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FOR

MEASUREMENT OF LIQUID HYDROCARBONS BY TURBINE METER SYSTEMS

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MEASUREMENT OF LIQUID HYDROCARBONS BY TURBINE METER SYSTEMS

FOREWORD

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INTRODUCTION

This standard has been prepared as a guide for design, installation, and operation of turbine meter systems in liquid hydrocarbon service. Primary emphasis is placed on the turbine meter and its accessories, but many of the concepts and innovations described are adaptable to other devices concerned with the volumetric measurement of liquid hydrocarbons. For details of specific equipment previously documented by the American Petroleum Institute, refer to *API Standard 1101: Measurement of Petroleum Liquid Hydrocarbons by Positive Displacement Meter (ANSI Z11.170-1965), API Standard 2531: Mechanical Displacement Meter Provers (ANSI Z11.171-1965)*, and *API RP 2533: Metering Viscous Hydrocarbons*.

The turbine meter has been recognized as an acceptable quantity measuring device for many years; however, its usefulness to the oil industry has become apparent only during the past decade. Improvements to the measuring element and the ever-increasing rates of flow jointly account for vigorous interest in a compact, mechanically simple, long-lived liquid meter.

The turbine meter consists of a rotor or propeller which senses the linear velocity of a flowing stream. The moving liquid imparts a rotational or tangential velocity to the rotor which is proportional to rate of flow. The movement of the rotor is detected by mechanical, optical, or electrical means and is recorded on an appropriate readout device.

Turbine meters have typical performance characteristics that are best described by meter performance curves (see Appendix A, Fig. A-1). Principal parameters, such as flow rangeability within tolerable limits of linearity and repeatability, are related to fluid properties (i.e., density, viscosity, and vapor pressure) and to mechanical meter characteristics (i.e., rotor mass, bearing friction, magnetic drag, and wetted area relating to fluid imposed drag on the turbine or rotor).

The combination of fluid properties and mechanical meter characteristics produces a deviation from an ideal of meter linearity. Accordingly, turbine meter selection should be governed by an assessment of the characteristic curves of the proposed turbine meter.

Turbine meters selected for the noted operating criteria, when properly installed and carefully proved, will perform continuous measurement with a minimum of inaccuracy.

Mechanically, turbine meters are well able to withstand the rigors imposed by severe flow overranging accompanied by extreme flow pulsations. However, they are susceptible to damage from extraneous solids entrained in the liquid, particularly if these are of significant size, but finely divided solid particles generally pass through the meter without causing damage. In rare cases where large objects become lodged in the meter, even to the point of stalling a rotor, fluid blockage with resultant overpressurization of the system is not likely to occur.

The turbine meter system effectively measures liquid volume, but it does not offer a universal solution to every flow measurement problem – at least not at this time. This standard describes how a turbine meter system works and endeavors to give the reader a technical background to better understand the details of its operation. The descriptive material is incorporated in the appendixes of the standard. A major effort has been made to describe techniques and effects that contribute to the successful attainment of a high degree of metering accuracy and reliability within a demonstrated turbine meter system capability. Achievement of this goal is the responsibility of the equipment manufacturer; but to an even greater degree, it becomes the responsibility of the ultimate user. Should the highest level of precision be unnecessary or unjustifiable, a number of the recommendations in this standard may be compromised. Certain of the recommendations should never be ignored. Therefore, those which, if not followed, would adversely influence the satisfactory performance of a turbine meter system have included the compulsary verb form *shall*. The word *should* indicates provisions which are advisory but not required in every instance. The word *may* indicates provisions which are optional and, consequently, are at the discretion of the user.

The intent of this standard is to give the reader the most complete and comprehensive information currently available. Because of the lack of experience in a number of operational areas, revisions to this standard will be required at some time in the future.

Sufficient leeway has been incorporated into this text so that experimentation and equipment improvements may be encouraged without creating undue hardship, while at the same time a procedure may be implemented to satisfactorily deal with each new application.

MEASUREMENT OF PETROLEUM LIQUID HYDROCARBONS

BY TURBINE METER SYSTEMS

SECTION I—INSTALLATION

SCOPE

1001 This section covers the selection and installation of turbine meters, their accessories, and associated equipment.

CHOICE OF METERS AND AUXILIARY EQUIPMENT

1002 All types of measurement systems must meet certain fundamental requirements. These include accurate proving facilities; adequate protective devices such as strainers, relief valves, and air or vapor eliminators; and dependable pressure and flow controls. A further fundamental requirement is that the proving of a turbine meter should, to the greatest possible extent, duplicate the normal operating conditions of the meter.

1003 Turbine meter installations include the measuring element and its readout devices. These components of a meter system may be installed either remotely from one another or integrally.

1004 Criteria that should be considered in the selection of a meter and its auxiliary equipment are:

a. Types of liquids the meter will measure, including viscosity, gravity ranges, vapor pressure, and corrosivity.

b. Range of operating flow rates and type of flow — continuous or intermittent.

c. Performance characteristics required for the application (see Appendix A, Fig. A-1).

d. Range of operating pressures and maximum allowable pressure loss through the meter when run at the maximum anticipated flow rate.

e. Temperature range within which meter will operate and the applicability of automatic temperature compensation.

f. Space available for meter installation.

g. Quantity and size of abrasive and corrosive contaminants that may be carried in the liquid stream.

h. Types of readout devices or indicating systems to be employed and signal preamplification, if required (see Appendix A, Fig. A-2)

i. Compatibility of auxiliary meter readout equipment and flow rate indication, if included in the system; ease and method of meter registration adjustment, if desired.

j. Power supply requirements for continuous or intermittent meter readout.

k. Electrical code requirements.

l. Type and method of proving to be employed.

m. Maintenance methods and cost.

n. Class and type of end connections.

1005 Automatic temperature compensators and gravity selectors, if installed, shall be chosen to respond to operating conditions within volume and temperature measurement tolerances required (see Appendix B, Par. B-23 through B-26).

1006 Valves that may affect measurement accuracy in a measurement system shall be capable of rapid yet smooth opening and closing. They shall provide a positive shutoff and should be equipped with a telltale bleed.

1007 Any bypass around a meter or battery of meters shall be provided with a blind or a positive shutoff device equipped with a telltale bleed.

1008 Spring-loaded or self-closing valves shall be of such design that they will not open to admit air when subjected to hydraulic hammering or to vacuum conditions.

1009 For intermittent flow service, valves shall be of the fast-acting, shock-free type to minimize the adverse effects of low flow rates when starting and stopping liquid movement.

FLOW STRAIGHTENING

1010 Turbine meter performance can be affected by liquid swirl and nonuniform velocity profiles induced by upstream piping configuration, valves, pumps, joint misalignment, and welding projections, icicles, or other obstructions. For these reasons, flow straightening is an important aspect in the design of the meter run.

1011 Flow straightening is an established common practice. It is accomplished by the use of sufficient lengths of straight pipe or a combination of straight pipe and straightening vanes employed in the meter run to condition the fluid flow immediately upstream and downstream of the turbine meter.

1012 When only straight pipe is employed, the fluid shear or internal friction between the fluid and pipe wall must accomplish flow straightening. Consideration should be given to computing the upstream pipe length in accordance with Appendix C.

1013 When straight pipe with an internal element is employed in either the upstream or downstream portions of the meter run, the internal elements usually consist of a cluster of tubes, vanes, or equivalent devices inserted longitudinally in the section of straight pipe (see Appendix A, Fig. A-3). Such straightening elements effectively assist in the flow straightening and conditioning requirement. Where this type of flow straightener is used upstream of the meter, the total straightening section is approximately 10 pipe diameters long and usually incorporates an upstream mixing chamber 2 to 3 pipe diameters long ahead of the straightening vanes, a straightening vane assembly 2 to 3 pipe diameters long, and a terminal mixing chamber – immediately before entry into the meter – approximately 5 pipe diameters long. Internal element flow straighteners may also consist of a series of perforated plates or wire mesh screens to accomplish the desired results, but these forms are less commonly used.

1014 Proper design and construction of the straightening vane assembly used in an internal element flow straightening section is important to ensure that swirl shall not be generated by this assembly, thus negating the function of the entire flow straightening section. It is recommended that:

a. Elements be manufactured from thin-wall tubing or light-gage metal vanes suitably smoothed on the leading and trailing edges.

b. No less than four tubes or vanes be employed.

c. In cross-section, the design be as nearly uniform and symmetrical as possible.

d. In straightening vane assemblies constructed of tube bundles, the L/D ratio of each individual tube of the bundle be at least 10 to 1 (see Appendix A, Fig. A-3, Item *d*).

e. Design and construction be sufficiently rugged to resist distortion or movement at high flow rates.

f. Alignment of straightening elements be parallel to the pipe axis.

g. General internal construction be clean and free of welding icicles, burrs, and oversize weld beads.

1015 In addition to the use of flow straightening sections, there shall be a maximum separation of the meter run from pumps, elbows, valves, and other fittings which may induce swirl. Flanges and gaskets shall be internally aligned.

PIPING INSTALLATION

1016 A schematic diagram for a turbine meter in liquid hydrocarbon service is presented in Fig. I-1 to provide a working basis for the design of a turbine meter run and related equipment. Certain items may or may not be required for a particular installation.

1017 Turbine meters normally are installed in a horizontal position. The manufacturer should be consulted if space limitations dictate another attitude.

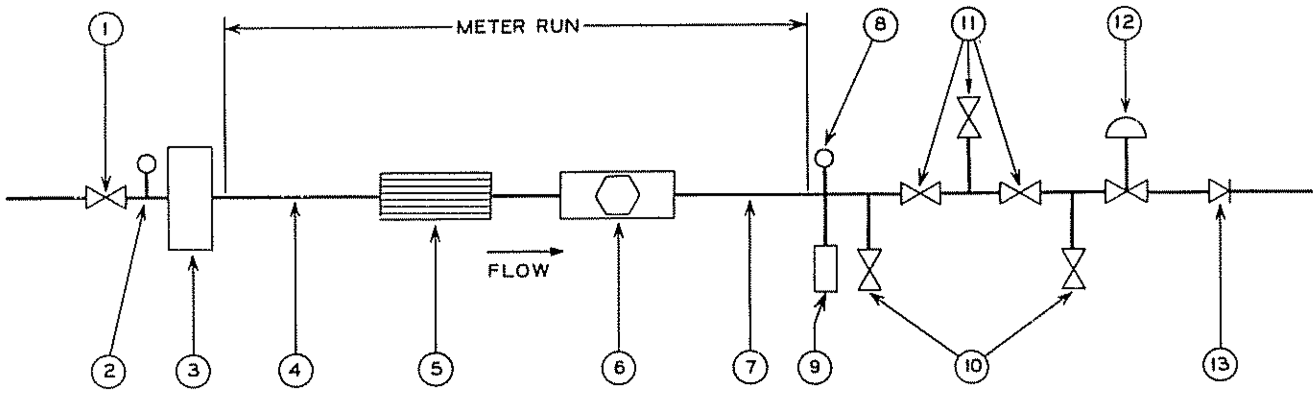
1018 Where the flow range is too great for any one meter or for its proving, the installation of a bank of meters in parallel may be used. If meters are operated in parallel, each individual meter shall be equipped with a readout device.

1019 Meters shall be installed in such a manner that they will not be subjected to undue strain and vibration. Provision should be made to minimize meter distortion caused by piping expansion and contraction.

1020 Measurement systems shall be installed in a manner which will result in maximum dependable operating life. In certain services, this requires that protective devices be installed to remove abrasive from the liquid or other entrained particles which could stop or cause premature wear of the metering mechanism. If strainers, filters, sediment traps, settling tanks, water absorbents, a combination of these items, or other suitable devices are required, they shall be sized and installed to prevent flashing of the liquid prior to its passage through the meter. These protective devices may be installed singly or in interchangeable battery form, depending on the importance of continuous service. In services where the liquid is clean or the installed meter does not require or warrant protection, elimination of protective devices may be desirable.

1021 Measurement systems shall be installed so that the meter will operate within its viscosity, pressure, temperature, and flow range.

1022 Meters shall be adequately protected from pressure pulsations and excessive surges as well as excessive pressures caused by thermal expansion of the liquid. This may require the installation of surge tanks, expansion chambers, relief valves, and/or other protective devices.



Legend:

1. Block valve
2. Pressure gage (optional)
3. Filter, air eliminator, and/or strainer (as required)
4. Straight pipe (Appendix C)
5. Straightening vane (as required)
6. Turbine meter
7. Straight pipe (with straightening vane, as required)
8. Pressure gage
9. Thermometer
10. Proving connections (should be downstream of meter run)
11. Valve with double-block and bleed or valves with a telltale bleed
12. Control valve (as required)
13. Check valve (as required)

NOTE: All sections of line which may be blocked between valves should have provisions for pressure relief.

FIG. I-1--Turbine Meter System Schematic Diagram.

1023 When an automatic device, such as a flow-limiting valve or restricting orifice, is required to prevent flows in excess of the maximum rated capacity of the meter, it should be installed downstream from the meter run, whenever possible. If a pressure-reducing device is used on the inlet side of the meter, it shall be installed as far upstream from the meter run as possible. It shall be adjusted so that sufficient pressure will be maintained on the outlet side of the meter run to prevent any vaporization of the metered liquid.

1024 Any condition that tends to contribute to the release of vapor from the liquid shall be avoided by proper system design and by operation of the turbine meter within the combined rated flow range and back-pressure requirement. Flow separation and vaporization in the turbine meter are best controlled by operating the meter within the manufacturer's rated range and at a minimum back pressure, *BP*, immediately downstream of the meter, equivalent to twice the pressure drop, $\Delta P'$, across the meter at maximum flow plus 1.25 times the vapor pressure at maximum operating temperature ($BP = 2\Delta P' + 1.25$ absolute vapor pressure). Location of the meter run should determine the need for incorporating or considering a back-pressure valve or a pressure-reducing valve (see Appendix A, Fig. A-4.)

1025 Each meter shall be installed in such a manner as to prevent passage of air or vapor through it. In some cases, it may be necessary to install vapor elimination equipment ahead of the meter to accomplish this objective. When air elimination equipment is used, the air-release vents shall be adequately piped to an appropriate and safe location.

1026 Meters and piping shall be installed so that accidental drainage or vaporization of liquid is avoided. The piping shall have no high points or pockets where air or vapor might accumulate and be carried through the meter by the added turbulence resulting from increased flow rate. The entire installation shall be such that air will not be introduced into the system through holes, leaky valves, piping, glands of pump shafts, or connecting lines.

1027 Lines from the meter to the prover shall be installed so that the possibility of trapping air or vapor is minimized. This can sometimes be accomplished by sloping the meter calibration line upward to the prover. The distance between a meter and its prover should be as short as possible. The size of the connecting lines shall be large enough to prevent a significant decrease in flow rate during proving.

1028 Piping shall be designed so that the volume of liquid retained in the piping from the meter to the point of delivery into the prover shall be the same at the end of each delivery.

1029 Special consideration should be given to locating each meter, its auxiliary equipment and piping to minimize commingling if different liquids are handled through them.

1030 Most turbine meters will register flow in both directions. When this is not desired, flow reversal should be prevented.

1031 A reliable thermometer, or a thermometer well permitting the use of a temperature-measuring device, shall be installed immediately downstream of a meter run to permit determination of metered stream temperatures. The thermometer specifications and installation details are the same as those prescribed for prover tank thermometers in API Standard 1101, Par. 2014 through 2017. If temperature-compensated meters are used, a suitable means for checking the operation of the compensating devices is required.

1032 A reliable recording or indicating pressure gage of suitable range and accuracy shall be installed in or near the inlet or outlet of every meter run where determination of the meter case pressure is required (see API Standard 1101, Par. 2018).

1033 Measurement systems shall be provided with either manual or automatic means to permit proving the meter under the same conditions of flow rate, pressure, temperature, and liquid characteristics as exist during the normal operation of the meter.

ELECTRICAL INSTALLATION

1034 Every turbine meter has the capability of producing an electrical output which may be used to operate a wide variety of readout devices. Many of the methods employed to produce this electrical signal are described and discussed in Appendix D.

1035 The output signal of a turbine meter may be considered to be a train of electrical pulses, with each pulse representing a discrete volume of liquid throughput. Two approaches have been taken to produce electrical pulses. The first method directly translates the mechanical motion of the rotor, or metering element, into electrical energy through magnetic induction. The second method requires that external electrical power be supplied to a proximity or photosensing device, which may be externally shaft driven, but does not actually generate electrical energy by the rotational movement of the metering element. In the first method, generally both pulse frequency and magnitude are proportional to flow rate. In the second method, only pulse frequency is proportional to flow rate since output voltage is virtually of constant magnitude.

1036 Most electronic readout devices condition a wave form for the counting of each pulse or measure the meter output frequency for flow rate indication. Signal strength may be of a relatively low-power level; thus installation conditions should be dealt with as necessary. Recommendations described herein will be applicable to all turbine meters but will be required for low-power-level signals.

1037 A turbine meter system is composed of a minimum of three components: the meter (pulse producer), the transmission line (pulse carrier), and the readout device (pulse counter and display). It is essential that these three components be compatible with one another and that each of the components meet the recommended specifications of the turbine meter manufacturer.

1038 Every turbine meter system must meet two general requirements to operate properly. First, the readout device shall be sufficiently sensitive to respond to every pulse produced by the turbine meter throughout its operating range. Second, the signal-to-noise ratio shall be sufficiently high so that spurious electrical signals will not influence the readout device.

1039 The signal output characteristics (see Appendix A, Fig. A-1) normally associated with turbine meters and their influence upon proper system operation are:

a. Pulse amplitude: Each readout device directly connected to the meter (pulse producer) must have proper sensitivity to operate with the pulse amplitudes generated over the rated operating flow range.

b. Pulse frequency: The maximum frequency limit of each readout device must be equal to, or greater than, the maximum output frequency of the turbine meter at its highest expected flow rate.

c. Pulse width: The duration of every pulse generated by a turbine meter must be long enough to be detected by the readout device.

d. Pulse shape: A sine wave output cannot be used to operate a readout device requiring a square wave input without adding proper preamplification and shaping.

1040 Great care must be exercised in the electrical transmission installation so that signal amplitude from the turbine meter can be maintained at the highest level while reducing the magnitude of the noise signals, whenever possible. Optimum signal level is maintained by:

a. Limiting the length of transmission line from the meter to the readout devices.

b. Observing the importance of proper impedance selection (see Appendix D, Par. D-10).

c. Using the best available and technically compatible signal transmission cable (see Par. 1042).

d. Introducing a signal preamplifier into the transmission system at the turbine meter, if transmission distance or manufacturer's requirements so dictate.

e. Ensuring that supply voltages to preamplifiers and constant amplitude pulse generating systems are of proper magnitude and do not exceed noise level or ripple requirements as specified by the equipment manufacturer.

f. Ensuring that all pickup coils are securely mounted and properly located.

g. Periodically inspecting and cleaning all terminals, connectors, connector pins, and wiring junctions.

h. Replacing components which, through deterioration, result in a weakened signal.

1041 Electrical noise may be the most troublesome element in turbine meter systems employing low-level signal outputs. Even high-level output systems require that proper steps be taken to eliminate false noise signals. Noise signals are superimposed on meter signals by three distinct methods: electromagnetic induction, electrostatic or capacitive coupling, and electrical conduction (see Appendix D).

1042 As the operation of the turbine meter system is the responsibility of the user, proper initial installation is of utmost importance. Great care must be exercised in effectively isolating the system from external electrical influences. To minimize unwanted noise signals, proper grounding and shielding of meter and prover detector transmission cables are mandatory. Major considerations are:

a. A shielded and jacketed signal cable shall be used. The recommendation of the meter manufacturer should be followed in selecting the proper number and size of conductors, the type and material used in the shield, the outer insulation requirements, and other considerations. At a minimum, twisted two or three conductor, stranded No. 18 to No. 22 Awg, braided shield, plastic or oil-resistant rubber insulated transmission wire is suggested.

b. The shield of the transmission cable shall be grounded only at one point to prevent the formation of a ground loop; grounding of the shield only at the readout is recommended.

c. A continuous run of transmission cable should be used, wherever possible. Where splices are absolutely necessary and totally unavoidable, continuity of the shield must be assured. The splice shall be wrapped with electrical tape to prevent inadvertent grounding.

d. When multiple readout devices are used and wired in parallel, shielded cable shall be used for interconnecting wiring. Grounding of each shield shall be at the same point.

e. The transmission line should be installed in a metallic conduit, wherever possible. This usually provides additional shielding against unwanted electromagnetic radiation.

f. The transmission line shall not share a conduit with anything other than shielded cables. The conduit may contain shielded cables from multiple turbine meters, detector switches operating a prover totalizer gating circuit, direct-current bridge-type temperature sensors, and the like. However, if the maximum electrical power – in terms of microwatts, milliwatts, or watts – carried by any one transmission cable is 10 or more times greater than the minimum power carried by any meter signal transmission cable, separate conduits should be provided.

g. Routing of the transmission line and conduit should not closely parallel conduits carrying power to electric motors, starters, and the like. Areas of stray electromagnetic radiation, such as motor starters and underground sump pumps, should be avoided.

h. When transmission cable is run in ducts, as well as inside control cabinets, every attempt should be made to keep the shielded cable bundle intact and separate from other conductors. When two or more transmission cables constitute a bundle, they should be twisted together so that neither transmission cable is subjected to heavy noise induction.

i. Band-pass filters and isolation transformers may be used as a method of attenuating spurious noise signals. These should be installed in accordance with the manufacturer's instructions.

j. Under conditions of extreme noise, it may be necessary to isolate the turbine meter from the piping system by installing gaskets and insulated bolt bushings and washers. This may be particularly necessary when cathodic protection rectifiers used for corrosion control are being interrupted during test periods.

k. Spare transmission cable run in a conduit with an active transmission line shall have the shield grounded at the same single point as the active line.

1043 The following formulas are suggested as a guide for approximating maximum transmission line length for any given turbine meter system. In areas where little noise is anticipated, these formulas are considered conservative.

a. For pickup output voltage of less than 1.000 v (1,000 mv) at minimum expected flow rates:

Transmission run length, in feet = mv (rms) output x 1.0 ft per mv.

b. For pickup output voltage from 1.000 v to 5.000 v (5,000 mv) at minimum expected flow rates:

Transmission run length, in feet = mv (rms) output x 1.5 ft per mv.

c. For output voltages of 5 v or more, including outputs from meter-mounted preamplifiers, at minimum expected flow rates:

Transmission run length, in feet = mv (rms) output x 2.0 ft per mv.

d. For frequency-modulated, wave absorption or other special pickup devices, the advice of the manufacturer should be followed.

e. In items (*a*) and (*b*) where the desired run length is greater than the values derived, it is recommended that a preamplifier be added to the transmission system. It should be mounted as close as practicable to the turbine meter.

1044 Special consideration must be given to the selection of readout devices for the turbine meter system. Initial considerations should include:

a. Environment: Ascertain the need for explosionproof, weatherproof, corrosionproof, or fungusproof devices. Evaluate the high- and low-temperature extremes.

b. Maintenance: Provide easy access for maintenance and obtain recommended spare parts for items that have a predictable failure rate such as nixie tubes and electromechanical registers. Alternative or backup devices and standby power supplies are suggested where continuous service is mandatory.

c. Compatibility: All readout devices shall be compatible with the turbine meter and the transmission system to which they are connected. In those instances where a readout device is a link in a data transmission system, special care must be taken to assure that it has an output compatible with the data transmission system.

1045 Readout devices are available to perform a number of different functions. They should be selected to assure readout in the desired form. The limits of each individual readout device should be noted so that it may perform optimally within the turbine meter system. Readout devices may be either analog or digital. Both devices are electronic units which sense turbine meter frequency but not voltage magnitude.

1046 Analog devices are used extensively in flow rate indication, multiple stream blending, process control, and similar applications. An analog output is obtained by conversion of frequency to a proportional direct-current or voltage. The proportional direct-current output usually displayed on a visual scale may be used to drive separate control circuits. Readout may be scaled in units of flow rate, such as barrels per hour, liters per minute, or percent of flow. The overall accuracy of an analog readout device varies between 0.1 to 2.0 percent of full-scale indication.

1047 Highest precision is obtained with a digital readout device which totalizes the individual pulses produced by the turbine meter throughout an interval to an accuracy of plus or minus one count. In its simplest form, the digital readout device indicates either total pulses received or pulses received per unit time from the meter. The basic pulse counter or pulse totalizer does not necessarily display flow or volumetric units until after calculations are performed with the appropriate factors to convert the accumulated pulses into units of volume or flow rate.

1048 A variety of electronic digital readout devices are available for use with turbine meter systems. The following outline indicates the types and classes in general use and includes devices for special applications. Readout resolution will be plus or minus one indicated unit; thus, the value of this unit of registration can be of extreme importance.

A. Pulse Totalizing Counters

Those which indicate every pulse received from the turbine meter and afford the highest degree of readout resolution. They usually incorporate two or more illuminated display units. These counters may be classified as follows:

a. Prover counters: Those in which a special gating circuit in the counter is triggered by switches in the proving system to start and stop the counter.

b. Digital flow rate indicators: Those in which a gating circuit in the counter starts and stops the counter over a preselected time interval. A fixed preselected time base provides uncorrected flow rate indication; a variable preselected time interval can provide corrected digital flow rate indication, since meter, temperature, and pressure factors may be incorporated, and corrected for, in the time base.

B. Computing Counters

Those in which readout is in terms of the number of multiples or pulses received by the counter. The readout of these counters may be by means of illuminated display but is normally accomplished with an electromechanical or mechanical register which requires that the incoming pulses be divided. These counters may be classified as follows:

a. Fixed ratio computing counters: Those in which the incoming pulses are normally divided by 10, 100, 1,000, etc., so that display is 1/10, 1/100, 1/1,000, etc., of the total pulses received. Some of these units are designed to divide by a fixed number other than a multiple of 10.

b. Variable ratio computing counters: Those in which the incoming pulses are divided (or multiplied and then divided) by variable divide circuits. The divide circuits are selected manually by means of external knobs or patch boards based on turbine meter pulses per volume under specific operating conditions. The selection is made on pulses per volume or the reciprocal of pulses per volume depending on the counter manufacturer. Readout is in direct units for a specific operating condition. Such counters may incorporate the meter, temperature, and pressure corrections into the variable ratio and read out the true net volume, where desired.

c. Quantity predetermining counters: Those in which contact closure is provided after a preset quantity is delivered. Quantity may be in terms of pulses for some devices or may be in terms of volume if the device also performs the function of a variable ratio computing counter. Repeat quantity measurement and batch quantity plus total quantity measurement options are available for some units.

d. Stepper-motor-driven counters: Those in which readout is by a mechanical counter driven by a stepper motor. The stepper motor is driven by an electronic converter. The converter divides total pulse input; stepper motor revolutions are directly related to converter pulse input.

C. Add-Subtract Counters

Those which discriminate between forward and reverse flow. Increasing registration results from flow in one direction, whereas flow in the opposite direction causes the unit to subtract digits.

1049 A totalizer is usually equipped with some form of visual display and may include a printing mechanism. The most commonly used methods for translating pulse information into numerical display, within certain limitations, are as follows:

a. Electromechanical registers: The first register wheel is driven by a relay and rachet assembly; most units have a maximum counting rate of 50 counts per second. The numerals are either displayed or printed.

b. Stepper-motor-driven registers and ticket printers: Incremental rotation or a step per input pulse is used to revolve the register wheels. The numerals on the wheels can be read either directly or printed on paper.

c. Electronic or illuminated display: The display usually takes the form of inert-gas-filled tubes or backlighted projection units that are capable of counting at a frequency higher than that encountered in turbine meter systems. Neither unit is capable of printing, although photographic recording systems are available.

d. Memory or storage registers: The registers display or print information only on command. This method is used for remote inquiry and data transmission, although a visual display may appear locally in illuminated form.

SECTION II—METER PROVING PROCEDURES

SCOPE

2001 This section covers proving procedures applicable to turbine meters in liquid hydrocarbon service. Meter proving procedures stated in API Standard 1101, Sect. III, and API Standard 2531, Sect. VIII, are applicable.

2002 Either of the two types of provers, volumetric or gravimetric, described in API Standard 1101, Sect. II, can be used to prove turbine meters. However, turbine meters, particularly in larger sizes, are capable of measurement at very high flow rates; therefore reference volumes should be designed especially for such use.

2003 With the volumetric or gravimetric method, either of the following types of provers can be employed:

a. Open provers: Those which are open to the atmosphere through unrestricted openings.

b. Closed provers: Those in which a pressure greater than atmospheric is or may be maintained during the meter-proving operations.

PROVISIONS

2004 A turbine meter should be proved in its permanent installation at the expected operating rates of flow, pressure, temperature, and viscosity on the liquid which it will measure in normal operation. When a meter is used to measure more than one product or grade of crude oil, the meter shall be proved on each such product or grade of crude oil which shows a significant difference in physical properties affecting overall measurement accuracy. The meter shall be oriented in the same position during proving as during operation so that an unusual bearing load does not adversely affect the performance.

2005 Turbine meters can be proved satisfactorily by either the standing start-and-stop or the running start-and-stop method, as described in API Standard 1101, Sect. III. The standing start-and-stop method is considered less desirable; however, if used, the following precautions must be observed:

a. The prover volume shall be sufficient for at least 1 min of flow at the maximum anticipated flow rate.

b. The start-stop valve is to be opened to the proving rate in as short a time as possible, but not so quickly as to cause shock or cavitation to occur within the meter run.

c. The valve must be closed quickly but without causing shock or damage to the meter or the manifolding. Reversed or oscillating flow must not occur when the valve is closed.

2006 The running start-and-stop method of proving is recommended for a turbine meter. In most applications, this method is considered the best universal technique for either the volumetric or gravimetric proving of a turbine meter.

2007 All turbine meters are capable of producing an electrical pulse output for proving. Highest readout precision is obtained with a pulse totalizing counter which accumulates the pulses generated by the meter during a proving run to within plus or minus one pulse. Such a proving counter will not necessarily readout directly into units of volume without a mathematical correction to convert indicated pulses to the units desired (see Par. 1048).

2008 For meter proving, the following points should be observed:

a. Prover counter shall display a minimum of five digits to within plus or minus one count.

b. Total count for a proving run should not be less than 10,000 discrete pulses and preferable more so that counter error of plus or minus one count will become ± 0.01 percent or less.

c. Input sensitivity shall be sufficient to have the capability of counting every input pulse of the amplitude generated by the meter at the proving rate.

d. Counter shall be equipped with a manual or electrical reset.

e. Prover counter shall have provisions for external start-and-stop through a gating circuit which is actuated by contact closures or equivalent. Mechanical latching relays are undesirable.

f. An acceptable form of pulse-doubling for a prover counter employs the technique of counting positive and negative pulses, or the equivalent, of the generated signal. Simple electronic frequency multiplication is not acceptable.

2009 The minimum proof volume should be such that a total of at least 10,000 pulses, preferably more, will be counted by a normal proving counter. Thus, if a meter produces 1,000 pulses per barrel, and a standard proving counter is used, the 10 bbl of volume will be needed; if the same meter is used with a doubling prover counter (see Par. 2008, Item *f*), then not less than 5 bbl of volume will normally be satisfactory.

2010 It is suggested that a minimum of five runs be made for each proof and the results averaged. This is particularly necessary in the early life or breaking-in period of a measurement system and after an overhaul (see Sect. IV, Par. 4006). Once the performance of a measurement system has been established, check provings of less than five runs may be considered satisfactory. Maintaining system factor control charts (see Appendix B) facilitates determining what is acceptable in the matter of repeatability and sets "action limits" within which all system factors can be deemed satisfactory.

MECHANICAL DISPLACEMENT PROVERS

2011 The preferred method of proving utilizes the mechanical displacement meter prover, described in API Standard 2531, and offers the following advantages for turbine meters:

a. Meters can be proved under actual operating conditions, at actual pressures, and on fluids which might otherwise be difficult to handle.

b. Stable-state flow conditions may be maintained throughout the meter proving run.

c. Time required for proving can be greatly reduced.

d. Combined elements of meter and prover lend themselves to automatic as well as remote operation.

MASTER METER PROVERS

A. General

2012 Any meter or battery of meters having an established master factor, which is maintained whenever the master meter is relocated, may be used to prove a turbine meter by the running start-stop method (see Appendix B, Par. B-5, and B-25, Example 1). The master factor shall be established with the same liquid and under similar operating conditions as the meter to be proven. Master meter proving is less precise than proving against a known volume, and reasonable results can be obtained only if extreme care is taken to guard against experimental errors. The most commonly encountered experimental errors are:

a. Inaccuracies in thermometry (see Appendix B), particularly when observed temperatures are "rounded off" to the nearest degree, can introduce errors of magnitude far greater than any other likely source. Therefore, it is recommended that the master meter, or meters, and the run of the turbine meter being proven be located as close together as is practicable. When this is done, temperatures and pressures may be assumed equal for purposes of volume correlation between the master meter and meter to be proven. When it is not possible to assure that the master meter and the meter to be proven are operating under nearly identical pressure and temperature conditions, then pressure and temperature shall be observed with the greatest possible precision, and appropriate corrections made.

b. Preferably, both master unit and meter to be proved should be equipped with prover counters connected in such a way that all counters can be started and stopped simultaneously.

c. Master meters should be installed downstream of the meter to be proved, whenever possible. In particular, the temporary installation of a master meter upstream of the meter to be proved may adversely affect the desired long-term performance of the turbine meter system.

B. Positive Displacement Meters with Master Factors

2013 If positive displacement meters with master factors are utilized, it is suggested that the units be equipped with pulse generators, or similar devices, capable of producing a high-resolution output. When so equipped, the reference volume for proof becomes the same as that described in Par. 2009, except that the meter producing the least number of pulses per unit volume shall be used to determine the minimum required length of run.

2014 Less sophisticated methods may be used to prove a turbine meter with positive displacement meters having master factors providing the following conditions are understood and acceptable:

a. Error resulting from reading the displacement meter register "on the fly" may cause an excessive scatter in readings.

b. Rate changes occurring during the proving cycle may cause the turbine meter to respond more rapidly than the displacement meter, resulting in possible scatter.

c. When a pulse generating device is not used with the positive displacement meter, the minimum run length should equal the least reading of the register times 10,000. That is, if the register can be consistently and precisely read to the nearest 1/10 bbl, the minimum proof volume would be 1,000 bbl; if to the nearest 1/100 bbl, the proof volume would be 100 bbl. If proof runs conducted in this manner are not satisfactory, a series of runs of larger volumes should be made until repeatability is satisfactory to all parties concerned.

C. Turbine Meters with Master Factors

2015 A turbine meter with a master factor may be utilized as a proving standard provided the following precautions are observed:

a. Both units have sufficient flow-straightening devices so that one unit does not adversely affect the performance of the other.

b. Electronic readouts are all properly grounded at the same single point.

c. Both counters are noisefree under zero flow and "open gate" conditions.

d. Both counters are started and stopped by the same initiating signal or contact closure. (Internal electronic gating circuits are recommended.)

VERIFICATION OF COUNTER REGISTRATION

2016 When a prover counter is used to determine a factor that is to be applied to a computing counter, the result of this factor as applied to, or performed by, the computing counter must be verified. This may be accomplished by operating both counters simultaneously for a period of time to assure readout resolution of one part in 10,000 for both counters. The appropriate factors to arrive at net volume for each counter are applied and these two net volumes compared. The difference between the two readout systems should be minimal and, if warranted, the cause of error should be determined and corrected. The registration of the computing counter may be verified by the proving counter. This is accomplished by gating the prover counter when it displays a nominal 10,000 pulses and by gating the checked counter when a whole digit is exactly displayed on the latter.

SECTION III–EFFECTS OF TEMPERATURE AND PRESSURE VARIATION ON METER MEASUREMENT

SCOPE

3001 This section describes the physical effects on a meter as the result of changing its internal liquid temperature or pressure, or both. These effects include mathematical corrections by which the quantity flowing through a meter may be determined for a condition of temperature and pressure other than that at which the meter was proved.

PROVISIONS

3002 Turbine meters tend to be viscosity sensitive. While for an individual meter it may be possible to develop an empirical equation whereby the meter factor at y centistokes can be computed if the meter factors are known at x and z centistokes, this cannot be done for turbine meters as a class. Although the viscosity of liquids is related to temperature, the sensitivity of turbine meters to viscosity variation implies a corresponding sensitivity to temperature changes which cannot be expressed in a quantitative way. However, the viscosity sensitivity of turbine meters is usually negligible at lower viscosities, and so for these liquids the unknown component is negligible. For these liquids, the temperature effects on turbine meters may be calculated by the methods described in this section and in Appendixes E and F.

Turbine meters also tend to be nonlinear over a flow rate range, but a general expression has not been derived to predict this deviation. As pressure changes normally result in changes in flow rate, a generally applicable expression for the pressure sensitivity of turbine meters cannot be isolated. However, the meter factor curve on low-viscosity liquids may be nearly linear over a wide range of flow rate, and in these conditions the pressure effects on turbine meters may be calculated by the methods described in this section and in Appendixes E and F.

The procedures described in this section and in Appendixes E and F are therefore applicable to turbine meters which are measuring lower viscosity liquids, but it is difficult to specify the lower viscosity limit. On light products and gasolines with a viscosity less than 1 cSt at 60 F, the procedures should predict the behavior of most turbine meters. As the liquid viscosity increases above 1 cSt at 60 F, the behavior may start to deviate because of the increasing sensitivity of the meter to viscosity and flow rate. As deviation depends on the size and the type of meter, it is impossible to stipulate an exact viscosity range. The procedures described should be applied only after accurate measurement has been achieved and all parties to the transaction are agreeable to the procedure. *For liquids more viscous than 15 cSt at 60 F, and for all crude oils, the mathematical treatment does not apply and is not recommended. Turbine meters for these liquids should always be proved at the metering conditions.*

3003 A limited change in the temperature or pressure of the more commonly metered light, refined liquids usually does not give rise to sufficient changes in viscosity, density, lubricity, etc., to cause significant effect on turbine meter accuracy. However, this is not necessarily the case with heavier hydrocarbon liquids or lighter liquefied gases. Therefore, when metering liquids where slight changes in physical properties from temperature and pressure are known to have little effect on meter performance, and where it is necessary to operate a meter (without reproving) at some pressure and/or temperature other than that at which the meter was proved, use of the mathematical corrections in this section will enable the maintenance of a reasonable degree of metering accuracy. The derivations of the correction factors C_{tsmpc} and C_{psmpc} which follow are based on metal properties and include a number of assumptions detailed in Appendix E. Although these are logically sound, it is preferable to prove a turbine meter at conditions which are identical to its expected operating conditions, whenever possible. The use of the mathematical correction procedure to get from one set of temperature and pressure conditions to another should be employed only with the knowledge that:

1. Potential error increases as the magnitude of the difference between the proving and operating conditions increases.

2. Meter proof establishes the accuracy of the meter at the proving conditions and, in so doing, physically accounts for all variables at those conditions.

DESCRIPTION OF EFFECTS

3004 The effect of changing the flow rate, viscosity, density, lubricity, and related variables in an operating meter cannot be conveniently expressed mathematically for all makes and sizes of meters. If only the variables temperature and pressure are isolated from those nonuniform effects, and if limited temperature and pressure changes have little or no significant effect on flow rate, viscosity, density, and so forth, it may be concluded that changing the temperature or pressure inside a meter changes only the physical dimensions of the liquid and the meter. The extent of these latter effects may be obtained from tables for the liquid and calculated for the meter. Changing the temperature of the metered liquid within a meter from that which existed during proof results in: 1, changes in the relative volume of the liquid, C_{tlm}, in accordance with *ASTM D 1250: Standard Petroleum Measurement Tables*; and, 2, changes in the physical dimensions of the meter due to thermal expansion or contraction of its housing and parts, C_{tsm}, as calculated in Par. 3010 and Appendix E. Changing the pressure of the metered liquid within a meter from that which existed during proof results in: 3, changes in the relative volume of the liquid due to compressibility, C_{plm}, in accordance with API Standard 1101, Table II; and, 4, changes in the physical dimensions of the meter arising from mechanical strain of its housing due to pressure, C_{psm}, as calculated in Par. 3016 and Appendix E. Only the foregoing four effects can be expressed in proper mathematical terms to permit reasonable measurement accuracy under varying operating conditions of temperature and pressure for all meters. Even then, the reliability of this mathematical technique diminishes as the extent of temperature and pressure variations increase.

BASIC FORMULA FOR METER FACTOR

3005 Insofar as flow rate, viscosity, density, lubricity, frictional resistance, and related variables are considered, a meter factor is valid only so long as the meter is measuring under the conditions of the variables which existed when the meter was proved and for which the meter factor was established. Therefore, reference conditions of a meter factor, insofar as the variables are concerned, are based on the conditions which existed when the meter was proved; the meter factor is applicable only so long as those proving conditions exist.

3006 With respect to the variables of temperature and pressure only, the reference conditions of a meter factor may be selected at any desired values. The most common technique (an alternative is described in Appendix F) uses reference conditions of temperature and pressure as follows:

Liquid temperature in the meter	= 60 F.
Liquid pressure in the meter	= pressure in meter at time of proving.
Meter housing temperature	= temperature of meter at time of proving.
Pressure in the meter housing	= pressure in meter at time of proving.

3007 The general formula for determining a meter factor having reference conditions as described in Par. 3006 is:

$$MF_{60\&pc} = \frac{(BV)\,(C_{tlp60})\,(C_{plpr})\,(C_{tsp60})\,(C_{pspr})}{(MR)\,(C_{tlm60})\,(C_{plmpc})\,(C_{tsmpc})\,(C_{psmpc})}$$

However, the preceding formula is greatly simplified *in normal applications* so that:

$$MF_{60\&pc} = \frac{(BV)\,(C_{plpr})\,(C_{tsp60})\,(C_{pspr})}{(MR)}$$

This assumes that a turbine meter is proven:

1. *Against a mechanical displacement meter prover; and*
2. *Operated at the conditions which existed at the time of proving.*

Then, the liquid temperature in the meter is identical to that in the prover so that C_{tlp60} and C_{tlm60} have an identical mathematical value and are self-cancelling. Also, the last three factors shown in the denominator are all unity (1.0000) since they are mathematically incorporated into the meter factor for identical operating and proving conditions.

In summary, the remainder of Sect. III may be ignored if the aforementioned two conditions are met in a turbine meter installation.

NOMENCLATURE

$MF_{60\&pc}$ = meter factor having reference conditions of temperature and pressure as follows:

Liquid temperature = 60 F.
Liquid pressure = pressure in meter at proving condition.
Meter temperature = temperature of meter at proving condition.
Meter pressure = pressure in meter at proving condition.

BV = base volume of mechanical displacement meter prover or prover tank when its internal pressure is 0 psig and its temperature is 60 F.

C_{tlp60} = correction factor for the temperature of the liquid in the prover to reduce the volume of liquid observed in or displaced from the prover at prover temperature to its equivalent volume at 60 F. To obtain C_{tlp60}, see ASTM D 1250.

C_{plpr} = correction factor for the pressure on the liquid in the prover to reduce the volume of liquid observed in or displaced from the prover at prover pressure to its equivalent volume at the reference pressure of measurement. The reference pressure of measurement for liquids having vapor pressures equal to or less than atmospheric is 0 psig. C_{plpr} is derived from the formula

$$V_l = (V_h)\left[\frac{1-(P_l-P_e)(F)}{1-(P_h-P_e)(F)}\right]$$

for converting a volume at a high pressure to its equivalent volume at a lower pressure (see API Standard 1101, Par. 3046). If

$$C_{plpr} = \frac{V_l}{V_h}$$

then,

$$C_{plpr} = \frac{1-(P_r-P_e)(F)}{1-(P_h-P_e)(F)}$$

Where:

P_r = reference pressure of measurement in pounds per square inch gage normally considered as 0 psig for liquids having vapor pressures less than atmospheric.

P_e = equilibrium pressure in pounds per square inch gage for the liquid in the prover, normally considered 0 psig for liquids having vapor pressures less than atmospheric.

F = compressibility factor in pounds per square inch for the liquid in the prover at prover temperature from API Standard 1101, Fig. 33 or Table II.

P_h = average pressure on liquid in the prover, in pounds per square inch gage.

C_{tsp60} = correction factor for the temperature of the steel in the prover to reduce the base volume of the prover at 60 F to its equivalent volume at the observed prover temperature. C_{tsp60} for mechanical displacement provers is obtained from API Standard 2531, Appendix B, Table I. C_{tsp60} for prover tanks is obtained from the C_{ts} values in API Standard 1101, Par. 3045.

C_{pspr} = correction factor for the pressure on the steel of the prover to reduce the base volume of the prover at 0 psig to its equivalent volume at the observed prover pressure. C_{pspr} for mechanical displacement provers is obtained from API Standard 2531, Appendix B, Table II. C_{pspr} for prover tanks is obtained as described in API Standard 1101, Par. 2116 through 2122. C_{pspr} for all meter provers operating at atmospheric pressure is equal to 1.0000.

MR = meter registration, closing meter reading minus opening meter reading during a meter proof or during any measuring period.

C_{tlm60} = correction factor for the temperature of the liquid in the meter to reduce the meter registration volume at the observed meter temperature to its equivalent *volume at 60 F*. C_{tlm60} is obtained from ASTM D 1250.

C_{plmpc} = correction factor for the pressure on the liquid in the meter to reduce the meter registration volume at meter operating pressure to the equivalent volume at meter proving pressure. When a meter is being proved, the proving and operating pressure are the same and C_{plmpc} is equal to 1.0000. When a meter is operated at the pressure at which it was proved, C_{plmpc} is equal to 1.0000. C_{plmpc} is obtained by use of the following formula (see API Standard 1101, Par. 3046):

$$C_{plmpc} = \frac{1-(P_p-P_{ep})(F_p)}{1-(P_o-P_{eo})(F_o)}$$

Where:

P_p = internal meter case pressure during meter proving, in pounds per square inch gage.

P_{ep} = equilibrium pressure at proving temperature.

F_p = compressibility factor per pounds per square inch for the liquid involved at the proving temperature from API Standard 1101, Fig. 33 or Table II.

P_o = internal meter case pressure during meter operation, in pounds per square inch gage. When proving a meter, $P_p = P_o$.

P_{eo} = equilibrium pressure at operating temperature. When proving a meter, $P_{ep} = P_{eo}$.

F_o = compressibility factor per pound per square inch for the metered liquid at the operating temperature from API Standard 1101, Fig. 33 or Table II. When proving a meter, $F_p = F_o$.

$C_{tsm\,pc}$ = correction factor for the temperature effect on the steel of the meter to reduce the meter registration for the size of the meter at operating temperature to the equivalent registration which would occur if the size of the meter was equal to that at which it was proved. When a meter is being proved, the proving and operating temperature are the same, and $C_{tsm\,pc}$ is equal to 1.0000. When a meter is operated at the temperature at which it was proved, $C_{tsm\,pc}$ is equal to 1.0000. To obtain $C_{tsm\,pc}$, see Appendix E, Fig. E-2.

$C_{psm\,pc}$ = correction factor for the pressure effect on the steel of a single-case meter to reduce the meter registration for the size of the meter at operating pressure to the equivalent registration which would occur if the size of the meter was equal to that at which it was proved. When a meter is being proved, the proving and operating pressure are the same, and $C_{psm\,pc}$ is equal to 1.0000. When a meter is operated at the pressure at which it was proved, $C_{psm\,pc}$ is equal to 1.0000. To obtain $C_{psm\,pc}$, see Appendix E, Fig. E-3.

BASIC FORMULA FOR METER THROUGHPUT

3008 The general formula for determining the throughput of a meter at any temperature or pressure, or both, using the meter factor from Par. 3007 is:

$$Q_{60\&r} = (MR)\,(MF_{60\&pc})\,(C_{tlm\,60})\,(C_{plm\,pc})\,(C_{tsm\,pc})\,(C_{psm\,pc})$$

Where:

$Q_{60\&r}$ = actual net quantity of liquid at 60 F and reference pressure passed through a meter as determined by the reference pressure used in determining C_{plp} and C_{psp}. Reference pressure is taken as 0 psig for liquids having vapor pressures equal to or less than atmospheric.

All other quantities of this equation are as defined in Par. 3007.

When a nontemperature compensated meter is operated at the temperature and pressure at which it was proved, $C_{plm\,pc}$, $C_{tsm\,pc}$, and $C_{psm\,pc}$ are equal to 1.0000 and the formula for throughput is simplified to:

$$Q_{60\&r} = (MR)\,(MF_{60\&pc})\,(C_{tlm\,60})$$

TEMPERATURE EFFECTS

Liquid

3009 The liquid correction factor $C_{tlm\,60}$ to reduce the meter registration at the observed meter temperature to its equivalent volume at 60 F is determined from ASTM D 1250. The reference condition of the meter factor, insofar as temperature of the liquid is concerned, is established at 60 F.

Meter Case and Parts

3010 The steel correction factor $C_{tsm\,pc}$ to reduce the meter registration for the size of the meter at operating temperature to the equivalent registration which would occur if the size of the meter was equal to that at which it was proved is determined by the formula:

$$C_{tsmpc} = [1 + (E_H)\,(\Delta t_{pc})]^2\,[1 + (E_R)\,(\Delta t_{pc})]$$

Where:

$C_{tsm\,pc}$ = correction factor to reduce the meter registration for the size of the meter at operating temperature to the equivalent registration which would occur if the size of the meter was equal to that at which it was proved.

E_H = mean linear coefficient of thermal expansion of the meter housing material.*

Δt_{pc} = meter operating temperature minus meter proving temperature. The algebraic sign of Δt_{pc} must be observed. If the operating temperature is less than the proving temperature, a negative value results which must be used in subsequent calculations.

E_R = mean linear coefficient of thermal expansion of the rotor material.*

The reference condition of the meter factor, insofar as temperature of the meter is concerned, is established as being the temperature of the meter at proving conditions.

This equation is discussed in Appendix E. To simplify the use of the equation, Fig. E-2 showing temperature correction factor, C_{tsm}, versus differential temperature, Δt, for the most frequently used housing and rotor materials appears in Appendix E. Enter Fig. E-2 with Δt on the abscissa and proceed vertically to the line representing the materials of which the meter is constructed. If the proving temperature was higher than the operating temperature, read C_{tsm} on the right-hand ordinate; if the proving temperature is lower than the operating temperature, read C_{tsm} on the left-hand ordinate.

3011 *Example I*

A turbine meter is proved at a flow rate of 3,000 BPH on 61 deg API motor-grade gasoline at a flowing temperature of 50 F and a pressure of 100 psig and has a meter factor of 1.0073. Later the meter is still measuring the same gasoline at 3,000 BPH and 100 psig but the flowing temperature has changed to 75 F. The meter housing is Type 304 stainless steel, and the rotor is Type 416 stainless steel. To determine C_{tsmpc}, solve by formula in Par. 3010:

E_H = (9.6) (10^{-6}) in. per in. per deg F for Type 304 stainless steel.

E_R = (5.5) (10^{-6}) in. per in. per deg F for Type 416 stainless steel.

$$\Delta t_{pc} = 75 - 50 = +25$$

$$C_{tsmpc} = \{1 + [(9.6)(10^{-6})](25)\}^2\{1 + [(5.5)(10^{-6})](25)\}$$

$$C_{tsmpc} = (1.000239)^2(1.0001375) = 1.0006$$

* The mean linear coefficients of thermal expansion per degree fahrenheit for the temperature range of 32 F to 212 F for the following stainless steels are referenced in *Materials Eng* 66 [5] Reinhold Publishing Corp., New York, Oct. (1967), and also appear in *Properties Data*, Republic Steel Corp., Cleveland, Ohio, as follows:

AISI Types 302 and 304 stainless steels	(9.6) (10^{-6})
AISI Type 316 stainless steel	(8.9) (10^{-6})
AISI Types 403, 410, and 416 stainless steels	(5.5) (10^{-6})
AISI Type 430 stainless steel	(5.8) (10^{-6})

The mean coefficient of thermal expansion per degree fahrenheit for the temperature range of 32 F to 212 F for mild steel is referenced in *ASTM D 1750: Standard Tables for Positive Displacement Meter Prover Tanks*, as follows:

AISI Type 1020 steel	(6.2) (10^{-6})

Solving by use of Fig. E-2, the operating temperature is greater than the proving temperature and the value of C_{tsmpc} is obtained from the scale on the left ordinate:

$$\Delta t_{pc} = 75 - 50 = +25$$

C_{tsmpc} = 1.0006 (rounded off from Fig. E-2).

3012 *Example II*

A turbine meter is proved at a flow rate of 1,800 BPH on a distillate at a flowing temperature of 68 F and a pressure of 62 psig and has a meter factor of 0.9982. Later the meter is still measuring the same distillate at 1,800 BPH and 62 psig but the temperature has changed to 34 F. The meter housing is Type 304 stainless steel, and the rotor is Type 416 stainless steel. To determine C_{tsmpc}, solve by formula in Par. 3010:

E_H = (9.6) (10^{-6}) in. per in. per deg F for Type 304 stainless steel.

E_R = (5.5) (10^{-6}) in. per in. per deg F for Type 416 stainless steel.

$$\Delta t_{pc} = 34 - 68 = -34$$

$$C_{tsmpc} = \{1 + [(9.6)(10^{-6})](-34)\}^2\{1 + [(5.5)(10^{-6})](-34)\}$$

$$C_{tsmpc} = (0.9996736)^2(0.999813) = 0.9992$$

Solving by the use of Fig. E-2, the operating temperature is less than the proving temperature and the value of C_{tsmpc} is obtained from the scale on the right ordinate of the graph.

$$\Delta t_{pc} = 34 - 68 = -34$$

C_{tsmpc} = 0.9992 (rounded off from Fig. E-2).

PRESSURE EFFECTS

Liquid

3013 The liquid correction factor C_{plmpc} to reduce the meter registration at the observed operating pressure to its equivalent volume at the pressure at which the meter was proved is obtained from information in API Standard 1101, Par. 3046 and Par. 4008 through 4011 and is determined as follows:

$$C_{plmpc} = \frac{1 - (P_p - P_{cp})(F_p)}{1 - (P_o - P_{co})(F_o)}$$

Where:

C_{plmpc} = correction factor to reduce the meter registration at the observed operating pressure P_o to its equivalent volume at the pressure at which the meter was proved P_p.

P_p = internal meter case pressure during the meter proving, in pounds per square inch gage.

P_{ep} = equilibrium pressure of metered liquid at the proving temperature, in pounds per square inch gage.*

F_p = compressibility factor in pounds per square inch for the metered liquid at the proving temperature from API Standard 1101, Fig. 33 or Table II.

P_o = internal meter case pressure during meter operation, in pounds per square inch gage.

P_{eo} = equilibrium pressure of metered liquid at the operating temperature, in pounds per square inch gage.*

F_o = compressibility factor in pounds per square inch for the metered liquid at the operating temperature from API Standard 1101, Fig. 33 or Table II.

The reference condition of the meter factor, insofar as pressure on the liquid is concerned, is established as being the pressure on the liquid at proving conditions.

3014 *Example I*

A turbine meter is proved at a flow rate of 3,000 BPH on 61 deg API motor-grade gasoline at a flowing temperature of 50 F and a pressure of 100 psig and has a meter factor of 1.0073. Later the meter is still measuring the same gasoline at 3,000 BPH and 50 F but the internal meter case pressure has become 625 psig. For the 625-psig operating condition, C_{plmpc} is as follows:

P_o = 625
P_{eo} and P_{ep} = 0
P_p = 100
F_p and F_o = 0.0000074 (from API Standard 1101, Table II, for 61 deg API motor-grade gasoline at 50 F).

Substituting,

$$C_{plmpc} = \frac{1-(100-0)\,(0.0000074)}{1-(625-0)\,(0.0000074)} = 1.0039$$

3015 *Example II*

A turbine meter is proved at a flow rate of 1,800 BPH on a 44 deg API distillate at a flowing temperature of 68 F and a pressure of 435 psig and has a meter factor of 0.9951. Later the meter is still measuring the same distillate at 1,800 BPH but the flowing temperature has changed to 75 F and the meter case pressure to 51 psig. At the new operating condition, C_{plmpc} is as follows:

P_o = 51
P_{eo} and P_{ep} = 0
P_p = 435
F_p at 68 F = 0.0000058 (from API Standard 1101, Table II, for 44 deg API distillate at 68 F).
F_o at 75 F = 0.0000059 (from API Standard 1101, Table II, for 44 deg API distillate at 75 F).

Substituting,

$$C_{plmpc} = \frac{1-(435-0)\,(0.0000058)}{1-(51-0)\,(0.0000059)} = 0.9978$$

Single-Case Meter Dimensions

3016 Both single- and double-case turbine meters are in use. The internal case of a double-case meter is always surrounded by essentially equal pressure; therefore, it will not expand and contract with operating pressure changes. *Double-case meters always have a steel correction factor of 1.0000 at all pressures.* However, all single-case meters are affected by pressure variations as follows.

The steel correction factor C_{psmpc} to reduce the meter registration resulting from the size of the meter at operating pressure to the equivalent registration which would occur if the size of the meter due to pressure was equal to that at which it was proved is determined by the simplified formula:

$$C_{psmpc} = 1 + (\Delta P_{pc})\,(Y)$$

Where:

ΔP_{pc} = internal meter case pressure during operation, P_o, minus internal meter case pressure during proving, P_p. The algebraic sign of ΔP must be observed. A negative value must be used as such in subsequent calculations.

Y = turbine meter modulus as determined by the formula

$$Y = \frac{(2-\gamma)\,(2R)}{(E)\left(1-\frac{A_T}{\pi R^2}\right)(2t)}$$

Where:

γ = Poisson's ratio (averaged at 0.333).
R = radius of meter housing bore.

*If equilibrium pressure is atmospheric pressure or below, use zero gage pressure.

E = modulus of elasticity of the metal of the housing.*
A_T = area of rotor.
t = wall thickness of meter housing.

The reference condition of the meter factor, insofar as metal strain of the meter is concerned, is established as being that caused by the pressure within the meter at proving conditions.

This formula is discussed in Appendix E. It provides the correction factor to enable measurement at a meter operating pressure other than the pressure which existed during the meter's proof. The correction factor considers only the physical changes in a meter's dimensions arising from metal strain because of pressure. It assumes there is no change in the volume of the rotor or stator with pressure changes and does not consider physical or accuracy variations arising from changes in liquid density, viscosity, frictional resistance, and lubricity.

3017 To simplify use of this formula, Fig. E-3 of the pressure correction factor C_{psm} versus ΔP is presented in Appendix E. The values along the abscissa of this graph represent the operating pressure minus the proving pressure, denoted as $\pm \Delta P$. If the operating pressure exceeds the proving pressure, ΔP is plus and the value of C_{psm} is obtained from the ordinate scale at the left. If the proving pressure exceeds the operating pressure, ΔP is minus and the ordinate scale at the right is used. To use Fig. E-3, first determine the value of the turbine meter modulus Y by substitution in the formula shown in Par. 3016. This requires a knowledge of the types of metals, the thickness of the turbine meter wall, t, the diameter of the bore of the meter, $2R$, and the area of the rotor, A_T. This information is best obtained from the manufacturer. A reasonable assumption of the value of Poisson's ratio, γ, may be taken as 0.333 and the value of the modulus of elasticity as indicated in Par. 3016. Next, determine the value of ΔP_{pc}. Proceed vertically from this latter point on the graph until the turbine meter modulus, Y, is intersected, then horizontally to the appropriate vertical scale for the pressure correction factor. It should be noted that once the value of Y for a given turbine meter is established, it will never change.

*The modulus of elasticity in tension for the following steels are referenced in *Materials Eng.* 66 [5] Reinhold Publishing Corp., New York, Oct. (1967), and also appear in *Properties Data*, Republic Steel Corp., Cleveland, Ohio, as follows:

AISI, all Series 300 stainless steels except Types 309, 310, and 330	$(28.0)(10^6)$ lb per sq in.
AISI, Series 309, 310, 330, and all Series 400 stainless steels	$(29.0)(10^6)$ lb per sq in.
AISI, Type 1020 carbon steel	$(30.0)(10^6)$ lb per sq in.

3018 *Example I*

A 6-in.-ID turbine meter of Type 304 stainless steel, with a housing wall thickness of 0.321 in. and a rotor area of 10.0 sq in., is proved at a flow rate of 3,000 BPH on 61 deg API motor-grade gasoline at a flowing temperature of 50 F and an internal meter case pressure of 100 psig and has a meter factor of 1.0073. Later the meter is still measuring the same gasoline at a flowing temperature of 50 F and at a rate of 3,000 BPH but the internal meter case pressure has become 625 psig. For the 625-psig operating condition, C_{psmpc} is as follows:

$$C_{psmpc} = 1 + (\Delta P_{pc})(Y)$$
$$\Delta P_{pc} = P_o - P_p = 625 - 100 = +525$$
$$Y = \frac{(2-\gamma)(2R)}{(E)\left(1 - \frac{A_T}{\pi R^2}\right)(2t)}$$
$$= \frac{(2-0.333)(2)(3)}{(28{,}000{,}000)\left(1 - \frac{10.0}{28.27}\right)(2)(0.321)}$$
$$= (8.61)(10^{-7})$$
$$C_{psmpc} = 1 + (525)[(8.61)(10^{-7})] = 1.0005 \text{ (rounded off)}.$$

or

$$C_{psmpc} = 1.0005 \text{ (rounded off from Fig. E-3)}.$$

3019 *Example II*

A 14-in.-ID turbine meter made of mild steel, with a housing wall thickness of 0.500 in. and a rotor area of 60.0 sq in., is proved at a flow rate of 12,000 BPH on distillate at a flowing temperature of 70 F and an internal meter case pressure of 450 psig and has a meter factor of 0.9992. Later the meter is still measuring the same distillate at a flowing temperature of 70 F and at a flow rate of 12,000 BPH but the internal meter case pressure has dropped to 120 psig. At the 120-psig operating condition, C_{psmpc} is as follows:

$$C_{psmpc} = 1 + (\Delta P_{pc})(Y)$$
$$\Delta P_{pc} = P_o - P_p = 120 - 450 = -330$$
$$Y = \frac{(2-0.333)(2)(6.5)}{(30{,}000{,}000)\left(1 - \frac{60.0}{132.72}\right)(2)(0.500)}$$
$$= (13.2)(10^{-7})$$
$$C_{psmpc} = 1 + (-330)[(13.2)(10^{-7})] = 0.9996 \text{ (rounded off)}.$$

or

$$C_{psmpc} = 0.9996 \text{ (rounded off from Fig. E-3)}.$$

EXAMPLE OF CALCULATION OF VOLUME METERED UNDER VARYING PRESSURE AND TEMPERATURE CONDITIONS

3020 The following example illustrates the overall application of correction factors necessary where temperature and pressure conditions vary during meter operation. The example is a composite of *Example 1* in Par. 3011, 3014, and 3018; and reference to them is required for the actual determination of the correction factor.

Conditions

A 6-in.-ID turbine meter with a 0.321-in. wall thickness, Type 304 stainless steel housing, and Type 416 stainless steel rotor with an area of 10.0 sq in. is proved with a mechanical displacement prover. The essential data for the proving are as follows:

Meter Data

Flow rate during proving .... 3,000 BPH
Liquid .... 61.0 deg API gasoline
Liquid temperature in meter .... 50.0 F
Liquid pressure in meter .... 100 psig
Meter registration during proof run .. 16.093 bbl

Prover Data

Base volume of prover .... 16.182 bbl
Liquid temperature in prover .... 48.0 F
Liquid pressure in prover .... 90 psig
Prover dimensions... 12-in. pipe x 0.375-in. wall

This meter undergoes two consecutive measurement periods, Q_1 and Q_2, insofar as temperature and pressure are concerned. Because of operating circumstances, it is impossible to prove the meter during the second measurement period. In both measurement periods, the flow rate is maintained at 3,000 BPH, and the measured liquid is the 61.0 deg API gasoline with which the meter was proved. The essential data for the two periods are as follows:

Measurement Period No. 1

Starting meter reading .... 878,432 bbl
Final meter reading .... 910,323 bbl
Liquid temperature in meter .... 50.0 F
Liquid pressure in meter .... 100 psig

Measurement Period No. 2

Starting meter reading .... 910,323 bbl
Final meter reading .... 1,011,480 bbl
Liquid temperature in meter .... 75.0 F
Liquid pressure in meter .... 625 psig

The meter is not equipped with a temperature compensator but the measurement is to be conducted on a 60 F basis at atmospheric pressure.

Problem

Determine the following items by calculation:

Equation (1), meter factor, $MF_{60\&pc}$.
Equation (2), quantity throughput for measurement period No. 1.
Equation (3), quantity throughput for measurement period No. 2.
Equation (4), total quantity throughput for both measurement periods.

Solution

From Par. 3007:

$$MF_{60\&pc} = \frac{(BV)\,(C_{tlp\,60})\,(C_{plpr})\,(C_{tsp\,60})\,(C_{pspr})}{(MR)\,(C_{tlm\,60})\,(C_{plm\,pc})\,(C_{tsm\,pc})\,(C_{psm\,pc})}$$

Referring to the proving data:

BV = 16.182 bbl.

$C_{tlp\,60}$ = 1.0075 from ASTM D 1250, Table 6, for 61.0 deg API at 48.0 F.

$$C_{plpr} = \frac{1-(0-0)\,(0.0000074)}{1-(90-0)\,(0.0000074)} = 1.0007$$

for prover at 90 psig and 48 F from Par. 3007 and API Standard 1101, Table II.

$C_{tsp\,60}$ = 0.9998 from API Standard 2531, Table I, for 48 F.

C_{pspr} = 1.0001 from API Standard 2531, Table II, for a prover with 12-in.-ID pipe x 0.375-in. wall.

MR = 16.093 bbl.

$C_{tlm\,60}$ = 1.0063 from ASTM D 1250, Table 6, for 61.0 deg API at 50.0 F.

$C_{plm\,pc}$ = 1.0000 for during a proof, the meter proving pressure is the meter operating pressure.

$C_{tsm\,pc}$ = 1.0000 for during a proof, the meter proving temperature is the meter operating temperature.

$C_{psm\,pc}$ = 1.0000 for during a proof, the meter proving pressure is the meter operating pressure.

$$MF_{60\&pc} = \frac{(16.182)\ (1.0075)\ (1.0007)\ (0.9998)\ (1.0001)}{(16.093)\ (1.0063)}$$

$$= 1.0073 \qquad (1)$$

From Par. 3008:

$$Q_{60\&r} = (MR)\,(MF_{60\&pc})\,(C_{tlm\,60})\,(C_{plm\,pc})\,(C_{tsm\,pc})\,(C_{psm\,pc})$$

For the first measurement period, Q_1, where the meter is operating at proving conditions:

MR = 910,323 – 878,432 = 31,891 bbl.

$MF_{60\&pc}$ = 1.0073

$C_{tlm\,60}$ = 1.0063 from ASTM D 1250, Table 6, for 61.0 deg API gravity at 50.0 F.

$C_{plm\,pc}$ = 1.0000 as the meter is being operated at the pressure at which it was proved.

$C_{tsm\,pc}$ = 1.0000 as the meter is being operated at the temperature at which it was proved.

$C_{psm\,pc}$ = 1.0000 as the meter is being operated at the pressure at which it was proved.

$$Q_1 = (910{,}323 - 878{,}432)\ (1.0073)\ (1.0063) \qquad (2)$$

Q_1 = 32,326 bbl at 60 F and 0 psig.

For the second measurement period, Q_2, where the meter is operating at 625 psig and 75 F:

MR = 1,011,480 – 910,323 = 101,157 bbl.

$MF_{60\&pc}$ = 1.0073 This was obtained during proof.

$C_{tlm\,60}$ = 0.9906 from ASTM D 1250, Table 6, for 61.0 deg API at 75.0 F.

$$C_{plm\,pc} = \frac{1 - (100 - 0)\ (0.0000074)}{1 - (625 - 0)\ (0.0000082)} = 1.0044$$

See formula in Par. 3013, Sect. III.

$C_{tsm\,pc}$ = 1.0006 See Par. 3011, *Example I.*

$C_{psm\,pc}$ = 1.0005 See Par. 3018, *Example I.*

$$Q_2 = (1{,}011{,}480 - 910{,}323)\ (1.0073)\ (0.9906)\ (1.0044)\ (1.0006)\ (1.0005) \qquad (3)$$

Q_2 = 101,493 bbl at 60 F and 0 psig.

$$\text{Total throughput} = Q_1 + Q_2 = 32{,}326 + 101{,}493 = 133{,}819 \text{ bbl at 60 F and 0 psig.} \qquad (4)$$

3021 Mathematical procedures for calculating correction factors to compensate for the effects of temperature and pressure changes on a meter's dimensions and on the volume of the metered liquids have been presented in Par. 3020. *This mathematical technique is based solely on the anticipated dimensional changes in metals and liquids with changes in temperature and pressure and does not account for variations in flow rates, viscosity, density, lubricity, frictional resistance, and other variables which, to some degree or other, accompany temperature or pressure changes within the meter and measured liquid.* Optimum accuracy of measurement is only obtained by proving a meter at the identical conditions under which it is expected to measure and obtaining the meter factor for these conditions.

SECTION IV—OPERATION AND MAINTENANCE OF METERING SYSTEMS

SCOPE

4001 This section covers recommended operating and maintenance practices for turbine meter installations.

CONSIDERATIONS AFFECTING OPERATION

4002 A turbine meter system consists of intricate mechanical and electrical components. Overall measurement accuracy depends upon the condition of those components. Additionally, the proving system, the frequency of meter proving, the correction factors used in proving, and the variations between operating and proving conditions are of importance. All parts of the measurement apparatus should be selected, operated, and maintained in such a way as to achieve the desired approach to overall tolerances which may be established by policy, mutual agreement, law, or regulation.

4003 Turbine meters should be operated within the specified flow range and the operating conditions which produce the desired accuracy (see Appendix A). They should be operated with the equipment recommended by the manufacturer.

4004 If a turbine meter is used to measure reversible flow, meter factors shall be obtained for each direction of flow, which usually requires that a bidirectional mechanical displacement meter prover be employed.

4005 Failure to ensure removal of foreign matter ahead of a turbine meter may result in meter damage or mismeasurement. Precautions should be taken against the collection of any foreign material, such as vegetation, fibrous materials, hydrates, or ice, within the turbine meter run.

PRECAUTIONS FOR OPERATION OF NEWLY INSTALLED METERS

4006 When placing a new meter installation in service, particularly on newly installed lines, suitable means should be taken to protect the meter from damage or malfunction by foreign matter such as slag, debris, welding spatter, thread cuttings, or pipe compound which might be carried to the metering mechanism by the initial passage of liquid. Suggested means of accomplishing such protection are temporary replacement of the meter by a spool, a bypass around the meter, removal of the metering element, or installation of a suitable protective device ahead of the meter.

INSTRUCTIONS FOR OPERATION OF METERS

4007 Definite operating instructions and standardized forms for reporting and computing proving data should be furnished to operating personnel. They may include the following items:

a. Instructions for a step-by-step method for meter proving, at a particular location.

b. Forms for keeping and instructions for interpreting measurement system control charts (see Appendix B) for each product or grade of crude for each meter.

c. Instructions for reporting to appropriate personnel whenever meter factors go "out-of-control" or shift beyond established tolerances (see Par. 4016).

d. Instructions setting forth general policy on frequency of meter proving and reproving upon changes of rates or other variables which affect meter performance.

e. Instructions for witnessing meter provings and/or meter proving readouts and printouts.

f. Standardized forms necessary to support proving reports (see Appendix A, Fig. A-5, or API Standard 1101, Fig. 34 through 42, and API Standard 2531, Fig. 12 through 15.)

g. Instructions for step-by-step computation and forms for recording of supporting evidence in proving reports. [Same references as in preceding item (*f*).]

h. Instructions for accounting and reporting of corrected metered volumes and all observed data.

4008 Some distinction should be made between those parts of the systems which can be checked by operating personnel, e.g., pressure gages, displacer diameter, and mercury thermometers, and the more critical components which may require the services of technical personnel. Normally, turbine meters and associated equipment can be expected to perform well for long periods. Indiscriminate adjustment of the more complicated parts or disassembly of equipment is neither necessary nor recommended.

METER PROVING

4009 It is recommended that a turbine meter be installed in a system that contains a permanent prover or connections for attachment of a portable prover.

The selection of proving methods shall be acceptable to all parties involved. Methods of proving and types of provers are described in Sect. II and in API Standards 1101 and 2531.

4010 A meter shall not be removed from its meter run for determination of meter factor. Significant inaccuracies may result from indiscriminate central proving of turbine meters. However, the proving of a unit to determine its general performance characteristics (see Appendix A, Fig. A-1) is acceptable provided the test conditions duplicate, as nearly as practicable, the installation and service in which the meter will ultimately be used.

FREQUENCY OF METER PROVING

4011 The frequency of proving for any particular turbine meter system depends upon so many aspects of the operating conditions that it is difficult to express it in chronological or throughput terms.

In general, provings should be quite frequent in the early history of a particular installation or measuring system. When sufficient test results have been gathered to establish the meter factor versus flow-rate curves for each product or grade of crude and to derive values for one standard deviation in a system factor value, then measurement system control charts (see Appendix B) can be established. After this has been done, each proving, or average of a group of provings, can be plotted on the control chart. Frequency of proving can taper off so long as factors are "under control" and overall accuracy of measurement is mutually acceptable to the parties involved.

Meters shall be proved after maintenance; and if such maintenance has shifted the performance curve of the meter, it is advisable to repeat the period of relatively frequent proving, set up new measurement system control charts, and once the value of one standard deviation has been established to again taper off the frequency of check proving. In any event, it is advisable for the interested parties to agree on a maximum permissible interval between check provings.

PROVING SYSTEM ACCURACY

4012 Measurement system control charts may be used effectively to disclose changes in the accuracy of prover systems. The control charts indicate a change in the overall meter installation operation. By a system of checking and elimination, the reason for the change in accuracy can be determined and necessary remedial action taken.

API Standard 1101 and *ISA-S31: Specification, Installation, and Calibration of Turbine Flowmeters** contain information on the maintenance of accuracy of prover systems.

Prover Tanks

4013 Any change (additions, deletions, or repairs) of volumetric prover appurtenances in or connected to the calibrated prover volume, or any internal corrosion or accumulation of foreign material, may affect the calibrated volume of the prover. The prover should be recalibrated after any significant change in gage glasses, thermometer wells, or spray lines. It should be inspected frequently for internal corrosion and for the accumulation of sediment, rust, valve lubricant, and other foreign matter. Gage scales should be inspected frequently, and the prover recalibrated if there is any indication of gage scale movement.

Mechanical Displacement Provers

4014 The displacer used in a mechanical displacement prover must be maintained in satisfactory condition to provide an adequate seal against the cylindrical chamber through which it moves. Displacer detection devices and switches must be maintained in satisfactory condition, but provision should be made for checking the prover volume subsequent to such maintenance in a unidirectional prover (see API Standard 2531). All critical valves should be equipped with a telltale bleed so that any valve malfunction resulting in leakage can be easily detected.

Gravimetric Provers

4015 With gravimetric provers, it is possible that the accuracy of the scales can be affected by such things as physical damage, corrosion of critical operating parts, connection interference, settlement, wind effects, wear on the knife edges, and friction. Determination of liquid gravity shall have a precision at least as significant as other measurements and data used in the proving.

MEASUREMENT SYSTEM CONTROL CHARTS

4016 A measurement system control chart is any suitable adaptation of the Statistical Control Chart Method (see Par. B-21) to meter-measurement problems as explained and discussed in Appendix B.

Measuremement system control charts are essen-

* Tentative standard being prepared for publication

tially plots of successive meter factors along the abscissa at the appropriate ordinate value and within limiting parallel abscissa representing $\bar{X} \pm 1\sigma$, $\bar{X} \pm 2\sigma$, and $\bar{X} \pm 3\sigma$, in which σ is the standard deviation. Such a chart should be maintained for each product, or grade of crude, over a range of rates, for each meter.

METHOD OF DIAGNOSIS FOR SERVICING

4017 Measurement system control charts (see Appendix B) can be used as a diagnostic tool for measurement trouble to show when and to what extent conditions may have deviated from accepted norms.

When measurement trouble is encountered, a systematic checking of the measurement system is recommended. The following components of the measurement system may be checked but not necessarily in the listed order:

a. All valves affecting meter proving.

b. Strainers, filters, air eliminators, and water removal equipment.

c. Pulse counters, coil, preamplifiers, signal transmission system, power supply, and all readout devices (see Appendix G).

d. Moving parts and bearing surfaces of the turbine meter.

e. Other parts of the meter and meter run.

f. Detector switches in the mechanical displacement meter prover, or appurtenances of the volumetric and gravimetric provers.

g. Displacer in the mechanical displacement prover.

h. Pressure, temperature, and gravity sensing devices.

i. Operation of meter system and prover at other than design conditions.

GLOSSARY

This glossary of terms is provided to achieve standardization of equipment nomenclature, procedural and functional terms, and phrases specifically oriented to the use of turbine meters in the petroleum industry. All terms not included herein have generally been accepted because of their previous inclusion in API Standard 1101, Appendix D. Manufacturers' trade names have not been included, but their equipment has been categorized in broad terms of function or purpose.

Accuracy: A deviation of an indicated measurement from an accepted primary reference standard.

Air eliminator: A device designed to separate and remove gases (air or vapor) from the flowing stream.

API gravity: An arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of degrees API. It may be calculated in terms of the following formula:

$$\text{Deg API} = \frac{141.5}{\text{sp gr } 60\text{ F}/60\text{ F}} - 131.5$$

Auxiliary equipment: The equipment which is installed in conjunction with a meter, such as an air eliminator, strainer, vacuum breaker, or regulating valve, to permit or facilitate the use or operation of the meter.

Back pressure: The operating pressure level as measured four pipe diameters downstream from the turbine meter, expressed in pounds per square inch gage.

Batch: A discrete volume of one type of liquid, usually designated as such when moved through a pipeline. (Sometimes referred to as a tender.)

Battery or bank of meters: An installation of meters connected in parallel.

Bidirectional meter: A meter designed to operate with flow from opposite directions.

Cavitation: The entire scale of phenomena taking place in and about an impeller or turbine meter rotor under conditions where local pressures fall close to or below the vapor pressure of the liquid. It covers not only the formation of vapor bubbles and their collapse, but also the destructive effect on the impeller or rotor metals.

Compressibility, apparent: The algebraic sum of the true compressibility of a liquid and the enlargement of the confining container as a result of pressure.

Compressibility, true: The absolute decrease in volume of a liquid caused by an increase in pressure.

Control chart: A graphical record of the constancy of measurement. On it are shown the $\pm 3\sigma$ limits of dispersion from the average system factor, $\bar{X}$, within which the measurement system is considered to be in control.

Counter: An accumulative digital meter readout device actuated by a pulsing electrical or mechanical force such that advancement of its numerical indication is stepwise and directly related to the frequency of its input pulses.

Displacer: An object, usually spherical or cylindrical in shape, which has elastic sealing surfaces so that when it moves along a pipe it contacts the walls tightly enough to prevent leakage. The object is driven through the prover pipe by the fluid stream and displaces a known quantity of fluid between two fixed, detecting devices. (See API Standard 2531, Sect. III, for specific types.)

Error: The difference between the indicated value and the true value. Error can be expressed by a variety of statistical measures such as maximum uncertainty $\pm 3\sigma$.

Filter, electrical: A circuit designed to pass or restrict alternating-current signals of a specified frequency range.

Flash: To suddenly release pressure on a liquid, resulting in partial or complete vaporization. (Sometimes referred to as flashing.)

Flow range: The minimum and maximum flow rates established by acceptable limits of meter accuracy, under stated operating conditions.

Flow rate: The rate of flow of a fluid expressed in volume or mass units per unit of time, e.g., barrels per hour (BPH) and gallons per minute (gpm).

Flow-rate-limiting-device: A device installed in a line and operated in such a manner as to prevent the rate of flow through the meter from exceeding the maximum desired flow rate.

Flow straightener: A device used to dissipate or minimize the radial velocity (or swirl) of the flowing stream so that its effect upon performance of the turbine meter becomes insignificant.

Frequency: The number of complete oscillations or cycles of a signal per unit time. Usually expressed as hertz (hz), in cycles per second.

Frequency range: The minimum and maximum frequency limits of a device.

High-vapor-pressure liquid: A liquid which, at the proving temperature of the meter, has an absolute vapor pressure equal to or higher than existing atmospheric pressure.

Linearity: The deviation or spread of calibration data points from an acceptable straight line over the defined flow range. (See Appendix A for graphical presentation.)

Linear range: The range of flow rates within which the linearity of a meter is specified. May be expressed as a ratio.

Low-vapor-pressure liquid: A liquid which, at the proving temperature of the meter, has an absolute vapor pressure less than existing atmospheric pressure.

Master factor (curve): A graphical plot of the meter factors determined by preproving of a meter, such that each meter factor point is a mean value, $\bar{X}$, of a set of n determinations with a known maximum uncertainty, $\pm 3\sigma$ (see Par. B-3).

Median: A point determined from a set of values (such as meter factors) so that half of them would be to the left of or above this point and half of them to the right of or below this point—the mid-most value. The average value with respect to frequency rather than with respect to magnitude (see Fig. B-1).

Meter capacity, maximum: The maximum rate of flow through a meter, as recommended by the meter manufacturer, for any specified liquid.

Meter capacity, minimum: The minimum rate of flow through a meter, as recommended by the meter manufacturer, for any specified liquid.

Meter factor: See Sect. III and Appendix F.

Meter reading: The number of units of volume, or equivalent thereof, read directly from a meter register or readout device at any particular moment.

Meter registration: The difference between opening and closing meter readings during an interval of operation of a meter.

Meter run: The turbine meter and the flow straightening vane or devices, upstream and downstream, which may be required to condition the fluid before it enters or after it leaves the meter.

Multimeter accumulator: A device or system for accumulating the registration of two or more meters in order that their total may be shown on a single readout device.

Noise (electrical): Undesirable, yet detectable signals which influence a readout device but are not related to actual flow rate.

Parameter: A quantity to which the operator may assign arbitrary values, as distinguished from a variable, which can assume only those values that the form of the function makes possible.

Pickup: A device for converting rotor movement directly into an electrical output signal.

Performance curve: A graphic presentation of the variation of a meter's factor, percent deviation, or pulses per unit volume with respect to flow rate. As indicated in Fig. A-1, the meter factor and/or percent deviation is the ordinate scale and the flow rate is the abscissa. All such performance curves should indicate the type of liquid and its temperature and viscosity. Additional engineering variables may be incorporated on the graph such as flow rate versus pressure loss, frequency, pulses per unit volume, and voltage output (see Fig. A-1).

Preamplifier: A device which amplifies and conditions the meter output signal for transmission.

Pressure loss: The differential pressure in pounds per square inch gage measured between points across a meter in accordance with *Instruments and Apparatus, Part 2: Pressure Measurement*, supplement to *ASME Prover Test Codes*. The length of the pipe between the points shall not include any portion that contains internal straightening elements. Pressure loss curves versus flow rate normally are obtained using water at 60 F but may be determined by using other liquids if so specified.

Prove: To determine the meter performance or the relationship between the volume of liquid which actually passes through a meter and the volume indicated by the meter (and its readout device).

Prover counter: Any counter used in the proof of a meter in such a way as to be gated to start and stop counting at the beginning and end of a proving run. Normally, such counters are used with running-start-stop proving procedures, have high-speed gating systems (electronic), and are capable of handling the pulse frequency developed by the meter.

Pulse generator: An accessory to a meter, designed to produce a signal frequency proportional to its input speed of rotation.

Readout device: A device which indicates or records meter intelligence in either analog or digital form.

Register: An accumulative type of meter readout device actuated by continuous mechanical rotation, such that advancement of its numerical indication is directly related to the rotation of its input drive.

Repeatability: The ability of a turbine meter system to reproduce its output during a series of consecutive proving runs under constant operating conditions.

Resolution: The smallest increment of the uniform system measured.

Running start-and-stop method: A meter-proving method wherein the opening and closing meter readings of the test run are determined at flowing conditions.

Standing start-and-stop method: A meter-proving method wherein the opening and closing meter readings of the test run are determined at no-flow conditions.

Strainer: A device installed upstream from a meter and equipped with screen wire or another medium intended to remove foreign matter from the stream.

Swirl: The rotational velocity or tangential velocity component of fluid flow in a pipe or tube.

Valve, back-pressure: A mechanical device for maintaining a steady upstream pressure.

Vapor eliminator: See *Air eliminator.*

Vapor pressure (absolute, true): The pressure of a vapor corresponding to a given temperature at which the liquid and vapor are in equilibrium.

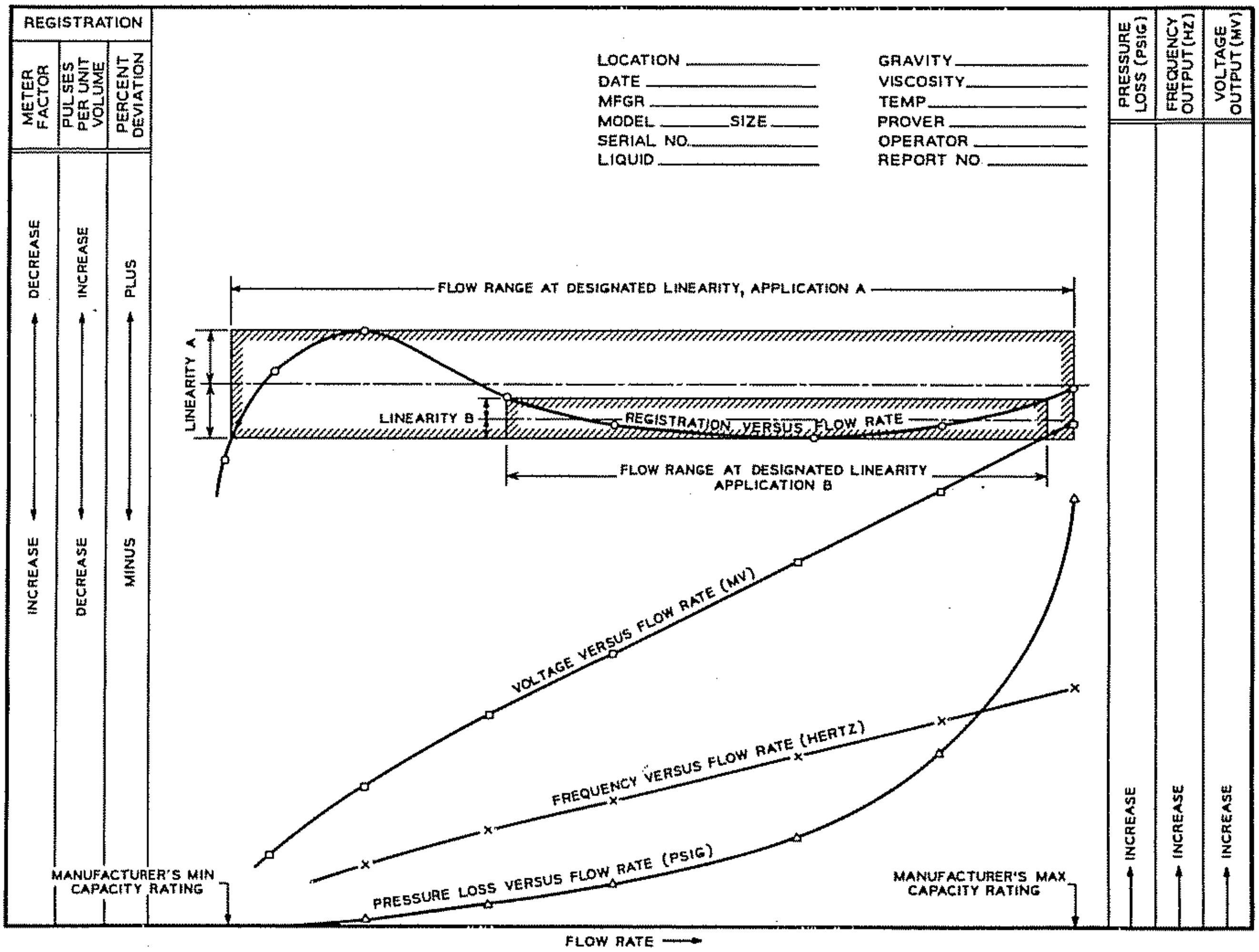
Voltage output: A measurement of peak-to-peak signal amplitude (alternating current) or average amplitude (direct current) at a stated load impedance and a specified frequency.

APPENDIX A

TURBINE METER SYSTEMS

This appendix provides illustrative descriptions of turbine meter performance characteristics, accessory readout instrumentation possibilities, recommended flow straightener assembly, meter performance curve, meter proving report, and turbine meter nomenclature (see Fig. A-1 through A-6).

In addition to the pictorial information presented, these illustrations provide a means of standardized formats, terminology, and data presentation. The intention of such a standardization is to simplify the communication between designers, operators, and manufacturers.



NOTE: Example not to be considered applicable or typical.

FIG. A-1--Turbine Meter Performance Characteristics.

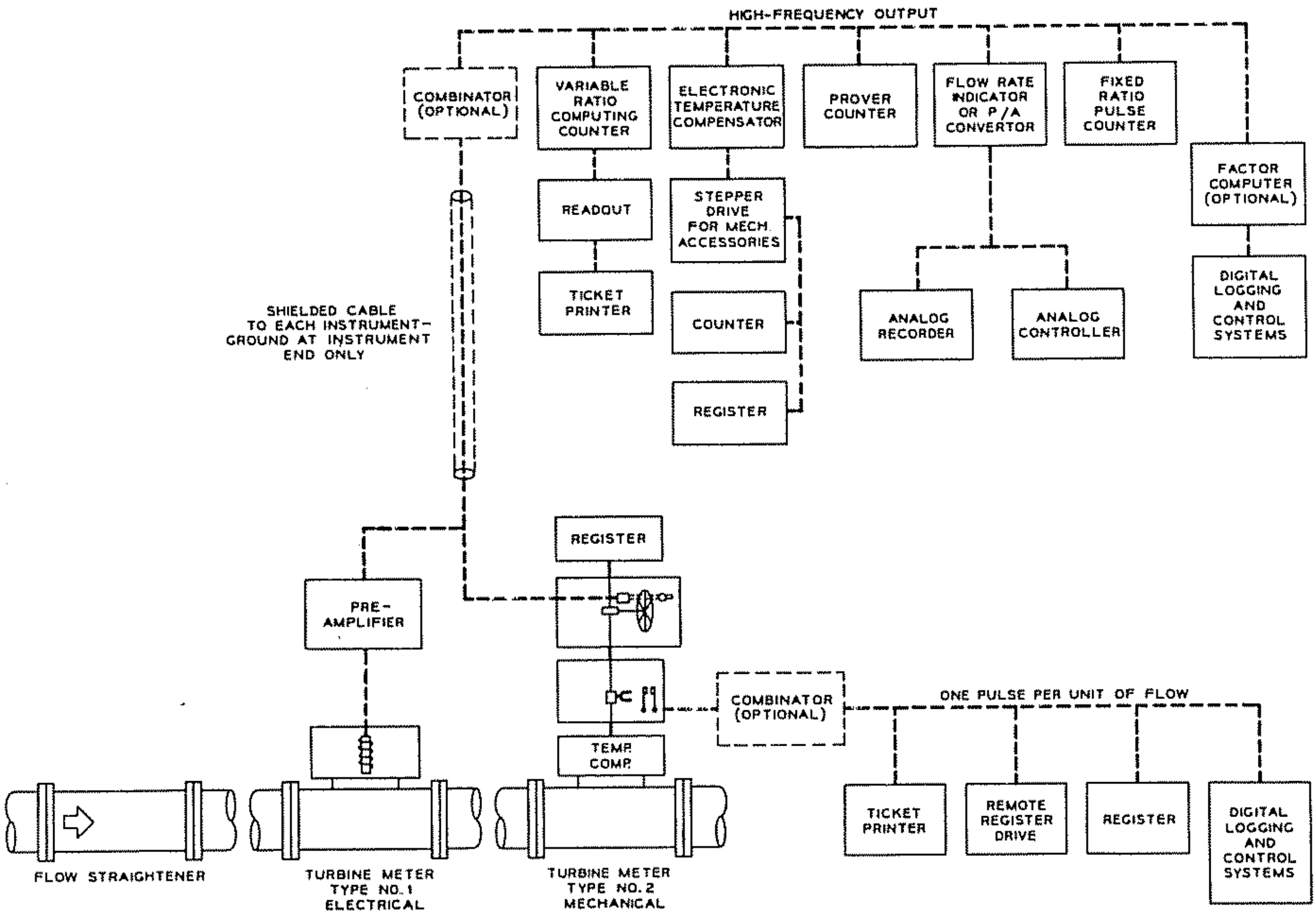
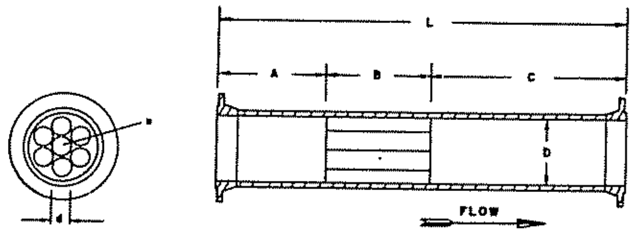


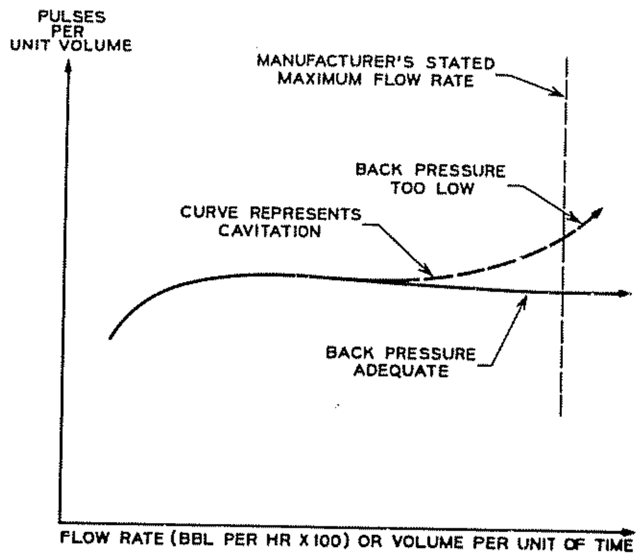
FIG. A-2--Available Turbine Meter Instrumentation.



Legend:

L = overall length of straightener assembly = 10*D* minimum.
A = length of upstream plenum = 2*D* to 3*D*.
B = length of tube or vane section = 2*D* to 3*D*.
C = length of downstream plenum = 5*D* minimum.
D = nominal diameter of meter.
n = number of individual tubes or vanes. *n* should be at least 4.
d = nominal diameter of individual tubes. *B*/*d* should be at least 10.

FIG. A-3--Recommended Flow Straightener Assembly.



NOTE: ALL CURVES FOR EXAMPLE ONLY.

FIG. A-4--Effects of Cavitation on Rotor Speed.

APPENDIX B

SYSTEM FACTOR CONTROL CHARTS

INTRODUCTION

B-1 API Standard 1101, Appendix C, notes:

A very practical approach to a determination of when to repair or inspect a meter will be found in a continuous log or plot of the factors obtained from that meter. . . .

If as many as four proof runs must be made without obtaining two results which check each other *within the preestablished allowable deviation*. . . .

B-2 Amplification and refinement of the continuous log or plot referred to in Par. B-1 can be obtained by using statistical methods, thus providing limits more valid than a "preestablished allowable deviation." Any preestablished allowable deviation may be too large or too small; therefore, the standard deviation, σ, of a set of system factors can be more useful and significant in analyzing a series of measurements. However, the standard deviation can be developed only after making sufficient proof runs in a measurement system on a given liquid to warrant drawing conclusions. Such conclusions are valid and useful and are not arbitrary.

B-3 Physical and chemical characteristics of a liquid may vary slightly. If meter performance varies significantly as a result of such difference, then different curves and standard deviations should be developed. Neither would be preestablished and all would be based upon a high degree of probability.

B-4 This appendix contains the essentials of some statistical methods that can be useful aids to engineering judgment in the field of measurement.

B-5 The control chart is an efficient and convenient method of recording effects of changes in both the precision and the systematic error of the system, the two influences upon which the proving accuracy or uncertainty depend.

B-6 The problems involved when the entire measurement system is being proved should not be overlooked, even though the proving results are simply referred to as "meter factors." It always should be kept in mind that there is more than one variable at work in a measurement system. Any significant changes in the precision characteristics or the systematic error of parts of the system will be evident as the system factors are plotted on the control chart. However, the chart will not tell *where* trouble is; it will merely ascertain whether the proving process is "in control" or "out of control."

B-7 For additional information see:

*ANSI Standards**

Z1.1: Guide for Quality Control
Z1.2: Control Chart Method of Analyzing Data
Z1.3: Control Chart Method of Controlling Quality During Production

ASTM Manual

STP 15-C: Quality Control of Materials

THE STATISTICAL MEASURES n, $\bar{X}$, and σ

B-8 There are many ways of presenting data to obtain useful information. The essential information, however, can be expressed in the three statistical measures known as n, $\bar{X}$, and σ. These measures are obtained from an accumulation or set of meter factors developed in any given liquid as follows:

n = number of determinations of successive meter factor values under consideration.

$\bar{X}$ = arithmetic mean of the n meter factor values (see Par. B-10).

σ = root mean square deviation of all the meter factor values from their average $\bar{X}$. This is a measure of the close occurrence of repeated observations of the same quantity (meter factor) performed under specified conditions (see Par. B-14).

B-9 The question to be answered by the essential information contained in n, $\bar{X}$, and σ is whether the performance of the proving system, including the meter being proven, is in control or not. The answer is more valid than if a preestablished or arbitrary deviation has been set up. Moreover, the values can be compared from year to year or from system to system.

B-10 System factors developed over a period, in any one product or grade of crude, for any rate or acceptable range of rates, show the two tendencies of centering and dispersing. The centering tendency is

* American National Standards Institute, formerly United States of America Standards Institute.

expressed as the average, $\bar{X}$. Thus, if X_1, X_2, X_3 . . . X_n are the meter factors being considered, then:

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \ldots X_n}{n}$$

B-11 The dispersing or deviating tendency expressed as σ could be either normal (symmetrical) or skewed (see Fig. B-1).

B-12 Under properly selected conditions and with sufficient determinations, factors for either turbine or positive displacement meters will disperse normally; that is, their arithmetic mean, $\bar{X}$, and their median will coincide. However, if a meter's performance curve has changes of direction or a considerable slope, skewing of deviations could result unless the precaution is taken to limit the factors under consideration to a narrow range of flow rates.

COMPUTATION OF $\bar{X}$, σ, AND THE 3σ ACTION LIMITS

B-13 All meters are more or less viscosity and rate sensitive, and dirt can occasionally affect meter factors. Therefore, it is necessary to select a period of normal meter operation to establish the value of $\bar{X}$, a representative period of time when results were satisfactory, but for which all results are nevertheless included. A desirable value for n would never be less than 25, preferable more. If such is not possible, provisional values of $\bar{X}$ and σ will suffice until better values can be obtained. Calculation of σ from too few determinations is only an estimated standard deviation for which the symbol s should properly be used.

B-14 The following example lists ten factors developed under normal operation. The number of factors, n, is insufficient and is used only as an illustration. D is used to signify $(\bar{X} - X_i)$; that is, D is the difference between $\bar{X}$ and each individual factor. Whether D is plus or minus does not matter, as it is subsequently squared.

Meter Factor Determination (Number)	Factor	D (10^{-4})	D^2 (10^{-8})
1	1.0012	0	0
2	1.0010	2	4
3	1.0015	3	9
4	1.0013	1	1
5	1.0014	2	4
6	1.0011	1	1
7	1.0009	3	9
8	1.0012	0	0
9	1.0010	2	4
10	1.0014	2	4
$n = 10$	$\bar{X} = 1.0012$		$\Sigma D^2 = (36)(10^{-8})$

Therefore,

$$\sigma = \sqrt{\frac{\Sigma D^2}{(n-1)}} = \sqrt{(4.0)(10^{-8})} = (2)(10^{-4}) = 0.0002$$

B-15 The value of σ, or more properly s (the estimated value), obtained previously by dividing the sum of the squares of all the deviations by $(n - 1)$ is a provisional standard deviation. It is based on the "t distribution" of random variables. The truly "normal distribution" requires that the sum of the squares of all the deviations be divided by n; but in such a case, as n is very large, the values of n and $(n - 1)$ become for all practical purposes the same.

B-16 With sufficient determinations, system factor values tend to sort themselves out so that distribution approaches the following:

68.3 percent of all factors will fall between $\bar{X} \pm 1\sigma$
95.5 percent of all factors will fall between $\bar{X} \pm 2\sigma$
99.7 percent of all factors will fall between $\bar{X} \pm 3\sigma$

B-17 Also, 50 percent of all the system factor values will tend to fall *within* the narrow span $\bar{X} \pm 2\sigma/3$ (see Fig. B-1.)

B-18 For practical purposes, all useable system factors will occur between $\bar{X} + 3\sigma$ and $\bar{X} - 3\sigma$. Whenever this occurs, the measurement system is said to be "in control." When values fall outside the $\pm 3\sigma$ action limits it is "out of control." The nature of the malfunction to be found is called the "assignable cause."

B-19 ANSI Standard Z1.2 states:

In the choice of action limits for indicating when to look for assignable causes of variation, an attempt is made to strike an economic balance with respect to the net consequences of two kinds of "errors" that may occur in practice; namely, looking for trouble that does not exist, and not looking for trouble that does exist.

B-20 Subject to the aforementioned cautions, the adaptation of statistical methods to liquid measurement control will provide results that are valid, prompt, easy to follow, and economical.

MEASUREMENT SYSTEM CONTROL CHARTS

B-21 A measurement system control chart is any suitable adaptation to liquid metering of the widely used Control Chart Method of Analysis and Presentation of Data.* The chart is to be used at the time a meter system proving is carried out, rather than later as a history of measurement experience. Therefore,

* *ASTM STP 15-C: Manual on Quality Control of Material,* Part 3.

METER PROVING REPORT
XYZ OIL CO., FRIENDSHIP, ORE.

DATE	LOCATION	REPORT NO

METER PROVEN	MAKE	SIZE	MODEL NO	SERIAL NO	PRESSURE RATING	NOM PULSES/BBL	COUNTER DIVISION RATIO
PROVING STANDARD	MAKE	SIZE	SERIAL NO	LOCATION	DATE OF CALIBRATION	CALIBRATION REPT. NO. ______ ☐ (ATTACHED)	BASE VOLUME OR MASTER FACTOR
LIQUID	PRODUCT OR GRADE	API GRAVITY	SPECIFIC GRAVITY	VISCOSITY	WEATHER CONDITIONS °F	COUNTER SERIAL NO	

RUN NO.	PROVER TYPE: ☐ Unidirectional Displacement / ☐ Bidirectional Displacement / ☐ VOLUMETRIC TANK: Bottom / ☐ MASTER METER: Closing	☐ VOLUMETRIC TANK: Top / ☐ MASTER METER: Opening	Total Volume / Gross Registration	METER PROVEN (DATA): Left to Right — Closing Reading	Right to Left — Opening Reading	Total Registration / Round Trip Registration / Gross Registration / Gross Registration	AVG FLOW RATE ☐ GPM ☐ BPH	TEMPERATURE Meter Proven °F	TEMPERATURE Proving Standard °F	PRESSURE Meter Proven PSIG	PRESSURE Proving Standard PSIG
1											
2											
3											
4											
5											
AVG											

(Note: The above DATA SECTION MAY BE EXTENDED AS REQUIRED, SINCE ONLY "ONE METER CALCULATION" IS NEEDED)

PROVER CALCULATIONS

Displacement Prover or Tank	Base Prover Volume ×	ASTM D 1250 C_{tlp60} ×	API STD 1101 C_{plpr} ×	API STD 2531 C_{tsp60} ×	API STD 2531 C_{pspr} =	NET PROVER VOLUME AT PROVING CONDITIONS
MASTER METER	GROSS REGISTRATION ×	MASTER FACTOR ×	(IF MASTER TURBINE USE FOLLOWING AS PER API STD 2534 APP. F.)	API STD 2534 C_{tsm60} ×	API STD 2534 C_{psmr} =	NET PROVER VOLUME AT PROVING CONDITIONS

METER CALCULATIONS

API STD 2534, SECT III	For nontemperature compensated meters, see API Std 2534, Par 3008			GROSS REGISTRATION	ASTM D 1250 C_{tlm60} × =	NET METER REGISTRATION AT PROVING CONDITIONS
API STD 2534, SECT III	For temperature compensated meters C_{tlm} is continually adjusted and is always 1.0000, see API STD 2534 Par 3008				GROSS REGISTRATION =	NET METER REGISTRATION AT PROVING CONDITIONS
API STD 2534, APP. F AND MASTER FACTOR	GROSS REGISTRATION ×	ASTM D 1250 C_{tlm60} ×	API STD 1101 C_{plmr} ×	API STD 2534 C_{tsm60} ×	API STD 2534 C_{psmr} =	NET METER REGISTRATION AT 60 F AND 0 PSI

METER FACTOR	NET PROVER VOLUME ÷	NET REGISTRATION =	METER FACTOR	API STD 2534, SECT III: AT ______ BPH ______ F, ______ PSIG	API STD 2534 APP F: AT ______ BPH, 60 F, 0 PSIG

(Note: The following CALCULATION is shown TO ILLUSTRATE FINAL STEP RELATING PROVING COUNTER TO OTHER READOUTS)

METER SYSTEM FACTOR	INPUT PULSES REQUIRED TO REGISTER ONE UNIT OF VOLUME ON READOUT OR	COUNTER DIVISION RATIO ×	METER FACTOR =	METER SYSTEM FACTOR OR	CDR=MSF÷MF

REMARKS OR COMMENTS:

NEW FACTOR EFFECTIVE ______

PREVIOUS DATA		
Date		
Rate		
Meter Factor		

WITNESSES:

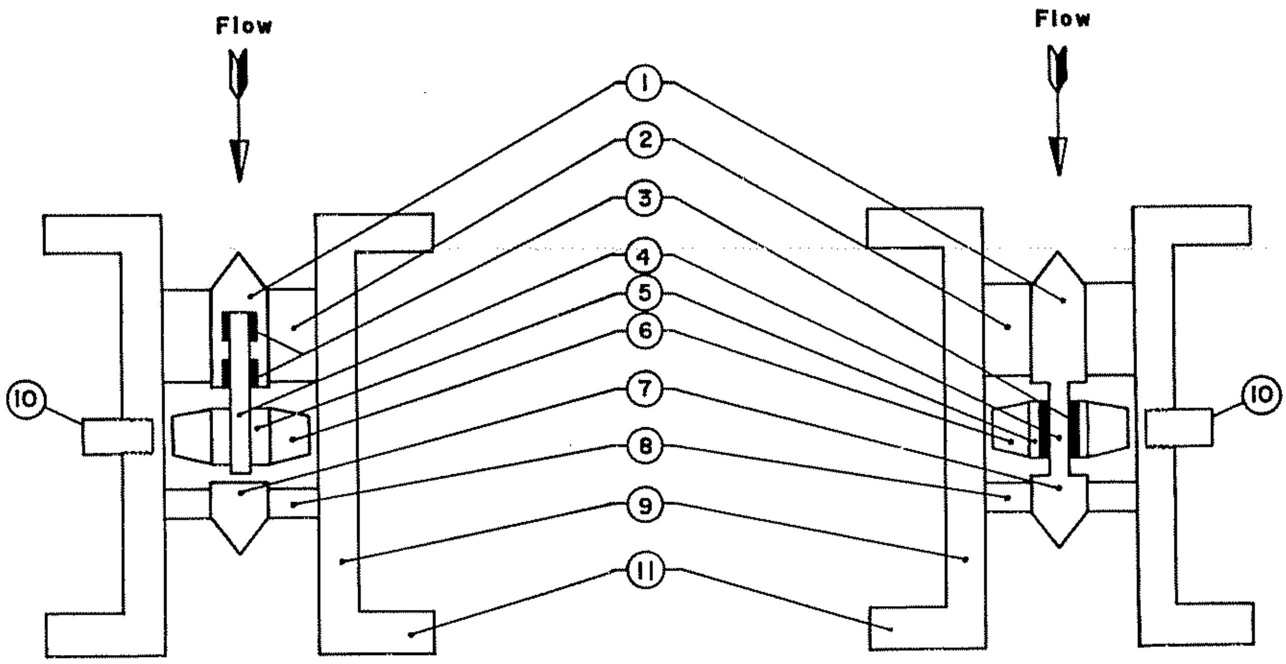
______ for: ______

______ for: ______

COMPANY REPRESENTATIVE

× ______

FIG. A-5--Meter Proving Form.



Legend:

1. Upstream stator
2. Upstream stator supports
3. Bearings
4. Shaft
5. Rotor hub
6. Rotor blade
7. Downstream stator
8. Downstream stator supports
9. Meter housing
10. Pickup
11. End connections

FIG. A-6--Nomenclature for Typical Turbine Meter Designs.

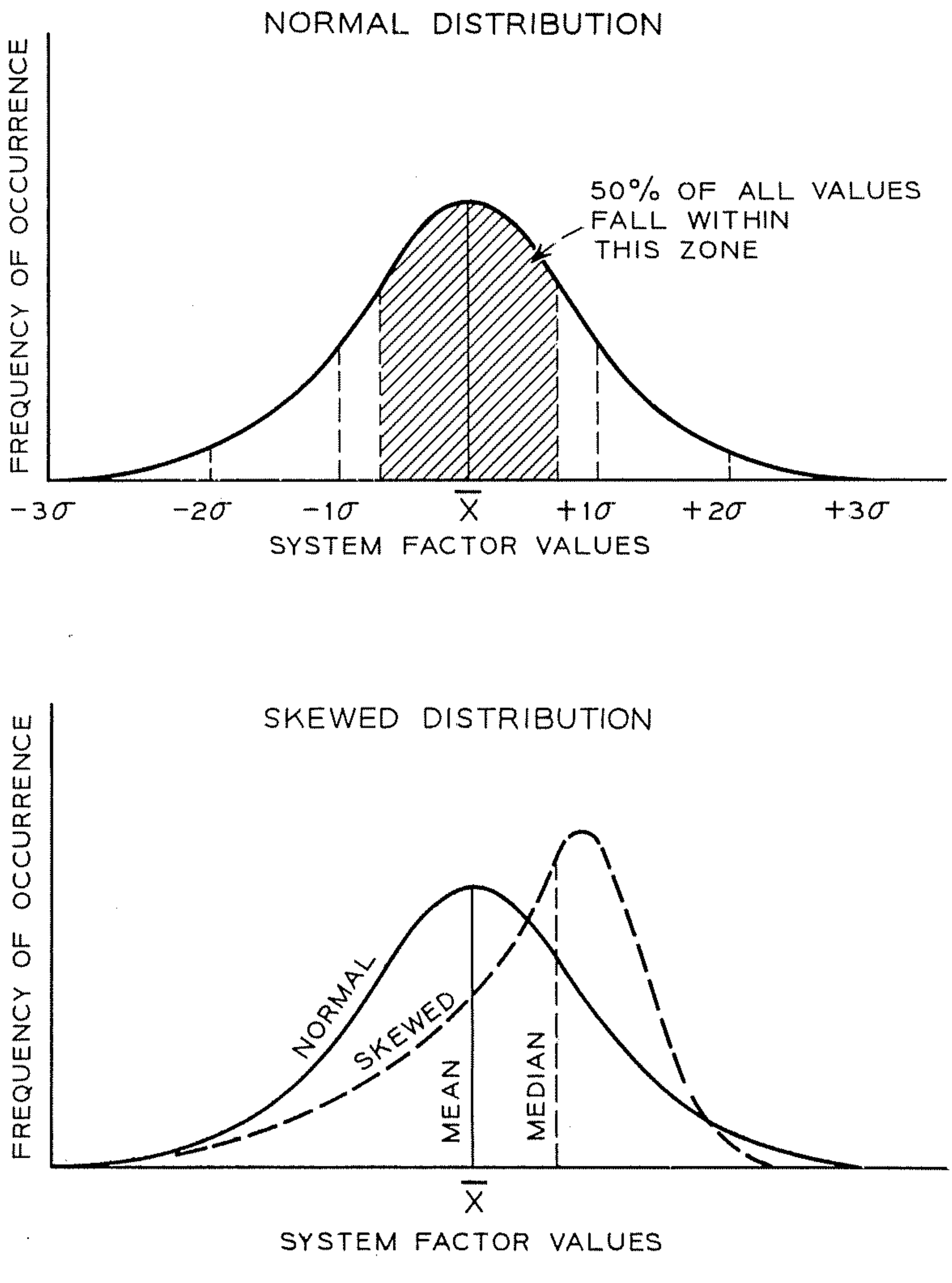


FIG. B-1--Statistical Distribution Curve.

the man who does the proving should plot the chart immediately after his results are available and before a meter factor is applied.

B-22 Three examples will suggest some of the possible adaptations of control charts to metering.

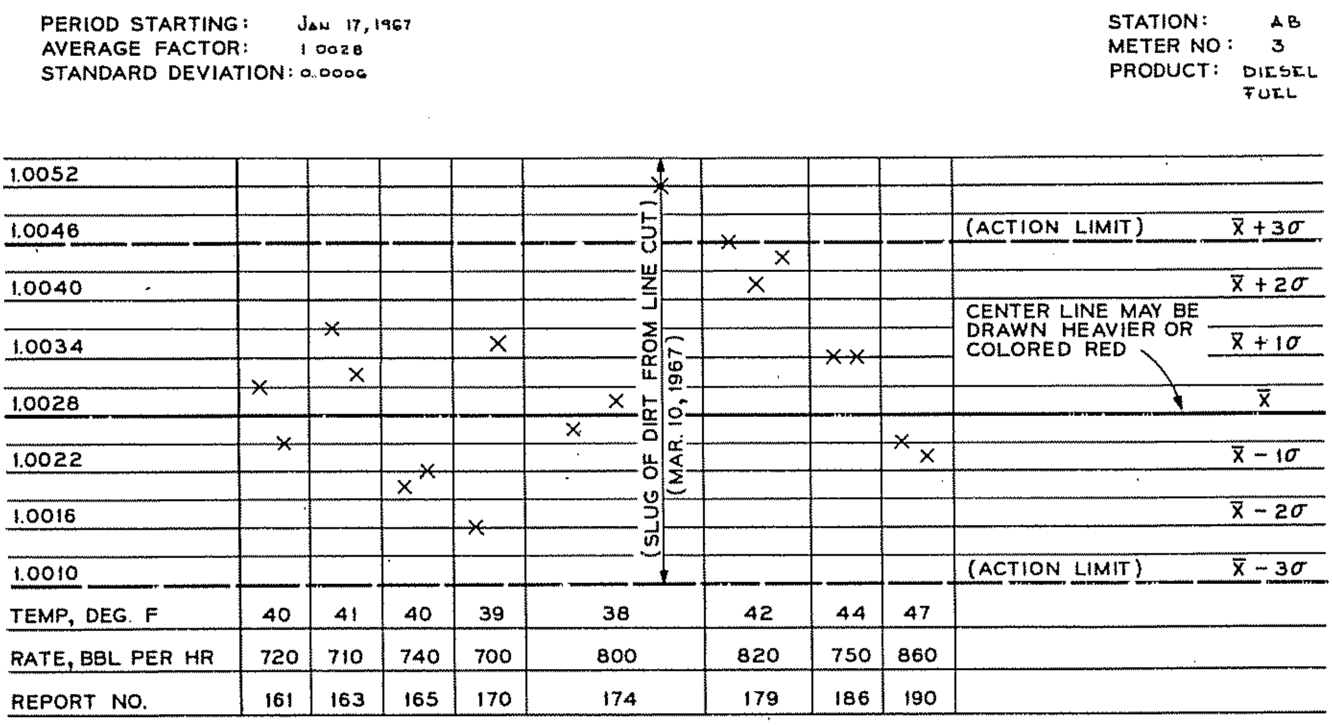
a. Example I

The first example, shown as Fig. B-2, is the most common and is useful for meters whose performance curve is flat, or almost so, over the range of rates and temperatures experienced in normal operation. In this example, factors were developed in pairs, in diesel fuel. The standard deviation, σ, has been shown by experience to be 0.0006 and the average factor, $\bar{X}$, to be 1.0028.

Each run (of a two-run proving) should be plotted, as shown in Fig. B-2. Temperature is posted because it affects the meter factor directly by changing internal dimensions, and indirectly because temperature affects viscosity which, in turn, affects the factor. Rate is posted for the same reason. If a gradual drift of factors develops and a drift in temperature is recorded, the assignable cause thus may be apparent. The report number is posted so supervisory personnel making an audit can readily refer to the supporting evidence. There must always be one chart for each product, or grade of crude, for any given meter or meter system.

Every determination of system factor should be plotted, as the occasional "bad" factor may serve as an advance warning that dirt, wear, damage, or other assignable cause is about to show itself more emphatically.

In Fig. B-2, the fourth proving gave factors of 1.0016 and 1.0036. These may be further apart than usual, but the average of the two is 1.0026, which is very close to the $\bar{X}$ value. As both factors were in control, no additional proving run was made.



NOTE: FOR EXAMPLE ONLY.

This format is suitable for systems with fairly constant rates or where performance curve is fairly flat.

FIG. B-2--System Factor Control Chart.

Repairs, service, or unusual occurrences to the measurement system should be shown on each appropriate control chart as a perpendicular line, with a date and notation to that effect. If the reference vessel is recalibrated or the switches or thermometer are adjusted, it should also be noted on the control chart with a perpendicular line and a date. A chart then becomes a very useful visual record of system performance, as well as a measurement control.

b. Example II

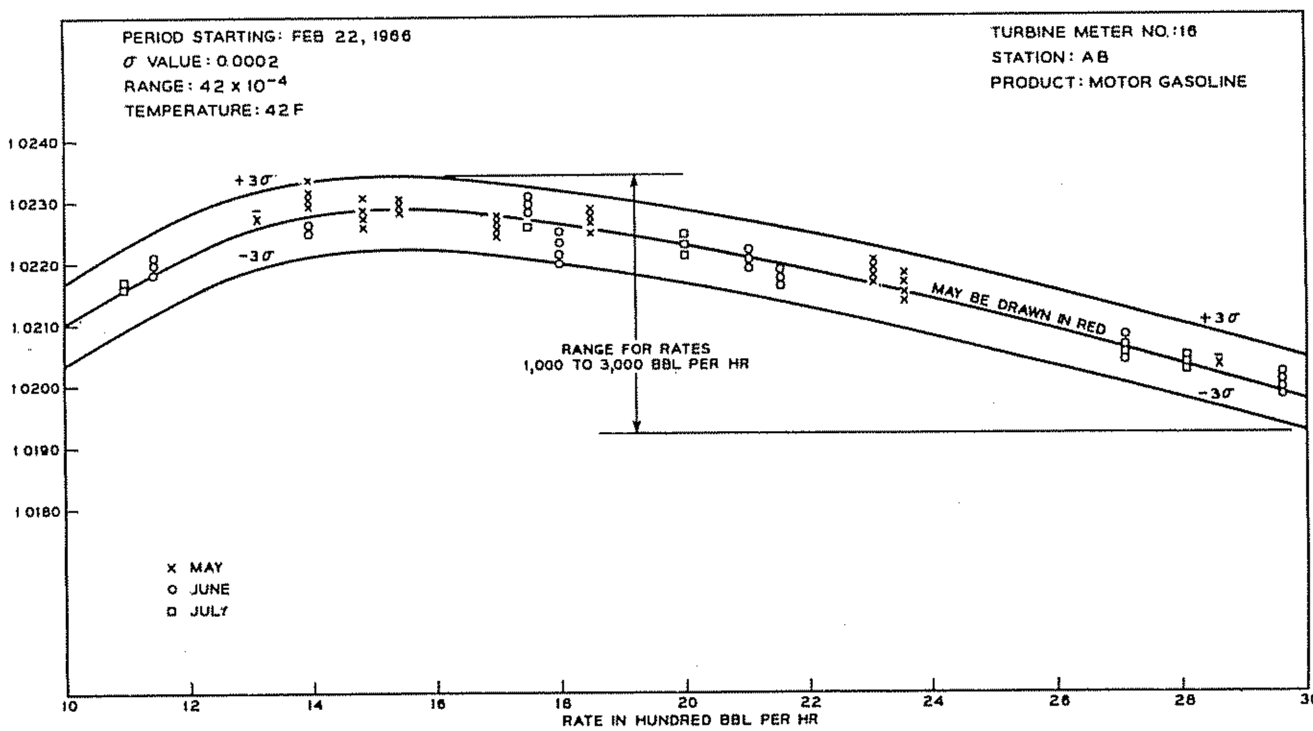
The second example of a system factor control chart is shown in Fig. B-3. It is a modification of the more usual form, which could be useful where a meter has been found to have a performance curve of the shape shown. The 1σ and 2σ lines are omitted and only the 3σ action limits are shown.

The factors plotted in Fig. B-3 vary between 1.0234 at a rate of 1,500 BPH to as low as 1.0192 at a rate of 3,000 BPH or by 0.0042. This spread is sometimes called the range* with the upper and lower rates of flow clearly stated or implied. Although the range in this example is 0.0042, the standard deviation can nevertheless be 0.0002, and the action limits at any given rate would be only six times σ apart, i.e., ± 0.0006.

c. Example III

The third example, shown on Fig. B-4, is another modification of the standard control chart shown in Fig. B-2. It can be useful during the startup period when all equipment is new and is being broken in simultaneously. For every proving run, the factor value is plotted by marking or filling the appropriate square. This form of chart can be useful because it shows at a glance the nature of factor distribution. A fairly large number of factors is required, but they are usually available at the breaking-in period of a new installation. The range of rates should be kept modest to avoid skewing due to rate alone. Standard deviation values may be left unshown and uncomputed because of the provisional nature of the chart. After this form of control chart has served its purpose, the types shown in Fig. B-2 or B-3 can be established using the statistical evidence accumulated to determine n, $\bar{X}$, and σ.

* See ASTM STP 15-C, Part 3, Par. 10.



NOTE: FOR EXAMPLE ONLY.

FIG. B-3--Measurement System Control Chart.

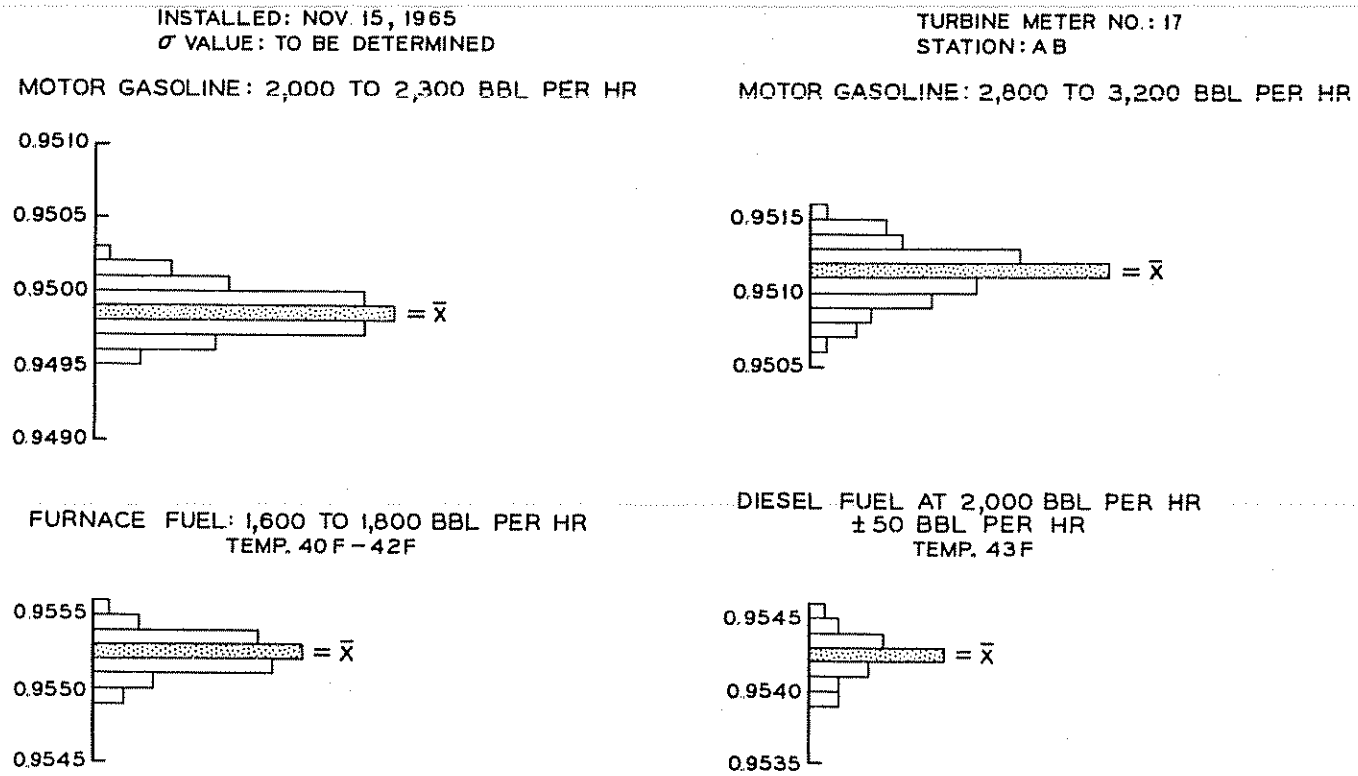


FIG. B-4--Provisional System Control Chart.

STANDARD DEVIATIONS OF SYSTEMS FROM SUBSYSTEM σ VALUES

B-23 All measurement systems consist of parts – meter, prover, thermometer, and the like – each of which is subject to some error. Their deviations from true value are experimental errors. A few of the causes of such errors in liquid measurement by meter are known, but are deliberately ignored because they are so small. Other causes are unknown and are unavoidably ignored. It is convenient to lump them all together and call them "accidental errors" and their net result "chance."

B-24 Errors in the several parts of a measurement system are potentially cumulative, so that the error of the system will tend to be greater than of any of its individual components.

B-25 Following are some useful mathematical rules for combining errors of subsystem variables:

a. Error of Sum or Difference

The error expressed in terms of standard deviation, of the sum or difference of two quantities, A and B, affected by errors, (expressed in terms of standard deviations of a and b) is equal to the square root of the sum of the squares of a and b.

$$\sigma_{A+B} = \pm\sqrt{a^2+b^2}$$

EXAMPLE 1

A turbine meter is proved against a bank of three positive displacement meters whose meter factors are known to have standard deviations of 0.0005, 0.0006, and 0.0007, respectively. The maximum uncertainty (or 3σ value) for the turbine system factor due to using the positive displacement meter bank as a reference is as follows:

$$\sigma = \sqrt{\sigma_1^2+\sigma_2^2+\sigma_3^2}$$

$$= \sqrt{(5^2+6^2+7^2)(10^{-8})}$$

$$= \sqrt{(110)(10^{-8})}$$

$$= (10.5)(10^{-4}) = 0.00105$$

For practical purposes the 3σ action limits for the turbine meter would be 0.0032 above and below the $\bar{X}$ value for the turbine meter system.

b. Error of Product of Two Quantities

The error expressed in terms of standard deviation of the product of two quantities, A and B, affected by errors expressed in terms of standard deviations of a and b is:

$$\sigma_{AB} = \pm\sqrt{(Ab)^2 + (Ba)^2}$$

EXAMPLE II

For a delivery of 11,800 gross bbl, the error introduced when line temperature is recorded to the nearest whole degree fahrenheit, and the barrel reading corrected for system factor to the nearest whole barrel, i.e., to a precision of ± 0.5 bbl, is as follows. The liquid thermal coefficient of expansion is 0.0006 per degree fahrenheit. Thus,

A = 11,800 bbl.
B = 1.0018 for 57 F in 58 deg API liquid.
a = ± 0.5 bbl (maximum uncertainty or 3σ).
b = (0.5) (0.0006) or ± 0.0003 (maximum uncertainty).

$$\text{Error in } AB = \sqrt{[(11{,}800)(0.0003)]^2 + [(1.0018)(0.5)]^2}$$

$$= \sqrt{(3.54)^2 + (0.5009)^2}$$

$$= \sqrt{12.53 + 0.2509}$$

$$= \sqrt{12.78}$$

$$= \pm 3.58 \text{ bbl}$$

For practical purposes, the delivery is 11,821 ± 4 net bbl, expressed as maximum uncertainty or ± 3σ. For all practical purposes, it will be noted that the error is due to thermometry, i.e., to rounding off to the nearest whole degree fahrenheit.

If it is required to calculate the standard deviation of an expression with three variables, such as observed barrels, A, system factor, B, and volume correction for temperature, C, with attendant errors of a, b, and c, respectively, the error in

$$ABC = \sqrt{(BCa)^2 + (ACb)^2 + (ABc)^2}$$

c. Error of Quotient of Two Quantities

The error expressed in terms of standard deviation of the quotient (B/A) of two quantities, A and B, affected by standard deviations error values of a and b is:

$$\sigma_{\frac{B}{A}} = \pm\frac{1}{A}\sqrt{\frac{Ba^2}{A} + b^2}$$

An example for this rule would be the estimation of error in a system factor in which B is the number of barrels in the prover or reference volume with an error of ± b, and A is the observed reading of a turbine meter in which readout is affected with an error of ± a. The values to be given to a and b have to be worked out first, using the error rules aforementioned before the quotient error rule can be applied.

B-26 The more compounded any value becomes, the greater its error. For example, if the error in line balance of a pipeline system is to be estimated, it will soon become apparent that a large number of values, each with its own error, enter into the calculation. Accumulated errors can be larger than expected.

SIGNIFICANT FIGURES

B-27 Meter factors, as well as the minimum volumes that are required in mechanical displacement meter provers described in API Standard 2531, and the resolution per unit volume generated by many turbine meters are all part of the goal of achieving measurement to five significant figures. Generally, the last value is doubtful for any given number of significant figures. Therefore, no undue emphasis should be placed on digits on or beyond the fourth decimal place in a system factor; particularly after an estimate has been made of the possible error in a system using the rules in Par. B-23 through B-26.

B-28 It is mathematically valid to calculate the average of a number of determinations (provings) greater than ten to an additional decimal place. It is also valid to calculate their standard deviation to yet another decimal place. However, neither of these steps is too practical in setting up system factor control charts; therefore, values of $\bar{X}$ and σ are rounded off accordingly (see ASTM STP 15-C, p. 41).

B-29 For example, if $\bar{X}$ were determined as 1.0012, and the variance (defined as σ^2) worked out to 13.0 times 10^{-8} then σ would be $\sqrt{(13.0)(10^{-8})}$ or

0.00036. For practical purposes, this would appear on the control chart as 0.0004. But the 3σ limits could be $\pm$ 3 times 0.00036 or 0.0011 rather than 0.0012. In practice, very few factors of a measurement system in a state of control will spread out to the $\pm 3\sigma$ limits. Therefore, it is just as well to draw the action limits at $\bar{X} \pm 3\sigma$ which is: 1.0012 $\pm$ 3 times 0.0004, i.e., at 1.0024 and 1.0000.

APPENDIX C

FLOW STRAIGHTENING TECHNOLOGY

SCOPE

C-1 Effective flow straightening can be obtained through the use of adequate lengths of straight pipe upstream and downstream of the meter. This appendix presents an empirical technique for computing the required length of upstream straight pipe for various installation configurations and operating conditions.

C-2 Experience has shown that a nominal length of 20 diameters of meter bore piping upstream of the meter and 5 diameters of meter bore piping downstream of the meter provides effective straightening in many installations. However, it is recommended that the required length of upstream piping be verified for each installation through the technique presented in this appendix. It should be noted that this technique does not predict the length of straight pipe required downstream of the meter. It is further recommended that a minimum of 5 diameters of meter bore piping be provided downstream of the meter for any installation.

CALCULATION OF UPSTREAM FLOW STRAIGHTENING LENGTH

C-3 Based upon empirical data, the length of straight pipe required upstream of the meter is given by:

$$L = (0.35D)\left(\frac{K_s}{f}\right) \qquad \text{(C-1)}$$

Where:

L = length of upstream meter bore piping, in feet.
D = nominal meter bore, in feet.
K_s = swirl velocity ratio, dimensionless.
f = Fanning pipe friction factor, dimensionless.

C-4 Values of the swirl velocity ratio, K_s, for a number of piping configurations are shown in Fig. C-1 through C-5; these data were derived from AGA Report No. 3, dated April, 1955, and revised January, 1969.

C-5 Equation (C-1) bears a remarkable similarity to the "Langhaar" equation as it relates to determining the length of transition. This length is defined as the minimum length of pipe required for a liquid to establish its characteristic velocity profile after undergoing an upstream disturbance. The Langhaar equation is

$$\frac{L}{D} = 0.058\,\frac{\rho V_A D}{\mu}$$

and is referenced in J. C. Hunsaker and B. G. Rightmire, *Engineering Applications of Fluid Mechanics*, p. 123, McGraw Hill Book Company (1947).

EXAMPLE OF CALCULATIONS

C-6 Determine the length of straight pipe run upstream of a 6-in. turbine meter for each of the configurations shown in Fig. C-1 through C-5 for the following conditions:*

$$Q = 2{,}000 \text{ gpm}$$
$$\nu' = 1.9 \text{ cSt}$$
$$D = 6/12 = 0.5 \text{ ft}$$

$$\text{Reynolds No., } R_n = \frac{263.6Q}{D\nu'} = \frac{(263.6)(2{,}000)}{(0.5)(1.9)} = (5.55)(10^5)$$
$$f = 0.0175$$

From Equation (C-1)

$$L = (0.35)(D)\left(\frac{K_s}{f}\right)$$

or

$$\frac{L}{D} = 0.35\,\frac{K_s}{f} \qquad \text{(C-2)}$$

or

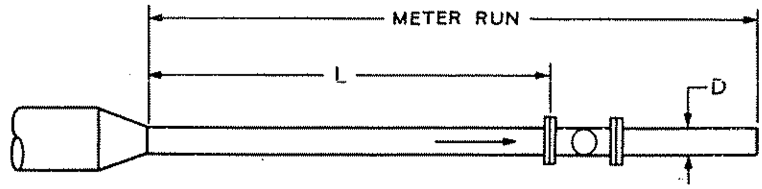
$$\frac{L}{D} = \frac{0.35K_s}{0.0175} = 20K_s$$

Then for

Figure No.	K_s	L (Inches)	L (Feet)	L/D Ratio
C-1	0.75	90	7.5	15
C-2	1.00	120	10.0	20
C-3	1.25	150	12.5	25
C-4	2.00	240	20.0	40
C-5	2.50	300	25.0	50

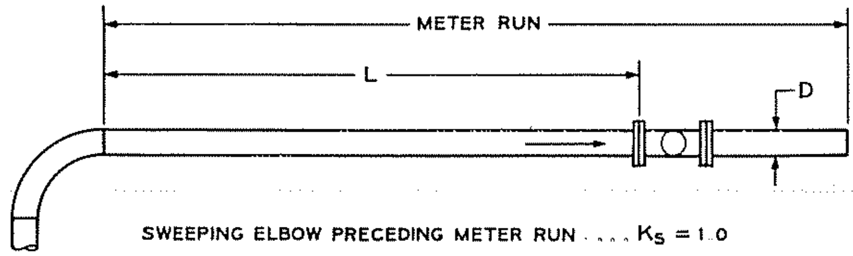
C-7 Since values of K_s are treated as relative coefficients in Par. C-6, the empirical coefficient K_s is assigned a value of 0.35 to agree with the basic recommendation of 20 diameters of straight pipe for the average installation.

*Nikuradse Curve, *Mater Eng* 66 [5] Reinhold Publishing Corp., New York, Oct. (1967).



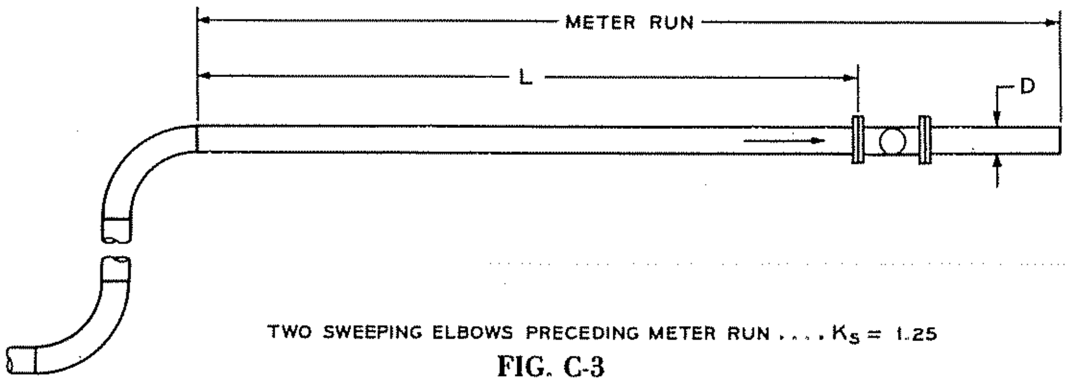
CONCENTRIC REDUCER PRECEDING METER RUN .... $K_S = 0.75$

FIG. C-1



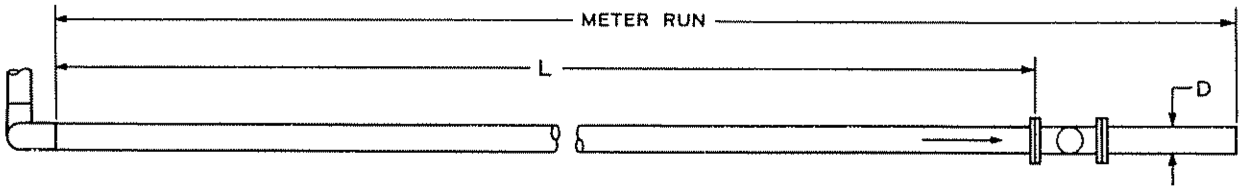
SWEEPING ELBOW PRECEDING METER RUN .... $K_S = 1.0$

FIG. C-2



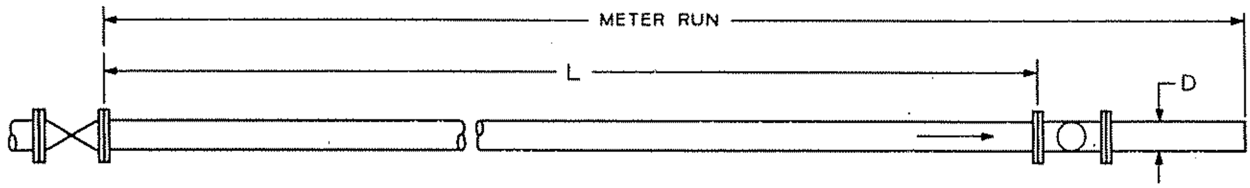
TWO SWEEPING ELBOWS PRECEDING METER RUN .... $K_S = 1.25$

FIG. C-3



TWO SWEEPING ELBOWS AT RIGHT ANGLES PRECEDING METER RUN.... $K_S = 2.0$

FIG. C-4



FULLY OPEN VALVE PRECEDING METER RUN ...... $K_S = 1.0$
PARTIALLY OPEN VALVE PRECEDING METER RUN ... $K_S = 2.5$

FIG. C-5

FIG. C-1 Through C-5--Values of Swirl Velocity Ratio, K_s, for Various Piping Configurations.

CONCLUSIONS

C-8 The L/D ratio is inversely proportional to the pipe friction factor and directly proportional to the swirl velocity ratio.

C-9 As $1/f$ is minimum for conditions of maximum pipe roughness for any given value of Reynolds number in the region of turbulent flow, it appears that the best straightening for minimum length of straight pipe occurs with a pipe of maximum roughness.

C-10 Equation (C-1) was evolved by grouping many relatively undefinable conditions in the flow stream and should not be considered a rigorous presentation. However, the simplicity of the resulting equation and the fact that it gives answers commensurate with experience suggests reliability in its application. The real value of equation (C-1) stems from its definition of the fundamental relationship of the swirl straightening characteristics within a length of straight pipe.

LAMINAR FLOW (SPECIAL CASE)

C-11 As $1/f$ is a function of Reynolds number, R_n, equation (C-2) can be written as:

$$\frac{L}{D} = (K_{\text{lam}})(R_n)(K_s) \qquad \text{(C-3)}$$

$$\frac{L}{D} = (K_{\text{lam}})\left(\frac{\rho V_E D}{\mu}\right)(K_s) \qquad \text{(C-4)}$$

Therefore, in the special case of laminar (lam) flow, L/D is directly proportional to mass density of the liquid, velocity, and pipe diameter and inversely proportional to dynamic viscosity.

APPENDIX D

SIGNAL GENERATION AND TRANSMISSION THEORY

INTRODUCTION

D-1 This appendix supplements and clarifies electrical installation requirements described in Sect. I.

ELECTRICAL SIGNAL GENERATION

D-2 The principal types of electrical signal-producing devices employed with turbine meters include the following:

a. *Inductance system:* The rotating element of the turbine meter employs permanent magnets which may be embedded in the hub, the blade tips, attached to a ring driven by the rotor, or attached to the rotor shaft. Regardless of the design employed, a magnetic flux from a moving magnet induces a voltage within a pickup coil located in close proximity to the magnetic field.

b. *Variable reluctance system:* A fixed permanent magnet is centered inside of the pickup coil housing so that a variation in the magnetic flux results from the passage of a highly permeable, magnetic rotor material within close proximity to the pickup coil.

c. *Photoelectric system:* A beam of light is interrupted by blades of the rotor, or elements of a member driven by the rotor, so that a pulsed signal output is developed.

d. *Magnetic reed switch system:* The contacts of a reed switch are opened and closed by magnets embedded in the rotor or in a rotating part of the turbine meter. The switch action causes a constant input to be interrupted so that a pulsed signal output is produced.

D-3 Of the preceding four systems, only the inductance and variable reluctance systems are truly generators in that both output frequency and voltage magnitude are proportional to rotor speed. The photoelectric and magnetic reed switch systems both require the application of an external constant voltage which is interrupted by the sensing devices so that a nearly pure, square-wave output results. The frequency of the output signal is directly proportional to rotor speed; the voltage magnitude varies only between zero and the input voltage and is not related to rotor speed.

D-4 The inductance and variable reluctance systems are considered to be low-power-level devices because they generate only a few milliwatts of electrical power. This output may be locally amplified and, in some instances, shaped at the turbine meter. The amplifier output may then be considered to be a high-level output. The photoelectric and reed switch systems are generally high-level devices, because the output level is controlled by the input voltage which they require. Ideally, high-power-level devices are less susceptible to noise problems because of the increased signal-to-noise ratio. However, each system has definite frequency limitations, which must also be considered when weighing one against the other.

TECHNIQUES FOR NOISE CONTROL

D-5 If noise voltage level can be kept below signal voltage level, the threshold level of the readout instrument can be adjusted to accept the signal level and reject the noise. A careful installation will be trouble-free and will keep noise level far below signal level.

D-6 Noise voltages may be induced in the flowmeter pickup coil by extraneous changing magnetic fields in much the same manner as the signal voltage. It makes no difference if the flowmeter is of the rotating magnet type, the inductance type, or the variable reluctance type. These extraneous signals may be produced from an a-c solenoid, an a-c relay coil, an unshielded transformer, a piece of rotating machinery, or even a single wire carrying heavy alternating currents (see Fig. D-1).

There are two basic methods of averting extraneous signals. The first method is to eliminate the effects of the flux on the coil. By proper orientation of either the flowmeter coil or the offending coil, the flowmeter coil can be made insensitive to the extraneous magnetic flux. This is effected by causing the extraneous flux lines to be perpendicular to the axis of the flowmeter coil (see Fig. D-2). In the second method it is sometimes difficult to determine the

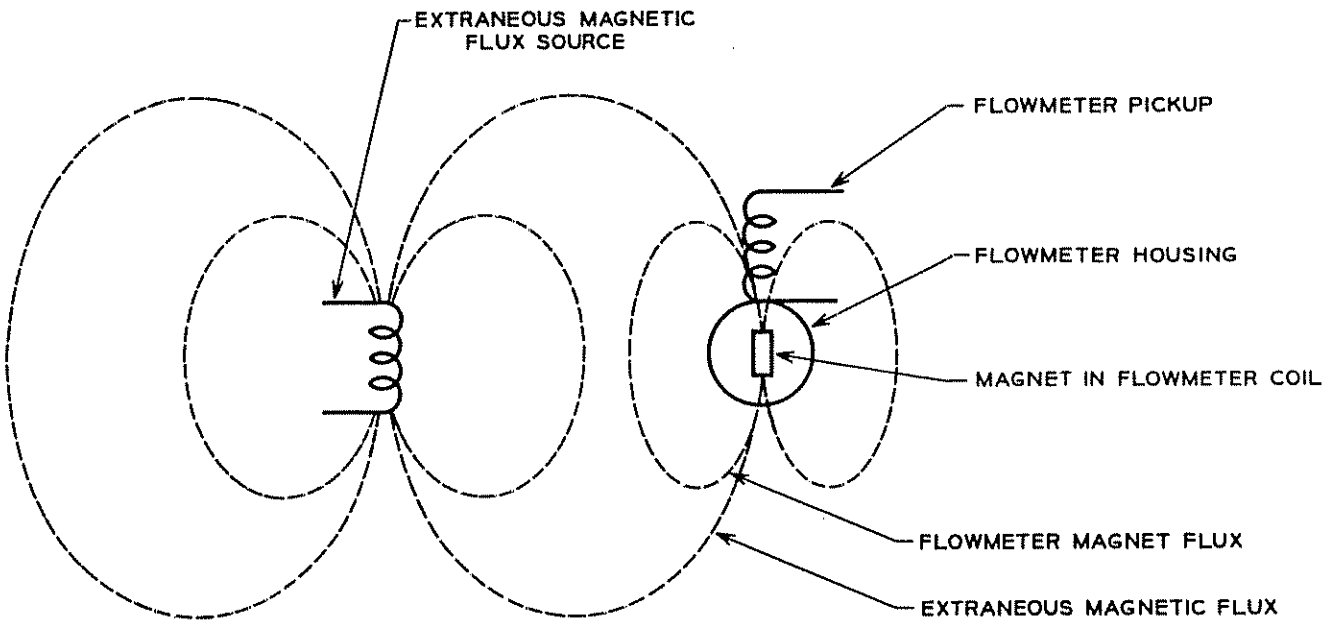


FIG. D-1--Extraneous Induction of Magnetic Flux in Flowmeter Coil.

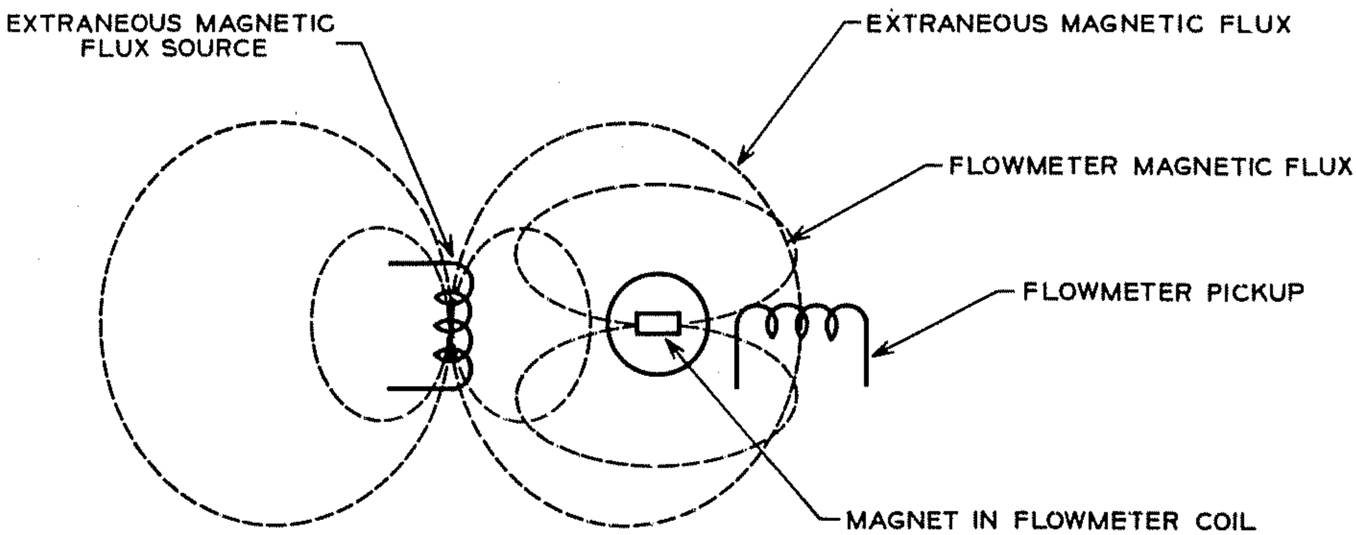


FIG. D-2--Orientation of Flowmeter Coil to Prevent Extraneous Flux Interference.

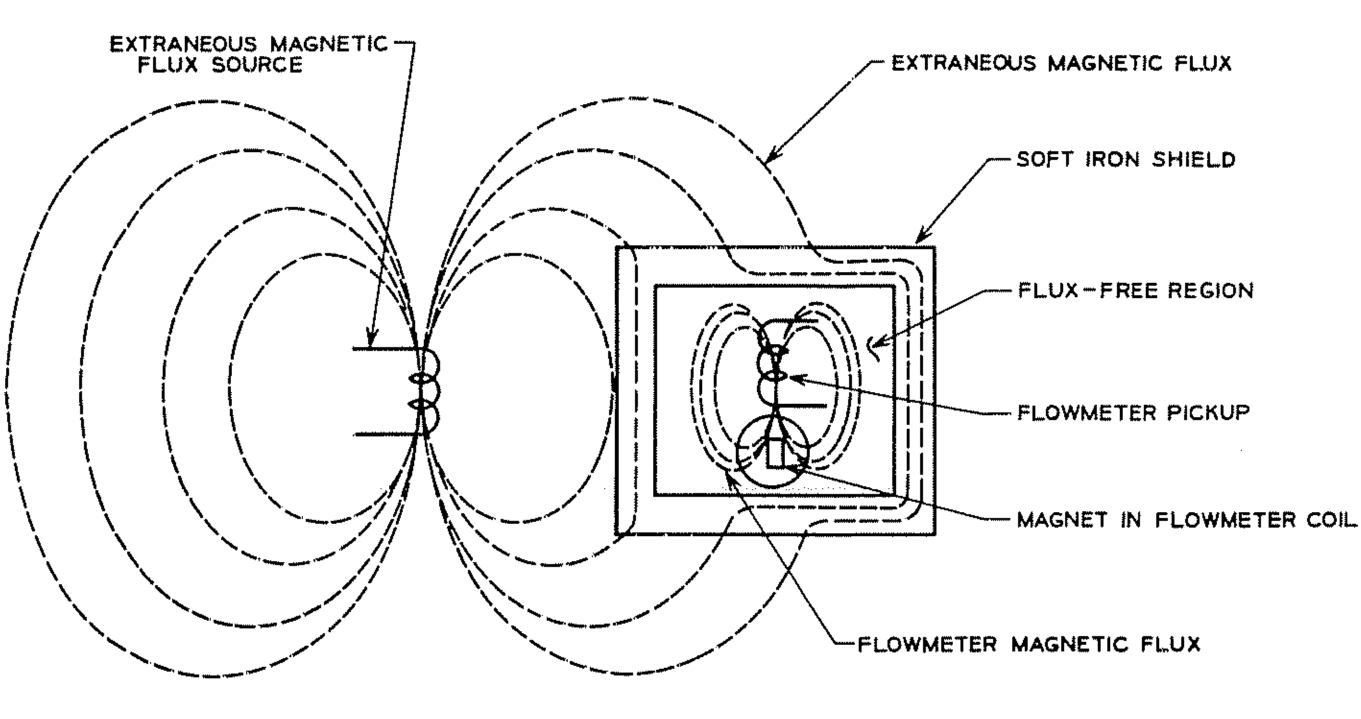


FIG. D-3--Shielding of Pickup to Prevent Extraneous Flux Interference.

exact flux paths. In these cases, it is best to find the position of least interference by trial and error. However, a more satisfactory method is to provide an alternate path for the offending flux through a soft metal conduit. The flux will be confined to the shield, leaving a flux-free region in which the flowmeter operates (see Fig. D-3).

D-7 The source of extraneous flux may be shielded by enclosing it in a soft metal conduit. The result is the same; the offending flux is prevented from getting into the flowmeter coil.

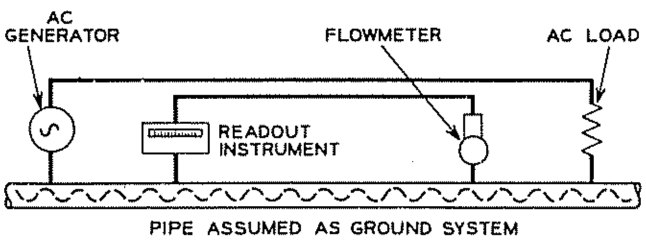


FIG. D-4--Introduction of Noise Signals by a Ground Loop.

D-8 Interfering signals may be introduced in the transmission of the flowmeter signal to the readout equipment because of a difference in potential between the flowmeter ground and the readout instrument ground. This difference in potential is brought about by load currents flowing in the ground system, causing a voltage drop between one place and another. Fig. D-4 shows a simplified grounding situation.

The pipeline ground system can be considered as a long drawn-out resistor. The a-c generator can be a transformer or the arcing contacts of a relay or a commutator. If the resistance between the generator and the load is 1/10 of an ohm, it requires only 10 amp in the load to produce a 1-v difference in potential. Fig. D-4 can be redrawn, as shown in Fig. D-5, to show the effects of the voltage difference in the ground system on the flowmeter readout system. The a-c ground potential difference generator represents the voltage drop in the ground path as the result of circulating currents.

Fig. D-6 shows an installation utilizing a common ground and a single wire.

The ground potential difference appears in series with the flowmeter, and the readout instrument is unable to distinguish between the two signals.

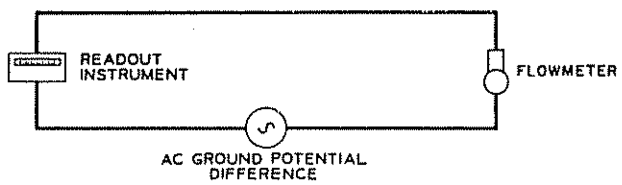


FIG. D-5--Potential Difference Caused by Lack of Grounding.

D-9 The a-c ground potential difference presents another method of objectionable noise introduction. The flowmeter coil is in a metal housing at the flowmeter ground potential. The coil can be considered as one capacitor plate and the housing as the other. Because the capacitive reactance is small, a low-impedance input to the readout equipment will tend to reduce this effect. Or, isolating the flowmeter housing from ground may eliminate the a-c ground potential difference. Thus, the effect of capacitive reactance may be minimized.

D-10 Impedances may adversely affect the results of the turbine meter system. If meter pickup (output) impedance is assumed constant, three possibilities exist with respect to readout (input) impedance: readout impedance may be higher, resulting in increased sensitivity to both signal and noise; readout impedance may be lower, resulting in decreased sensitivity to both signal and noise and possible loss of registration at low flow rates or low power supply voltages; or readout impedance may equal pickup impedance, resulting in maximum transfer of signal energy. Adding readout devices to a single pickup or preamplifier may change the impedance relationship and possibly affect the meter system.

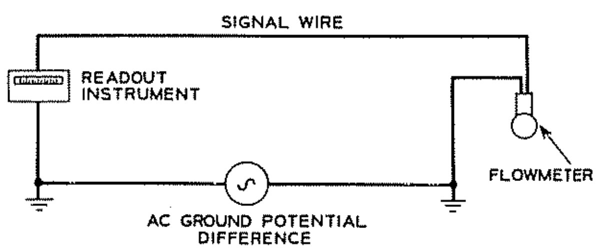


FIG. D-6--Potential Difference Caused by Grounding at Two Points.

CHECKLIST FOR TURBINE METER ELECTRICAL SYSTEM

D-11 The following inspection should be made prior to releasing a new meter installation for measurement service or when trouble occurs:

a. Check polarity of readout devices relative to:

1. Indicated common or ground terminal.
2. Power source for d-c operated instruments.

b. Verify power supply at readout devices so that:

1. Voltage levels are acceptable.
2. Voltage regulation is within specification.

c. Check continuity of electrical transmission lines.

d. Check continuity of pickup coil winding.

e. Check resistance to ground terminal of:

1. Each wire of transmission cable.
2. Electrostatic shield of transmission cable: *Before* connecting to ground and relative to metal conduit (high resistance to metal conduit).
   After connecting to ground.
3. Coil winding.

f. Recheck ground connections and effective resistance to ground.

g. With no flow through flowmeter and with system power on, make certain that all readout devices are inactive.

h. Adjust signal sensitivity control on readout devices in accordance with manufacturer's instructions, if applicable.

i. Check flowmeter signal for:

1. Amplitude.
2. Form.
3. Noise levels at both flowmeter and readout devices.

j. Follow on-line test procedure for each readout device as recommended by the manufacturer.

TEST EQUIPMENT FOR ELECTRICAL SYSTEM

D-12 The following electrical testing equipment is suggested as minimal for inspecting and checking out the electrical portions of a turbine meter and prover installation:

a. Battery-operated volt-ohm meter: A volt-ohm meter operated by battery.

b. General-purpose oscilloscope: A wide-band scope with controlled triggering characteristics is preferable to a simple synchronized scope. Battery operation may be desirable in large or remote field installations.

c. Multirange a-c millivoltmeter: A meter for use with inductance and reluctance pickups. The minimum range should be 0 mv to 50 mv. A battery-operated unit may be desirable in large or remote field installations.

d. Multirange audio signal source: A signal generator having a minimum range of 10 hz with attenuators capable of reducing signal amplitudes to at least 10 mv.

APPENDIX E

DERIVATION OF TEMPERATURE AND PRESSURE EFFECTS FOR CHANGE OF METER DIMENSIONS

SCOPE

E-1 This appendix provides the derivation of the correction factors C_{tsmpc} and C_{psmpc} introduced in Par. 3010 and 3016, respectively, in this standard. The method of applying them, along with the correction factors C_{tlm60} and C_{plmpc} for change in liquid dimensions with change of temperature and pressure, is illustrated in Par. 3020. The application of this mathematical method of modifying meter factor for changes brought about by temperature and pressure acting upon internal dimensions and liquid compressibility is not recommended for use with crude oils or for hydrocarbon liquids with a viscosity greater than 15 cSt (see Par. 3002).

DERIVATION OF C_{tsmpc}

E-2 A simplified equation relating indicated throughput to actual throughput, based on operation at a different temperature than the temperature during proving, is derived. The derivation considers only the physical changes in the dimensions of the meter resulting from temperature changes and assumes that no warpage of the rotor blades occurs as the temperature changes.

E-3 The derivation does not consider variations in the measured liquid density, viscosity, lubricity, and so forth, arising from temperature changes in the liquid.

E-4 Fig. E-1 will serve as a reference in the subsequent derivation.

$$MF_{pc} = \frac{\text{Volume delivered during proof}}{\text{Volume registered during proof}} = \frac{Q_1}{f} \qquad \text{(E-1)}$$

$$Q_1 = (K)(A)(V) \qquad \text{(E-2)}$$

Where:

MF_{pc} = meter factor obtained during a meter proof referenced to proving conditions.
Q_1 = flow rate.
f = turbine meter output frequency.
K = constant of proportionality.
A = flow area in plane of rotor.
V = fluid velocity in plane of rotor.

$$W_R = (K_1)(f)(R_e) \qquad \text{(E-3)}$$

Where:

W_R = angular velocity of turbine blade at effective radius.
R_e = effective radius of turbine blade at proving temperature.
K_1 = constant of proportionality.

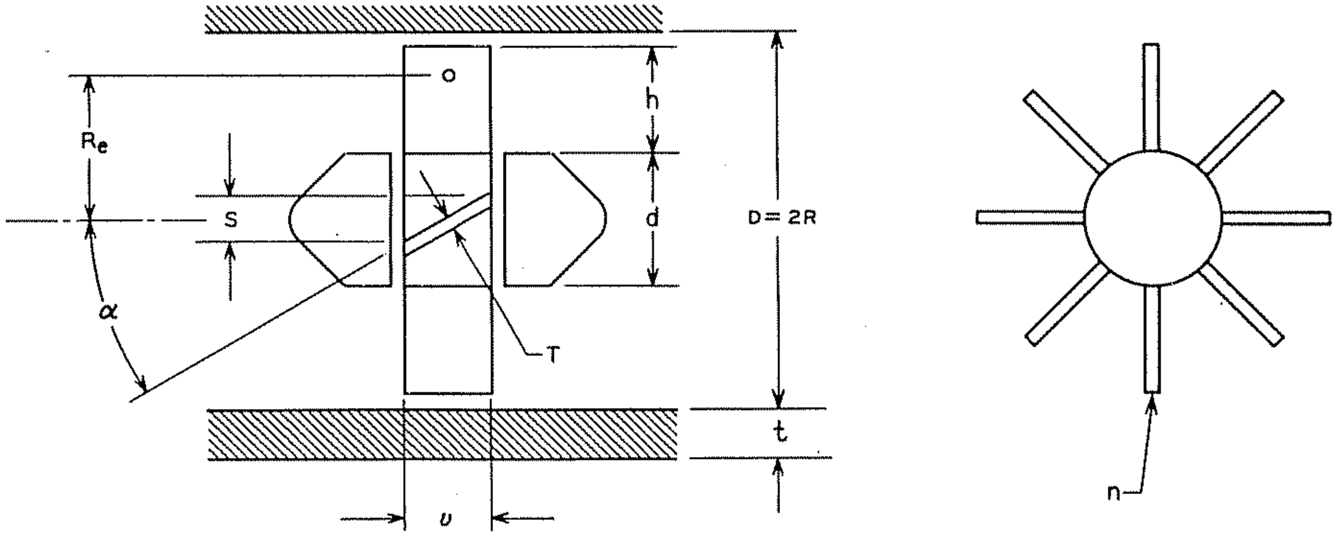


FIG. E-1--Reference Drawing.

$$t' = \frac{S}{W_E} = \frac{S}{(K_1)(f)(R_c)} \quad \text{(E-4)}$$

Where:

t' = time for turbine blade to rotate through increment S.
S = incremental angular blade displacement of effective radius.

Assuming fluid to be flowing in a straight line parallel to turbine meter centerline,

$$V = \frac{v}{t'} = \frac{\frac{v}{S}}{(K_1)(f)(R_c)} = \frac{(K_1)(f)(R_c)(v)}{S} \quad \text{(E-5)}$$

Where:

v = width of turbine blade.

$$\tan a = \frac{S}{v} \quad \text{(E-6)}$$

Where:

a = blade angle of turbine.

Substituting equation (E-6) in equation (E-5),

$$V = \frac{(K_1)(f)(R_c)}{\tan a} \quad \text{(E-7)}$$

and

$$f = \frac{(V)(\tan a)}{(K_1)(R_c)} \quad \text{(E-8)}$$

Substituting equations (E-2) and (E-8) in equation (E-1),

$$MF_{pc} = \frac{(K)(A)(V)}{\frac{(V)(\tan a)}{(K_1)(R_c)}} = \frac{(K)(K_1)(A)(R_c)}{\tan a} \quad \text{(E-9)}$$

$$A = \frac{(\pi)(D^2)}{4} - \frac{(\pi)(d^2)}{4} - \frac{(n)(h)(T)}{\cos a} \quad \text{(E-10)}$$

$$A = \left(\frac{\pi}{4}\right)(D^2 - d^2) - \frac{(n)(h)(T)}{\cos a} \quad \text{(E-11)}$$

Where:

D = diameter of meter bore at proving temperature.
d = diameter of hub (stator).
n = number of blades on the turbine.
h = blade length.
T = blade thickness.

As the turbine hub diameter, d, bears a relatively constant relationship to the bore diameter, D, it can be stated that

$$d = (X)(D) \quad \text{(E-12)}$$

$$d^2 = (X^2)(D^2) \quad \text{(E-13)}$$

Where:

X = a constant of proportionality.

Also, the blade area bears a relatively constant relationship to the bore diameter, D, so

$$\frac{(n)(h)(T)}{\cos a} = (Z^2)(D^2) \quad \text{(E-14)}$$

Where:

Z = a constant of proportionality.

Substituting equations (E-11), (E-13), and (E-14) in equation (E-9),

$$MF_{pc} = \frac{(K)(K_1)\left[\frac{\pi}{4}(D^2 - X^2D^2) - (Z^2)(D^2)\right](R_c)}{\tan a} \quad \text{(E-15)}$$

$$MF_{pc} = \frac{(K)(K_1)\left[\frac{\pi}{4} - \frac{\pi}{4}(X^2) - Z^2\right](D^2)(R_c)}{\tan a} \quad \text{(E-16)}$$

For any given meter it may be said that

$$K_2 = \frac{(K)(K_1)\left[\frac{\pi}{4} - \frac{\pi}{4}(X^2)(Z^2)\right]}{\tan a} \quad \text{(E-17)}$$

Where:

K_2 = a constant of proportionality

and:

$$MF_{pc} = (K_2)(D^2)(R_c) \quad \text{(E-18)}$$

$$D' = D[1 + (E_H)(\Delta t_{pc})] \quad \text{(E-19)}$$

$$R_c' = R_c[1 + (E_R)(\Delta t_{pc})] \quad \text{(E-20)}$$

Where:

D' = diameter of meter bore at operating temperature.
E_H = thermal coefficient of expansion of housing.
Δt_{pc} = operating temperature minus proving temperature.
R_c' = effective radius of turbine blade at operating temperature.
E_R = thermal coefficient of expansion of rotor.

$$(MF_{pc})(C_{tsmpc}) = (K_2)(D'^2)(R_c') \quad \text{(E-21)}$$

$$(MF_{pc})(C_{tsmpc}) = (K_2)(D^2)[1+(E_H)(\Delta t_{pc})]^2(R_c)[1+(E_R)(\Delta t_{pc})]$$

or

$$C_{tsmpc} = \frac{(K_2)(D^2)[1+(E_H)(\Delta t_{pc})]^2(R_c)[1+(E_R)(\Delta t_{pc})]}{MF_{pc}} \quad \text{(E-22)}$$

Substituting equation (E-18) in equation (E-22),

$$C_{tsmpc} = \frac{(K_2)(D^2)[1+(E_H)(\Delta t_{pc})]^2(R_c)[1+(E_R)(\Delta t_{pc})]}{(K_2)(D^2)(R_c)} \quad \text{(E-23)}$$

Simplifying,

$$C_{tsmpc} = [1+(E_H)(\Delta t_{pc})]^2[1+(E_R)(\Delta t_{pc})] \quad \text{(E-24)}$$

E-5 The algebraic sign of Δt_{pc} must be observed. If the operating temperature is less than the proving temperature, a negative value results which must be used as such in subsequent calculations.

E-6 Equation (E-24) involves a cubic form of thermal expansion and has no relation to the meter size.

E-7 When the operating temperature exceeds the proving temperature, the pulses per unit volume generated by the turbine decrease, resulting in C_{tsmpc} being larger than 1.0000. Similarly, when the operating temperature is lower than the proving temperature, more pulses per unit volume are generated and C_{tsmpc} is less than 1.0000.

E-8 The use of Fig. E-2 will enable a quick determination of C_{tsmpc} for any proving and operating temperature conditions of most meters. For a meter made of special metals or metals not shown on the graph, E_H and E_R may be established for the metals and a line for it indicated on the graph by substitution in the formula.

DERIVATION OF C_{psmpc}

E-9 A simplified equation relating indicated throughput to actual throughput, based on operation at a different pressure than the pressure during proving, is derived. The derivation considers only the physical changes in the meter housings of single-case meters resulting from pressure changes and assumes that no change in the volume of the rotor occurs.

E-10 The derivation does not consider variations in the measured liquid density, viscosity, lubricity, and so forth, arising from pressure changes in the liquid.

E-11 The derivation is based on the extent of variation of the indicated meter registration being directly related to the variation of flow area in the plane of the rotor.

$$C_{psmpc} = \frac{A_o}{A_p} \quad \text{(E-25)}$$

Where:

C_{psmpc} = correction factor for changes in the physical dimensions of a meter arising from pressure change.
A_o = flow area at operating pressure.
A_p = flow area at proving pressure.

$$A_p = (\pi)(R^2) - A_T \quad \text{(E-26)}$$

Where:

R = radius of meter housing bore.
A_T = area of rotor.

$$A_o = (\pi)(R+\Delta R)^2 - A_T \quad \text{(E-27)}$$

Where:

ΔR = change in radius of meter because of pressure variation.

Substituting equations (E-26) and (E-27) in equation (E-25),

$$C_{psmpc} = \frac{(\pi)(R+\Delta R)^2 - A_T}{(\pi)(R^2) - A_T} \quad \text{(E-28)}$$

The area of the rotor can be considered a fixed percentage of the housing bore area

$$A_T = (\pi)(B^2)(R^2) \quad \text{(E-29)}$$

Where:

B = grouped constant of proportionality.

Substituting equation (E-29) in equation (E-28),

$$C_{psmpc} = \frac{(\pi)(R+\Delta R)^2 - (\pi)(B^2)(R^2)}{(\pi)(R^2) - (\pi)(B^2)(R^2)} \qquad \text{(E-30)}$$

$$C_{psmpc} = \frac{R^2 + (2)(R)(\Delta R) + \Delta R^2 - (B^2)(R^2)}{(R^2)(1-B^2)} \qquad \text{(E-31)}$$

$$C_{psmpc} = \frac{1 + \frac{2\Delta R}{R} + \frac{\Delta R^2}{R^2} - B^2}{1-B^2} \qquad \text{(E-32)}$$

$$C_{psmpc} = \frac{1-B^2}{1-B^2} + \frac{\frac{2\Delta R}{R}}{1-B^2} + \frac{\frac{\Delta R^2}{R^2}}{1-B^2} \qquad \text{(E-33)}$$

The term $\frac{\frac{\Delta R^2}{R^2}}{1-B^2}$ may be dropped as insignificant.

Then,

$$C_{psmpc} = 1 + \frac{\frac{2\Delta R}{R}}{1-B^2} \qquad \text{(E-34)}$$

Considering the meter housing as a thin-walled cylinder,

$$\Delta R = \frac{R}{E}\left[\frac{(\Delta P_{pc})(R)}{t} - \frac{(\gamma)(\Delta P_{pc})(R)}{2t}\right] \qquad \text{(E-35)}$$

Simplifying,

$$\Delta R = \frac{(\Delta P_{pc})(R^2)}{E}\left(\frac{2-\gamma}{2t}\right) \qquad \text{(E-36)}$$

Where:

E = modulus of elasticity in tension, in pounds per square inch.
ΔP_{pc} = pressure change that produces ΔR.
t = wall thickness of meter housing.
γ = Poisson's ratio.

Substituting equation (E-36) in equation (E-34),

$$C_{psmpc} = 1 + \frac{\frac{(2)(\Delta P_{pc})(R^2)}{ER}\left(\frac{2-\gamma}{2t}\right)}{1-B^2} \qquad \text{(E-37)}$$

$$C_{psmpc} = 1 + \frac{\frac{(2)(\Delta P_{pc})(R)}{E}\left(\frac{2-\gamma}{2t}\right)}{1-B^2} \qquad \text{(E-38)}$$

Equation (E-38) can be simplified by considering the dimensional constants associated with any given meter as a modulus Y that remains fixed, i.e., never changes for that particular meter, where:

$$Y = \frac{(2-\gamma)(2R)}{(E)(1-B^2)(2t)} = \frac{(2-\gamma)(2R)}{(E)\left(1-\frac{A_T}{\pi R^2}\right)(2t)} \qquad \text{(E-39)}$$

Then from equation (E-38),

$$C_{psmpc} = 1 + (\Delta P_{pc})(Y) \qquad \text{(E-40)}$$

Where:

Y = from equation (E-39).
ΔP_{pc} = operating pressure minus proving pressure $= P_o - P_p$.
P_o = pressure during operation.
P_p = pressure during proving.

E-12 The algebraic sign of ΔP_{pc} must be observed. If the operating pressure is less than the proving pressure, a negative value results which must be used as such in subsequent calculations.

E-13 The final expression, equation (E-40), shows that the pressure effect is a function of the meter radius divided by the housing wall thickness.

E-14 The use of Fig. E-3 will enable a quick determination of C_{psmpc} for any proving and operating pressure conditions of a meter provided the value of Y for it has been previously determined. In the calculation of Y for a meter, it may be advisable to consult the meter manufacturer for the necessary dimensions and type of meter housing material. C_{psmpc} for any double-case meter is 1.0000 at all pressures.

SUMMARY

E-15 When it is necessary to correct for both temperature and pressure effects, it may be done as indicated in Sect. III, Par. 3020, or as in Appendix F.

E-16 The preceding derivations have described mathematical procedures for calculating correction factors to compensate for the changes in the dimensions of a meter arising from temperature and pressure changes subsequent to proving a meter. Their use is not advocated in lieu of reproving a meter where optimum measurement accuracy is required.

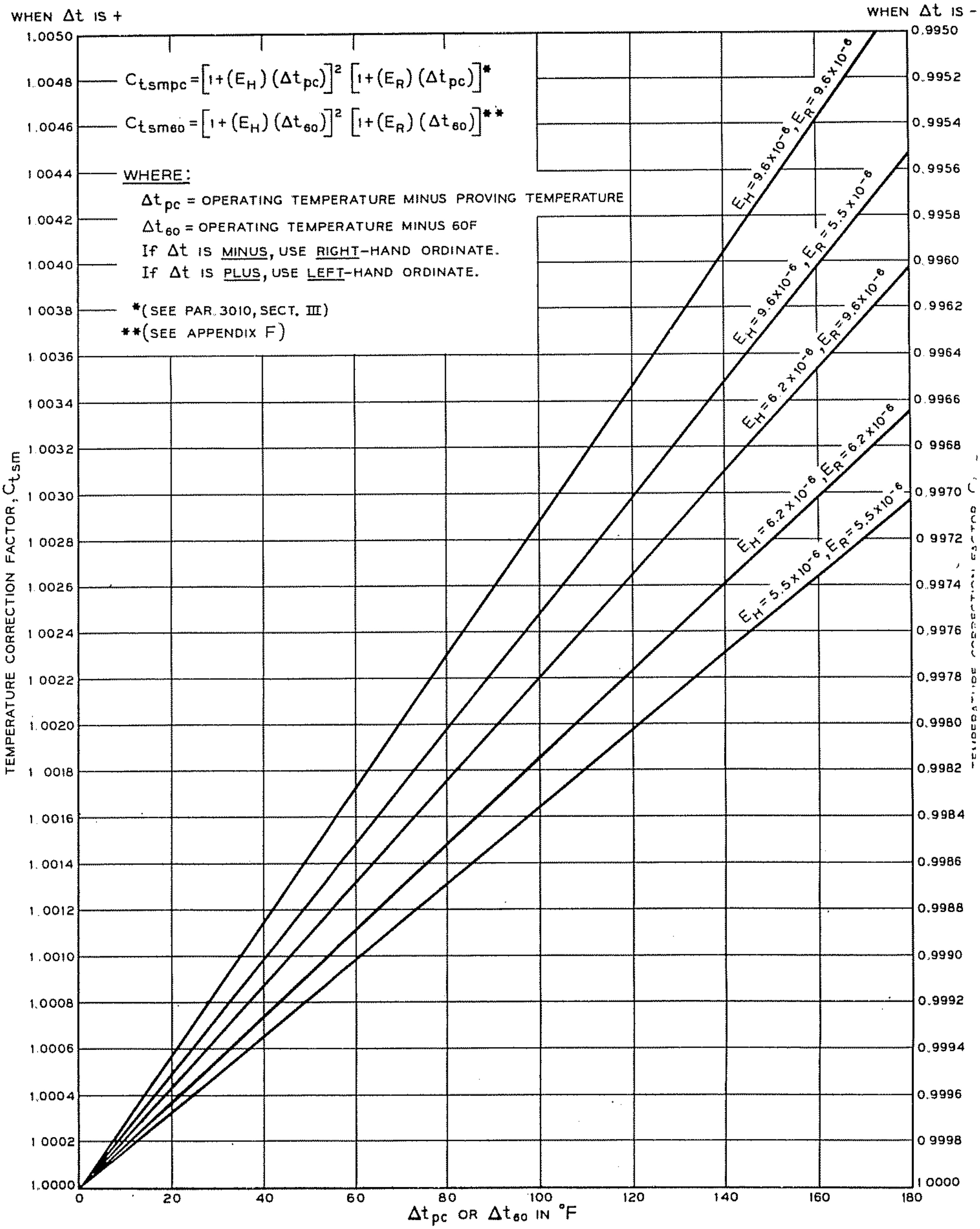


FIG. E-2--Temperature Correction Factor to Account for Change in Meter Dimensions with Change in Temperature.

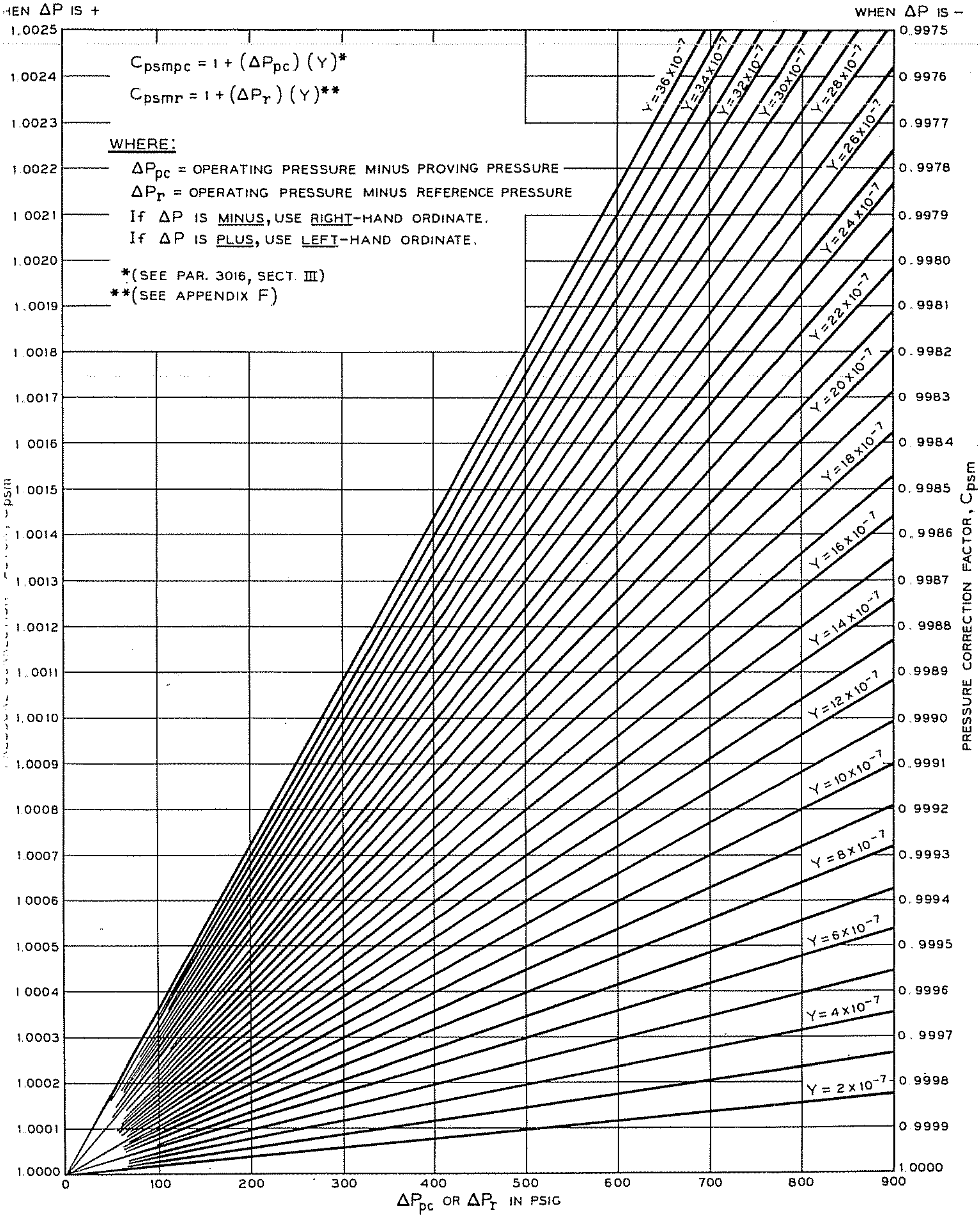


FIG. E-3--Pressure Correction Factor to Account for Meter Strain Arising from Pressure.

APPENDIX F

ALTERNATE METHOD OF APPLYING TEMPERATURE AND PRESSURE CORRECTIONS

DIGEST OF SECT. III

F-1 This alternate method is not recommended for use when measuring crude oils or hydrocarbon liquids with a viscosity greater than 15 cSt (see Par. 3002). Sect. III of this standard presents the formulas for the calculation of meter factor and quantity throughput, respectively:

$$MF_{60\&pc} = \frac{(BV)(C_{tlp60})(C_{plpr})(C_{tsp60})(C_{pspr})}{(MR)(C_{tlm60})(C_{plmpc})(C_{tsmpc})(C_{psmpc})}$$

and

$$Q_{60\&r} = (MR)(MF_{60\&pc})(C_{tlm60})(C_{plmpc})(C_{tsmpc})(C_{psmpc})$$

These formulas are based on the establishment of reference conditions for the meter factor as follows:

C_{tlm60} = liquid temperature in the meter = 60 F.
C_{plmpc} = liquid pressure in the meter
= pressure in meter at time of proving.
C_{tsmpc} = meter housing temperature
= temperature of meter at time of proving.
C_{psmpc} = pressure in the meter housing
= pressure in meter at time of proving.

F-2 Because C_{plmpc}, C_{tsmpc}, and C_{psmpc} are all equal to 1.0000 when a meter is being proved as well as when it is being operated at conditions identical to those under which it was proved, the computations are significantly simplified for those types of metering installations. At the same time, the formulas are applicable at any operating temperature and pressure other than that which existed at proving; because C_{plmpc}, C_{tsmpc}, and C_{psmpc} reference the meter factor to the proving condition of temperature and pressure. These correction factors are only necessary therefore, when a meter departs from the conditions of temperature and pressure at which it was proved. When the corrections are employed in throughput calculations, it is imperative that the proving temperature and pressure be known and used as the reference base.

ALTERNATE METHOD

F-3 In certain types of metering installations, particularly those in which a computer is employed to perform throughput calculations or where rapidly or widely fluctuating temperatures or pressures are encountered, it may be expedient to use a meter factor having standardized reference conditions of temperature and pressure instead of the reference conditions of temperature and pressure which existed at the time of proving, as advocated in Sect. III. Such an alternate meter factor can be used at any operating temperature or pressure, and the corrections C_{tlm60}, C_{plmr}, C_{tsm60}, and C_{psmr} can be calculated without knowledge of the temperature and pressure at which the meter was proved. It is designated as $MF_{60\&r}$ signifying that it is a meter factor having standardized reference conditions of temperature and pressure as follows:

C_{tlm60} = liquid temperature in the meter = 60 F.
C_{plmr} = liquid pressure in the meter
= reference pressure of measurement.*
C_{tsm60} = meter housing temperature = 60 F.
C_{psmr} = pressure in the meter housing
= reference pressure of measurement.*

F-4 The use of $MF_{60\&r}$ means that in calculating either the meter factor or the net throughput, the registration indicated by a meter at the operating temperature and pressure must always be reduced to its equivalent volume at 60 F and 0 psig by the application of correction factors for all four variables.

*The reference pressure of measurement for liquids having vapor pressures equal to or less than atmospheric is 0 psig.

F-5 The formulas for determining meter factor $MF_{60\&r}$ and net throughput $Q_{60\&r}$ are as follows:

$$MF_{60\&r} = \frac{(BV)(C_{tlp60})(C_{plpr})(C_{tsp60})(C_{pspr})}{(MR)(C_{tlm60})(C_{plmr})(C_{tsm60})(C_{psmr})}$$

$$Q_{60\&r} = (MR)(MF_{60\&r})(C_{tlm60})(C_{plmr})(C_{tsm60})(C_{psmr})$$

Where:

$MF_{60\&r}$ = meter factor having reference conditions of temperature and pressure as follows:

Liquid temperature in the meter = 60 F.
Liquid pressure in the meter = 0 psig (or other reference pressure).
Meter housing temperature = 60 F.
Pressure in the meter housing = 0 psig (or other reference pressure).

$Q_{60\&r}$ = actual net quantity of liquid at 60 F and 0 psig (or other reference pressure) passed through a meter.

BV = base volume of mechanical displacement prover or prover tank when its internal pressure is 0 psig and its temperature is 60 F.

C_{tlp60} = correction factor for the temperature of the liquid in the prover to reduce the volume of liquid observed in or displaced from the prover at prover temperature to its equivalent volume at 60 F. C_{tlp60} is obtained from ASTM D 1250.

C_{plpr} = correction factor for the pressure on the liquid in the prover to reduce the volume of liquid observed in or displaced from the prover at prover pressure to its equivalent volume at the reference pressure of measurement. The reference pressure of measurement for liquids having vapor pressures equal to or less than atmospheric is 0 psig. C_{plpr} is derived from the formula

$$V_l = (V_h)\left[\frac{1-(P_l-P_e)(F)}{1-(P_h-P_e)(F)}\right]$$

for converting a volume at a high pressure to its equivalent volume at a lower pressure (see API Standard 1101, Par. 3046). If

$$C_{plpr} = \frac{V_l}{V_h}$$

then,

$$C_{plpr} = \frac{1-(P_r-P_e)(F)}{1-(P_h-P_e)(F)}$$

Where:

P_r = reference pressure of measurement in pounds per square inch gage, considered as 0 psig for liquids having vapor pressures equal to or less than atmospheric.

P_e = equilibrium pressure in pounds per square inch gage for the liquid in the prover, normally considered 0 psig for liquids having vapor pressures less than atmospheric.

F = compressibility factor in pounds per square inch for the liquid in the prover at prover temperature from API Standard 1101, Fig. 33 or Table II.

P_h = average pressure on liquid in the prover, in pounds per square inch gage.

C_{tsp60} = correction factor for the temperature of the steel in the prover to reduce the base volume of the prover at 60 F to its equivalent volume at the observed prover temperature. C_{tsp60} for mechanical displacement provers is obtained from API Standard 2531, Appendix B, Table I. C_{tsp60} for prover tanks is obtained from the table of C_{ts} values in API Standard 1101, Par. 3045.

C_{pspr} = correction factor for the pressure on the steel of the prover to reduce the base volume of the prover at 0 psig to its equivalent volume at the observed prover pressure. C_{pspr} for mechanical displacement provers is obtained from API Standard 2531, Appendix B, Table II. C_{pspr} for prover tanks is obtained as described in API Standard 1101, Par. 2116 through 2122. C_{pspr} for all meter provers operating at atmospheric pressure is equal to 1.0000.

MR = closing meter reading minus opening meter reading during a meter proof or during any measuring period.

C_{tlm60} = correction factor for the temperature of the liquid in the meter to reduce the meter registration volume at the observed meter temperature to its equivalent *volume at 60 F*. C_{tlm60} is obtained from ASTM D 1250, and its use establishes the reference condition of the meter factor, insofar as temperature of the liquid is concerned, as being 60 F.

C_{plmr} = correction factor for the pressure on the liquid in the meter to reduce the meter registration at the observed operating pressure to its equivalent volume *at 0 psig* or other reference pressure. When a meter is being proved, its pressure while proving is its operating pressure. C_{plmr} is obtained from API Standard 1101, Par. 3046 and 4008 through 4011 and is determined as follows:

$$C_{plmr} = \frac{1-(P_r-P_{er})(F_r)}{1-(P_o-P_{eo})(F_o)}$$

Where:

P_r = reference pressure for the meter factor, considered as 0 psig for liquids having vapor pressures equal to or less than atmospheric.*

P_{er} = equilibrium pressure of metered liquid in pounds per square inch gage at the reference temperature.†

F_r = compressibility factor per pound per square inch for the metered liquid at the reference temperature from API Standard 1101, Fig. 33 or Table II.

*When $P_r = 0$, the formula becomes

$$C_{plmr} = \frac{1}{1-(P_o-P_{eo})(F_o)}$$

†If equilibrium pressure is atmospheric pressure or below, use zero gage pressure.

P_o = observed internal meter case pressure during meter operation, in pounds per square inch gage.
F_o = compressibility factor per pound per square inch for the metered liquid at the operating temperature from API Standard 1101, Fig. 33 or Table II.

C_{tsm60} = correction factor for the temperature effect on the steel of the meter to reduce the meter registration for the size of the meter at operating temperature to the equivalent registration which would occur if the size of the meter was equal to its size at 60 F. When a meter is being proved, the pressure while proving is the operating pressure. C_{tsm60} is obtained from Fig. E-2 or calculated as follows (see Appendix E):

$$C_{tsm60} = [1+(E_H)(\Delta t_{60})]^2[1+(E_R)(\Delta t_{60})]$$

Where:

E_H = mean linear coefficient of thermal expansion of the meter housing material from Par. 3010.
Δt_{60} = meter operating temperature minus 60 F. The algebraic sign of Δt_{60} must be observed. If the operating temperature is less than 60 F, a negative value results which must be used in the calculation.
E_R = mean linear coefficient of thermal expansion of the meter rotor material from Par. 3010.

The reference condition of the meter factor, insofar as the temperature of the meter is concerned, is established as being 60 F.

C_{psmr} = Correction factor for the pressure effect on the steel of the meter to reduce the meter registration at the size of the meter at operating pressure to the equivalent registration which would occur if the size of the meter was equal to its size at 0 psig (reference pressure). When a meter is being proved, the pressure while proving is the operating pressure. C_{psmr} is obtained from Fig. E-3 or calculated as follows (see Appendix E):

$$C_{psmr} = 1+(\Delta P_r)(Y)$$

Where:

ΔP_r = internal meter case pressure during operation minus the reference pressure. For liquids having vapor pressures equal to or less than atmospheric, the reference pressure is 0 psig. Normally, the algebraic sign of ΔP_r should be plus, but technically its sign must be observed in the calculation.
Y = as determined by the formula in Par. 3016.

The reference condition of the meter factor, insofar as the pressure on the meter is concerned, is established as being 0 psig or other reference pressure.

EXAMPLE OF CALCULATION OF VOLUME METERED UNDER VARYING PRESSURE AND TEMPERATURE CONDITIONS USING ALTERNATE METHOD

F-6 The following example illustrates the overall application of correction factors by the alternate method where varying pressure and temperature conditions are encountered in turbine meter operation.

Conditions

F-7 All of the conditions, meter data, prover data, measurement periods, and meter readings of this example are identical to those indicated in Sect. III, Par. 3020.

Problem

F-8 Calculate the following items using the alternate meter factor $MF_{60\&r}$ having standardized reference conditions of 60 F and 0 psig (reference) as described in this appendix:

Equation (F-1), meter factor, $MF_{60\&r}$.
Equation (F-2), quantity throughput for measurement period No. 1.
Equation (F-3), quantity throughput for measurement period No. 2.
Equation (F-4), total quantity throughput for both measurement periods.

Solution

F-9 From the alternate formula of this appendix,

$$MF_{60\&r} = \frac{(BV)(C_{tlp60})(C_{plpr})(C_{tsp60})(C_{pspr})}{(MR)(C_{tlm60})(C_{plmr})(C_{tsm60})(C_{psmr})}$$

Referring to the proving data,

BV = 16.182 bbl.
C_{tlp60} = 1.0075 from ASTM D 1250, Table 6, for 61.0 deg API at 48.0 F.

$$C_{plpr} = \frac{1-(0-0)(0.0000074)}{1-(90-0)(0.0000074)}$$

= 1.0007 for 61.0 deg API at 48.0 F.

C_{tsp60} = 0.9998 from API Standard 2531, Table I, for 48 F.
C_{pspr} = 1.0001 from API Standard 2531, Table II, for prover with 12-in.-ID pipe x 0.375-in. wall for 90 psig.

MR = 16.093 bbl.
C_{tlm60} = 1.0063 from ASTM D 1250, Table 6, for 61.0 deg API at 50.0 F.

$$C_{plmr} = \frac{1-(0-0)(0.0000074)}{1-(100-0)(0.0000074)}$$

= 1.0007 for 61 deg API at 50 F from API Standard 1101, Table II.

C_{tsm60} = 0.9998, calculated as follows:

E_H = $(9.6)(10^{-6})$ in. per in. per deg F for Type 304 stainless steel from Par. 3010.
E_R = $(5.5)(10^{-6})$ in. per in. per deg F for Type 416 stainless steel from Par. 3010.
Δt_{60} = 50 − 60 = −10

$$C_{tsm60} = \{1+[(9.6)(10^{-6})](-10)\}^2 \{1+[(5.5)(10^{-6})](-10)\}$$

C_{tsm60} = 0.9998
or from Fig. E-2:
C_{tsm60} = 0.9998

C_{psmr} = 1.0001, calculated as follows:

$$Y = \frac{(2-0.333)(6)}{(28{,}000{,}000)\left[1-\frac{10}{(3.14)(9)}\right](2)(0.321)}$$

Y = $(8.61)(10^{-7})$
ΔP_r = 100−0 = + 100
C_{psmr} = $1+(100)[(8.61)(10^{-7})]$
C_{psmr} = 1.0001

or from Fig. E-3:

C_{psmr} = 1.0001

$$MF_{60\&r} = \frac{(16.182)(1.0075)(1.0007)(0.9998)(1.0001)}{(16.093)(1.0063)(1.0007)(0.9998)(1.0001)}$$

$$MF_{60\&r} = 1.0067 \qquad \text{(F-1)}$$

F-10 From the alternate formula of this appendix,

$$Q_{60\&r} = (MR)(MF_{60\&r})(C_{tlm\,60})(C_{plm\,r})(C_{tsm\,60})(C_{psm\,r})$$

For the first measurement period, Q_1, where the meter is operating at proving conditions,

MR = 910,323 − 878,432 = 31,891 bbl.
$MF_{60\&r}$ = 1.0067 from Equation (F-1).
$C_{tlm\,60}$ = 1.0063 from ASTM D 1250, Table 6, for 61.0 deg API gravity at 50.0 F.

$$C_{plmr} = \frac{1-(0-0)(0.0000074)}{1-(100-0)(0.0000074)} = 1.0007$$

$C_{tsm\,60}$ = 0.9998 from Fig. E-2 for $\Delta t_{60} = -10$
$C_{psm\,r}$ = 1.0001 from Fig. E-3 for $\Delta P_r = 100$ and $Y = (8.61)(10^{-7})$

$$Q_1 = (910{,}323 - 878{,}432)(1.0067)(1.0063)(1.0007)(0.9998)(1.0001) \quad \text{(F-2)}$$

Q_1 = 32,326 bbl at 60 F and 0 psig.

For the second measurement period, Q_2, where the meter is operating at 625 psig and 75 F,

MR = 1,011,480−910,323=101,157 bbl.

$MF_{60\&r}$ = 1.0067 from meter proof.

$C_{tlm\,60}$ = 0.9906 from ASTM D 1250, Table 6, for 61.0 deg API at 75.0 F.

$$C_{plmr} = \frac{1-(0-0)(0.0000082)}{1-(625-0)(0.0000082)} = 1.0052$$

Where:

$P_r = 0$, $P_o = 625$ psig, and temperature = 75 F.

$C_{tsm\,60}$ = 1.0004 from Fig. E-2,

Where:

$\Delta t_{60} = 75 - 60 = +15$ and operating temperature is greater than reference temperature.

$C_{psmr} = 1 + (625)[(8.61)(10^{-7})] = 1.0005$ from Fig. E-3,

Where:
$\Delta P_r = 625$, $Y = (8.61)\ (10^{-7})$, and operating pressure is greater than reference pressure.

$$Q_2 = (1{,}011{,}480 - 910{,}323)(1.0067)(0.9906)(1.0052)(1.0004)(1.0005) \quad \text{(F-3)}$$

Q_2 = 101,493 bbl at 60 F and 0 psig.

Total throughput = $Q_1 + Q_2$
= 32,326 + 101,493
= 133,819 bbl at 60 F and 0 psig.* (F-4)

*This is the same quantity as calculated in Sect. III, Par. 3020.

APPENDIX G

TROUBLE-SHOOTING GUIDE

INTRODUCTION

G-1 This appendix is a guide to aid in the repair of turbine metering systems which are malfunctioning. Its purpose is the isolation of trouble for expeditious restoration of service.

SPARE PARTS AND SPECIAL TOOLS

G-2 It is assumed that a complete set of manufacturer's recommended spare parts and any special tools required for proper maintenance are available.

G-3 An oscilloscope for observation of electrical signals is helpful to determine the nature and form of the pulses as received by the counter. (For details see Appendix D.)

SOURCES OF TROUBLE

G-4 *Mechanical*:

1. Foreign material clinging to rotor blades.
2. Foreign material damage to, or loss of, rotor blades.
3. Foreign material damage to valve seats and displacer causing leakage.
4. Foreign material clinging to, or stopping up, straightening vane.
5. Worn or defective bearings.
6. Worn or defective output shaft (where applicable).
7. Excessive drag on output shaft (where applicable).
8. Ferrous material clinging to permanent magnets.

G-5 *Electrical*:

1. Proving—
   - *a.* Defective displacer detector switch.
   - *b.* Defective pickup.
   - *c.* Defective transmission circuit (circuit open or unshielded).
   - *d.* Presence of strong electrical field.
   - *e.* Defective proving counter (refer to manufacturer's operating manual).
   - *f.* Defective preamplifier.
2. Remote register—
   - *a.* Defective pickup coil or impulse contactor.
   - *b.* Defective transmission circuit.
   - *c.* Defective accumulator device (refer to manufacturer's operating manual).
   - *d.* Defective preamplifier.

G-6 Three major sources of trouble in the counting circuit and the suggested steps to their elimination are outlined in Fig. G-1, G-2, and G-3. Although these illustrations deal primarily with digital totalizers, they are equally applicable to various analog type of indicating devices commonly used with many applications of turbine meters. Knowledge of the instruments involved is essential, and an operation manual is helpful. If a totalizer does not count, refer to Fig. G-1. If a totalizer counts fast (overcounts), refer to Fig. G-2. If a totalizer counts slow (drops counts) or counts intermittently or irregularly, refer to Fig. G-3.

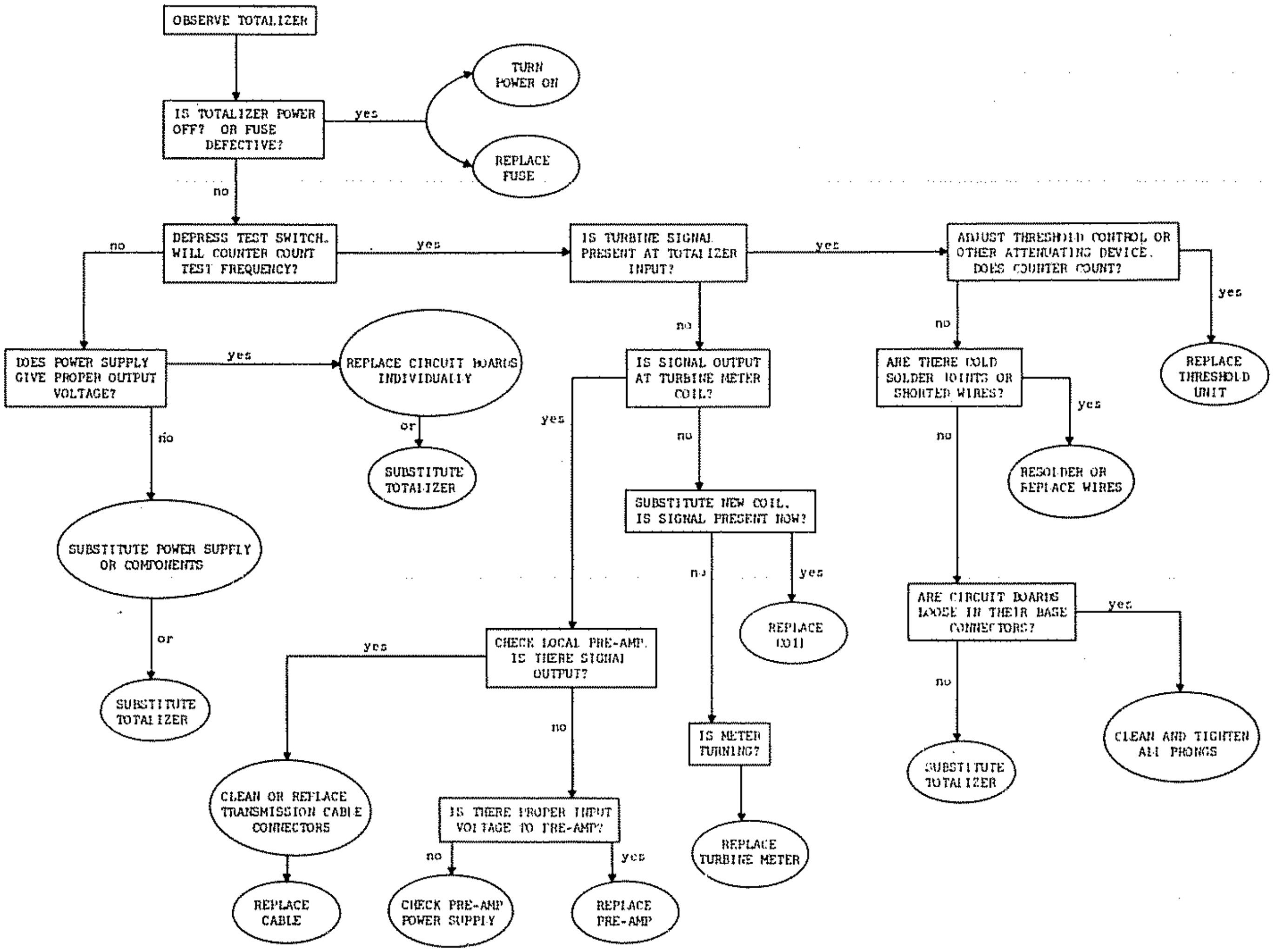


FIG. G-1--Totalizer Does Not Count.

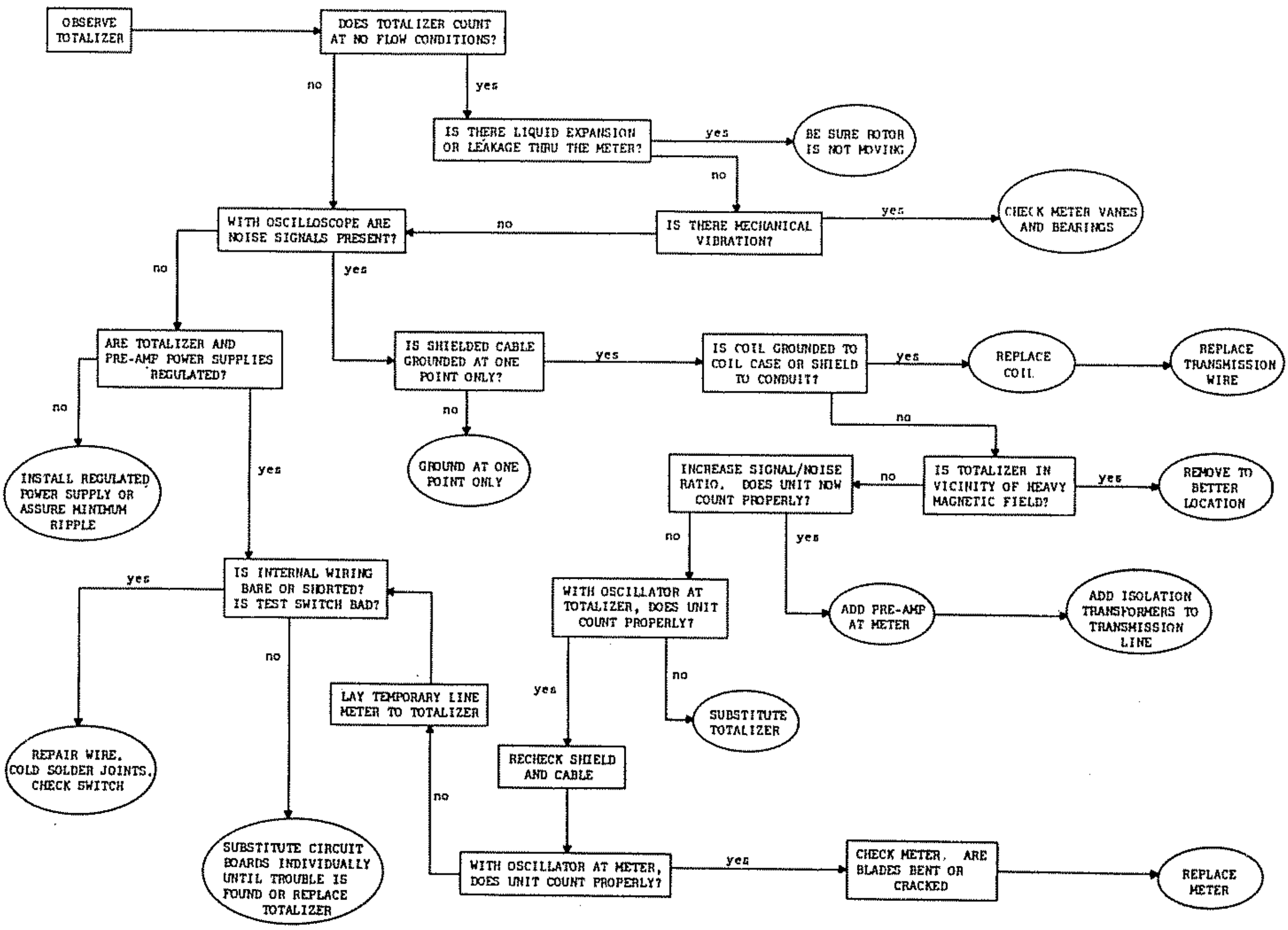


FIG. G-2--Totalizer Counts Fast (Overcounts).

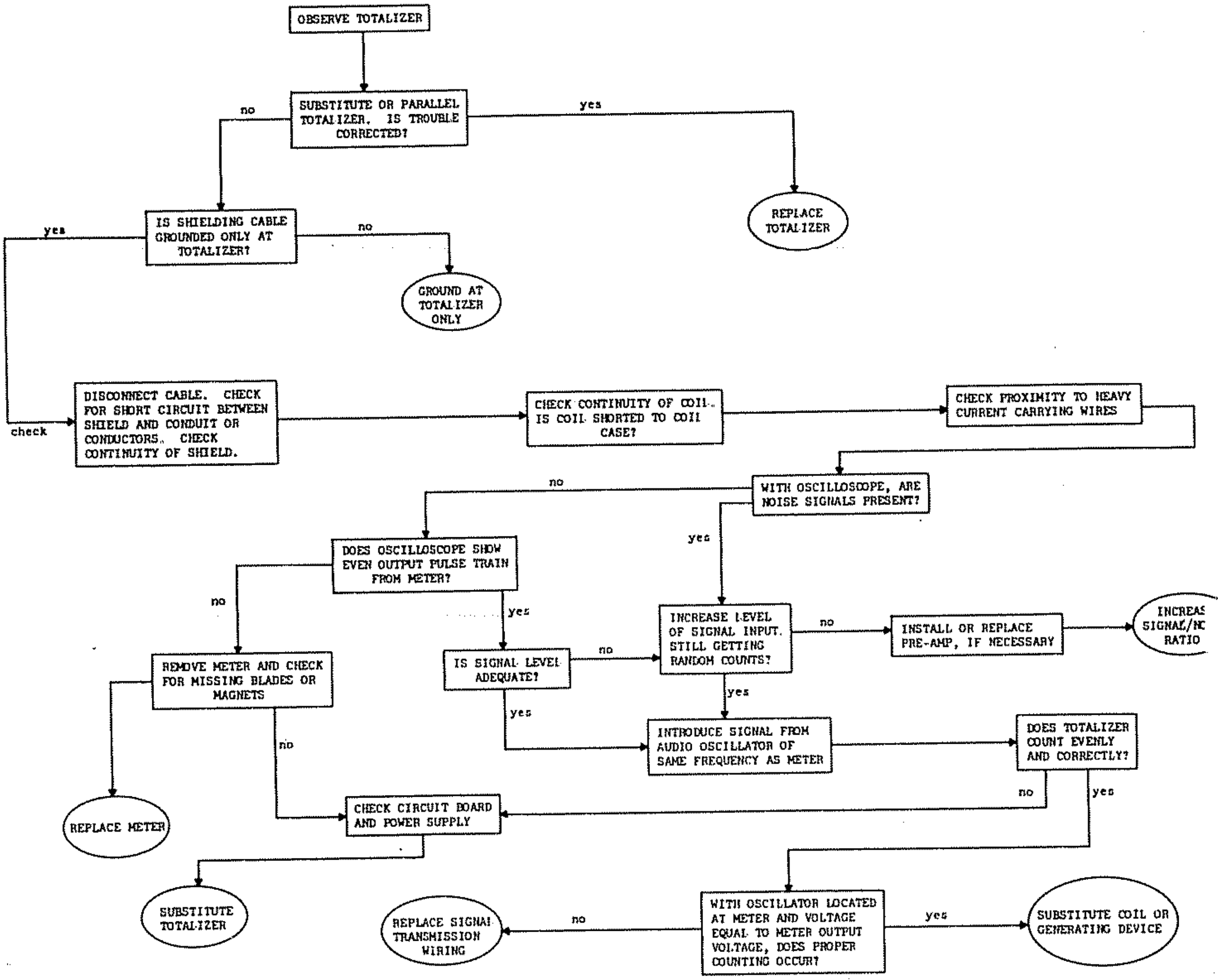


FIG. G-3--Totalizer Drops Count (Counts Slowly, Intermittently, or Irregularly).

3M—March 1970
3M—Sept 1971