter-relationships between all of these technologies provide for a more complete and accurate diagnosis of the condition of the machine.

N.22.2 Thermography

N.22.2.1 Thermography is the application of infrared measuring technologies to observe and quantify the thermal energy emitted by an object. By measuring and trending the heat signature of various components of a machine or its associated equipment, users can often detect heat inducing problems.

N.22.2.2 Thermography should be used at least before and after each major outage, to monitor switch-gear, breakers, and control relays providing electrical power to the machine in accordance with ASTM E1934-99, Paragraph 3.5.

N.22.3 Lube Oil Analysis

N.22.3.1 Monitoring Techniques

Machine lubricating oil should be monitored for wear debris, lubricant cleanliness (foreign material such as water and particulates), and oil chemistry in accordance with the applicable sections of ASTM D6224 and ASTM D7416-08, *Standard Practice for Analysis of In-Service Lubricants Using a Particular Five-Part Integrated Tester.*

N.22.3.2 New Oil

New oil should be sampled and tested in accordance with the recommended tests given in ASTM D6224, Table 1, turbine type oils, before being put into the machine bearings.

N.22.3.3 Used Oil

Used oils should be sampled at each major outage, in accordance with ASTM D6224, preferably while running or at least within 25 minutes of being shutdown. Used oils should be tested in accordance with the recommended test methods given in ASTM D6224. Used oil that is to be left in service should also have an oxidation stability test as specified in ASTM D6224.

N.22.4 Motor Current Signature Analysis

N.22.4.1 Motor current signature analysis should include the measurement of the N_p multiplied by slip frequency sidebands of the line frequency component and the rotor bar and stator slot passing frequencies.

N.22.4.2 Motor current signature analysis should be performed prior to each major outage and after every outage where maintenance work is performed on the machine.

N.22.5 Motor Electrical Monitoring and Testing

N.22.5.1 The motor electrical operating parameters (current, voltage, winding temperatures, etc.) should be monitored in accordance with the manufacturer's recommendations, industry standards and practice, and plant experience.

N.22.5.2 The following parameters, as applicable, should activate an audible alarm in the control room and should be displayed:

a) current,

b) phase balance,

c) winding temperature,

d) cooling water flow rate,

e) oil level,

f) winding cooler leakage.

N.22.5.3 Motors should be tested in accordance with the applicable parts of NEMA MG 1, motors and generators, Paragraph 3.6.

N.23 Wireless Signal/Data Transmission

N.23.1 Introduction

The purpose of this section is to discuss when to apply wireless connectivity with respect to condition monitoring.

NOTE 1 Please refer to the Informative Annex Q on wireless connectivity for a broader treatment of the general topic.

NOTE 2 Wireless connectivity is not permitted for machinery protection functions within this standard.

N.23.2 Application of Wireless Connectivity

N.23.2.1 Wireless connectivity can help justify the investment in a CMS and/or an expansion to an existing system by providing a cost-effective alternative to a traditional hardwired implementation. The reduced per point implementation cost can apply equally to existing plant upgrades as well as new plant construction.

N.23.2.2 The risk involved with wireless connectivity is that it may reduce the overall reliability and security of the system.

N.23.2.3 In all cases, the end user is responsible to conduct a financial and technical analysis as to whether wireless is appropriate for their application.

N.23.3 Functional Considerations

The broad scope of condition monitoring applications does not allow for the definition of a single solution. The wireless connectivity needed to transmit large volumes of dynamic data (e.g. a critical machine start-up event, live dynamic data during steady state machine operation) is very different than when the link is used to monitor a static value (overall vibration, temperature or other process parameters) and periodically transmit a few bytes of information. Therefore, it is necessary to design the wireless network to meet the functional needs of the application.

N.23.4 Wireless Configurations for Condition Monitoring

N.23.4.1 In Figure N.35, the application of high and low bandwidth networks is based on functionality.

NOTE Refer to the informative Annex Q on wireless connectivity for the definition of high and low bandwidth networks.

N.23.4.2 High bandwidth networks may be necessary to meet the level of performance users have come to expect from similar hardwired systems, and this would likely be the preferred implementation for the first three configurations. In a full implementation of condition monitoring, these configurations could include transmission of static and/ or dynamic data types under steady state and/ or transient machine operating conditions—potentially including continuous update of the data display in near real time.

N.23.4.3 A low bandwidth network may be used for applications where lower throughput is sufficient as illustrated in configurations 4 and 5 of Figure N.35. In these cases, the information being broadcast is likely limited to intermittent static and/ or dynamic data.

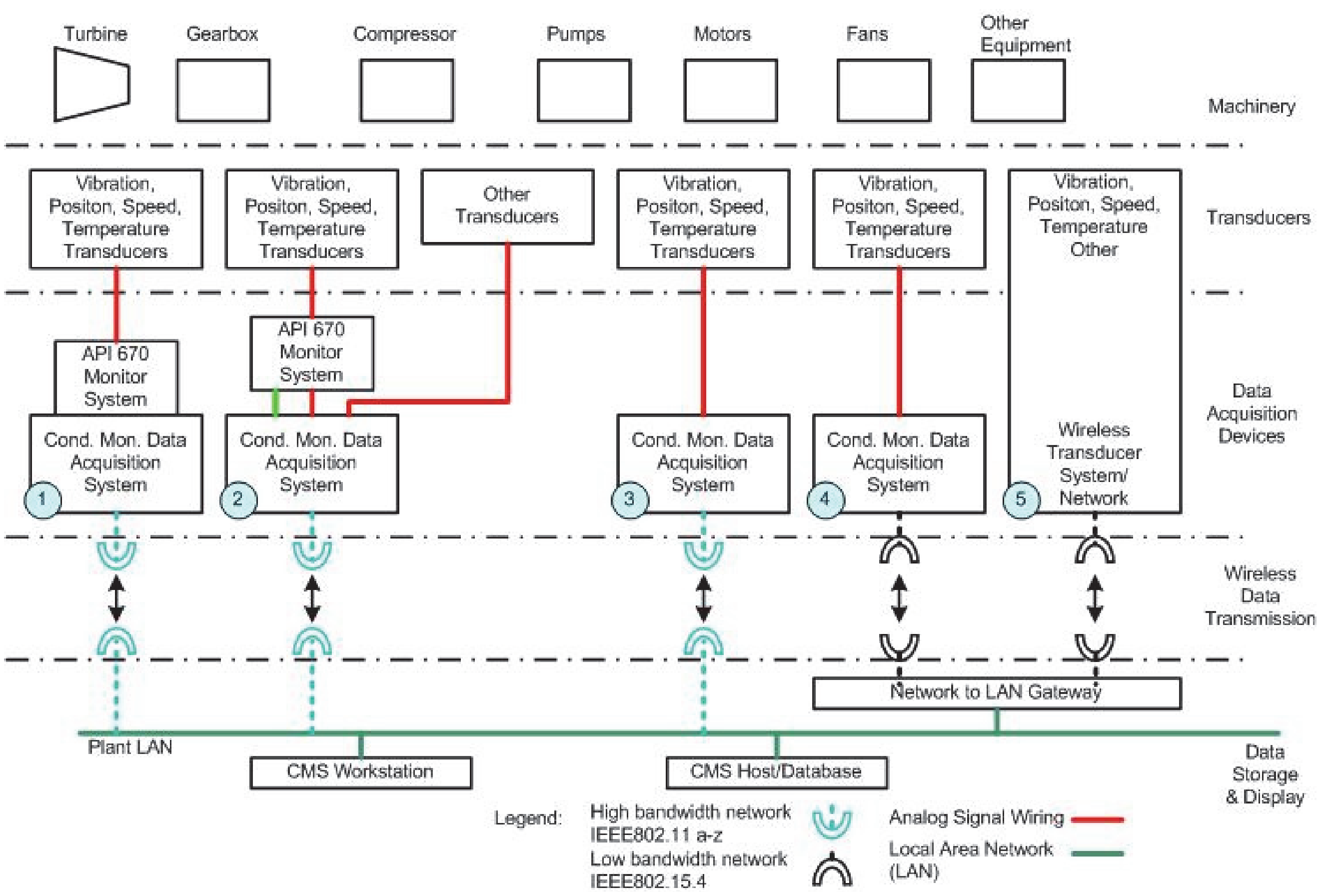


Figure N.35—Condition Monitoring Configurations with Wireless Connectivity

The figure depicts five different possible configurations of wireless connectivity for condition monitoring. The first two demonstrate how it may be combined with an API 670 MPS. The last three illustrate how it may be implemented independently.

1) API 670 MPS with integral high bandwidth condition monitoring data acquisition system.

2) API 670 MPS with separate high bandwidth condition monitoring data acquisition system connected to the buffered raw signal outputs in an API 670 MPS. Additional transducers not covered by the API 670 MPS may be accommodated.

3) High bandwidth condition monitoring data acquisition system connected directly to transducers.

4) Low bandwidth condition monitoring data acquisition system connected directly to transducers.

5) Low bandwidth integrated wireless transducer, and condition monitoring data acquisition network.

N.23.4.4 While it is possible for the condition monitoring system to be an integral part of the API 670 machinery protection system (configuration 1 of Figure N.35) or for input signal sources to be common between the condition monitoring and API 670 machinery protection systems (configuration 2 of Figure N.35), the implementation of a condition monitoring system shall not in any way compromise or interfere with the full implementation of machinery protection as outlined in the normative section of this standard.

N.24 Calibration and System Verification

Calibration and system verification should be performed per the manufacturer's recommendations and/or the plant maintenance program. Consideration of the performance of the sensor (e.g. bias current and trend of line frequency components, either 50 Hz or 60 Hz) may be used in determining calibration.

Annex O
(normative)

Overspeed

O.1 Steam Turbine Based Maximum Rotor Speed Calculations

This annex is used to calculate the maximum rotor speed of a typical non-reheat steam turbine during an overspeed shutdown event. However, it does not apply to gas turbines or steam turbines that incorporate reheat operations.

O.2 Scope

O.2.1 Following the initiation of a shutdown by the overspeed shutdown system, the speed of the rotor system will increase because of the following.

a) The energy input to the turbine during the signal delay time, T_s. This delay includes the response time of the electronic overspeed shutdown device as well as the response time of all the components between the electronic overspeed shutdown device and the steam shutdown valve such as the hydraulic shutdown block, hydraulic piping runs, and solenoid valves. The power input corresponds to the maximum turbine power.

b) The energy input to the turbine during the stop valve(s) closing time, T_v. This power input corresponds to a certain fraction (f) of the maximum turbine power. For example, for a valve with a linear response characteristic, $f = 0.5$.

c) The energy input to the turbine from any steam (or condensate that can flash to steam) contained within the turbine system when the turbine is operating at maximum output. The steam will expand to the exhaust pressure. The power from this source may be partly or wholly expanded during the time the stop valve is closing or after the valve has become closed if the steam is trapped in a region downstream of the stop valve such as extraction piping. It is assumed that a certain fraction of this power is available for accelerating the rotor system.

O.2.2 The maximum speed attained by the rotor, N_{max}, may be determined by evaluating the rotor energy at the time the shutdown is initiated, then adding the energy that is applied to the rotor by the steam until the energy sources are removed and dissipated. Referring to Figure O.1, this is the starting kinetic energy at overspeed shutdown setpoint plus all the energy input to the rotor during the period between the initiation of a shutdown and the final closure of the stop valve(s). The final speed can be calculated using the peak kinetic energy and inertia of the rotor. These calculations will tend to be conservative (actual excursion should be less than the calculated excursion) because the energy consumed by the parasitic losses (bearing friction, windage) has not been subtracted from the total energy of the rotor after the shutdown sequence is initiated. The accuracy of these calculations can be improved if these losses are included.

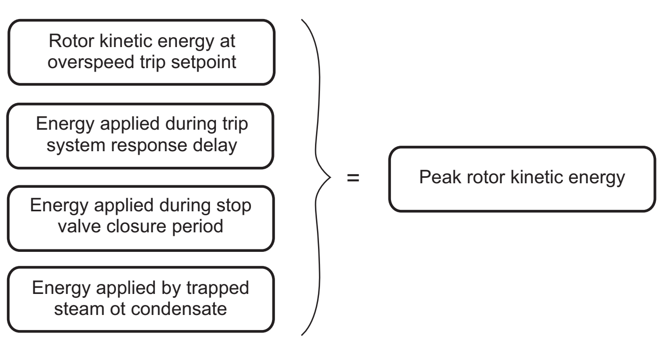


Figure O.1—The Peak Kinetic Energy of the Rotor

O.2.3 Calculations in SI Units

O.2.3.1 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_T} \text{ (rpm/s) [turbine rotor uncoupled]} \quad (O.1)$$

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_C} \text{ (rpm/s) [complete train]} \quad (O.2)$$

where

k is 9.1189×10^4 [rpm^2-kg-m^2/(kW-s)];

$P_{g(max)}$ is the turbine rated power (kW);

N_T is the setpoint of overspeed shutdown device (rpm);

WR^2 is the rotational inertia of a rotor (kg-m^2);

$WR^2{}_T$ is the rotational inertia of turbine rotor (uncoupled) (kg-m^2);

$WR^2{}_C$ is the rotational inertia of the complete train (kg-m^2).

O.2.3.2 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k_2 \times WR^2 \times N^2 \text{ (kW-s)} \quad (O.3)$$

$$E_T = k_2 \times WR^2 \times N_T{}^2 \text{ (kW-s)} \quad (O.4)$$

$$E_T = k_2 \times WR^2{}_C \times N_T{}^2 \text{ (kW-s) (complete train)} \quad (O.5)$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 5.49×10^{-6} [kW-s-min^2/(kg-m^2)].

O.2.3.3 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \text{ (kW-s)} \quad (O.6)$$

where

T_s is the signal time delay (seconds)—the period of time between when an overspeed shutdown condition occurred and the time the shutdown valve(s) starts to close. This time period includes sensor delays, logic solver I/O scan rate delays, logic solver program scan rate delays × 2 (this is the worst case delay), shutdown solenoid delays, and shutdown oil-header delays.

O.2.3.4 The energy added to the rotor during the closure time of the stop valve is

$$\Delta E_{\mathrm{v}} = f \times T_{\mathrm{v}} \times P_{\mathrm{g(max)}} \text{ (kW-s)} \tag{O.7}$$

where

T_{v} is the closure time for stop valve (seconds)—the time which the valve needs to travel from fully open to fully closed;

f is the fraction of maximum steam flow that passes through the stop valve during closure period.

O.2.3.5 If the stop valve characteristics are linear, the energy added during the closure time of the stop valve would be half the turbine max power times the closure time. In this case, f would be 0.5. The energy added to the rotor by the expansion of steam that is trapped within the turbine is

$$\Delta E_{\mathrm{e}} = k_3 \eta \left[\sum W_{1\mathrm{i}} u_{1\mathrm{i}} - \sum W_{2\mathrm{i}} u_{2\mathrm{i}} - \sum (W_{1\mathrm{i}} - W_{2\mathrm{i}}) h_{2\mathrm{i}} \right] \text{ (kW-s)} \tag{O.8}$$

where

k_3 is 1.0 kW-s/kJ;

η is the steam turbine efficiency;

$W_{1\mathrm{i}}$ is the mass of steam and condensate contained within each “i” space inside the turbine when the turbine is operating at its maximum output (kg);

$u_{1\mathrm{i}}$ is the internal energy for each of the steam $W_{1\mathrm{i}}$ masses, estimated at the actual pressures and temperatures that exist at the various “i” spaces when operating at maximum output (kJ);

$W_{2\mathrm{i}}$ is the weight of steam in the “i” spaces defined for $W_{1\mathrm{i}}$ after expansion has ceased (kg);

$u_{2\mathrm{i}}$ is the internal energies for the $W_{2\mathrm{i}}$ masses of steam in the “i” spaces after isentropic expansion (kJ);

$h_{2\mathrm{i}}$ is enthalpies of the $W_{2\mathrm{i}}$ masses of steam after isentropic expansion (kJ).

O.2.3.6 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped steam.

$$E_{\mathrm{max}} = E_{\mathrm{T}} + E_{\mathrm{s}} + E_{\mathrm{v}} + E_{\mathrm{e}} \text{ (kW-s)} \tag{O.9}$$

O.2.3.7 The maximum speed attained by the rotor can be calculated using Equation (O.10) and Equation (O.11) as follows.

$$N_{\mathrm{max}} = \sqrt{\frac{E_{\mathrm{max}} \times 10^6}{k_2 \times \mathrm{WR}^2_{\mathrm{T}}}} \text{ (rpm) (turbine uncoupled)} \tag{O.10}$$

$$N_{\mathrm{max}} = \sqrt{\frac{E_{\mathrm{max}} \times 10^6}{k_2 \times \mathrm{WR}^2_{\mathrm{C}}}} \text{ (rpm) (complete train)} \tag{O.11}$$

O.3 Calculations in USC Units

O.3.1 Generator Drive

O.3.1.1 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2} \text{ (rpm/s)} \quad \text{(O.12)}$$

where

k is 2.164×10^6 rpm^2-lb-ft^2/(kW-s);

$P_{g(max)}$ is the turbine rated power (kW);

N_T is the setpoint of overspeed shutdown device (rpm);

WR^2 is the rotational inertia of a rotor (lb-ft^2);

WR^2_T is the rotational inertia of turbine rotor (uncoupled) (lb-ft^2);

WR^2_C is the rotational inertia of the complete train (lb-ft^2);

O.3.1.2 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k_2 \times WR^2 \times N^2 \text{ (kW-s)} \quad \text{(O.13)}$$

$$E_T = k_2 \times {WR^2}_T \times {N_T}^2 \text{ (kW-s) (turbine uncoupled)} \quad \text{(O.14)}$$

$$E_T = k_2 \times {WR^2}_C \times {N_T}^2 \text{ (kW-s) (complete train)} \quad \text{(O.15)}$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 2.31×10^{-7} [kW-s-min^2/(lb-ft^2)].

O.3.1.3 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \text{ (kW-s)} \quad \text{(O.16)}$$

where

T_s is the signal time delay (seconds).

O.3.1.4 The energy added to the rotor during the closure time of the stop valve is

$$\Delta E_v = f \times T_v \times P_{g(max)} \text{ (kW-s)} \quad \text{(O.17)}$$

where

T_V is the closure time for stop valve (seconds);

f is the fraction of the maximum turbine output during the stop valve closure period.

Stop valves typically have characteristics that result in f being less than 1 but greater than 0.5. The stop valve manufacturer may furnish typical values of f for the valve in question.

O.3.1.5 The energy added to the rotor by the expansion of steam that is trapped within the turbine is

$$\Delta E_e = k_3 \eta \left[\sum W_{1i} u_{1i} - \sum W_{2i} u_{2i} - \sum (W_{1i} - W_{2i}) h_{2i} \right] \text{ (kW-s)]} \quad \text{(O.18)}$$

where

k_3 is 1.055 kW-s/BTU;

η is the steam turbine efficiency;

W_{1i} is the mass of steam and condensate contained within each "i" space inside the turbine when the turbine is operating at its maximum output (lbm);

u_{1i} is the internal energy for each of the steam W_{1i} masses, estimated at the actual pressures and temperatures that exist at the various "i" spaces when operating at maximum output (BTU/lbm);

W_{2i} is the weight of steam in the "i" spaces defined for W_{1i} after expansion has ceased (lbm);

u_{2i} is the internal energies for the W_{2i} masses of steam in the "i" spaces after isentropic expansion (BTU/lbm);

h_{2i} is enthalpies of the W_{2i} masses of steam after isentropic expansion (BTU/lbm).

O.3.1.6 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped steam.

$$E_{max} = E_T + E_s + E_v + E_e \text{ (kW-s)} \quad \text{(O.19)}$$

O.3.1.7 The maximum speed attained by the rotor can be calculated using Equation (O.20) and Equation (O.21), as follows.

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times \mathrm{WR}^2{}_T}} \text{ (rpm) (turbine uncoupled)} \quad \text{(O.20)}$$

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times \mathrm{WR}^2{}_C}} \text{ (rpm) (complete train)} \quad \text{(O.21)}$$

O.3.2 Mechanical Drive

O.3.2.1 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_T} \text{ (rpm/s) (turbine uncoupled)} \quad (O.22)$$

$$\alpha_c = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_C} \text{ (rpm/s) (turbine coupled)} \quad (O.23)$$

where

k is 1.614×10^{-6} rpm^2-lb-ft^2/(HP-s);

$P_{g(max)}$ is the turbine rated power (HP);

N_T is the setpoint of overspeed shutdown device (rpm);

$WR^2{}_T$ is the rotational inertia of turbine (uncoupled) (lb-ft^2);

$WR^2{}_C$ is the rotational inertia of the complete train (coupled) (lb-ft^2).

O.3.2.2 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k \times 10^{-7} \times WR^2 \times N^2 \text{ (HP-s)} \quad (O.24)$$

$$E_T = k_2 \times WR^2{}_T \times N_T{}^2 \text{ (HP-s) (turbine uncoupled)} \quad (O.25)$$

$$E_T = k_2 \times WR^2{}_C \times N_T{}^2 \text{ (HP-s) (complete train)} \quad (O.26)$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 3.10×10^{-7} [HP-s-min^2/(lb-ft^2)].

O.3.2.3 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \text{ (HP-s)} \quad (O.27)$$

where

T_s is the signal time delay (seconds).

O.3.2.4 The energy added to the rotor during the closure time of the stop valve is

$$\Delta E_v = f \times T_v \times P_{g(max)} \text{ (HP-s)} \quad (O.28)$$

where

T_V is the closure time for stop valve (seconds);

f is the fraction of maximum steam flow that passes through the stop valve during closure period.

If the stop valve characteristics are linear, the energy added during the closure time of the stop valve would be half the turbine max power times the closure time. In this case, f would be 0.5.

O.3.2.5 The energy added to the rotor by the expansion of steam that is trapped within the turbine is

$$\Delta E_e = k_3 \eta \left[\sum W_{1i} u_{1i} - \sum W_{2i} u_{2i} - \sum (W_{1i} - W_{2i}) h_{2i} \right] \text{ (HP-s)} \quad \text{(O.29)}$$

where

k_3 is 1.415 HP-s/BTU;

η is the steam turbine efficiency;

W_{1i} is the mass of steam and condensate contained within each "i" space inside the turbine when the turbine is operating at its maximum output;

u_{1i} is the internal energy for each of the steam W_{1i} masses, estimated at the actual pressures and temperatures that exist at the various "i" spaces when operating at maximum output;

W_{2i} is the weight of steam in the "i" spaces defined for W_{1i} after expansion has ceased;

u_{2i} is the internal energies for the W_{2i} masses of steam in the "i" spaces after isentropic expansion;

h_{2i} is enthalpies of the W_{2i} masses of steam after isentropic expansion.

O.3.2.6 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped steam.

$$E_{max} = E_T + E_s + E_v + E_e \text{ (HP-s)} \quad \text{(O.30)}$$

O.3.2.7 The maximum speed attained by the rotor can be calculated using Equation (O.31) and Equation (O.32), as follows.

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2_T}} \text{ (rpm) (turbine uncoupled)} \quad \text{(O.31)}$$

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2_C}} \text{ (rpm) (complete train)} \quad \text{(O.32)}$$

Annex P
(informative)

Reciprocating Compressor Monitoring

P.1 Introduction

The purpose of this document is to provide guidance in the selection and application of permanently installed on-line monitoring systems. This document does not address periodic monitoring systems.

P.2 Scope

This annex covers instruments for on-line monitoring systems applicable to reciprocating compressors addressed by API 618. Further information can be found in that document.

P.3 Monitored Points/Parameters

Monitored parameters associated with reciprocating compressors are segregated into two categories: protective signals (Table P.1) and condition based signals (Table P.2).

Table P.1 and Table P.2 list possible measurement points for a reciprocating compressor. Recommended signals are indicated by "R" and optional signals are indicated by "O." Table P.1, "protective signals" (lines 1 to 8) notes "Alarm" (A) and "Shutdown" (S) indications noted by API 618, Fifth Edition, Table 5. Table P.1 (lines 9 to 25) notes additional protective signals discussed in this annex. Table P.2 notes "condition signals" discussed in this annex.

The application and installation requirements of these transducers are discussed in following sections.

P.4 Sensors

P.4.1 General

Typical sensor design definitions for centrifugal equipment applications are located in Section 3, and their applications are noted throughout the standard. However, some of these typical sensors are used is unique ways for reciprocating compressors. There are also sensors that are only used in monitoring reciprocating compressors. This section provides information for these unique applications.

P.4.2 Unique Reciprocating Sensor Applications

P.4.2.1 Proximity Transducers

11-mm probes are recommended for reciprocating compressor rod drop applications because of their extended linear range over standard 8-mm probes. Surface coatings may affect the linearity and dynamic range of the probe.

P.4.2.2 Seismic Transducers (Vibration Sensors)

Reciprocating compressor vibration is measured by devices sensing component velocity or acceleration. Device type depends on the frequency and nature of the vibration. Vibration switches and moving coil type seismic sensors are not recommended.

P.4.2.3 Pressure Transducers

A transducer converts one type of energy to another. For most cylinder pressure sensing requirements, a transducer is necessary because of responsiveness and pressure range. Electrical output is proportional to the magnitude of the pressure.

P.4.2.4 Transmitters

In general, a transmitter consists of a sensor and a signal conditioner, usually combined into one assembly. The electrical output is proportional to the magnitude of the sensed condition and bounded by a range (lower and upper limits (i.e. 4 to 20 mA). Sensor types include pressure, differential pressure, flow, liquid level, etc. It is also possible to combine a temperature sensor with a transmitter; however, they are frequently read directly.

P.4.2.5 Temperature Sensors

Capillary temperature sensors consist of a bulb and flexible tube filled with a liquid and terminating in an instrument head or box. This head or box may contain a visual readout (dial or digital) and may include a dry contact output. The flexible tubing allows the instrument head to be located nearby (on a free standing support or a local gauge board). Applications may be limited by the size or mounting requirements of the sensing bulb, length and protection of the flexible tubing.

Eutectic temperature sensors consist of a low melting temperature (fusible) plug that retains a spring loaded pin. When melted, the pin is released to trip a lever on a stationary valve or microswitch. When the valve is opened a secondary fluid is released and a pressure switch provides an appropriate signal. Actuation of a microswich provides a more direct signal.

Electric temperature sensors are typically passive sensing devices such as thermocouples or RTDs. A thermocouple is a bimetallic junction of two dissimilar metals and an RTD is constructed of a fine gauge wire wound on a bobbin. Both types are usually contained within a metal enclosure, such as a metal tube. Their output varies linearly with a change in temperature, within a defined range. Thermocouples produce a microcurrent and RTDs change in resistance. Signal output may be visualized through a digital readout or processed through a monitoring rack, equipment PLC, or plant DCS.

P.4.3 Transducer Function and Installation

P.4.3.1 General

This section outlines functions and installations of special transducers for reciprocating compressor application. Application of each arrangement is dependent on site monitoring objectives.

P.4.3.2 Cylinder Pressure

A critical measurement for reciprocating compressor performance monitoring is cylinder pressure. The cylinder pressure transducers are installed on the head end and crank end of each cylinder.

The application of on-line monitoring systems and the desire to maintain the ability for routine reciprocating compressor portable devices have increased the size and weight of this assembly. To address the physical supporting requirements for this hardware, consideration needs to be given on new equipment to apply flanged connections. Threaded connections need to be braced or supported to the cylinder to eliminate the possibility of failure.

P.4.3.3 Piston Rod Drop

Proximity transducers are used to measure the drop of the piston rod during operation. Typically, a single probe is mounted in the vertical orientation to monitor piston rod drop, which is directly related to rider band wear. An optional second horizontal probe per rod, and a once-per-revolution sensor may be installed to assist in condition based diagnostics.

The vertical probe is typically mounted in the 6 o'clock position. Probes and cables are to be installed to prevent inadvertent contact with the piston rod and allow access through the distance piece cover for maintenance or adjustment.

Eutectic type piston rod drop detection may be considered for noncritical applications.

P.4.3.4 Frame and Running Gear Vibration

P.4.3.4.1 General

In this section, the term vibration sensor can mean either an accelerometer or piezoelectric velocity transducer; either is acceptable as recommended by the OEM.

P.4.3.4.2 Frame

Frame vibration sensors are used to detect overall vibration in the frame, generally produced by mechanical forces, and are mounted in the horizontal direction on the sides of the frame at diagonal corners. To detect frame movement or looseness, vibration sensors need to be mounted at each corner in the vertical direction.

Depending on transducer mounting direction, the monitored frequency range should be from $^1/_2$X running speed up to at least 20X running speed.

P.4.3.4.3 Running Gear—Frame

Frame running gear vibration sensors are utilized to detect mechanical or process induced impacts in the connecting rod-to-crankshaft portion of the running gear. These vibration sensors are mounted in the horizontal direction on the side of the machine opposite that of each throw.

P.4.3.4.4 Running Gear—Crosshead Guide

Crosshead guide vibration sensors are utilized to detect mechanical or process induced impacts in the connecting rod-to-crosshead and crosshead-to-piston rod portion of the running gear. They are typically mounted in the vertical direction on the top or bottom of the crosshead guide. The vibration sensors should be installed on a stiffening rib if possible.

Monitors may need to be configured to accept higher frequencies (up to 7 kHz with a 2 kHz minimum) in order to detect mechanical impacts depending on machine characteristics. Contact your machine protection vendor for their recommendations.

P.4.3.5 Cylinder

Installation of cylinder accelerometers may be used for either impact or valve condition monitoring. Impact monitoring accelerometers should be located on the outer head or outer cylinder wall in the axial direction. Valve condition monitoring may locate accelerometers on the suction and discharge side of the cylinder or on each valve cover.

P.4.3.6 Temperature

P.4.3.6.1 Bearings

Main crankshaft bearings are monitored by 100-ohm platinum 3 wire RTDs or thermocouples. They are typically spring loaded, externally mounted, and include a conduit head for access to leads and replacement.

P.4.3.6.2 Connecting Rod Bearings, Crosshead/Wrist Pins, and Crosshead Shoes

Monitoring of connecting rod crankshaft (big) end or crosshead (small end) bearings, crosshead/wrist pins, and crosshead shoes is typically provided by eutectic devices. This sensor provides an all-or-nothing type signal for a predetermined high temperature indication. Once triggered, the device cannot be reset, and it requires replacement. A radar type sensing system may be considered for providing discrete temperature measurement. For crosshead shoe temperature measurement, consideration may be given to indirect measurement of the crosshead shoe-to-crosshead guide boundary by an RTD or thermocouple.

Connecting rod bearings may fail because of insufficient lubrication caused by insufficient rod reversal or reduction/loss of oil supply pressure. Increased temperature may also be caused by excessive wear.

P.4.3.6.3 Valve/Valve Cover

Valve temperature sensors are installed typically in the valve cover from an accessible radial direction as it is usually not feasible to sense valve components directly. These devices sense process gas temperature in either the suction or discharge valve chambers. When used, these signals are continuously monitored and trended. Variance of these temperatures (beyond the changes in process gas temperature) is generally considered to be due to a change in valve operation or sealing component degradation.

P.4.3.6.4 Process Gas Stream

Suction and discharge gas temperatures are very important for condition monitoring. This is implemented by a thermocouple or RTD inserted into a thermowell, mounted in the bottle nozzle of each pulsation suppression device and extends into the gas stream.

P.4.3.7 Speed Pickups/Triggers

The installation requirement of a shaft rotation sensor is dependent on the monitoring system selected and is coordinated with the selected monitoring system vendor. Systems require either a once-per-revolution trigger or a multitoothed event wheel. Consideration should be given to spare or redundant probes.

P.4.3.8 Radar Wireless Temperature Monitoring Devices

P.4.3.8.1 Installation of radar wireless monitoring systems should be discussed with system supplier and the compressor OEM prior to installation. Finite element analysis of the connecting rod is recommended prior to installing the system on the rod to have minimal impact on the rod integrity. It is also recommended to have the OEM install the system and test during the factory mechanical run test. Installation details should be reviewed to make sure the sensors do not restrict oil flow to any components.

P.4.3.8.2 The installation requirements vary between the following categories:

a) crank pin bearing (connecting rod big end) sensors may be installed in the locations typically used for a eutectic type devices;

b) wrist pin/cross pin bushing sensors are may be located in the wrist pin or mounted directly on the connecting rod small end bearing.

P.4.3.9 Motor Vibration

Vibration sensors are frequently installed in the motor bearing(s). An acceleration or velocity type sensor is selected as appropriate for the driver speed. Displacement probes may not be appropriate for slow speed machines but will provide gap monitoring. Bearing type (sleeve or antifriction) will affect sensor selection.

P.4.3.10 Pressure Packing

On all machines, pressure packing is located on the crank end of the cylinder, in the outboard end of the distance piece. Depending on the process gas, size, and design of the machine, this packing may require external sources for either liquid cooling (water or oil), or inert gas buffering, or both.

Additional rod packing may be implemented for two compartment type distance pieces and is located in the wall separating them. This is termed intermediate rod packing.

Liquid cooling is usually provided from the same console as the cylinder jacket system. Additional instrumentation (temperature and flow) may be implemented for each packing and again at the common return manifold. Where a separate console is provided (for either an oil coolant or separate temperature control), any additional instrumentation and control for that console is defined on the datasheet.

An inert gas buffer may be required because of the nature of the process gas for toxicity or flammability reasons. Instrumentation and control is located in the main buffer panel, and additional monitoring instrumentation may be implemented for each packing to verify flow or discharge temperature.

P.4.3.11 Process Gas Sampling Points

Where there is a requirement to determine process gas composition, samples may be obtained from the cylinder pressure taps or at points installed in the plant piping in close proximity to the compressor. In duties where there are variations in gas composition, it is important to monitor the process gas characteristics and assess the impact of the operational changes to the compressor.

P.4.4 Reciprocating Compressor Protection Recommendations

P.4.4.1 Alarm and Shutdown Recommendations

API 618, Fifth Edition, Table 5 covers the basic recommended alarms and shutdowns. When a monitoring system is installed, additional alarms and shutdowns may be considered.

P.4.4.2 Alarm and Shutdown Parameters

P.4.4.2.1 Low Frame Lube Oil Pressure

A shutdown will be based on (a) transmitter(s) located at the end of the supply manifold. In recognition of the importance of this signal, multiple transmitters with voting logic implemented are usually installed. Voting logic is typically two-out-of-three of these signals.

P.4.4.2.2 High Frame Vibration

Continuous monitoring of compressor frame vibration requires the minimum of one sensor horizontally mounted at each of two opposite corners of the frame. Additional sensing points may be considered. Shutdown is required for levels determined to cause immediate and severe damage. Alarm(s) may be appropriate for auxiliary points at lower levels of severity.

P.4.4.2.3 High Level in Separator

A separator is a device located in the plant piping, upstream of the compressor suction nozzle(s). Its purpose is to remove entrained liquid from the process gas before entering the cylinder(s). Removal of accumulated condensate is essential to help prevent severe mechanical damage to major machine components. While typically applied prior to the first stage, some process gasses may require additional moisture removal at successive stages. Where the liquid/ condensate is multiphase, the use of any density reliant level transmitters is not recommended (varying densities of multiphase condensate will yield inaccurate levels). The use of radar liquid level transmitters has been successful. Alarm and shutdown sensing should be applied, and voting logic should be considered.

P.4.4.2.4 Low Frame Lube Oil Level

This alarm is implemented by a sensor located in the system oil reservoir, typically a liquid level sensing type switch suited to machine vibration and oil surface turbulence. Alternately, a transmitter type sensor may be considered if these and low liquid depths are appropriately addressed.

P.4.4.2.5 High Oil Filter Differential Pressure

This alarm is implemented by a differential pressure device that measures oil pressure upstream and downstream of the main lube oil filter.

P.4.4.2.6 Cylinder Lubricator System Failure

For compressors designed for lubricated operation, this alarm is implemented by one or more sensors in the cylinder lubricator system. Basic protection is characterized by a sensor in the pressure/flow generating device. In divider block systems, this may be a cycle counter or output. For pump to point systems, this may be a pressure sensor. Extended protection is characterized by verification of oil flow at the point of use. Generally, immediate shutdown of the machine is not necessary and limited continuing operation may impact wear component life. Accordingly, repeated annunciation and acknowledgement of the alarm on a fixed time basis is appropriate.

P.4.4.2.7 Jacket Coolant System Failure

For compressors designed with cylinder water jackets that require an external source of circulating water, this alarm is implemented by one or more sensors in the water circulation/cooling system. Basic protection is characterized by a pressure transmitter in the discharge of the cooling water console. Extended protection is characterized by verification of water flow after the point of use. Generally, immediate shutdown of the machine is not necessary and limited continuing operation may impact wear component life. Accordingly, repeated annunciation and acknowledgement of the alarm on a fixed time basis is appropriate.

P.4.4.2.8 High Gas Discharge Temperature for Each Cylinder

High discharge temperature shutdowns are a recommendation of API 618, 5th Edition, but several different philosophies exist as to whether they should be specified. Services with the potential for gas decomposition or auto ignition may need to shut down where other services may not.

High temperatures in the cylinder have a detrimental effect on the operational life of modern wear components. The components affected are piston rings, piston rider bands, pressure packing rings and valve components.

The vendor and purchaser should discuss the value of shutting down on this condition to determine the best action.

P.4.4.2.9 High Crosshead Vibration

Continuous monitoring of compressor crosshead vibration requires the minimum of one sensor mounted in the vertical direction on the top or bottom of the crosshead guide. Crosshead guide vibration may provide earlier indication of running problems than frame vibration. Shutdown is required for levels determined to cause immediate and severe damage. Alarm(s) may be appropriate for auxiliary points at lower levels of severity.

P.4.5 Potential Additional Sensing Points

P.4.5.1 General

The following additional points may be considered for instrumentation.

P.4.5.2 Process Gas Pressure

Process gas pressure alarms or shutdowns trips are used to avoid frame overloading due to an unacceptable change in the sensed pressure and are defined by the compressor manufacturer during detailed machine design. These points may include low suction, high discharge, or high differential pressure for one or more stages.

P.4.5.3 Piston Rod Drop

The majority of horizontal reciprocating compressors rely on piston rider bands to support the piston and prevent contact with the cylinder liner. As these bands wear, the piston rod drops in the cylinder and moves in the rod packing in a corresponding amount. Typically, rider band wear is of an extended duration. Monitoring rod drop is a means of sensing the amount of rider band wear. In the event of full rider band depletion, there is a risk of the piston contacting the cylinder wall.

Two types of sensing devices are typically used. The use of a trip in this instance is not usually recommended; the rod drop should be monitored and the monitoring system fitted with an alarm if wear is becoming excessive.

Eutectic type devices provide a rudimentary level of detection. The type used here typically implements the valve/fluid/pressure switch design. Some units may also include and RTD for temperature sensing of the fusible plug. Importantly, this type of device has no advance indication of condition until the piston rod makes contact with the device.

Noncontacting type sensing provides an advanced level of detection and can aid in early detection of running gear problems. Rod position sensing may be expanded by implementing two probes, one in each of the vertical and horizontal directions.

P.4.5.4 Calculated Performance

Condition based monitoring systems are available that sense, measure and monitor various machine characteristics. Primarily these include stage pressures and temperatures, piston position (during the compression cycle), valve temperatures, piston rod position, frame vibration, etc. in the calculations. Rod loads and rod reversal may be imputed through evaluation of the pressure-volume elements.

P.5 Protective Signals

Protective signals are hard wired directly to the monitoring system and are used for machine protection. These signals may be shared with a CMS as long as the operation (normal or fault) of the CMS will in no way compromise the operation of the protective system (4.8).

P.6 Condition Signals

Condition type signals (Table P.2) represent a large part of the monitored system. These signals are required to monitor the machine, auxiliary systems, and process parameters. Most of condition data should be available for trending and analysis by the unit control panel, condition based monitoring system, plant supervisory control system (DCS) or other operator interface system. Signals also include those from Table P.1. Signals used in both a condition monitoring function and a protective function are hard wired in accordance with P.6.

Table P.1—Typical Protective Signals

	Monitored Point/Parameter	Signal Type	Sensor	Alarm	Shutdown
1	High Gas Discharge Temperature (at Each Cylinder)	Temperature	RTD or Thermocouple	R	
2	Low Frame Lube Oil Pressure	Pressure	Pressure Transmitter	R	R
3	Low Frame Lube Oil Level (at Sump)	Level	Level Transmitter	R	
4	Cylinder Lubricator System Failure	Cycle Counter, Pressure	Pressure Transmitter	R	
5	High Lube Oil Console Oil Filter Differential Pressure	Differential Pressure	Differential Pressure Transmitter	R	
6	High Frame Vibration	Vibration	Accelerometer	R	R
7	High Liquid Level in Suction Separator/Scrubber	Level	Level Transmitter	R	R
8	Jacket Coolant System Failure	Temperature	RTD or Thermocouple	R	
9	Flywheel or Crankshaft	Speed/Rotational Reference	Magnetic Pickup or Displacement Probe	R	
10	Crosshead Guide	Vibration	Accelerometer	R	R
11	Cylinder	Vibration	Accelerometer	R	
12	Cylinder Valves	Vibration	Accelerometer	O	O
13	Cylinder End(s) Pressure Tap	Pressure	Dynamic Pressure Transducer	R	R
14	Piston Rod Drop	Distance	Displacement Probe	R	R
15	Main Driver	Vibration	Accelerometer/ Velocity Sensor or Displacement Probe	R	R
16	Process Gas Stage Differential Pressure	Differential Pressure	Differential Pressure Transmitter	R	R
17	Low Suction Pressure/ High Differential Pressure	Pressure/ Differential Pressure	Pressure/Differential Pressure Transmitter	O	O
18	High Rod Loads (Calculated)	Pressure	Dynamic Pressure Transducer	O	O
19	Loss of Rod Reversal (Calculated)	Pressure	Dynamic Pressure Transducer	O	O
20	High Main Bearing Temperatures	Temperature	RTD or Thermocouple	O	O
21	High Crankpin Bearing Temperatures	Temperature	RTD or Thermocouple	O	O
22	High Crosshead Pin Bearing Temperatures	Temperature	RTD or Thermocouple	O	O
23	Motor Hood—Heat Exchanger Leak Detection—High (TEWAC Motors)	Level	Level Transmitter	O	O

Table P.2—Typical Condition Signals

	Monitored Point/Parameter	Signal Type	Sensor	Recommended or Optional
Process Parameters				
1	Suction Pressure—Nozzle at Each Stage	Pressure	Pressure Transmitter	R
2	Discharge Pressure—Nozzle at Each Stage	Pressure	Pressure Transmitter	R
3	Suction to Discharge Nozzle Differential Pressure at Each Stage	Differential Pressure	Differential Pressure Transmitter	O
4	Suction Temperature—Nozzle at Each Cylinder	Temperature	RTD or Thermocouple	R
5	Discharge Temperature—Nozzle at Each Cylinder	Temperature	RTD or Thermocouple	R
6	Initial Inlet or Final Discharge Total Flow	Flow	Flow Transmitter	O
7	Separator/Scrubber	Level	Level Transmitter	R
Frame and Running Gear				
8	Frame Lube Oil Level at Sump	Level	Level Transmitter	R
9	Oil Header Supply Temperature	Temperature	RTD or Thermocouple	R
Valves and Pressure Packing				
10	Valve Cover Temperature—Suction	Temperature	RTD or Thermocouple	R
11	Valve Cover Temperature—Discharge	Temperature	RTD or Thermocouple	R
12	Pressure Packing Temperature	Temperature	RTD or Thermocouple	R
13	Pressure Packing Vent Temperature	Temperature	RTD or Thermocouple	R
14	Pressure Packing Vent Flow	Flow	Flow Transmitter	O
15	Distance Piece Pressure	Pressure	Pressure Transmitter	O
16	Buffer Gas Supply Pressure	Pressure	Pressure Transmitter	R
17	Buffer Gas Supply Flow	Flow	Flow Transmitter	O
Main Drive Motor				
18	Motor Stator Temperature	Temperature	RTD	R
19	Motor Bearing(s) Temperature	Temperature	RTD or Thermocouple	R
20	Motor Hood—Filter Differential Pressure (WPII Motors)	Differential Pressure	Differential Pressure Transmitter	R
21	Motor Hood—Heat Exchanger Leak Detection (TEWAC Motors)	Level	Moisture Sensor or Level Transmitter	O
22	Motor Hood—Cooling Water Flow (TEWAC Motors)	Flow	Flow Transmitter	O
23	Motor Internal Temperature	Temperature	Temperature Transmitter	R
24	Motor Enclosure (Purged/Pressurized Motors)	Pressure	Purge Controller (System Specific)	O
25	Motor Run Time	Time	Motor Protection Module	R
26	Motor Amps	Amps	Current Transformer	R
Frame Lube Oil System				
27	Oil Pump Supply Temperature	Temperature	RTD or Thermocouple	R
28	Heat Exchanger—Water Inlet Temperature	Temperature	RTD or Thermocouple	O

Table P.2—Typical Condition Signals (Continued)

	Monitored Point/Parameter	Signal Type	Sensor	Recommended or Optional
29	Heat Exchanger—Water Outlet Temperature	Temperature	RTD or Thermocouple	O
30	Lube Oil Motor Run Status	Status	Signal from Motor Control System or DCS	O
Jacket Water System (If Applicable)				
31	Tempered Water Temperature at Main Supply Header	Temperature	RTD or Thermocouple	R
32	Return Line Temperature at Each Cylinder	Temperature	RTD or Thermocouple	R
33	Tempered Water System Flow Rate	Flow	Flow Transmitter	R
34	Nontempered Water Temperature to Pressure Packing	Temperature	RTD or Thermocouple	R
35	Return Line Temperature from Each Packing	Temperature	RTD or Thermocouple	O
36	Reservoir Level	Level	Level Transmitter	O
37	Reservoir Temperature	Temperature	RTD or Thermocouple	O
38	Jacket Water Motor Run Status	Status	Signal from Motor Control System or DCS	O
Cylinder Lubricator				
39	Cylinder Lubricator—Pump to Point	Pressure	Pressure Transmitter	R
40	Cylinder Lubricator—Divider Block	Count	Cycle Count from Limit Switch	R
41	Lubricator Flow	Derived Flow	Cycle Monitor System	O
42	Lubricator Cycle Time	Time	Cycle Monitor System	O
43	Lubricator Reservoir Level	Level	Level Transmitter	R
Hydraulic Valve Control System (If Applicable)				
44	Hydraulic Oil Supply Header Pressure	Pressure	Pressure Transmitter	R
45	Hydraulic Oil Supply Header Temperature	Temperature	RTD or Thermocouple	R
46	Filter Differential Pressure	Differential Pressure	Differential Pressure Transmitter	R
47	Hydraulic Oil Return Header Pressure	Pressure	Pressure Transmitter	R
48	Reservoir Level	Level	Level Transmitter	R
49	Reservoir Temperature	Temperature	RTD or Thermocouple	R
50	Motor Run Status	Status	Signal from Motor Control System or DCS	O

Annex Q
(informative)

Considerations when Using Wireless Connectivity Technologies

Q.1 Introduction

The benefits provided by monitoring plant assets and processes have been well documented. Traditionally, these monitoring tasks have been accomplished using permanently installed devices that were hardwired back to a monitoring and/or control system. Because of the cost and process disruption associated with the installation and maintenance of these conventional wired systems, their implementation has frequently been limited to only the most critical applications. The advent of new technologies for wireless data transmission, however, has reduced both the cost and complexity of monitoring systems. This minimizes or may even eliminate the disruption to the process. These factors combined create the opportunity for wider scale implementation.

Q.2 Scope

Q.2.1 The scope of this informative annex is to provide a framework for evaluating the suitability of proper wireless connectivity for condition monitoring of machinery assets such as motors, pumps, fans, compressors, and others.

Q.2.2 As discussed in Informative Annex N of this standard, potential applications for wireless connectivity may include predictive maintenance, optimization, and/or preventative maintenance. In addition to condition monitoring, wireless connectivity may be used in a broad range of applications including: monitoring and display of process parameters as well as certain configuration or adjustment tasks. It should be noted, however, that the use of wireless connectivity for machinery protection functions is explicitly restricted by this standard. As always, it remains the responsibility of the end user to determine whether wireless connectivity is appropriate for any specific application.

Q.2.3 For the purposes of this document, “wireless connectivity” refers to a method for transmitting signals or data via a radio communication between fixed assets. Applications for wireless connectivity involving mobile assets and/or mobile personnel are not currently addressed here.

NOTE Wireless connectivity is not compliant with the API 670 standard for any application involving machine protection monitoring or machine shutdown. See the normative section of this standard for a specific listing of restrictions and prohibitions.

Q.3 Considerations

The following questions may be of assistance in determining whether wireless monitoring is suitable for a specific application.

a) What initial and future cost savings might be achieved by avoiding the installation and maintenance of conduit and wiring?

b) What data collection interval is required to detect the expected faults?

c) What is the volume of data being transmitted in each instance?

d) What wireless topology configuration offers the best level of redundancy for the application under consideration?

e) What ability does the proposed wireless system have to adapt to changes in the environment (e.g. moving assets, momentary obstructions, etc.)

f) What future needs might occur to expand the monitoring system and how scalable is the wireless solution?

Various aspects of these topics are outlined in this annex.

Q.4 Conflicting Comments

In case of conflict between this informative annex and an inquiry or order, the information included in the order shall govern. Similarly, in the case of conflict between this informative annex and the normative section of this standard, the information included in the normative section shall govern.

Q.5 Functional Requirements

Q.5.1 General

The following functional requirements directly impact the wireless system characteristics and shall be considered during design.

NOTE It remains the responsibility of the end user to determine whether wireless connectivity is appropriate for their application.

Q.5.2 Bandwidth

Q.5.2.1 Bandwidth is an important factor to consider when evaluating the suitability of wireless communication for a given function. For the purposes of this document, high bandwidth network and low bandwidth network should be defined as follows:

a) high bandwidth network refers to the IEEE 802.11 standard, *Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Local Area Networks,* also known as WiFi;

b) low bandwidth network refers to the IEEE 802.15.4 standard, *Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)*, also known as device-to-device networks.

Q.5.2.2 Low bandwidth networks are frequently implemented in applications that involve polling one or more sensors at a defined interval. The intermittent nature of the monitoring task is more compatible with the concept of a self-powered device. Currently, most wireless devices employ batteries although other options for powering the device are discussed later in this document. By limiting monitoring to a regular interval, it becomes practical to implement power management techniques that can substantially extend the usable life of the device without having to update the power source.

Q.5.2.3 When high bandwidth networks are implemented, however, it is generally impractical to use anything except conventional hardwired line power for the device and its network communications. This allows the device to sustain a persistent communication link that is continuously broadcasting data back to the host system.

Q.5.3 Data Type

A key design parameter when considering wireless connectivity is the type of data to be transmitted. A static (i.e. nonwaveform) data sample will typically consists of only a few bytes. In contrast, a dynamic (i.e. waveform) data sample may require considerably more bytes, depending on resolution. As such, dynamic data may require more bandwidth.

Q.5.4 Desired Update Rate

Another key design parameter is related to network latency, or the data update rate requirement. Some applications require continuous data, while others require much less frequent updates—perhaps hourly or daily. The maximum data update rate on a given wireless network is a function of the available bandwidth, and the priority allocated to the condition monitoring data.

Q.5.5 Criticality of Application

The importance of receiving the monitored data at the expected time shall be evaluated and understood. This will dictate network availability and reliability requirements, which are dependent upon the following:

a) the network's ability to respond to interference resulting from changes in the environment (e.g. relocation of assets, momentary obstructions);

b) the network's bandwidth available to transmit data;

c) the selection of an appropriate protocol.

Q.5.6 Data Security

The data security level is an important parameter that shall be determined. In some applications, government regulations and/or IT department policies may influence whether a particular protocol is suitable or not. As such, the following issues should be considered when evaluating the security of a given wireless connectivity protocol:

a) authentication of sender and receiver;

b) verification that data is valid;

c) encryption of data;

d) reliable management of encryption key;

e) ability to maneuver around a blocked communications space (e.g. antijamming).

Q.5.7 Interoperability

Industry standard protocols should be deployed to ensure interoperability of different wireless systems. Multiple industry standards are available or are under development from industry groups and standards organizations.

Q.5.8 Power Management

Q.5.8.1 General

Power management is a key issue when selecting and installing a wireless communication link. The determination of the best power source shall be evaluated in conjunction with multiple other criteria including the network type, desired update rate, and the criticality of the function. The following discussion outlines several of the more common approaches in use at the time of writing. It should be noted that the power source shall be self-contained in order to create a truly wireless system.

Q.5.8.2 Line Power

AC line power (115/240 Vac) or DC power may be available near the location where a wireless device, router, or gateway is being installed. While this implementation provides virtually unlimited power for both measurement and broadcasting, the device is no longer considered fully "wireless." Also, AC line power will typically need to be housed in conduit, driving up installation costs and complexity. DC power sources may not have the same requirement.

Q.5.8.3 Batteries/Power Modules

Battery power offers the attraction of eliminating the power cable while providing a completely self-contained device. This makes installation both simpler and less expensive. One of the primary limitations with battery operation is that the duty cycles for both measurement and broadcasting should be carefully calculated to achieve an acceptable operating life. Regardless of the theoretical battery life, eventually the battery will need to be replaced. Random failure can also occur. Therefore, a strategy needs to be defined to track the remaining life of installed batteries along with a plan for when and how to replace and dispose of depleted batteries.

Q.5.8.4 Solar

For outdoor applications, solar cells may offer the potential for extended power. Potential drawbacks, however, include the higher initial implementation cost as well as the requirement to regularly inspect the panels for damage due to wind, hail, rain, or other factors.

Q.5.8.5 Energy Harvesting

Energy harvesting techniques may be used in combination with or without battery back-up to provide power. Techniques include recovering energy from ambient vibration or thermal gradients.

Q.6 Wireless System Architecture

Q.6.1 System Components

The system components of a wireless monitoring system may include the following.

a) *Wireless Sensors*—A wireless sensors is a device that measures some quantifiable aspect of the process or the condition of the assets involved in executing the process and then transmits one or more of these values wireless to another device in the wireless network.

b) *Wireless “Smart” Sensors*—“Smart” sensors also return information about the sensor itself such as remaining battery life, sensor calibration and/or drift values, and error messages about sensor operation or performance.

c) *Receivers*—A receiver is a terminating device that is hardwired back to the system host. Its function is to receive the signals broadcast by one or more wireless devices and then to report them back to the host for evaluation and/or storage.

d) *Gateways*—A gateway is a terminating device similar to a receiver, with the added capability that it can both receive information from and broadcast information to one or more wireless devices.

e) *Routers*—A router is a device that is used to span distances longer than inherently possible using other system components. The router wirelessly receives information from one device and then wirelessly rebroadcasts it to another device.

f) *Router/Gateways*—A router/gateway combines the functionality of the router and the gateway. An option to power the device allows extended system range. The router receives information from a sensor or from another router wirelessly and then wirelessly rebroadcasts it to another router or sends it via the built-in gateway to a wired network.

Q.6.2 Point-to-Point Communication

Q.6.2.1 General

The simplest form of wireless connectivity is a direct point-to-point link between an individual transmitter and receiver.

Q.6.2.2 Unidirectional

A unidirectional broadcast of information is focused over a specific path, and it can typically be accomplished with lower power requirements and/or greater bandwidth compared to omnidirectional devices (see Figure Q.1). However, because they are to a large extent dependent on line-of-sight, they can be more vulnerable to interference.

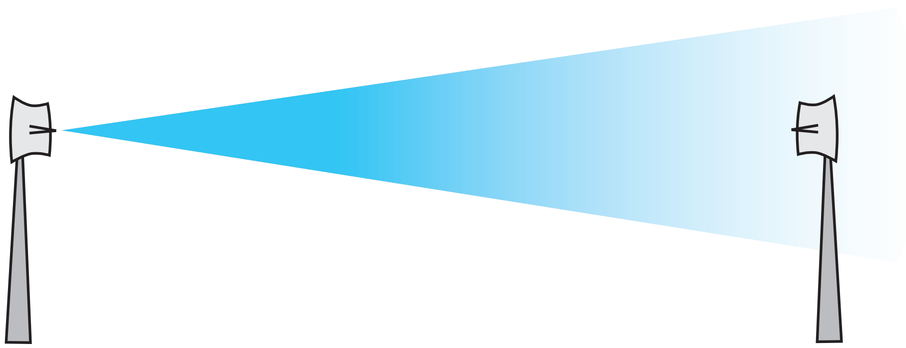


Figure Q.1—Unidirectional Wireless Communication

Q.6.2.3 Omnidirectional

An omnidirectional broadcast of information goes out equally in all directions establishing a broadcast radius for each device (see Figure Q.2). This type of link is still dependent on line-of-sight, but it is less sensitive to the specific location of the other device.

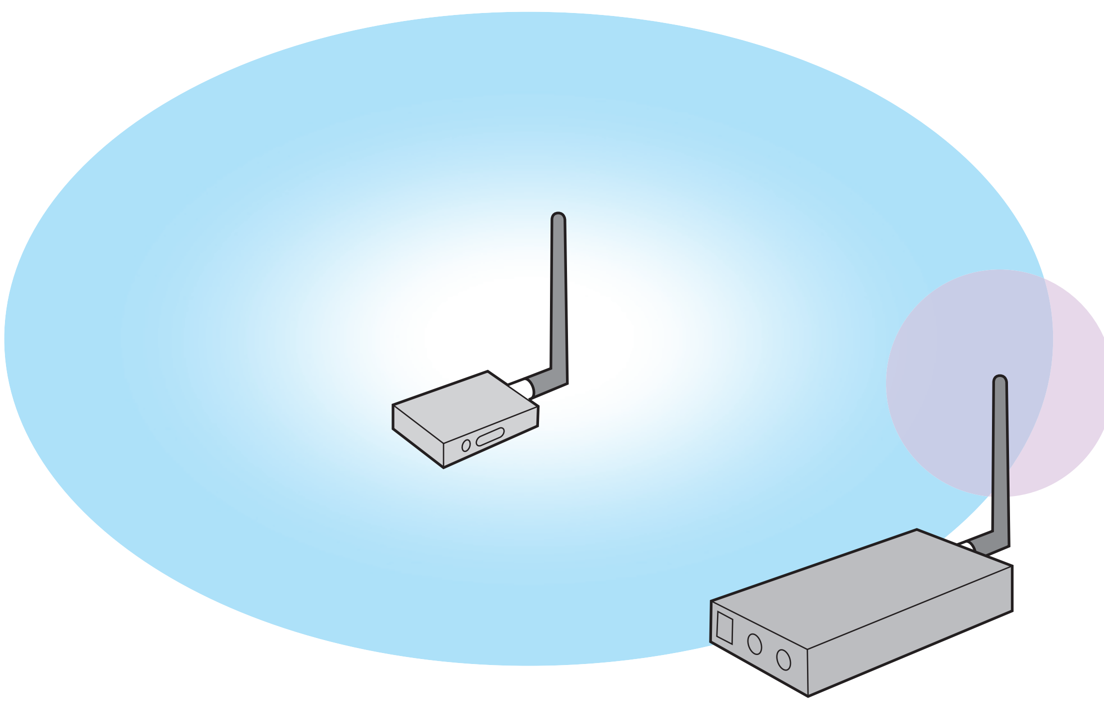


Figure Q.2—Omnidirectional Wireless Communication

Q.6.3 Network Topology

Q.6.3.1 General

The topography of a wireless network is simply the way network components are arranged. It describes the physical layout of devices, routers, and gateways, as well as the data flow paths between them. Three of the most common wireless topologies for in-plant applications are star, mesh, and cluster tree. By understanding the strengths and weaknesses of these and other configurations, it is possible to determine which topology is best for a specific application. The various components of a wireless communication system are then configured into a network using one of several different network architectures.

Q.6.3.2 "Star" Array

Devices configured in a star topology communicate only with a receiving station (e.g. receiver or gateway) and not with each other; therefore, each device shall be located within the broadcast radius of the receiving station. A drawback of the star topology (see Figure Q.3) is that communication can be disrupted if the line-of-sight transmission path between a device and the receiving station is obstructed. Transmissions to or from that device will be lost until the obstruction is removed.

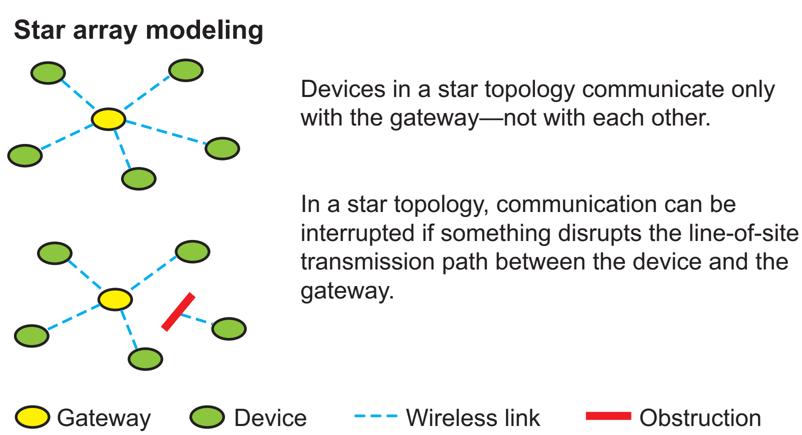


Figure Q.3—Star Topology Network

Q.6.3.3 Mesh Network

Q.6.3.3.1 A wireless network utilizing a time synchronous mesh protocol offers significant advantages over the conventional star array discussed above. In this configuration, each device is capable of communicating not only with a receiving station but also with any other device within range. With this approach, the network can extend virtually indefinitely as long as there are neighboring devices that can relay data.

Q.6.3.3.2 Mesh networks (see Figure Q.4) are referred to as self-organizing because the components in the system communicate with each other to determine the optimum path for data transmission across the network.

Q.6.3.3.3 Self-organizing mesh networks also offer the capability for the network to be self-healing. If, after an effective network configuration has been determined, an individual link becomes obstructed, the system automatically attempts to reconfigure the network to redirect data packets via alternative paths. This same principle is employed when a device on the network is relocated, when a device fails, or when localized radio frequency interference occurs such as that caused by motors starting up or the strike of an arc welder. This capability dramatically increases the robustness and reliability of wireless networks.

NOTE One or more scheduled transmissions may be lost during the healing period.

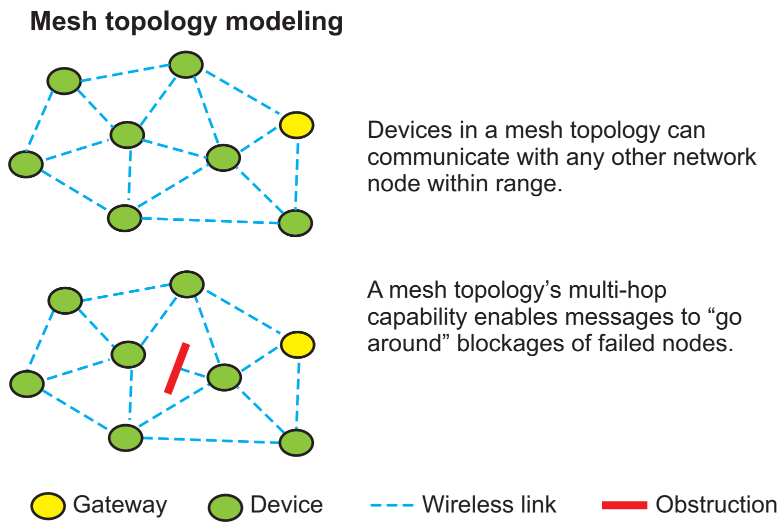


Figure Q.4—Mesh Topology Network

Q.6.3.4 Cluster Tree Topology

A cluster tree topology (see Figure Q.5) is a hybrid where wireless devices in a star topology are clustered around the gateway in a mesh topology. This blends the advantages of both topologies: potentially low power consumption of the "star" portions of the cluster tree and extended range and fault tolerance of the "mesh" portions. However, a site survey is required to make sure the end devices in each star have a clear line-of-sight to their assigned router as there is no backup path for each device to communicate with its assigned router if there are changes or interference.

Q.6.4 Wireless Network Topology and Device Management Tools

When establishing the preferred implementation of wireless connectivity for a specific application, it is advisable to model the network topology prior to installing any devices.

Following deployment of devices, a device management tool should be used to determine the reliability of the Wireless network by logging communication and sensor faults. It should be possible to replace wireless sensors without restarting the other network modules.

Q.7 Bidirectional Communication

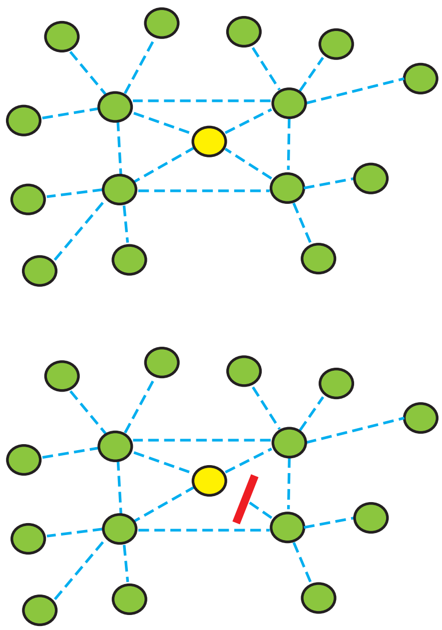
Q.7.1 General

A wireless communication link can communicate in one or both directions.

Q.7.2 Report Device Values

The most basic functionality of a wireless communication link is to report back information. In this mode, the remote device is typically configured using a field communicator or other programming device. Once commissioned, it will measure and report back values as outlined in its configuration until such time as the configuration is altered via a field communicator or other programming device residing on the wired side of the network.

Cluster tree topology modeling



A cluster tree topology combines point-to-point communications from device to router with point-to-point multipoint communications between routers and gateways.

If the direct, single-hop transmission path between a router and gateway is interrupted, messages can multi-hop through other routers to reach their destination.

Figure Q.5—Cluster Tree Topology Network

Q.7.3 Acquisition Requests

To extract the maximum benefit from a wireless communication link, it is recommended to consider bidirectional communication. This allows the system to broadcast commands to the device as well as having the device broadcast measured parameters back to the system. In this type of implementation, the device can be remotely retasked by utilizing configuration software typically located on the plant monitoring network.

Q.7.4 On-demand Acquisition

In addition to altering the configuration of the device to modify its normal monitoring tasks, it is desirable to be able to generate a remote request for on-demand acquisition. In this mode, the remote device is temporarily tasked with a special or extended monitoring activity. This ability can be helpful during transitional periods such as commissioning or maintenance of plant assets or installation of new plant assets. It may also be beneficial during process disruptions.

Q.8 Industrial Wireless Standards

Electronic communications standards are developed under the auspices of IEEE to ensure efficient communications among or between devices and networks. Protocols used in wireless (and wired) industrial communications shall be consistent with IEEE standards. These standards help ensure—but do not guarantee—compatibility of communications systems. Standard protocols can guarantee communication compatibility, but not data compatibility.

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