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ASME PTC 29-2005

Speed-Governing Systems for Hydraulic Turbine-Generator Units

Performance Test Codes

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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The American Society of Mechanical Engineers

Three Park Avenue • New York, NY 10016

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This Code will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to ASME PTC 29-2005.

ASME issues written replies to inquiries as code cases and interpretations of technical aspects of this document. Code cases and interpretations are published on the ASME website under the Committee Pages at http://www.asme.org/codes/ as they are issued.

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

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NOTICE

All Performance Test Codes must adhere to the requirements of ASME PTC 1, General Instructions. The following information is based on that document and is included here for emphasis and for the convenience of the user of the Code. It is expected that the Code user is fully cognizant of Sections 1 and 3 of ASME PTC 1 and has read them prior to applying this Code.

ASME Performance Test Codes provide test procedures that yield results of the highest level of accuracy consistent with the best engineering knowledge and practice currently available. They were developed by balanced committees representing all concerned interests and specify procedures, instrumentation, equipment-operating requirements, calculation methods, and uncertainty analysis.

When tests are run in accordance with a Code, the test results themselves, without adjustment for uncertainty, yield the best available indication of the actual performance of the tested equipment. ASME Performance Test Codes do not specify means to compare those results to contractual guarantees. Therefore, it is recommended that the parties to a commercial test agree before starting the test and preferably before signing the contract on the method to be used for comparing the test results to the contractual guarantees. It is beyond the scope of any Code to determine or interpret how such comparisons shall be made.

FOREWORD

A Joint AIEE–ASME (IEEE–ASME) Subcommittee on a Recommended Specification Covering the Speed Governing of Hydraulic Turbine-Generators was organized in 1944. The specifications prepared by this subcommittee were issued in September 1950 as AIEE (IEEE) Publication No. 605 entitled "Recommended Specification for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators."

As a result of the publication of these specifications, the ASME Board on Power Test Codes Committee recognized the need of a code for testing hydraulic turbine governors and organized Power Test Code Committee No. 29 in 1955 to prepare this document.

This committee prepared a code that was approved by the Power Test Codes Committee on March 7, 1963. Final publication was delayed, however, until a number of suggestions made by the standing committee were considered and satisfactorily resolved. Reconciliation of these comments was effected through the efforts of Mr. W. K. Cave, member of the committee, who undertook to complete the assignment on behalf of the group. The code was approved and adopted by the Council of the Society by action of the Board of Codes and Standards on December 9, 1964.

In February 1993, through the efforts of the Board on Performance Test Codes' member George H. Mittendorf, Jr., the Performance Test Code (PTC) Committee 29 was reestablished to update the code.

The members of PTC Committee 29 wish to dedicate this document to the memory of William (Bill) Duncan. Bill served as the Committee's Vice Chairman from 1993 until his untimely death in an airplane crash on October 8, 1997. Bill's accomplishments were many, but nothing was more significant than organizing and supporting the validation of the draft of this code with actual site testing of an hydraulic turbine governor.

ASME PTC 29-2004 was adopted by the American National Standards Institute as an American National Standard on February 23, 2005.

PERFORMANCE TEST CODE COMMITTEE 29 ON SPEED GOVERNING SYSTEMS FOR HYDRAULIC TURBINE GENERATOR UNITS

(The following is the roster of the Committee at the time of approval of this Code.)

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CORRESPONDENCE WITH THE PTC 29 COMMITTEE

General. ASME Codes are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Code may interact with the Committee by requesting interpretations, proposing revisions, and attending Committee meetings. Correspondence should be addressed to:

Secretary, PTC 29 Standards Committee
The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

Proposing Revisions. Revisions are made periodically to the Code to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Code. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Code. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Interpretations. Upon request, the PTC 29 Committee will render an interpretation of any requirement of the Code. Interpretations can only be rendered in response to a written request sent to the Secretary of the PTC 29 Standards Committee.

The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Code for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings which are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Attending Committee Meetings. The PTC 29 Standards Committee holds meetings or telephone conferences, which are open to the public. Persons wishing to attend any meeting or telephone conference should contact the Secretary of the PTC 29 Standards Committee or check our Web site, http://www.asme.org/codes/.

INTRODUCTION

This Test Code provides uniform methods and procedures for conducting and reporting of performance tests on speed governors applied to conventional hydraulic turbines. The tests described in this Code may be performed in the factory or at the jobsite. A working knowledge of hydraulic turbine controls, speed governor fundamentals, test measurement methods, and the application and use of test and measurement equipment are presumed prerequisites.

This Code was prepared with attention paid to other national and international standards for speed governors. Specifically, the tests described in this Code are useful in determining compliance with IEEE 125 and IEC 308. Unless otherwise specified, all references within this Code refer to other ASME performance test codes and standards, including, but not limited to, Definitions and Values (PTC 2) and Supplements on Instruments and Apparatus (PTC 19 series). These auxiliary documents, where and to the extent applicable, form a part of this Code.

This Code includes three general categories of tests: performance tests, operational tests, and optional tests. The performance and operational tests form the body of the Code, and are required to qualify as a Code test. The optional tests are intended to offer guidance in ancillary governor functions that do not affect governor performance and are appended to this Code. An uncertainty analysis is also appended to the Code to serve as a guide to determining the uncertainty of the test results.

SPEED-GOVERNING SYSTEMS FOR HYDRAULIC TURBINE-GENERATOR UNITS

Section 1
Object and Scope

ASME Performance Test Codes (PTCs) provide uniform rules and procedures for the planning, preparation, execution, and reporting of performance test results. These codes provide guidelines for test procedures which yield results of the highest level of accuracy based on current engineering knowledge, taking into account test costs and the value of information obtained from testing. PTCs were developed by balanced committees representing many concerned interests.

When tests are conducted in accordance to a code, the test results themselves, without adjustment for uncertainty, yield the best available indication of actual performance of the equipment tested. ASME PTCs do not specify means to compare those results to contractual guarantees. Therefore, it is recommended that the parties to a commercial test agree, before starting the test and preferably prior to signing the contract, on the method to be used for comparing the results to the contractual guarantees. It is beyond the scope of any PTC to determine or interpret how such comparisons are made.

Test uncertainty is an estimate of the limit of error of a test result. It is the interval about a test result that contains the true value with a given probability or level of confidence. It is based on calculations utilizing statistics, instrumentation information, calculation procedure, and actual test data.

Code tests are suitable for use whenever performance must be determined with minimum uncertainty. They are meant specifically for equipment operating in an industrial setting.

PTCs are generally not used in troubleshooting equipment. However, they can be used to quantify the magnitude of performance anomalies of equipment that is suspected to be performing poorly, or to confirm the need for maintenance, if simpler means are not adequate. PTCs are excellent sources or references for simpler routine or special equipment test procedures. Conducting periodic performance tests on equipment can uncover the need for further investigation, which can lead to preventative maintenance or modification.

1-1 OBJECT

This Code defines uniform test methods and procedures to determine the performance characteristics of a hydraulic turbine speed governor. It is intended that this Code may be applied to either factory acceptance testing of a new speed governor or evaluation of an existing speed governor.

1-2 SCOPE

This Code applies to speed governors used on conventional, constant-speed hydraulic turbines. This Code is applicable to electronic-hydraulic and mechanical-hydraulic speed governors. These governors are commonly used to control reaction and impulse-type hydraulic turbines (fixed or variable geometry) and pump turbines operating in generation mode.

1-2.1 Performance Characteristics

This Code specifies procedures for conducting tests to determine the following performance characteristics of hydraulic turbine speed governors:

(*a*) droop
  (*1*) permanent
  (*2*) temporary
(*b*) deadband and deadtime
  (*1*) speed
  (*2*) position
  (*3*) power
(*c*) stability index
  (*1*) governing speedband
  (*2*) governing powerband
(*d*) step response
(*e*) gain
  (*1*) proportional gain
  (*2*) integral gain
  (*3*) derivative gain
(*f*) setpoint adjustment
  (*1*) range of adjustment
  (*2*) ramp rate

1-2.2 Operational Characteristics

This Code also establishes the rules and procedures for the conduct of tests to determine the following

Table 1-1 Allowable Test Uncertainties

Parameter Measured	Units of Measurement	Maximum Uncertainty
Permanent speed droop	%	±0.05% abs
Temporary speed droop	%	±2.0% abs
Speed deadband	% of rated speed	±0.002% abs
Position deadband	% of full stroke	±0.01% abs
Power deadband	% of rated power	±0.05% abs
Speed deadtime	% of rated speed	±0.02 sec
Position deadtime	% of full stroke	±0.02 sec
Governing speedband	% of rated speed	±0.03%
Governing powerband	% of rated power	±0.04%
Proportional gain	. . .	±0.2
Integral gain	Seconds^{-1}	±0.2 sec^{-1}
Derivative gain	Seconds	±0.2 sec
Setpoint range	% of range	±0.5%
Ramp rate	% of range per second	±1%/sec
Gate/blade relationship	% of dependent stroke	±0.5%
Needle/deflector relationship	% of dependent stroke	±0.5%
Servomotor timing	Seconds	±0.2 sec

operational characteristics of hydraulic turbine speed governors:

(*a*) gate/blade relationship (dual regulated reaction turbines)

(*b*) needle/deflector relationship (impulse turbines)

(*c*) full-rate servomotor timing and cushion time

1-3 TEST UNCERTAINTY

This Code establishes a limit for the uncertainty of each test required. Individual test uncertainties shall be calculated in accordance with the procedures defined herein and in ASME PTC 19.1, Test Uncertainty. A sample uncertainty analysis is presented in Appendix A. The allowable uncertainty levels of the individual tests are presented in Table 1-1.

Tests conducted by the methods, procedures, and instrumentation accuracies in accordance with this Code will result in uncertainties that are equal to or lower than those specified in Table 1-1. Post-test uncertainty analysis rationale is included in Appendix A.

Section 2 Definitions and Descriptions of Terms

The Code on Definitions and Values (ASME PTC 2) and referenced portions of Supplements on Instruments and Apparatus (ASME PTC 19 series) shall be considered as part of this Code, and their provisions apply unless otherwise specified. PTC 2 contains definitions of terms, values of physical constants, and conversion factors common to equipment testing and analysis.

The international system of units (SI) is used throughout this Code, with the U.S. customary units shown in parentheses. Conversion factors shall be in accordance with ASME Guide SI-1, ASME Orientation and Guide for Use of SI (Metric) Units.

The terms, definitions, symbols, and units in this Code are listed in Table 2-1.

Table 2-1 Definitions

Term	Definition	Symbol	Units SI	Units U.S.
Acceptance test	The evaluating action(s) to determine if a new or modified piece of equipment satisfactorily meets its performance criteria, permitting the purchaser to "accept" it from the supplier	. . .	. . .	. . .
Accuracy	The closeness of agreement between a measured value and the true value	. . .	. . .	. . .
Base reference conditions	The values of all the external parameters, i.e., parameters outside the test boundary to which the test results are corrected	. . .	. . .	. . .
Bias error	See systematic error	. . .	. . .	. . .
Calibration	The process of comparing the response of an instrument to a standard instrument over some measurement range and adjusting the instrument to match the standard if appropriate	. . .	. . .	. . .
Compensating mechanism	Includes those elements of the governor-control mechanism that modify the motion of the turbine-control mechanism to prevent over-travel, thus producing stability. Stability is obtained by modifying the input-error signal with a signal that is a function of the derivative(s) of speed. Derivative of speed should be determined: (*a*) by direct electrical or mechanical measurement as used in the "derivative" or "accelero-tachometric" types, or (*b*) by indirect measurement by means of a dashpot or equivalent device in combination with the restoring connections as used in the "dashpot" or "temporary droop" types	. . .	. . .	. . .
Damping time constant	Time constant of the integral action of the governor, defined by the slope of the governor step response curve with $b_p = K_P = K_D = 0$ and input signal $x = 1$ (see Fig. 2-1)	T_d	s	sec
Dashpot reset time	For mechanical governors, the decay time constant for the temporary droop feedback	T_r	s	sec
Deadband	The maximum band between two values inside of which the variation of controlled variable does not cause any governing action. This term can be applied to controlled variables such as speed, power, or level (see Fig. 2-2).	I_x	%	%
Deadtime	Time interval between a specified type of change in input signal and the first detectable movement of the servomotor that results from this change (see Fig. 2-3).	T_q	s	sec
Derivative filter time constant	The filter time constant applied to the derivative gain term in order to reduce the derivative response to high noise frequencies. The derivative filter may comprise either one or two stages of filtration.	T_V	s	sec
Derivative gain	The ratio of the relative servomotor position change resulting from the rate of change of relative speed with $b_p = K_I = K_P = 0$ (see Fig. 2-4)	K_D	s	sec
Distributing valve	The element of the hydraulic-control mechanism that controls the flow of hydraulic fluid to the turbine-control servomotor(s)	. . .	. . .	. . .
Droop	Droop is a characteristic that defines the relationship between two controlled variables. It is the ratio of relative change of one variable and the resulting relative change of the second variable. See also speed droop and power droop.	. . .	. . .	. . .
Electronic governor	Refers to a governing system that uses an electronic means of sensing and processing the input signal to the governor. This can be an analog circuit or a digital device.	. . .	. . .	. . .
Frequency	Frequency output of the generator	f	Hz	Hz
Frequency and power transducers	Measures generator operation and transmits this information to the governor in a form the governor can respond to. They consist of electrical devices and the necessary conditioning devices to provide a signal compatible with the governor.	. . .	. . .	. . .
Gate limit	A device that acts on the governor system to prevent the turbine-control mechanism from opening beyond the position that the device is set	. . .	. . .	. . .
Governing system or governor system	The combination of devices and mechanisms that respond to changes of speed, power, water level, or their setpoints and position the turbine servomotor(s) in a characteristic manner. Includes the position transducer, speed sensing device, speed responsive elements, hydraulic control mechanism, and hydraulic pressure supply system.	. . .	. . .	. . .

Table 2-1 Definitions (Cont'd)

Term	Definition	Symbol	Units	
			SI	U.S.
Hydraulic power unit	Consists of the necessary oil pumps, motors, pressure regulating devices, pressure switches, and oil sump tank necessary to provide hydraulic power to the governor system	HPU	. . .	. . .
Hydraulic pressure supply system	Includes the HPU, pressure accumulator, and the necessary piping connections to the turbine servomotors	. . .	. . .	. . .
Influence coefficient	See sensitivity; the ratio of the change in a result to a unit change in a parameter	. . .	. . .	. . .
Insensitivity	One-half of the deadband	$I_x/2$	%	%
Instrument	A tool or device used to measure physical dimensions of length, thickness, width, weight, or any other value of a variable. These variables can include: size, weight, pressure, temperature, fluid flow, voltage, electric current, density, viscosity, and power. Sensors are included which may not, by themselves, incorporate a display but transmit signals to remote computer type devices for display, processing, or process control. Also included are items of ancillary equipment directly affecting the display of the primary instrument, e.g., ammeter shunt. Also included are tools or fixtures used as the basis for determining part acceptability.	. . .	. . .	. . .
Integral gain	The slope of the governor transient response with $b_p = 0$ and input signal $x = 1$. $K_D = K_P = 0$.	K_I	s^{-1}	sec^{-1}
Isolated operation	The generating unit is the only source of electrical energy supplying the electrical load, if any	. . .	. . .	. . .
Measurement error	The true, unknown difference between the measured value and the true value	δ	. . .	. . .
Mechanical governor	Refers to a governing system that uses a mechanical means for sensing and processing the speed of the unit	. . .	. . .	. . .
Overspeed	The increase in speed (expressed in % of rated speed) following a sudden reduction of load demand	. . .	%	%
Parallel operation	The generating unit supplies energy to an electrical network that also is supplied by other sources of electrical energy	. . .	. . .	. . .
Parties to a test	Those persons and companies interested in the results	. . .	. . .	. . .
PID	A controller strategy comprising the summation of Proportional, Integral, and Derivative gain terms processing a composite error input to produce a governor output command	. . .	. . .	. . .
Position transducer	A physical device for measuring servomotor position and the necessary electrical or mechanical devices to convert this information for use by the governor	. . .	. . .	. . .
Power	Net power output of generator	P_e	kw	kw
Power droop, permanent (also known as speed regulation)	Power droop is the ratio of a speed change to the resulting power output change (see Fig. 2-5).	b_e	%	%
Precision error	See random error	. . .	. . .	. . .
Pressure rise	The increase in pressure measured at the entrance to the turbine (expressed in % of steady-state penstock pressure) following sudden closure of the turbine-control mechanism	. . .	%	%
Primary variables	Those used in calculations of test results. They are further classified as Class 1: primary variables are those which have a relative influence coefficient of 0.2 or greater Class 2: primary variables are those which have a relative influence coefficient of less than 0.2 Refer to PTC 19.1 for the determination of relative sensitivity coefficients	. . .	. . .	. . .
Proportional gain	Proportional is defined as the magnitude of the step of the governor transient response with $b_p = K_D = K_I = 0$ and input signal $x = 1$	K_P	. . .	. . .
Ramping rate for setpoint adjustment	The rate of change of a controlled variable expressed in units of setpoint per second. The setpoint should be calibrated in units of watts % of rated speed, % of servomotor position, or any other controlled variable	. . .	. . .	. . .
Random error	Sometimes called precision; the true random error that characterizes a member of a set of measurements. ε varies in a random, Gaussian-Normal manner, from measurement to measurement	ε	. . .	. . .

Table 2-1 Definitions (Cont'd)

Term	Definition	Symbol	Units SI	Units U.S.
Random uncertainty	An estimate of the ± limits of random error with a defined level of confidence (usually 95%)	$2S$	. . .	. . .
Rated speed	The design speed for the generating unit	n_p	r/min	rpm
Secondary variables	Variables that are measured but do not enter into the calculation	. . .	. . .	. . .
Sensitivity	See influence coefficient; the ratio of the change in a result to a unit change in a parameter	. . .	. . .	. . .
Serialize	An instrument is assigned a unique number and that number is permanently inscribed on or to the instrument so that it can be identified and tracked	. . .	. . .	. . .
Servomotor	The element of the governing system that moves the turbine-control mechanism	. . .	. . .	. . .
Servomotor capacity	Product of the maximum servomotor stroke and the force of maximum servomotor pressure	$F_M Y_{max}$	N · m	ft-lb
Servomotor cushion time	The elapsed time that the rate of servomotor travel is retarded	T_c	s	sec
Servomotor force	The opening and/or closing force generated by the servomotor	F	N	lb
Servomotor stroke	The travel of the main servomotor from full closure of the turbine control mechanism to any intermediate position. The maximum servomotor stroke (Y_{max}) is the travel between full closure and full open stops of the turbine control mechanism.	Y	m	in.
Servomotor time	The elapsed time for one full servomotor stroke at maximum velocity (see Fig. 2-6).	T_f	s	sec
Speed	Rotational speed of the generating unit	n	r/min	rpm
Speed adjustment range	The difference (expressed in % of rated speed) between the maximum and minimum speed settings of the governor system	. . .	%	%
Speed deviation	The difference between the actual speed of rotation and a reference speed	Δn	r/min	rpm
Speed droop, permanent	The ratio of a relative speed change and the resulting relative servomotor position change. Logically this should be referred to as "position droop." See Fig. 2-7.	b_p	%	%
Speed droop, temporary	The equivalent permanent speed droop when $b_p = K_I = K_D = 0$ (for electronic-hydraulic governors) or when $b_p = 0$ and $T_r = \infty$ (for mechanical-hydraulic governors)	b_t	%	%
Speed responsive elements	Those elements that are directly responsive to speed, which determine speed error and influence the action of other elements of the governing system	. . .	. . .	. . .
Speed sensing device	The means used to transmit a signal proportional to the speed of the turbine to the speed responsive elements. It can be mechanical, either through belts or gearing, or electrical, either through potential transformers in the driven generator leads or through an independent generator that is coupled to the main generator shaft.	. . .	. . .	. . .
Speed transducer speed sensing device	For a transducer measuring turbine speed and the necessary electrical or mechanical devices to convert this information for use by the governor	. . .	. . .	. . .
Stability	The capability of the governor system to position the turbine-control mechanism so that sustained oscillations of turbine speed or power output are not produced by the governor system during operation under steady-state load demand or following a change to a new steady-state load demand. Forced oscillations (i.e., dither) of the governor system introduced to reduce friction are excluded because the dither frequency is generally high enough so no measurable oscillations are transmitted to the turbine-control mechanism.	. . .	. . .	. . .
Systematic error	Sometimes called bias; the true systematic or fixed error that characterizes every member of any set of measurements from the population. It is the constant component of the total measurement error (δ).	β	. . .	. . .
Systematic uncertainty	An estimate of the ± limits of systematic error with a defined level of confidence (usually 95%)	B	. . .	. . .
Test boundary	Identifies the energy streams required to calculate corrected results	. . .	. . .	. . .
Test reading	One recording of all required test instrumentation	. . .	. . .	. . .

Table 2-1 Definitions (Cont'd)

Term	Definition	Symbol	Units SI	Units U.S.
Test run	A group of test readings	. . .	. . .	. . .
Traceable	Records are available demonstrating that the instrument can be traced through a series of calibrations to an appropriate ultimate reference such as National Institute for Standards and Technology (NIST)	. . .	. . .	. . .
Turbine-control mechanism	Includes those elements of the turbine that control the energy input to the turbine and the system of connected linkage that is actuated by the governor-control mechanism	. . .	. . .	. . .
Uncertainty	$\pm$ U is the interval about the measurement or result that contains the true value for a given confidence level	U	. . .	. . .

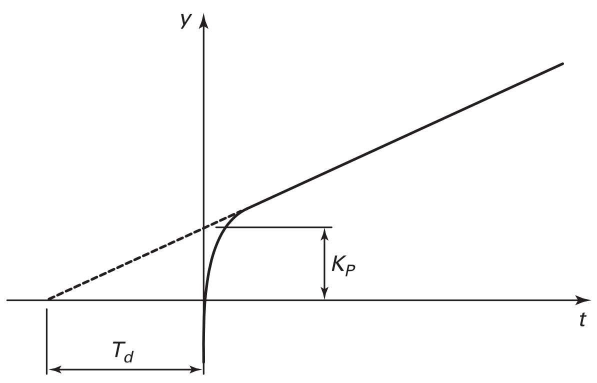

Fig. 2-1 Damping Time Constant

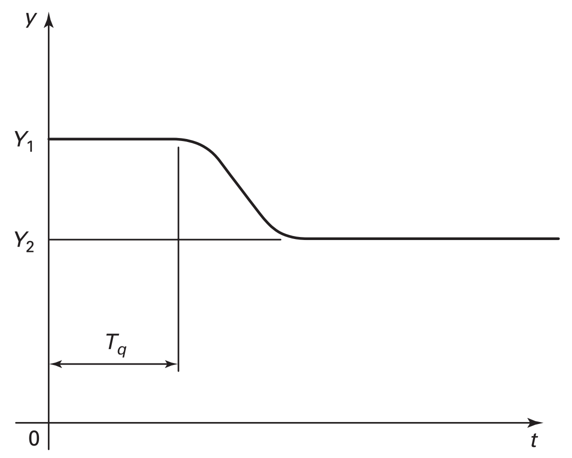

Fig. 2-3 Deadtime

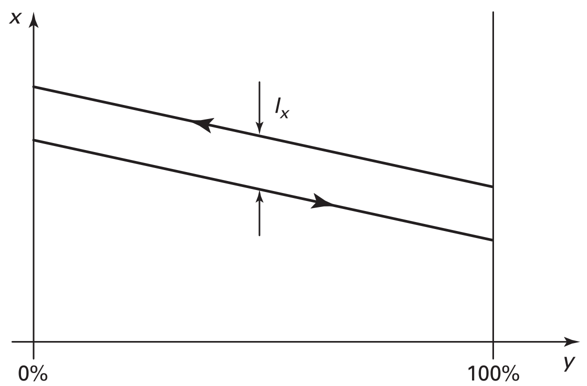

Fig. 2-2 Deadband

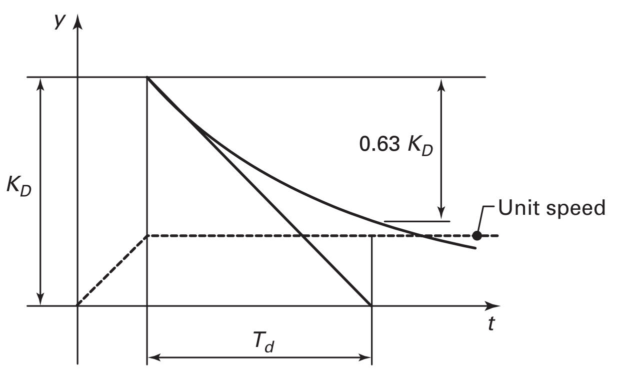

Fig. 2-4 Derivative Gain

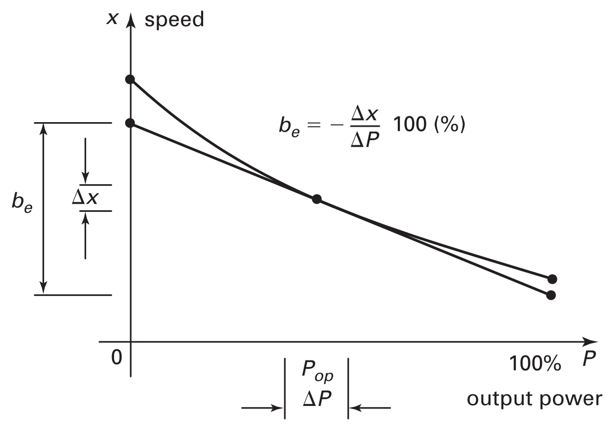

Fig. 2-5 Power Droop

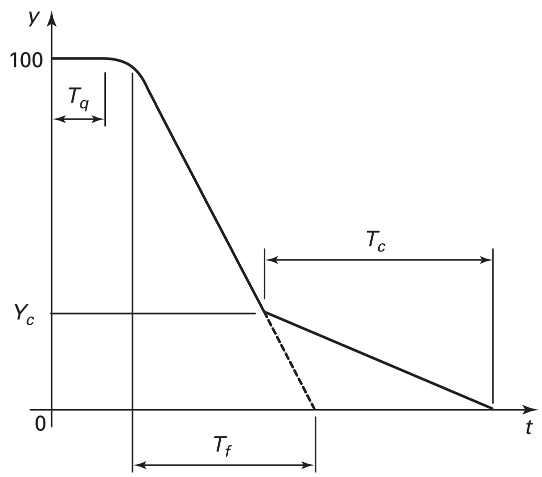

Fig. 2-6 Servomotor Time

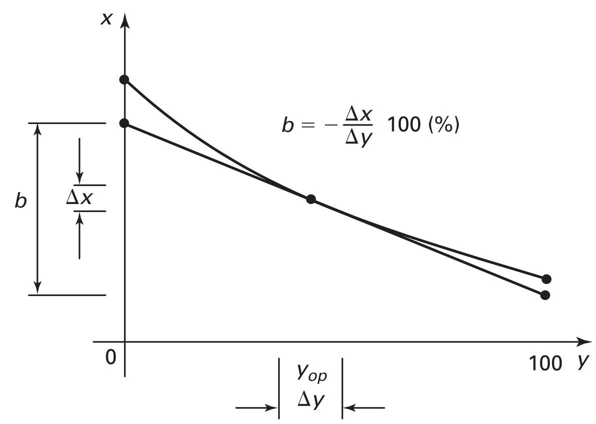

Fig. 2-7 Speed Droop

Section 3
Guiding Principles

3-1 INTRODUCTION

This section provides guidance on the conduct of governor performance testing and outlines the steps required to plan, conduct, and evaluate a Code test. Test results are to be reported per the data collected and calculations performed in strict accordance with this Code.

Because of the variety of ways by which governor performance may be specified, all of the tests included in this Code may not be required for any particular governor installation.

3-2 PREPARATIONS FOR TESTING

A detailed test plan must be prepared prior to conducting a Code test. It will document agreements on all issues affecting the conduct of the test and provide detailed procedures for performing the test. The test plan should be approved prior to the testing by authorized signatures of all parties to the test.

3-2.1 Commercial Acceptance Testing

For an on-site acceptance test, a separate agreement will be required between the parties to the test, outlining the departures from expected turbine-generator performance and setting forth an agreement whereby such departures are allowed for in establishing the governing performance. This agreement shall include statement of corrections which shall be applied to the speed-governing performances to compensate for hydraulic turbine-generator performances.

3-2.2 General Precaution

Reasonable precautions should be taken when preparing to conduct a code test. Indisputable records shall be made to identify and distinguish the equipment to be tested and the exact method of testing selected. Descriptions, drawings, or photographs all may be used to give a permanent, explicit record. Instrument location shall be predetermined, agreed by the parties to the test, and described in detail in test records. Redundant, calibrated instruments should be provided for those instruments susceptible to in-service failure or breakage.

Any dimensions or information regarding the physical condition of parts of the equipment to be tested, which may be required for calculation purposes or are to be included in the report, should be obtained and recorded before the test is made. Serial numbers and any plant data should be recorded to identify all equipment related to the test.

Careful inspection and checks shall be made before, during, and after the tests to insure that the turbine-generator unit is operating properly. The governor system and all of its associated equipment shall be carefully checked and properly adjusted prior to the test.

Follow safety rules and regulations.

3-2.3 Agreements

Prior to any tests, there shall be agreement on the exact method of testing and the methods of measurement. Among such items are:

(*a*) object of test
(*b*) location and timing of test
(*c*) test boundaries
(*d*) selection of instruments: number, location, type
(*e*) method of calibration of instruments
(*f*) confidentiality of test results
(*g*) number of copies of original data required
(*h*) data to be recorded, method of recording and archiving data
(*i*) values of measurement uncertainty and method of determining overall test uncertainty
(*j*) method of operating equipment under test, including that of any auxiliary equipment, the performance of which may influence the test result
(*k*) methods of maintaining constant operating conditions as near as possible to those specified
(*l*) method of determining duration of operation under test conditions before test readings are started
(*m*) system alignment or isolation
(*n*) organization of personnel, including designation of engineer responsible for conducting test
(*o*) duration and number of test runs
(*p*) frequency of observations
(*q*) base reference conditions
(*r*) methods of correction and values used for corrections for deviations of test conditions from those specified
(*s*) methods of computing results
(*t*) method of comparing test results with specified performance
(*u*) conditions for rejection of outlier data or runs
(*v*) intent of contract or specification if ambiguities or omissions appear evident
(*w*) pretest inspections
(*x*) temperatures
(*y*) servomotor size
(*z*) pipe dimensions
(*aa*) head and flow conditions for on-site tests as defined in ASME PTC 18
(*ab*) reference power output as defined in ASME PTC 18

3-2.4 Preliminary Test Runs

Preliminary test runs, with records, serve to determine if equipment is in suitable condition to test, to check instruments and methods of measurement, to check adequacy of organization and procedures, and to train personnel. All parties to the test may conduct reasonable preliminary test runs as necessary. Observations during preliminary test runs should be carried through to the calculation of results as an overall check of procedure, layout, and organization. If such a preliminary test run complies with all the necessary requirements of the appropriate test code, it may be used as an official test run within the meaning of the applicable code.

3-3 TESTS

3-3.1 Preparation

For acceptance and other official tests, the manufacturer or supplier shall have reasonable opportunity to examine the equipment, correct defects, and render the equipment suitable to test. The manufacturer, however, is not thereby empowered to alter or adjust equipment or conditions in such a way that regulations, contract, safety, or other stipulations are altered or voided. The manufacturer may not make adjustments to the equipment for test purposes that may prevent immediate, continuous, and reliable operation at all capacities or outputs under all specified operating conditions. Any actions taken must be documented and immediately reported to all parties to the test.

3-3.2 Starting and Stopping

Acceptance and other official tests shall be conducted as promptly as possible following initial equipment operation and preliminary test runs. The equipment should be operated for sufficient time to demonstrate that intended test conditions have been established, e.g., steady state. Agreement on procedures and time should be reached before commencing the test.

3-3.3 Readjustments

Once testing has started, readjustments to the equipment that can influence the results of the test should require repetition of any test runs conducted prior to the readjustments. No adjustments should be permissible for the purpose of a test that are inappropriate for reliable and continuous operation following a test under any and all of the specified outputs and operating conditions.

3-3.4 Data Collection

Data shall be taken by automatic data collecting equipment or by a sufficient number of competent observers. Automatic data logging and advanced instrument systems shall be calibrated to the required accuracy. No observer shall be required to take so many readings that lack of time may result in insufficient care and precision. Consideration shall be given to specifying duplicate instrumentation and taking simultaneous readings for certain test points to attain the specified accuracy of the test.

3-3.5 Conduct of Test

The parties to the test shall designate a person to direct the test, hereafter called the test coordinator. Intercommunication arrangements between all test personnel, all test parties, and the test coordinator should be established. Complete written records of the test, even including details that at the time may seem irrelevant, should be reported. Controls by ordinary operating (indicating, reporting, or integrating) instruments, preparation of graphical logs, and close supervision should be established to give assurance that the equipment under test is operating in substantial accord with the intended conditions. If the test is commercial, accredited representatives of the purchaser and the manufacturer or supplier should be present at all times to assure themselves that the tests are being conducted with the test code and prior agreement.

3-4 INSTRUMENTS

3-4.1 Location and Identification of Instruments

Transducers shall be located to minimize the effect of ambient conditions on uncertainty, e.g., temperature or temperature variations. Care shall be used in routing lead wires to the data collection equipment to prevent electrical noise in the signal. Manual instruments shall be located so that they can be read with precision and convenience by the observer. All instruments shall be marked uniquely and unmistakably for identification. Calibration tables, charts, or mathematical relationships shall be readily available to all parties of the test. Observers recording data shall be instructed on the desired degree of precision of readings.

3-4.2 Frequency and Timing of Observations

The timing of instrument observations will be determined by an analysis of the time lag of both the instrument and the process so that a correct and meaningful mean value and departure from allowable operating conditions may be determined. Sufficient observations shall be recorded to prove that steady-state conditions existed during the test where this is a requirement. A sufficient number of observations shall be taken to reduce the random component of uncertainty to an acceptable level.

3-5 OPERATING CONDITIONS

3-5.1 Operating Philosophy

The tests should be conducted as closely as possible to specified operating conditions, and thus reduce and minimize the magnitude and number of corrections for deviations from specified conditions.

3-5.2 Permissible Deviations

The equipment tested should be operated to ensure its performance is bounded by the permissible fluctuations and deviations specified.

3-5.3 Inconsistent Measurements

If any measurement influencing the result of a test is inconsistent with some other like measurement, although either or both of them may have been made strictly in accordance with the rules of the individual test code, the cause of the inconsistency shall be identified and eliminated.

All tests are to be performed under operating conditions on free governor control, with pressure regulator or synchronous bypass valve and, for an adjustable-blade-propeller turbine, with the blade-control mechanism in normal operation.

If the test results show malfunctioning of the unit and any of its accessories, the defects shall be corrected before the test series is repeated.

Parties to the test may agree to changes in test conditions while the test is in progress. All such special agreements shall be made in writing and included in the test report.

3-6 RECORDS

3-6.1 Data Records and the Test Log

For all acceptance and other official tests, a complete set of data and a complete copy of the test log shall become the property of each of the parties to the test. The original log; data sheets, files, and disks; recorder charts; tapes; etc., being the only evidence of actual test conditions, must permit clear and legible reproduction. Copying by hand is not permitted. The completed data records shall include the date and time of day the observation was recorded. The observations shall be the actual readings without application of any instrument corrections. The test log should constitute a complete record of events, including details that at the time may seem trivial or irrelevant. Erasures on or destruction or deletion of any data record, page of the test log, or recorded observation is not permitted. If corrected, the alteration shall be entered so that the original entry remains legible and an explanation is included. For manual data collection, the test observations shall be entered on carefully prepared forms that constitute original data sheets authenticated by the observer's signatures. For automatic data collection, printed output or electronic files shall be authenticated by the test coordinator and other representatives of the parties to the test. When no paper copy is generated, the parties to the test must agree in advance to the method used for authenticating, reproducing, and distributing the data. Copies of the electronic data files must be copied onto tape or disks and distributed to each of the parties to the test. The data files shall be in a format that is easily accessible to all. Data residing on a machine should not remain there unless a backup, permanent copy is made.

3-6.2 Analysis and Interpretation

During the conduct of a test, or during the subsequent analysis or interpretation of the observed data, an obvious inconsistency may be found. If so, reasonable effort should be made to adjust or eliminate the inconsistency. Failing this, test runs should be repeated.

The adjustment of instruments, recording devices, or other test apparatus, to the unit or governor system, shall be made only after full agreement is reached between the parties to the test.

Section 4 Instruments and Methods of Measurement

4-1 INSTRUMENT SPECIFICATIONS

All instruments shall be of sufficient precision and accuracy to meet the uncertainty requirements identified in Table 1-1 for each test.

(*a*) Multichannel recorder with minimum of two channels, capable of continuous recording of the controlled variable feedback (typically unit speed) and servomotor position or output power feedback signal to record input and output parameters. Speed trace accuracy of ±2% and frequency response of DC to 20 Hz. Strip chart or electronic recordings are acceptable examples of multichannel recorders.

(*b*) Position transducer to measure stroke of the control device servomotor. Accuracy shall be within ±0.1% of the test span. Nonlinearity shall be within ±0.1% over the test span.

(*c*) Adjustable voltage power supply or signal generator capable of holding output to within ±0.005% of full range and making step changes to within ±0.01% of full range to provide speed signal to the governor.

(*d*) Adjustable frequency signal generator capable of holding frequency to within ±0.005% of full range between 0 and 100% and making step changes to within ±0.01% of full range to provide speed signal to the governor.

(*e*) Adjustable-speed governor ballhead drive to drive the governor ballhead for simulated unit speed signal to the governor. The drive shall be capable of driving the ballhead within ±0.005% of rated ballhead speed and making step changes of ±0.1% of the rated speed.

(*f*) Pressure transducers: Accuracy of ±1.0% of the test span is required. Nonlinearity shall be within ±0.10% over the test span.

(*g*) Watt transducer: Accuracy shall be within ±0.1% of the full range. Nonlinearity shall be within ±0.01% over the test span.

(*h*) Frequency transducer: Accuracy shall be ±0.02% of 100% speed. Response shall be less than 0.5 sec to 99% of final value.

(*i*) All input steps shall be small enough to avoid nonlinear behavior of the governor.

4-2 PERFORMANCE TESTS—ELECTRONIC GOVERNOR

4-2.1 Droop

The tests should be performed either in the shop on the governor alone, or at the site with the governor connected to the turbine with the turbine at standstill. The controlled variable shall be simulated with a precision signal generator for the entire range of operation. Droop shall be tested for at least three droop settings, including the maximum and intermediate (midpoint) settings. The test shall be performed with increasing controlled variable values and shall be repeated with decreasing controlled variable values. Droop graphs shall be developed based on the test points.

Instruments are as follows:

(*a*) multichannel recorder
(*b*) position transducer
(*c*) adjustable voltage power supply or signal generator
(*d*) adjustable frequency signal generator
(*e*) frequency transducer

4-2.1.1 Permanent Droop Test Procedure

(*a*) Perform the test with the turbine at standstill and dewatered. The governor shall be in speed control mode for the test.

(*b*) Set permanent droop to 1%. See Fig. 2-7.

(*c*) Connect speed signal source (Method 1) or speed reference signal (Method 2) to one channel of a multichannel recorder. Install position transducer to the con-

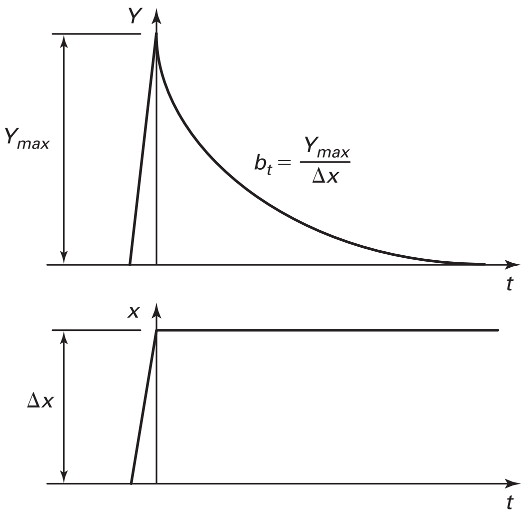

Fig. 4-1 Temporary Droop

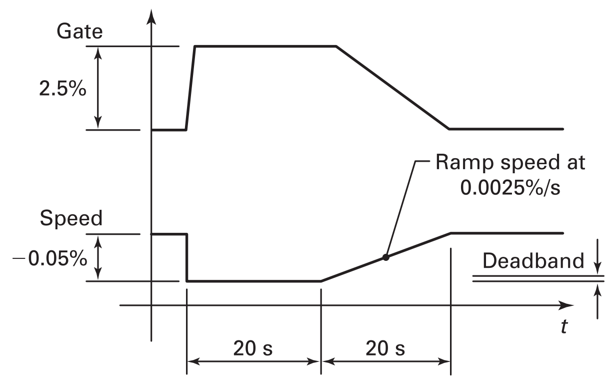

Fig. 4-2 Speed Deadband

trol device servomotor, or use the signal from an existing position transducer. Connect the position transducer signal to the multichannel recorder.

(*d*) Calculate the speed change (ΔSpeed) required to obtain a 20% servomotor change using Eq. (1).

$$\text{Droop} = 100\% \times \Delta\text{Speed}/\Delta\text{Servomotor Position} \qquad (1)$$

EXAMPLE: With droop of 1%, the formula is 1% = 100% × ΔSpeed / 20%. Therefore, ΔSpeed = 0.2%.

(*e*) *Method 1*. Apply a speed input frequency to the governor that represents normal speed. Adjust the speed reference to bring the turbine servomotor to approximately 10% below the specified servomotor opening at which the permanent droop is to be measured (but not less than 5% or greater than 75%). Record the actual servomotor position, speed input frequency, and speed reference setting. Either decrease the speed input frequency or increase the speed reference by the increment calculated in step (d) above. Record the actual servomotor position, speed input frequency, and speed reference setting.

(*f*) *Method 2*. Apply a speed input to the governor that represents normal speed. Adjust the speed reference to bring the turbine servomotor to approximately 10% opening. Record the actual servomotor position, speed input frequency, and speed reference setting. Either decrease the speed input frequency or increase the speed reference setting in increments as calculated in step (d) above. Repeat four times and record the actual speed reference setting, speed input frequency, and servomotor position for each step. Servomotor positions should be approximately 10%, 30%, 50%, 70%, and 90% for the five speed signal frequencies or speed reference settings used.

(*g*) Repeat procedure at mid-level and maximum required permanent droop settings.

4-2.1.2 Temporary Droop Test Procedure

(*a*) Perform the test with the turbine at standstill and dewatered. The governor shall be in the appropriate control mode for the test.

(*b*) Set temporary droop to minimum required temporary droop setting.

(*c*) Connect input signal generator to governor and to a multichannel recorder for either test method used. Install position transducer to the control device servomotor or use existing position transducer. Connect the position transducer to the multichannel recorder.

(*d*)(*1*) *Method 1.* Set the permanent droop, integral, and derivative gains to zero. The temporary droop is then determined similarly to the permanent droop (see para. 4-2.1.1).

(*2*) *Method 2*. Alternatively, the temporary droop can be measured without disabling the permanent droop and the return motion of the damping device, but by measuring and recording the output signal of the damping device (command signal), Y, following a step change in the controlled variable, x. See Fig. 4-1.

(*e*) Repeat procedure at mid-level and maximum required temporary droop settings.

4-2.2 Deadband and Deadtime

Instruments are as follows:

(*a*) multichannel recorder
(*b*) position transducers
(*c*) frequency or speed transducers
(*d*) watt transducer
(*e*) variable voltage power supply or signal generator
(*f*) variable frequency signal generator

4-2.2.1 Speed Deadband and Deadtime Test Procedure

(*a*) *Speed Deadband*

(*1*) Set governor in speed control mode. Set permanent droop to 2%.

(*2*) Scale position signal to use a minimum of 30% of the available chart recorder's channel displacement for a

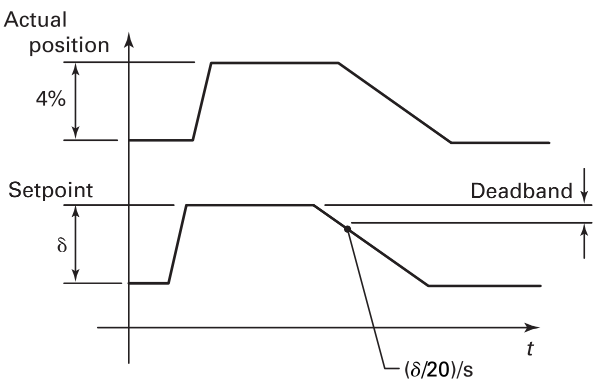

Fig. 4-3 Position Deadband

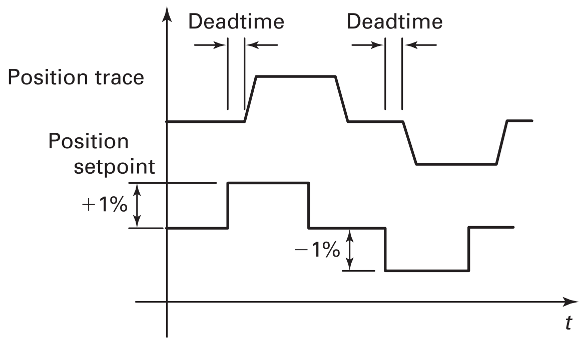

Fig. 4-4 Position Deadtime

4% servomotor position change. Scale speed signal to use a minimum of 30% of the available chart recorder's channel displacement for a 0.05% speed step and/or ramp.

(*3*) Input a normal frequency speed input into the governor and set the speed adjustment to position the servomotor at approximately 50% opening.

(*4*) Inject a −0.05% speed step, hold this setting for 20 sec minimum, then begin to ramp speed back to normal at 0.0025%/sec. See Fig. 4-2.

(*5*) Repeat this test by alternating the initial step between plus and minus speed steps. A complete test consists of four alternating steps.

(*6*) Governor gain settings are to be normal gains for the application. If test is being simulated (e.g., factory testing), then estimated gains shall be used.

(*b*) *Speed Deadtime*

(*1*) Set governor in speed control mode. Set permanent droop to 5%.

(*2*) Connect servomotor position transducer to a chart recorder, and connect speed input signal to a chart recorder.

(*3*) *On-Line Test*. Bring unit to 10% rated load. Verify that charts of servomotor position and time are ready. Reject the load.

(*4*) *Off-Line Test.* To simulate the unit's behavior in response to a 10% load change, ramp the speed input at a rate of 2% per second, or according to Eq. (2), as agreed by the parties to the test.

$$a = P_r / T_m \tag{2}$$

where

a = acceleration rate, %/s.
P_r = load power change, % of rated power
T_m = mechanical starting time of unit, sec

(*5*) Governor gain settings are to be normal gains for the application. If test is being simulated (e.g., factory testing), then estimated gains shall be used.

4-2.2.2 Position Deadband and Deadtime Test Procedure. Examples of position control modes that are subject to deadband and deadtime testing can include blade control of a Kaplan turbine, needle control of an impulse turbine, synchronous bypass valve control, and head/tail water level control. The position control mode(s) to be tested should be discussed and agreed by the parties to the test.

(*a*) *Position Deadband*

(*1*) Set governor in the proper position control mode. Set permanent droop to 5%.

(*2*) Scale the controlled variable signal to use a minimum of 30% of the available chart recorder's channel displacement for the range required to derive the 4% change in servomotor position.

(*3*) Input a normal frequency speed input into the governor and set the speed adjustment to position the servomotor at approximately 50% opening. Inject an error signal with magnitude δ sufficient to achieve a 4% change in servomotor position. Hold this setting for 20 sec minimum, then begin to ramp back to normal at the ramp rate in Eq. (3). See Fig. 4-3.

$$\text{ramp rate} = (\delta / 20)\ \%/\text{s} \tag{3}$$

(*4*) Repeat this test by alternating the initial error signal between plus and minus steps. A complete test consists of four alternating steps.

(*5*) Governor gain settings are to be normal gains for the application. If the test is being simulated (e.g., factory testing), then estimated gains shall be used.

(*b*) *Position Deadtime*. Position control loops should have filters associated with them to dampen out signal fluctuations. If possible, set these filters to minimum for the purpose of the deadtime test.

For control of other features, e.g., pond level control, impose a $\pm\delta$ [as calculated in step (3) above] forcing function of the control's setpoint and observe the corresponding deadtime. See Fig. 4-4.

4-2.2.3 Power Deadband Test Procedure

(*a*) Set governor in the power control mode. Set permanent droop to 5%.

(*b*) Scale servomotor position signal to use a minimum of 30% of the available chart recorder's channel displacement for 4% servomotor position change. Scale the power setpoint signal to use a minimum of 30% of the available chart recorder's channel displacement for the range required to derive the 4% change in servomotor position. Call this value δ.

(*c*) Input a normal frequency speed input into the governor and adjust the power setpoint to position the servomotor at approximately 50% opening.

(*d*) Inject a power setpoint error signal with magnitude δ, hold this setting for 20 sec, and then begin to ramp back to normal at a ramp rate from Eq. (3).

(*e*) Repeat this test by alternating the initial error signal between plus and minus steps. A complete test consists of four alternating steps.

(*f*) Governor gain settings are to be normal gains for the application. If test is being simulated (e.g., factory testing), then estimated gains shall be used.

4-2.3 Stability Index

The degree of stability achieved by a governor system is judged by the magnitude of the sustained oscillations of speed and power output from the turbine that are produced by the governor system. While the governor deadband illustrates performance for the governor alone, the stability index illustrates regulating performance for the governor and turbine. Turbine control mechanism friction, lost motion, rough zone operation, and operation in the area of the slow closure device can influence the stability index. The indexes are influenced by the adjustment of the governor's control parameters (PID adjustments, etc.) and permanent speed droop.

If compensation or PID settings are automatically varied at various gate openings, operating mode, or output, the stability index is determined with governor settings that are relevant and automatically selected for the subject gate opening, operating mode, or power output.

Instruments are as follows:

(*a*) speed or frequency transducer
(*b*) watt transducer
(*c*) multichannel recorder

4-2.3.1 Steady-State Governing Speed Band Test Procedure

(*a*) Connect a frequency or speed measuring device and a wattmeter to the generator, or utilize existing instrumentation.

(*b*) *Method 1: Off-Line Test, to Be Used for all Applications*. Bring the unit to speed no load, with the generator disconnected from the grid. The steady-state speed should be within ±1% of rated speed. Record the peak-to-peak oscillation of speed after steady-state speed is reached. If the unit is equipped with gate limit, perform a second measurement to identify frequency oscillations that are not created by the governor. Lower the gate limiter until it corresponds to the current gate position. Raise the speed reference above where the speed influences the gate-limited governor. Record the peak-to-peak speed oscillation. Neglect slow drift in speed.

(*c*) *Method 2: On-Line Test, for Field Test of Isolated System Operation Only*. The following portion of the test is only feasible if the unit can be operated independently into a steady isolated load. Any automatic generator voltage regulator should be disabled. Operate the unit at rated speed and at steady-state power output. Record speed and power output simultaneously. Use only portions of the speed record obtained during periods when steady-state power output exists.

4-2.3.2 Steady-State Governing Power Band Test Procedure

(*a*) Connect the frequency or speed-measuring device to the generator or generator terminals. Connect a recording wattmeter to the generator terminals.

(*b*) Operate the unit within ±1% of nominal speed connected to the network. Unless otherwise specified, the speed droop should be set at 5%. Automatic generator voltage control or power generation control should be disabled during the duration of the test.

(*c*) Unless other agreement is reached, the subject steady-state power for acceptance test purposes should be varied between 90% and 40% of the nominal power output, adjusted to the test head according to ASME PTC 18, para. 5.5.

(*d*) Record the peak-to-peak power oscillations, ΔP, during a period when the fundamental component of power varies less than 3% of rated power output.

(*e*) If the unit is equipped with gate limit, undertake a second measurement to identify if there are power oscillations that are not created by the governor. This second test is undertaken with the unit still operating in the same load regime and the recording measurement equipment connected. Lower the gate limiter until it corresponds to the current gate position. Raise the speed reference above where the speed influences the gate-limited governor. Record the peak-to-peak power oscillation.

4-2.4 Step Response

Instruments are as follows:

(*a*) multichannel recorder
(*b*) position transducer
(*c*) frequency signal generator

4-2.4.1 Step Response Test Procedure

(*a*) Set and record control time constants, T_D (network and isolated if applicable). Reference Fig. 2-1.

(*b*) Set the permanent speed droop at 5%.

(*c*) Inhibit the derivative action either by setting its gain to zero (if possible) or by setting its time constant at the lowest authorized value.

(*d*) Connect gate position transducer to one channel of the recorder.

(*e*) Connect output of frequency transducer to one channel of the recorder.

(*f*) Apply a speed signal to correspond to nominal frequency and adjust the governor to position the turbine servomotor to approximately 50% stroke.

(*g*) Initiate a +0.5% frequency step change.

(*h*) Record servomotor position response.

(*i*) Repeat with −0.5% speed change.

(*j*) Repeat for a minimum of four control time constant settings, equally spaced between minimum and maximum.

4-2.5 Gain Measurement

Instruments are as follows:

(*a*) adjustable frequency signal generator

(*b*) multichannel recorder, frequency response analyzer, or dynamic signal analyzer

4-2.5.1 Proportional Gain Test Procedure. Proportional gain can be calculated directly as $K_P = 1/b_t$. See para. 4-2 for droop test procedures.

4-2.5.2 Integral Gain and Damping Time

(*a*) *Integral Gain Test Procedure*

(*1*) Set the integral gain adjustment and record setpoint on data sheet for each setting tested.

(*2*) Set the gain of proportional and derivative functions to produce no contribution.

(*3*) Connect the output of the adjustable frequency signal generator to one channel of the recorder. As an option to measure integral gain, a frequency response analyzer can be used instead of the multichannel recorder and adjustable frequency signal generator to produce an input signal and analyze the output signal. Apply a calibrated 1 radian/sec (0.159 Hz) input signal instead of a 2% input signal.

(*4*) Connect the output of the proportional integral derivative (PID) circuit or logic sequence to another channel of the recorder.

(*5*) Apply a calibrated 2% input signal from the output of the adjustable frequency signal generator to the input of governor PID module or logic sequence.

(*6*) Record the input signal to the PID circuit or logic sequence and the output signal from the PID circuit or logic sequence for each gain setting tested.

(*b*) *Integral Gain/Damping Time Procedure*

(*1*) Set temporary droop, b_t, to 100%.

(*2*) Set permanent droop to 0%.

(*3*) Connect output of frequency signal generator to one channel of the recorder.

(*4*) Apply a calibrated 2% input signal from the output frequency signal generator to the input of the governor PID module or logic sequence.

(*5*) Connect servomotor position transducer or gate command signal to one channel of the recorder.

(*6*) Record servomotor response or gate command signal response.

(*7*) Measure damping time, T_d, from servomotor or gate command signal response.

(*8*) Integral gain, K_I, is the inverse of the damping time.

4-2.5.3 Derivative Gain Test Procedure

(*a*) Set derivative gain adjustment and record setpoint on data sheet for each setting tested.

(*b*) Set the gain of proportional and integral functions to zero.

(*c*) Connect the output of the adjustable frequency signal generator to one channel of the recorder.

(*d*) Connect the output of the PID circuit or logic sequence to another channel of the recorder.

(*e*) Apply a calibrated 2% peak-to-peak sine wave input signal from the output of the adjustable frequency signal generator to the input of governor PID module or logic sequence.

(*f*) Record the input signal to the PID circuit or logic sequence and the output signal from the PID circuit or logic sequence for each gain setting tested.

4-2.6 Setpoint Adjustment

Setpoint adjustment will be described for a speed setpoint. The limits of speed adjustment range should be determined either by a shop test or by operating the unit isolated from any load. The same test procedure can be used for other setpoint adjustments such as power, gate limit, or water level by substituting the appropriate word for speed in the procedures.

Instruments are as follows:

(*a*) multichannel recorder

(*b*) speed transducer

4-2.6.1 Range of Adjustment Test Procedure

(*a*) Set the speed droop changer to zero permanent droop.

(*b*) Operate the unit disconnected from the line.

(*c*) Set the setpoint adjustment to its low limit and record the steady-state governed speed.

(*d*) Set the setpoint adjustment to its high limit and record the steady-state governed speed.

4-2.6.2 Ramp Rate Test Procedure. This determination is made with the unit disconnected from the line.

(*a*) Measure the elapsed time required for the speed adjustment reference to travel from its high limit to its low limit with the speed adjustment operated continuously.

(*b*) Measure the elapsed time required for the setpoint reference to travel from its low limit to its high limit with the setpoint operated continuously.

4-3 OPERATIONAL TESTS — ELECTRONIC GOVERNOR

4-3.1 Gate/Blade Relationship for Dual Regulated Reaction Turbine

These tests are to be performed for dual regulated reaction turbines. The tests should be performed either in the shop on the governor alone, or at the site with the governor connected to the turbine with the turbine at standstill. The differential head signal shall be simulated for the entire range of operation. The test shall be performed with head progressing in a constant direction. 3-D cam graphs shall be developed based on the test points.

(*a*) Instruments are as follows:

(*1*) multichannel recorder

(*2*) position transducers to measure stroke of the wicket gate servomotor and the blade tilt

(*3*) adjustable voltage power supply or signal generator

(*4*) adjustable frequency signal generator

(*b*) *Gate/Blade Relationship Test Procedure*

(*1*) Perform the test with the turbine at standstill and dewatered, or in the shop on the governor set up with servomotors and feedback arrangements to simulate wicket gate and blade tilt movements.

(*2*) Install position transducers to the wicket gate servomotor and to the blade tilt feedback mechanism. Connect position transducers to multichannel recorder; connect adjustable voltage power supply or signal generator to governor.

(*3*) Simulate and maintain rated speed by using an adjustable voltage power supply, signal generator, or adjustable speed drive.

(*4*) Simulate and maintain constant minimum head input signal to governor by adjusting the power supply or signal generator for head simulation.

(*5*) Adjust wicket gates from the fully closed to the fully open position; record wicket gate servomotor positions and runner blade tilts for the set head signal with blades coming to steady state.

(*6*) Repeat test for at least four more increasing heads, including maximum head, at mutually agreeable, equally spaced intervals between minimum and maximum heads.

(*7*) For mechanical feedback systems, repeat tests at the same head values, starting from maximum head, to minimum head.

4-3.2 Needle/Deflector Relationship for Impulse Turbine

These tests are to be performed for impulse turbines with dual control. The tests should be performed on the governor set up with prototype or test servomotors (if the needles and deflectors are not linked mechanically or hydraulically) or with the governor connected to the turbine and the turbine at standstill.

(*a*) *Instruments are as follows:*

(*1*) multichannel recorder

(*2*) two position transducers to measure needle and deflector positions

(*3*) adjustable frequency signal generator

(*b*) *Needle/Deflector Relationship Test Procedure*

(*1*) Perform the test with the turbine at standstill and dewatered, or in the shop, on the governor set up with servomotors and feedback arrangements to simulate needle and deflector movements.

(*2*) Install position transducers to the needle servomotor and to the deflector feedback mechanism. Connect position transducers to multichannel recorder. Connect adjustable frequency signal generator (for digital governors) or adjustable speed drive (for mechanical governors) to governor.

(*3*) Produce needle closure movement from the fully open to the fully closed position at the maximum rate of needle closure. Repeat the test for at least four slower rates of needle closure, including the rate that does not produce deflector movement. This can be achieved by means such as adjusting speed signal input to the governor or changing setpoints and ramping rates.

(*4*) Repeat the test, starting from at least four more needle positions equally spaced between the fully open and fully closed positions, and for different rates of needle movement.

4-3.3 Full Rate Servomotor Time and Servomotor Cushion Time

Instruments are as follows:

(*a*) position transducer

(*b*) multichannel recorder

4-3.3.1 Test Procedure — On Site, Turbine Depressurized

(*a*) Depressurize the turbine unit by closing the guard gate or guard valve, and/or draining the spiral case or penstock as required.

(*b*) Install position transducer on servomotor to sense servomotor position.

(*c*) Connect position transducer to recorder to record servomotor position versus time.

(*d*) Ensure the hydraulic system is free of air by bleeding air from the servomotors. Operate the servomotors rapidly from 5% open to 95% open and back, several strokes, while bleeding a small stream of oil from the top of each servomotor.

(*e*) Adjust the open and close control setpoints that control the full rate movement of the servomotors, and note the setting, if calibrated, or measure the position of the adjustment mechanism relative to a stationary feature.

(*f*) Adjust the servomotor cushion setpoints (if equipped with adjustable cushion).

(*g*) While recording servomotor position versus time, initiate full rate servomotor movement from 0% to 100%. Allow the servo(s) to stabilize at 100%.

(*h*) While recording servomotor position versus time, initiate full rate servomotor movement from 100% to 0%.

(*i*) Repeat the procedure for each setpoint to be tested.

(*j*) Before repressurizing the turbine, adjust to the setpoints determined to produce full rate open and close servomotor motion times that are safe for the turbine, generator, and water system.

CAUTION: Units with pressure regulators may require special procedures, as the regulators can drastically affect full rate servomotor motion. Test procedures for such units should be agreed by all involved parties prior to testing.

4-3.3.2 Test Procedure—On Site, Full Turbine Pressure

(*a*) Install position transducer on servomotor to sense servomotor position.

(*b*) Connect position transducer to recorder to record servomotor position versus time.

(*c*) With the turbine depressurized, ensure the hydraulic system is free of air by bleeding air from the servomotors. Operate the servomotors rapidly from 5% open to 95% open and back, several strokes, while bleeding a small stream of oil from the top of each servomotor.

(*d*) Adjust the open and close control setpoints that control the full rate movement of the servomotors, and note the setting, if calibrated, or measure the position of the adjustment mechanism relative to a stationary feature.

CAUTION: Test only setpoints that have been determined to produce full rate open and close servomotor motion times that are safe for the turbine, generator, and water system.

(*e*) Adjust the servomotor cushion setpoints (if equipped with adjustable cushion).

(*f*) While recording servomotor position versus time, initiate full load rejection following the procedures in para. 7-2.

(*g*) Repeat the procedure for each setpoint to be tested.

CAUTION: Units with pressure regulators may require special procedures as the full water pressure on the regulators can drastically affect full rate servomotor motion. Test procedures for such units should be agreed by all involved parties prior to testing.

4-4 PERFORMANCE TESTS — MECHANICAL GOVERNOR

4-4.1 Droop for Mechanical Governor

The tests should be performed either in the shop on the governor alone, or at the site with the governor connected to the turbine with the turbine at standstill. The controlled variable shall be simulated with a precision signal generator for the entire range of operation. Droop shall be tested for at least three droop settings, including the maximum and intermediate (midpoint) settings. The test shall be performed with increasing controlled variable values and repeated with decreasing controlled variable values. Droop graphs shall be developed based on the test points.

Instruments are as follows:

(*a*) multichannel recorder

(*b*) position transducer

(*c*) adjustable voltage power supply or signal generator

(*d*) adjustable speed governor ballhead drive

(*e*) frequency transducer

4-4.1.1 Permanent Droop Test Procedure

4-4.1.1.1 Governor

(*a*) Perform the test with the turbine at standstill and dewatered. The governor shall be in the appropriate control mode for the test.

(*b*) Set permanent droop to 1%.

(*c*) Calculate the speed change required to cause a 20% servomotor change using the formula: droop = 100% × ΔSpeed/ΔServomotor Position. (For example, with droop of 1%, the formula is 1% = 100% × ΔSpeed/20%. Therefore, ΔSpeed = 0.2%.)

(*d*)(*1*) *Method 1.* Apply a speed input to the governor that represents normal speed. Adjust the speed reference to bring the turbine servomotor to 10% opening. Record the actual servomotor position and speed reference. Vary the speed input in increments calculated in step (c) above. Repeat four times, and record actual data of speed and servomotor position. Servomotor position should be approximately 30%, 50%, 70%, and 90% for the four speed changes.

(*2*) *Method 2.* After performing a calibration of an external speed reference device, apply a speed input to the governor that represents normal speed. Adjust the speed reference to bring the turbine servomotor to 10% opening. Record the actual servomotor position and speed reference. Vary the speed reference in increments calculated in step (c) above. Repeat four times and record actual data of speed reference and servomotor position. Servomotor position should be approximately 30%, 50%, 70%, and 90% for the four speed reference changes.

(*3*) *Method 3.* This method applies to calculating the permanent droop setting on a mechanical governor that does not have calibrated droop or speed adjustment indicating mechanisms. Turbine needs to be operational for this method. Bring unit to speed no load. Before synchronizing, record the servomotor position. Synchronize the unit and load the unit with the speed adjustment to approximately maximum load (for best results, servomotor position should be between 80% and 95%). Do not load to maximum gate. Disable any automatic circuits that can alter the speed adjustment setting. Unload the unit using gate limit and open the generator breaker. Then increase the gate limit, taking care to observe that the gate limit is not restraining the servomotor position. Allow the unit to reach equilibrium, and record the turbine speed and the servomotor position.

(*e*) Repeat procedure at mid-level and maximum required permanent droop settings (Methods 1 and 2) or at suitably determined droop settings (Method 3), as practical.

4-4.1.1.2 Governor With Turbine. The test can be performed with the turbine at standstill and dewatered using an adjustable-speed governor ballhead drive or operating on line.

(*a*) Install speed or frequency indicator so that it will also record off-line speed of the unit.

(*b*) Set droop to minimum required droop setting or 1%, whichever is greater.

(*c*) Operate the unit at steady-state rated speed (x_r) at rated power output. Record the corresponding speed-changer position and servomotor stroke (Y_r).

(*d*) After performing a calibration of an external speed reference device, adjust the speed reference by at least five uniform step changes between the minimum and maximum operating values. The relative value of speed reference shall be plotted against the relative value of gate position to develop the droop graph.

(*e*) Repeat the procedure at mid-level and maximum required droop settings.

4-4.1.2 Temporary Droop Test Procedure

(*a*) Set permanent speed droop to 1% or minimum required setting, whichever is greater.

(*b*) Set unit speed to rated speed.

(*c*) Use speed changer to set gate to 40%.

(*d*) When gate position has stabilized, completely close the dashpot needles.

(*e*) Initiate a 1% speed change.

(*f*) Record gate position versus time.

(*g*) Repeat procedure at mid-level and maximum required temporary droop settings.

4-4.2 Deadband and Deadtime for Mechanical Governor

Instruments are as follows:

(*a*) multichannel recorder

(*b*) position transducers

(*c*) frequency or speed transducers

(*d*) adjustable speed governor ballhead drive

4-4.2.1 Speed Deadband and Deadtime Procedure

(*a*) Set permanent speed droop to minimum required droop setting or 1%, whichever is greater.

(*b*) Set speed reference to move gate position to 50%.

(*c*) On-line test: If the governor is being tested on site with the turbine generator in operation, place the unit on line and allow normal system load variations to produce system frequency changes. If system frequency variations are inadequate, initiate plus and minus speed reference changes.

(*d*) Separate governor speed drive: The governor should be tested off site or on site with the turbine depressurized. Using a variable frequency power source, run the ballhead at the ballhead speed corresponding to nominal power system frequency. Initiate +0.01% step changes in the ballhead speed. Repeat with −0.01% step changes in ballhead speed. Repeat with larger step changes if required to observe deadband.

(*e*) Simultaneously measure and record unit speed or frequency changes and movement of the ballhead output shaft.

(*f*) Observe the maximum range of speed deviation that causes no corresponding ballhead output shaft movement.

(*g*) Repeat test procedure using 1.0% step changes in the ballhead speed, and observe the time between the input and the first observable change in output.

4-4.2.2 Position Deadband and Deadtime Procedure — Mechanical Input and Output

(*a*) Set permanent speed droop to minimum required setting or 1%, whichever is greater.

(*b*) Install position transducers on the input mechanism and on the output mechanism.

(*c*) Calibrate the input position transducer based on full range of the input mechanism.

(*d*) On-line test: If the governor is being tested on site with the turbine generator in operation, place the unit on line at 50% gate.

(*e*) Separate governor speed drive: The governor should be tested off site or on site with the turbine depressurized. Using a variable frequency power source, run the ballhead at ballhead speed corresponding to nominal power system frequency and set the governor speed reference to correspond to a 50% turbine gate.

(*f*) Simultaneously measure and record input and output mechanism position changes with the two-channel recorder.

(*g*) Initiate +0.1% step changes in the position of the input mechanism using a speed change, a speed reference change, governor gate limit, or by using a temporary drive mechanism on the input mechanism. Repeat procedure using −0.1% step changes. Repeat with larger step changes if required to observe deadband.

(*h*) From the recording, observe the maximum range of input deviation that causes no corresponding movement of the output mechanism.

(*i*) For the overall position deadband and deadtime, measure the movement of the ballhead output arm versus the movement of the turbine control servomotor.

(*j*) Repeat test procedure using 1.0% step changes in the position of the input mechanism, and observe the time between the input and first observable change in output.

4-4.2.3 Position Deadband and Deadtime Procedure — Electromechanical Transducer Position

(*a*) Depressurize the turbine and connect the variable voltage power supply to the electromechanical transducer position reference.

(*b*) Install a position transducer on the wicket gate servomotor, blade control mechanism, and/or turbine control gate or valve mechanism, or connect recording devices to existing transducers.

(*c*) Apply a speed signal to the governor to correspond to nominal power system frequency and set the speed reference to correspond to an intermediate gate position.

(*d*) Simultaneously measure and record input signal and output mechanism position changes with the two-channel recorder.

(*e*) Initiate plus and minus 0.05, 0.03, 0.02, and 0.01% step changes in the signal to the electromechanical transducer.

4-4.3 Steady-State Governing Speed Band and Step Response for Mechanical Governor

The purpose of these tests is to determine the dynamic response characteristics of the governor system. A step change in the speed signal or speed reference is injected to perturb the governor ballhead or command module. The response of the governor module and the electrical, hydraulic, and/or mechanical subsystems is recorded for evaluation.

Instruments are as follows:
(*a*) multichannel recorder
(*b*) position transducer
(*c*) adjustable-speed governor ballhead drive

4-4.3.1 Steady-State Governing Speed Band Test Procedure

(*a*) Connect a frequency or speed measuring device and a wattmeter to the generator, or utilize existing instrumentation.

(*b*) *Method 1*. Off-line test, to be used for all applications. Bring the unit to speed no load, with the generator disconnected from the grid. The steady-state speed should be within ±1% of rated speed. Record the peak-to-peak oscillation of speed after steady-state speed is reached. If the unit is equipped with gate limit, perform a second measurement to identify frequency oscillations that are not created by the governor. Lower the gate limiter until it corresponds to the current gate position. Raise the speed reference above where the speed influences the gate-limited governor. Record the peak-to-peak speed oscillation. Neglect slow drift in speed.

(*c*) *Method 2.* On-line test, for field test of isolated system operation only. The following portion of the test is only feasible if the unit can be operated independently in an isolated grid with a steady-state load. Any automatic generator voltage regulator should be disabled. Operate the unit at rated speed and at steady-state power output. Record speed and power output simultaneously. Use only portions of the speed record obtained during periods when steady-state power output prevails.

4-4.3.2 Step Response Test Procedure

(*a*) Set main dashpot needle and dashpot bypass needle (if applicable).

(*b*) Set the permanent speed droop at 4% (or any significant value, i.e., higher than 3%).

(*c*) Connect gate position transducer to one channel of recorder.

(*d*) Connect output of ballhead drive to one channel of recorder.

(*e*) Drive governor ballhead at nominal speed.

(*f*) Apply a +2% speed change to the governor ballhead.

(*g*) Record gate position response.

(*h*) Repeat with −2% speed change.

(*i*) Repeat for a minimum of four dashpot needle settings, equally spaced between minimum and maximum.

(*j*) Repeat with dashpot bypass energized (if applicable).

4-5 OPERATIONAL TESTS — FULL RATE SERVOMOTOR TIME AND SERVOMOTOR CUSHION TIME FOR MECHANICAL GOVERNOR

Instruments are as follows:
(*a*) position transducer
(*b*) multichannel recorder

4-5.1 Test Procedure — On Site, Turbine Depressurized

(*a*) Depressurize the turbine unit by closing the guard gate or guard valve, and/or draining the spiral case or penstock as required.

(*b*) Install position transducer on servomotor to sense servomotor position.

(*c*) Connect position transducer to recorder to record servomotor position versus time.

(*d*) Ensure the hydraulic system is free of air by bleeding air from the servomotors. Operate the servomotors rapidly from 5% open to 95% open and back, several strokes, while bleeding a small stream of oil from the top of each servomotor.

(*e*) Adjust the open and close control setpoints that control the full rate movement of the servomotors, and note the setting, if calibrated, or measure the position of the adjustment mechanism relative to a stationary feature.

(*f*) Adjust the servomotor cushion setpoints (if equipped with adjustable cushion).

(*g*) While recording servomotor position versus time, initiate full rate servomotor movement from 0% to 100%. Allow the gates to stabilize at 100%.

(*h*) While recording servomotor position versus time, initiate full rate servomotor movement from 100% to 0%.

(*i*) Repeat the procedure for each setpoint to be tested.

(*j*) Before repressurizing the turbine, adjust to the setpoints determined to produce full rate open and close servomotor motion times that are safe for the turbine, generator, and water system.

CAUTION: Units with pressure regulators may require special procedures as the full water pressure on the regulators can drastically affect full rate servomotor motion. Test procedures for such units should be agreed upon by all involved parties prior to testing.

4-5.2 Test Procedure — On Site, Full Turbine Pressure

(*a*) Install position transducer on servomotor to sense servomotor position.

(*b*) Connect position transducer to recorder to record servomotor position versus time.

(*c*) With the turbine depressurized, ensure the hydraulic system is free of air by bleeding air from the servomotors. Operate the servomotors rapidly from 5% open to 95% open and back, several strokes, while bleeding a small stream of oil from the top of each servomotor.

(*d*) Adjust the open and close control setpoints that control the full rate movement of the servomotors, and note the setting, if calibrated, or measure the position of the adjustment mechanism relative to a stationary feature.

CAUTION: Test only setpoints that have been determined to produce full rate open and close servomotor motion times that are safe for the turbine, generator, and water system.

(*e*) Adjust the servomotor cushion setpoints (if equipped with adjustable cushion).

(*f*) While recording servomotor position versus time, initiate full load rejection following the procedures in para. 7-2.

(*g*) Repeat the procedure for each setpoint to be tested.

CAUTION: Units with pressure regulators may require special procedures as the full water pressure on the regulators can drastically affect full rate servomotor motion. Test procedures for such units should be agreed by all involved parties prior to testing.

Section 5
Computation of Results

5-1 DATA REDUCTION

Following each test, when all test logs and records have been completed and assembled, they should be examined critically to determine whether or not the limits of permissible deviations from specified operating conditions have exceeded those prescribed by the individual test code. Adjustments of any kind should be agreed upon and explained in the test report. If adjustments cannot be agreed upon, the test run(s) may have to be repeated. Inconsistencies in the test record or test result may require tests to be repeated in whole or in part in order to attain test objectives. Corrections resulting from deviations of any of the test operating conditions from those specified are applied when computing test results.

5-2 PERFORMANCE TEST RESULTS — ELECTRONIC GOVERNOR

5-2.1 Droop

5-2.1.1 Permanent Droop Results. The permanent droop, b_p, is calculated as follows:

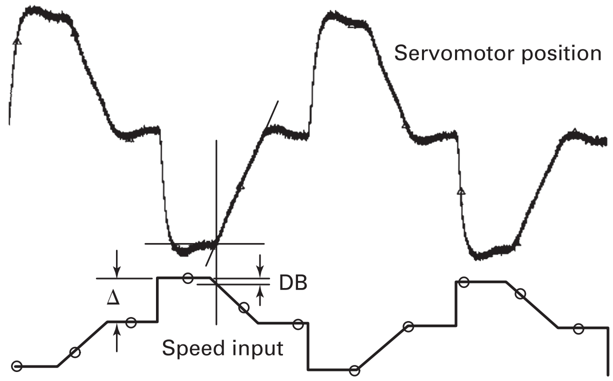

Fig. 5-1 Speed Deadband (Sample Test Plots)

(*a*) *Method 1* (permanent droop at a specified operating point)

$$b_p\ (\%) = (\Delta x/\Delta y) \times 100\% \tag{4}$$

where

b_p = permanent droop, %

x_0 = controlled variable corresponding to Y_0, % of the nominal value

x_1 = controlled variable corresponding to Y_1, % of the nominal value

Y_1 = servomotor stroke or corresponding output of the maximum nominal value, %

Y_0 = servomotor stroke or corresponding output of the maximum nominal value, approximately equal to the specified operating point, %

$\Delta x = x_0 - x_1$

$\Delta y = Y_1 - Y_0$

(*b*) *Method 2* (permanent droop as the slope of a line determined by a set of data points). Method 2 may be used to determine if the speed droop characteristic is essentially constant over the full operating range of the turbine servomotor. From the test recordings, express each data point of speed (or speed reference) as a percent of rated speed. Express each data point of turbine servomotor position as a percent of design stroke. Plot the data points on a rectilinear graph of speed (or speed reference) versus servomotor position. If the plotted points essentially define a straight line, calculate the slope of the line from the data pairs plotted using Eq. (4), where Δx and Δy are any corresponding increments of controlled variable and servomotor position for any two points that lie on the defined line. If the plotted points do not define a straight line, permanent droop must be determined at a selected operating point using Method 1. This selected operating point must be noted in the report of the results of the test of permanent droop.

NOTE: Permanent droop is expressed as a positive quantity, although according to conventional rectangular coordinate systems, the slope is considered negative when plotting speed versus servomotor position.

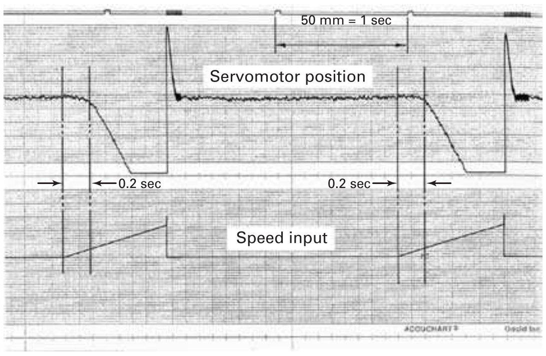

Fig. 5-2 Speed Deadtime

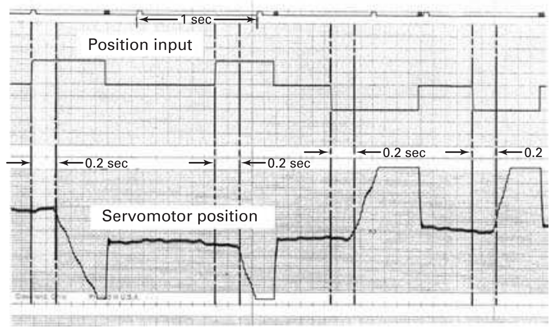

Fig. 5-4 Position Deadtime (Sample Test Plots)

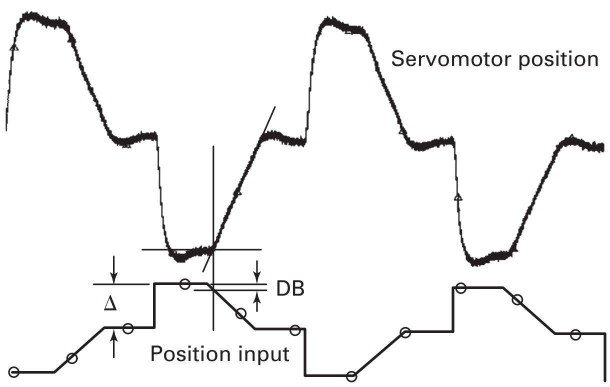

Fig. 5-3 Position Deadband (Sample Test Plots)

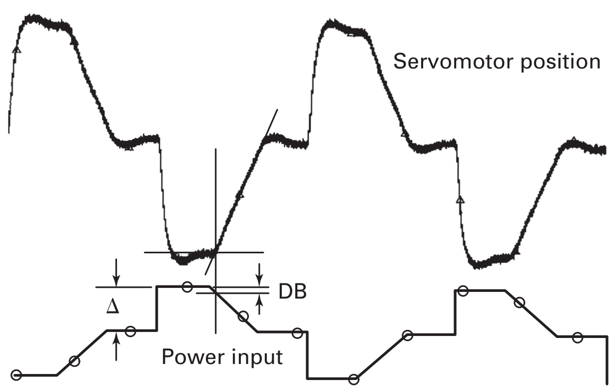

Fig. 5-5 Power Deadband

5-2.1.2 Temporary Droop Results. The temporary droop is calculated by dividing the value of the relative step change in the controlled variable by the relative value of the output signal and subtracting permanent droop as follows:

$$b_t = dx/dy - b_p \tag{5}$$

total droop, % = [(speed change, %)/(gate change, %)] 100
temporary droop = total droop − permanent droop

From the test recordings, determine the slope of the servomotor excursion due to the step change induced. Refer to Fig. 4-1 for examples. The temporary droop is measured by determining the y-intercept of the response chart as identified by the slope of the response curve.

5-2.2 Deadband

5-2.2.1 Speed Deadband and Deadtime Results

(*a*) *Speed Deadband*. From the test recordings, measure the magnitude of the speed change required to demonstrate a servomotor position change. Determine the ratio of the measured change to the calibrated speed step. This ratio multiplied by the speed step is the speed deadband. See Fig. 5-1.

(*b*) *Speed Deadtime*. From the test recordings, determine the elapsed time between the time the speed ramp begins and the first measurable movement of the servomotor trace. This time, expressed in seconds, is the speed deadtime. See Fig. 5-2.

5-2.2.2 Position Deadband and Deadtime Results

(*a*) *Position Deadband*. From the test recordings, measure the magnitude of the input position change required to demonstrate an output servomotor position change. Determine the ratio of the measured change to the calibrated position step. This ratio multiplied by the position step is the position deadband. See Fig. 5-3.

(*b*) *Position Deadtime.* From the test recordings, determine the elapsed time between the time the input position step change begins and the first measurable movement of the servomotor trace. This time, expressed in seconds, is the position deadtime. See Fig. 5-4.

5-2.2.3 Power Deadband Results. From the test recordings, measure the magnitude of the power change required to demonstrate a servomotor position change. Determine the ratio of the measured change to the calibrated power step. This ratio multiplied by the power step is the power deadband. See Fig. 5-5.

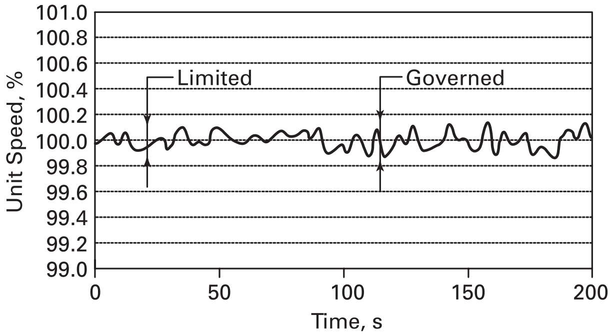

Fig. 5-6 Steady-State Speed Band

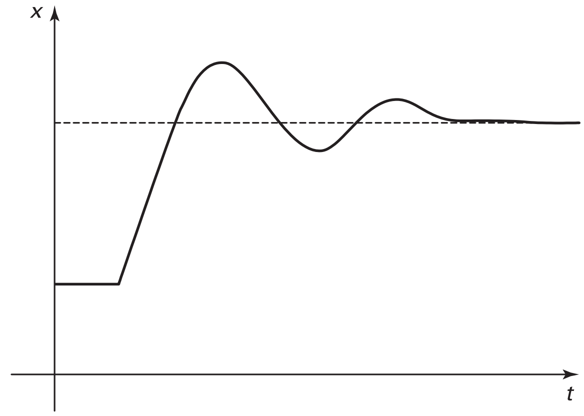

Fig. 5-8 Step Response

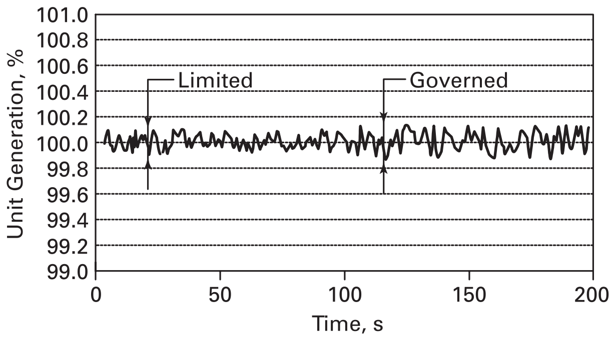

Fig. 5-7 Steady-State Power Band

5-2.3 Stability Indexes

5-2.3.1 Steady-State Governing Speed Band Results
(*a*) *Method 1*. From the test recordings obtained with the unit operating free from gate limit, determine the minimum and maximum speed recorded. Next, from the test recordings obtained with the gate limit imposed, repeat the examination of minimum and maximum speeds recorded. The difference between these values is the steady-state speed band. See Fig. 5-6.

(*b*) *Method 2*. From the test recordings obtained with the unit operating free from gate limit, determine the minimum and maximum speed recorded. The difference between these values is the steady-state speed band. See Fig. 5-6.

5-2.3.2 Governing Power Band Results. From the test recordings obtained with the unit operating free from gate limit, determine the minimum and maximum power recorded. Next, from the test recordings obtained with the gate limit imposed, repeat the examination of minimum and maximum power recorded. The difference between these values is the steady-state power band. See Fig. 5-7.

5-2.4 Step Response Results

Use the procedure in para. 4-2.4.1 to compare actual governor performance to desired performance as determined by computer simulation.

In the absence of a computer simulation, and taking into consideration any special operating circumstances that can take precedence, it is generally advisable to observe a response to the step test that resembles a 0.7 critically damped system. See Fig. 5-8.

5-2.5 Gain Adjustments

5-2.5.1 Proportional Gain Results. Proportional gain is calculated as the ratio of the percent output signal from the proportional integral derivative (PID) element to the % input signal to the PID element with the integral and derivative gain set to zero.

5-2.5.2 Integral Gain Results. Integral gain is calculated as the ratio of the percent output signal from the PID element to the time integral of the percent input signal to the PID element, with the proportional and derivative gain set to zero.

Integral gain can be calculated by taking the inverse of damping time, T_d.

$$K_I = 1/T_d \tag{6}$$

5-2.5.3 Derivative Gain Results. Derivative gain is calculated as the ratio of the percent output signal from the PID element to the time derivative of the percent input signal to the PID element, with the proportional and integral gain set to zero.

$$K_D = (\text{\% change in gate})/(\text{frequency change rate}) \tag{7}$$

5-2.6 Setpoint Adjustments

5-2.6.1 Range Adjustment Results. Take the difference between the high limit and the low limit for the values as recorded in para. 4-2.6.1 from the speed

Table 5-1 Permanent Droop

Parameter	Description	Result
Gate (SNL)	Servomotor position at speed no load	
Speed (normal)	Normal synchronous speed	
Gate (load)	Servomotor position at loaded condition (80%–95%)	
Speed 2	Speed with breaker open and increased speed adjustment	
Gate 2	Servomotor position with breaker open and increased speed adjustment	

recorded in para. 4-2.6.1. This is the setpoint adjustment range.

5-2.6.2 Ramp Rate Adjustment Results. Divide the setpoint adjustment range recorded in para. 4-2.6.2 by the time recorded in para. 4-2.6.2. These are the respective setpoint adjustment ramping rates.

5-3 OPERATIONAL TEST RESULTS — ELECTRONIC GOVERNOR

5-3.1 Gate/Blade Relationship for Dual-Control Reaction Turbines

Compare recorded gate and blade position curves to verify that the gate/blade relationship is in accordance with the design.

5-3.2 Needle–Deflector Relationship for Impulse Turbine

Compare recorded needle and deflector movement curves to verify that the needle–deflector relationship is in accordance with the design.

5-3.3 Full Rate Servomotor Time and Servomotor Cushion Time

5-3.3.1 Full Rate Servomotor Time Results. Full rate opening time is calculated as the time required for the servomotor to move from 25% to 75% of full servomotor travel multiplied by 2.

Full rate closing time is calculated as the time required for the servomotor to move from 75% to 25% of full servomotor travel multiplied by 2.

5-3.3.2 Servomotor Cushion Time Results. This is calculated as the time between an observable change in the slope of the servomotor position versus time recording, and the time the servomotor reaches its final position.

5-4 PERFORMANCE TEST RESULTS — MECHANICAL GOVERNOR

5-4.1 Droop

5-4.1.1 Permanent Droop Results

(*a*) *Method 1 and Method 2*. From the test recordings, measure the speed (Method 1) or speed adjustment (Method 2) and servomotor position of each step recorded. Express each data point of speed (or speed adjustment) as a percent of rated speed. Express each data point of turbine servomotor travel as a percent of design stroke. The permanent droop is calculated using Eq. (4) from this data.

NOTE: Permanent droop is expressed as a positive quantity, although according to conventional rectangular coordinate systems, the slope is considered negative.

(*b*) *Method 3*. From the data collected during the test, complete Table 5-1.

Permanent speed droop is calculated by the formula

$$\text{permanent droop} = \frac{\text{change in speed}}{\text{change in servomotor position}} \tag{8}$$

$$= \frac{100\,[\text{speed 2} - \text{speed (normal)}]}{\text{gate 2} - \text{gate (SNL)}}$$

5-4.1.2 Temporary Droop Results. From the test recordings, determine the slope of the gate response. Refer to Fig. 4-1. Extend the tangent line to establish both the y-intercept (gate movement) and the x-intercept (time element). The temporary droop is calculated using the y-intercept. The temporary droop is defined as the inverse of the proportional gain, K_P:

$$b_t = 1/K_P \tag{9}$$

5-4.2 Deadband and Deadtime

5-4.2.1 Speed Deadband and Deadtime Results. From the test recordings obtained by procedure 4-4.2.1(e), determine the time elapsed between the first observable speed rise and the first observable servomotor movement. This time increment is the speed deadtime.

5-4.2.2 Position Deadband and Deadtime Results

(*a*) *Position Deadband*. From the test recordings, determine the magnitude of the input position change required to demonstrate an output servomotor position change. Determine the ratio of the measured change to the calibrated position step. This ratio multiplied by the position step is the position deadband. See Fig. 5-3.

(*b*) *Position Deadtime*. From the test recordings, determine the elapsed time between the time the input position step change begins and the first measurable movement of the servomotor position trace. This time, expressed in seconds, is the position deadtime. See Fig. 5-4.

5-4.3 Steady-State Governing Speed Band and Step Response

5-4.3.1 Steady-State Governing Speed Band Results

(*a*) *Method 1.* From the test recordings obtained with the unit operating free from gate limit, determine the minimum and maximum speeds recorded. Next, from the test recordings obtained with the gate limit imposed, repeat the examination of minimum and maximum speeds recorded. The difference between these values is the steady-state speed band. See Fig. 5-6.

(*b*) *Method 2.* From the test recordings obtained with the unit operating free from gate limit, determine the minimum and maximum speeds recorded. The difference between these values is the steady-state speed band. See Fig. 5-6.

5-4.3.2 Step Response Results. Use the procedure in para. 4-2.4.1 to compare actual governor performance to desired performance as determined by computer simulation. In the absence of a computer simulation, and taking into consideration any special operating circumstances that can take precedence, it is generally advisable to observe a response to the step test that resembles a critically damped system (that is, an overshoot, followed by an undershoot and finally a smaller overshoot before settling into the desired equilibrium value). See Fig. 5-8.

5-5 OPERATIONAL TEST RESULTS — MECHANICAL GOVERNOR

5-5.1 Full Rate Servomotor Time and Servomotor Cushion Time Results

5-5.1.1 Results — On-Site, Turbine Depressurized. Full rate opening time is calculated as the time required for the servomotor to move from 25% to 75% of full servomotor travel multiplied by 2.

Full rate closing time is calculated as the time required for the servomotor to move from 75% to 25% of full servomotor travel multiplied by 2.

5-5.1.2 Servomotor Cushion Time Results. These are calculated as the time between an observable change in the rate of change of the servomotor position versus time recording, and the time the servomotor reaches its final position.

Section 6
Report of Results

6-1 GENERAL REQUIREMENTS

The Test Report shall be prepared for the purpose of formally presenting recorded and observed data and computed results. It shall contain sufficient information to prove that all tests have been conducted and results computed in accordance to this Code.

Only items required to satisfy the stipulated objectives need be recorded and reported.

The complete Test Report should contain, in addition to the tabulated test results, authenticated copies of the original log sheets. Instrument readings shall be recorded as observed. Corrections and corrected values shall be entered separately in the test record.

6-2 TEST REPORT FORM

At a minimum, the report should include the following distinctive sections:

(*a*) an executive summary containing

(*1*) a brief description of the object, result, and conclusions reached

(*2*) signature of test coordinator(s)

(*3*) signature of reviewer(s)

(*4*) approval signature(s)

(*b*) the detailed report of

(*1*) authorization for the tests, their object, contractual obligations and guarantees, stipulated agreements, by whom the test is directed, and the representative parties to the test

(*2*) description of the equipment tested and any other auxiliary apparatus, the operation of which may influence the test result

(*3*) method of test, giving arrangement of testing equipment, instruments used and their location, operating conditions, and complete description of methods of measurement not prescribed by the individual code

(*4*) summary of measurements and observations

(*5*) methods of calculation from observed data and calculation of probable uncertainty

(*6*) correction factors to be applied because of deviations, if any, of test conditions from those specified

(*7*) primary measurement uncertainties, including method of application

(*8*) the test performances stated under both of the following headings:

(*a*) test results computed on the basis of the test operating conditions, instrument calibrations only having been applied

(*b*) test results corrected to specified conditions if test operating conditions have deviated from those specified

(*9*) tabular and graphical presentation of the test results

(*10*) discussion and details of the test results' uncertainties

(*11*) discussion of the test, its results, and conclusions

(*c*) appendices and illustrations to clarify description of the circumstances, equipment, and methodology of the test; description of methods of calibrations of instruments; outline of details of calculations, including a sample set of computations, descriptions, and statements depicting special testing apparatus; result of preliminary inspections and trials; and any supporting information required to make the report a complete, self-contained document of the entire undertaking

6-3 UNCERTAINTY ANALYSIS

6-3.1 Pretest Uncertainty Analysis

In planning a test, a pretest uncertainty analysis allows corrective action to be taken prior to the test, either to decrease the uncertainty to a level consistent with the overall objective of the test, or to reduce the cost of the test while still attaining the objective. This is most important when deviations from code-specified instruments or methods are expected. An uncertainty analysis is useful to determine the number of observations.

6-3.2 Post-Test Uncertainty Analysis

A post-test uncertainty analysis determines the uncertainty intervals for the actual test. This analysis should confirm the pretest systematic and random uncertainty estimates. It serves to validate the quality of the test results or to expose problems.

Section 7
Optional Tests

7-1 OVERSPEED SIMULATION

This test is performed either in the manufacturer's shop or on site with the turbine dewatered. The purpose of the test is to verify the ability of the governor to close the gates in a simulated unit overspeed situation.

7-1.1 Test Equipment

(*a*) Multichannel recorder.

(*b*) Position transducer(s) as required to measure movement of turbine control mechanism(s). Accuracy shall be within ±1.0% of the operating range of full close to full open. Nonlinearity shall be within ±0.10% over the operating range of full close to full open.

(*c*) Adjustable frequency signal generator capable of providing a 100% speed input signal to the governor and producing a step change at least 10% above 100% speed (mechanical governor only).

7-1.2 Test Procedure

(*a*) Set the speed input or ballhead speed to 100% speed.

(*b*) Use the speed changer to move the servomotor position to 100%.

(*c*) Make a sudden speed step change to at least 110% speed while measuring and recording turbine control mechanism movement.

7-2 LOAD REJECTION TESTS—ON SITE

During load rejection, the rate of closure of the turbine control mechanism will influence the magnitude of hydraulic transients in the water conduits and the overspeed experienced by rotating parts. The purposes of this test are to verify proper governor operation during the load rejection, and to measure actual hydraulic transient pressures and unit overspeed.

Test parties shall agree to loads from which the load rejections shall be performed and a sequence of testing that will ensure safe operating pressures and speeds are not exceeded.

7-2.1 Test Equipment

(*a*) Multichannel recorder.

(*b*) Position transducer(s) as required to measure movement of turbine control mechanism(s) and water bypass devices. Accuracy shall be within ±1.0% of the operating range of full close to full open. Nonlinearity shall be within ±0.10% over the operating range of full close to full open.

(*c*) Pressure transducers as required to verify hydraulic transient pressures. Accuracy of ±1.0% of the operating range of minimum to maximum anticipated transient pressure is required. Nonlinearity shall be within ±0.10% over the anticipated operating range of minimum to maximum transient pressure.

(*d*) Speed transducer with operating range or design speed to maximum anticipated transient speed. Accuracy shall be within ±1.0% of the range of design speed to maximum anticipated overspeed. Nonlinearity shall be within ±0.10% over the range of design speed to maximum anticipated overspeed.

7-2.2 Test Procedure

(*a*) Verify rate of movement of turbine control mechanism(s) and water bypass devices to ensure acceptable hydraulic transients and unit overspeed. (See para. 5-5.1.1 on testing rate of turbine control mechanism movement.)

(*b*) Calibrate pressure transducers, position transducers, speed transducer, and recording device between minimum and maximum expected transient values.

(*c*) Perform load rejection from the load and in the sequence agreed to by test parties. Initiate load rejections using one or more of the following procedures as required to simulate all anticipated load rejection operations:

(*1*) With the unit at specified load, open the generator power circuit breaker.

(*2*) With the unit at specified load, initiate unit shutdown through the governor complete shutdown device.

(*3*) With the unit at specified load, initiate shutdown through the governor partial shutdown device.

(*d*) Evaluate test data to ensure safe pressures and speed have not been exceeded and will not be exceeded in subsequent tests.

(*e*) If agreed to by all parties, readjust rate of movement of turbine control mechanisms and repeat test or continue with test sequence.

7-3 ACCUMULATOR CAPACITY

The purpose of this test is to determine the amount of servomotor strokes that can be provided by the accumulator alone before the servomotor stall pressure is reached. The test shall be done in the field with actual servomotor and piping connected, the turbine dewatered, and the governor at normal operating pressure.

7-3.1 Test Equipment

A pressure gauge shall be connected to each servomotor and a stopwatch used to confirm proper opening and closing times during the test. Optionally, pressure sensors and a multichannel recorder may be substituted to record test data.

7-3.2 Test Procedure

With the servomotor in the fully closed (0%) position, disable all oil pumps and air compressors, if applicable. Stroke the servomotor fully open (100%) at the normal opening rate. Record the servomotor pressure, then wait 1 min. Stroke the servomotor fully closed (0%) at the emergency closing rate. Record the servomotor pressure, then wait 1 min. Continue this opening and closing procedure until the accumulator reaches minimum operating pressure or minimum operating level, noting the number of servomotor strokes successfully completed.

7-4 ACCUMULATOR ACTIVE VOLUME

The oil accumulator active volume is defined as the oil volume between the oil levels in the accumulator corresponding to the lowest pressure setting at the higher end of the operating pressure range (when pumps stop) and the highest pressure setting at the lower end of the pressure range (when first pump starts).

7-5 OIL PUMP CAPACITY

The oil pump capacity shall be determined by dividing oil accumulator active volume by the time required to charge the accumulator from the lower to upper pressure switch settings.

7-6 HYDRAULIC SYSTEM PRESSURE CONTROL RANGE

Pressure control range is the difference between upper and lower pressure of the operating range. To make this measurement, the system shall be allowed to operate with the pressure decreasing until the pressure switch activates the first oil pumps. This is the lower end of the pressure control range. The pumps will be shut off by the pressure switch. The pressure that this occurs at is the upper end of the pressure control range.

7-7 STEADY-STATE OIL CONSUMPTION

The system consumption shall be computed by dividing the oil accumulator active volume by the time for the system pressure to drop from the upper to lower pressure switch setting. This shall be done for two conditions, unit at shutdown with the governor pressurized and unit at rated load (on cam if the unit is a Kaplan).

7-8 FREQUENCY RESPONSE TEST

A governor-controlled hydrogenerator stability margin can be quantified through its frequency response. The validity of frequency response testing depends on linear system operation.

The amplitude of input signals shall be chosen to retain linear behavior of the governor under test (1% displacement range of governor elements). Nonlinearities, such as governor integrator limits and ramping (usually introduced by the manufacturer to improve large signal response), shall be disabled if otherwise activated during testing.

Removal of nonlinearities as well as any other alteration from the standard governor configuration shall be specified by written agreement between the parties prior to the test. A pilot verification test prior to performance testing can be conducted, upon parties' mutual agreement, to verify linear governor response to the chosen input signal amplitude.

Table 7-1 Customary Frequency Response Tests

Component to Be Tested	Test Input	Computation Input	Output	Remarks
Governor	Speed deviation (3) or generation reference (6), depending on the loop to be tested	Speed deviation (3) or generation reference (6), depending on the loop to be tested	Servomotor command (4)	Verify governor dynamics, open loop
Servomotor positioner	Speed deviation (3)	Servomotor command (4)	Servomotor position (5)	Verify servomotor positioner dynamics, closed loop
Hydrogenerator and conduit	Speed deviation (3)	Servomotor position (5)	Speed (1) Power (2)	Off-line test, open loop On-line test, open loop
Overall system	Speed deviation (3)	Speed deviation (3)	Speed (1) or power (2)	Check overall stability, open loop

GENERAL NOTE: See Fig. 7-2.

The elemental governor subsystems to be tested shall be agreed upon before the test. The required inputs and resulting outputs to be recorded shall be selected from those specified in Table 7-1.

As a speed governor cannot operate linearly full range, the test shall be performed at several pre-agreed-upon load points (for example, 0%, 30%, 60%, and 100% full load).

7-8.1 Test Equipment Requirements

(*a*) Multichannel recorder.

(*b*) Position transducer(s) as required to measure movement of turbine control mechanism(s). Accuracy shall be within ±1.0% F.S. Linearity shall be within ±0.10% F.S.

(*c*) Watt transducer.

(*d*) Variable frequency signal generator capable of providing a 100% speed input signal to the governor and capable of being modulated by another frequency generator (electronic governor) or variable speed governor ballhead drive (mechanical governor) with same specifications.

(*e*) 0.01–10 Hz (low frequency or LF) sinusoidal signal generator. The results are computed from the records; thus, high instrument accuracy is not required.

NOTE: A dynamic signal analyzer, if desired, can replace signal generators and strip-chart recorders. Properly programmed, a signal analyzer will perform frequency response tests and produce printouts of the required Bode diagrams.

WARNING: During the test, the actual speed of the unit is not under governor control. It is imperative that overspeed protections be sufficiently pretested and fully operational.

7-8.2 Test Procedure

(*a*) Mount a speed transducer switching device as shown in Fig. 7-1.

(*b*) Connect the LF generator output to one recorder input channel.

(*c*) Connect the inputs and outputs selected from Fig. 7-2 to the recorder inputs.

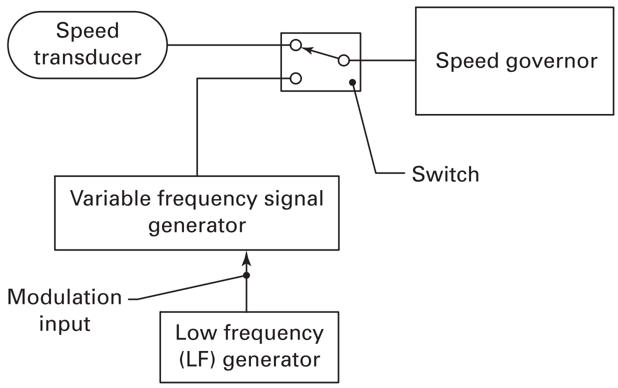

Fig. 7-1 Frequency Response Test Setup

(*d*) Connect the speed transducer to one switch input, the variable frequency signal generator to the other input, and the speed transducer governor input to the switch output. See Fig. 7-1.

(*e*) With the switch in the speed transducer position, perform a startup and synchronize to grid.

(*f*) Set the amplitude of the LF generator to minimum and switch the speed signal from speed transducer to variable-frequency signal generator position.

(*g*) Adjust the LF generator amplitude to obtain a peak-to-peak frequency deviation compatible with linear operation of the system under test (typically 0.1 Hz to 0.2 Hz).

(*h*) Set the LF generator at 10 mHz.

(*i*) Record for two cycles of LF signal input.

(*j*) Repeat and obtain recordings for LF generator settings of 20 mHz, 50 mHz, 70 mHz, 0.1 Hz, 0.2 Hz, 0.5 Hz, 0.7 Hz, 1 Hz, 2 Hz, 5 Hz, 7 Hz, and 10 Hz.

(*k*) Set the amplitude of the LF generator to zero.

(*l*) Switch the speed signal switch from signal generator to speed transducer.

7-8.3 Computation of Results

The following describes the computation required for reducing frequency response test data to the asso-

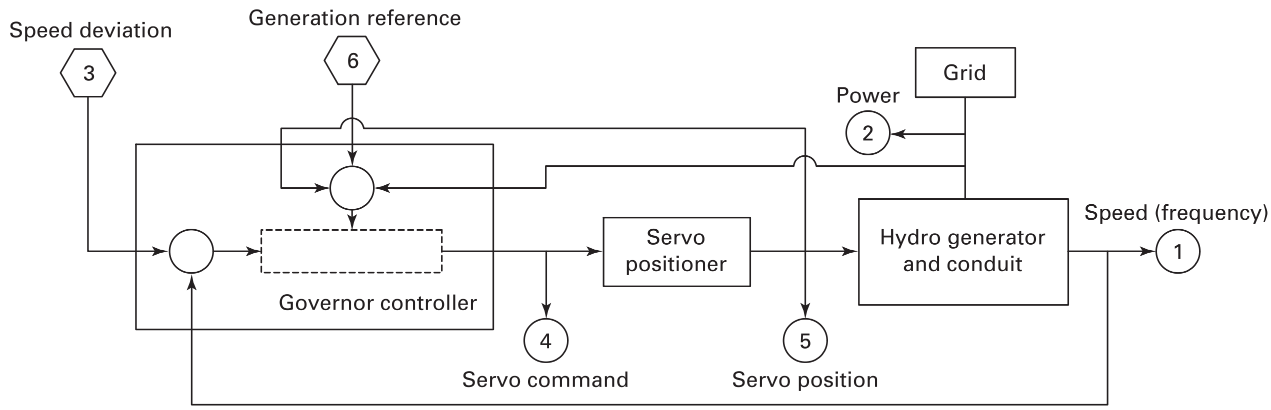

Fig. 7-2 Frequency Response Inputs and Outputs

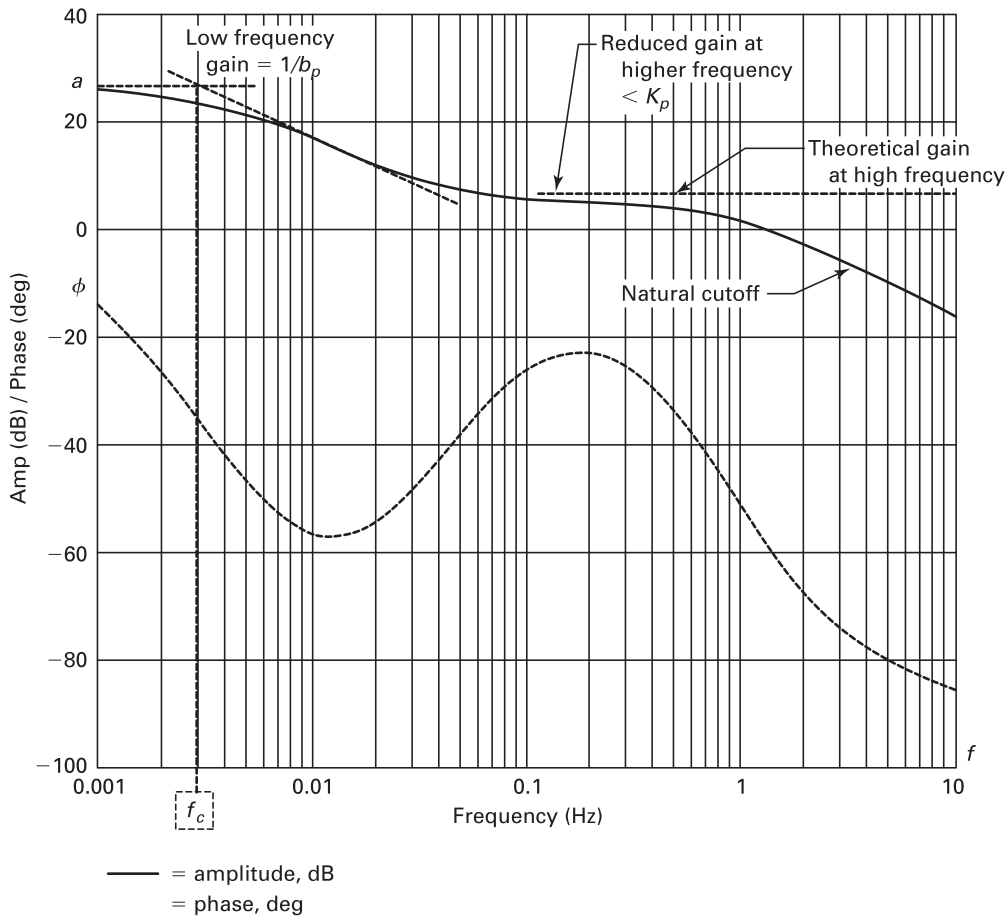

Fig. 7-3 Frequency Response Diagram

ciated transfer function. Computations shall be repeated for each input/output pair tested. Alternatively, transfer functions are obtained from a dynamic signal analyzer.

(*a*) At each frequency, measure equally scaled input and output amplitudes from strip-chart recordings.

(*b*) Compute the gain as

$$G_{dB} = 20 \log (\text{output/input}) \text{ for any one frequency} \quad (10)$$

(*c*) At every frequency, measure the signed time difference between the zero-crossing point of the rising input signal and that of the rising output signal, referring to the input as the time origin. Verify the set value of frequency by zero-crossings measurement of the input signal period.

(*d*) Compute the phase as

$$\Phi_{\text{deg}} = -360 \text{ (measured time/period)} \tag{11}$$

(*e*) On semi-log graph paper, draw the gain and phase curves (diagrams) versus frequency.

The sample diagram in Fig. 7-3 shows the open loop frequency response of a proportional plus integral (PI) controller with permanent speed droop. The following governor settings are established from the given frequency response diagram:

(*1*) Permanent speed droop, b_p, is given by 1/G0, where G0 is the constant gain at very low frequency. In the above example,

$$\text{G0} \approx 26 \text{ dB} \approx 20 \text{ and } b_p \approx 1/20 \approx 5\% \tag{12}$$

The following two computations are significant only if the derivative action has been disabled (which is the case for the PI governor in the example):

(*a*) The theoretical constant gain at higher frequency, *Ghf*, is given by the formula

$$Ghf = \frac{K_P}{1 + K_P \times b_p} \tag{13}$$

(*b*) Thus, the proportional gain is given by

$$K_P = \frac{Ghf}{1 - b_p \times Ghf} \tag{14}$$

In the above example, $Ghf \approx 6$ dB = 2 and $b_p \approx 0.05$, so $K_P \approx 2.2$ (i.e., temporary speed droop $b_t \approx 0.45$).

(*2*) Damping time constant, T_d, is given by the formula

$$T_d = 2\pi \frac{1}{(1 + K_P \times b_p) f_c} \tag{15}$$

where

f_c = cut-off frequency shown on the frequency response (Bode) diagram

In the above example, $f_c \approx 0.003$ Hz, $b_p \approx 0.05$, and $K_P \approx 2.2$, so $T_d \approx 5.7$ s.

(*3*) Stability (phase) margin is given on the overall open loop (i.e., from governor speed deviation input to unit speed output) Bode diagram of the system. It is 180 deg minus the measured phase at the frequency where the open loop gain equals 1 (known as the gain crossover or the 0 dB point). It is generally agreed that the system will be stable in operation if the phase margin is 45 deg or more.

In the above example, the phase margin is 180 − 60 = 120 deg [but in this particular case (frequency response of an element, i.e., the governor), the figure has no significance].

Likewise, it is possible to determine the stability margin of the servo-positioner, which is itself a closed loop system. For such a test, the position loop shall be open during the test (i.e., the feedback position transducer is disconnected).

NONMANDATORY APPENDIX A UNCERTAINTY ANALYSIS

A-1 INTRODUCTION

The uncertainty of any measurement or calculation is defined as the measured value's likely deviation, according to an agreed metric, from the true value. Uncertainty is often expressed as the average deviation, the probable error, or the standard deviation resulting from systematic and random errors as defined in ASME PTC 19.1-1998.

ASME PTC 29 specifies the measurement of numerous performance parameters. These parameters are machine/governor attributes, functions, or settings that remain invariant to operating conditions within measurement accuracy requirements. As a result of this invariance, the practice has developed and adopted testing techniques that are satisfied by single datum collection for any particular test parameter at a particular operating point.

Calculating uncertainty involves methods prescribed in ASME PTC 19.1-1998. Uncertainty calculations for single datum tests adapt PTC 19.1-1998 to the special case where random error is unavailable. Hence, the uncertainty analysis derives from systematic errors alone. Systematic errors, in turn, derive from the accuracy of the test instruments, calibration inaccuracies, etc.

The objective of this Appendix is twofold. The first portion is included to satisfy ASME codes uncertainty estimation requirements. The second is to ascertain whether standard instruments will result in parameter measurement uncertainty within engineering expectations, in which case field pretest and posttest certification of the involved instruments' accuracies is required.

While protocol is developed for single datum collection, this Code in no way precludes specifying multiple test data acquisition. For uncertainty analysis direction in those cases that necessarily involve random error considerations, the reader is referred to PTC 19.1-1998 and a number of texts on the subject.[1]

A-2 SAMPLE CALCULATION

Of the parameters defined in PTC 29, speed droop involves the most comprehensive mathematical and graphical computation to arrive at measurement uncertainty. Therefore, permanent speed droop is selected for sample calculation.

Table A-1 Typical Permanent Droop Test Data

Frequency (50 Hz base)	Gate Position, %
49.00	90.1
49.50	70.1
50.00	50.1
50.50	30.1
51.00	10.1

Speed droop is the mechanically or electronically implemented strategy used to set the unit's power response to the unit's speed deviations. It also allows load sharing among interconnected units. The governor's sensed unit speed input is subtracted from a command signal speed adjustment, producing the unit speed error. Wicket gate position is fed back through the speed droop multiplier, and that product is also subtracted from the unit speed error. A unit speed rise causes the governor to begin closing the wicket gates. This closing action ends at a new turbine power output level where the gate position feedback cancels the speed error imbalance. Speed droop can be used both for isolated and grid-connected operation.

PTC 29 defines speed droop as the ratio of the relative change in unit speed to the resulting relative change in wicket gate servomotor position. Speed droop is calculated by first plotting on a graph the unit speed versus the wicket gate servomotor position, from data collected at five evenly distributed points within servomotor travel limits. Speed droop is the negative of the line's slope and is usually expressed in percent.

Measurement errors exist both in the unit speed data and in the wicket gate servomotor position data. For this example, the data accuracies used for acceptable instruments are 0.00005 (0.005%) for unit speed error (s.e.) and 0.001 (0.1%) for wicket gate servomotor position error (p.e.). A typical data set for calculating speed droop is given in Table A-1. The data consists of five equally spaced readings covering essentially full wicket gates servomotor travel, excluding end points. The Table A-1 data is used to perform a sample uncertainty analysis and an instrument-accuracy based uncertainty verification.

[1]Colemann, H. W. and Steele, W. G., Experimentation and Uncertainty Analysis for Engineers, 2nd Edition, Chapter 7, John Wiley and Sons, Inc., New York, 1999.

A-2.1 Uncertainty Analysis

The following procedure is adapted from "Comprehensive Approach to Linear Regression Uncertainty" in the text[1] by Colemann and Steele. It is indicated there that "the most general form of the expression for the uncertainty in the slope (our permanent droop) is" a function of both speed and gates position random and systematic uncertainties, and of the correlated systematic uncertainties between speed readings, between position readings, and between speed and position readings.

As already stated, invariant test conditions, especially with commonly used digital readouts, result in negligible random uncertainty contribution and promote a single datum collection practice. Correlated systematic uncertainties are based on systematic reading or instrument errors. In practice, speed and position are measured by different instruments, no two data points are taken at the same point on a voltmeter's scale, and data may be taken on different scales, precluding the possibility of self- or cross-correlation assessment. The relevant terms remaining in Eq. (7.27)[1] are those for the systematic uncertainty of speed and of gates position.

$$U_m^2 = \sum_{i=1}^{N} (\partial m/\partial Y_i)^2 \, B_{Y_i}^2 + \sum_{i=1}^{N} (\partial m/\partial X_i)^2 \, B_{X_i}^2$$

For constant $B_{Y_i}s$ and $B_{X_i}s$, the relation simplifies to

$$U_m^2 = B_Y^2 \sum_{i=1}^{N} (\partial m/\partial Y_i)^2 + B_x^2 \sum_{i=1}^{N} (\partial m/\partial X_i)^2$$

where B_X and B_Y are the systematic uncertainties (instruments' reading accuracies in our case) for position and speed, respectively. The first-order regression slope, m, is determined from[1]

$$m = \frac{N \sum_{i=1}^{N} X_i Y_i - \sum_{i=1}^{N} X_i \sum_{i=1}^{N} Y_i}{N \sum_{i=1}^{N} X_i^2 - \left(\sum_{i=1}^{N} X_i \right)^2}$$

Numerical calculations for the partial derivatives and final computations for U_m and m, performed by spreadsheet using Table A-1 data and given $B_X = 0.001$ and $B_Y = 0.00005$ instrument accuracies, result in $U_m = 0.000125$ or 0.25% of m and $m = 0.05$ or 5%. It may now be reported that the m population interval, μ_m, containing permanent droop to 95% confidence is

$$m - U_m < \mu_m < m + U_m$$

or

$$0.05 - 0.000125 < \mu_m < 0.05 + 0.000125$$

If additional systematic error conditions for which correction is impossible exist, then the analysis must include them in an expanded version of the U_m^2 equation.

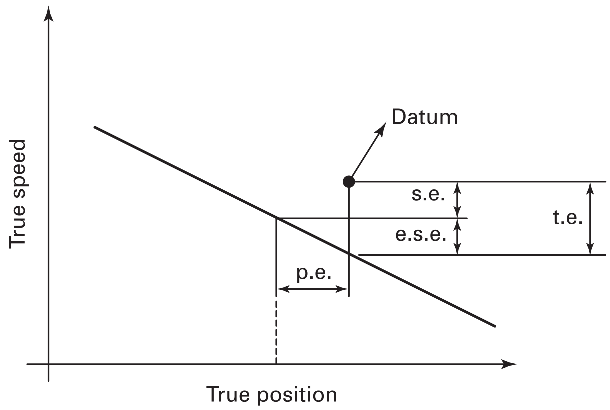

Fig. A-1 Equivalent Speed Error

A-2.2 Instrument-Accuracy Based Analysis

The following uses previously stated acceptable instruments readout accuracies of 0.00005 for unit speed error (s.e.) and 0.001 for wicket gate servomotor position error (p.e.). It is assumed that the true value of speed droop is 0.05 (5.00%) in this sample computation. It should be noted that the resulting speed droop uncertainty depends upon the assumed true value.

To simplify the uncertainty computation of speed droop, the position error (p.e.) in the wicket gate data is converted into an equivalent speed error (e.s.e.). For a droop value of 0.05, the e.s.e. will be the product of the position error and the droop. See Fig. A-1.

$$\text{e.s.e} = (\text{droop})(\text{p.e.}) = (0.05)(0.001) = 0.00005$$

The total error (t.e.) becomes the root-sum-square of the speed error and the equivalent speed error,

$$\begin{aligned} \text{t.e.} &= \sqrt{(\text{s.e.})^2 + (\text{e.s.e.})^2} \\ &= \sqrt{(0.00005)^2 + (0.00005)^2} = 0.000071 \end{aligned}$$

A typical data set for calculating speed droop will consist of five equally spaced readings covering essentially the full travel of the wicket gate servomotor, excluding endpoints. To compute the maximum possible impact of data errors upon the computed speed droop value, it is assumed that the maximum negative total error dislocation of data points occurs for the first two points, the maximum positive dislocation of data occurs for the last two points, and the middle point is exact. The translated total error dislocation data on the unit speed versus gate position plane is shown in Fig. A-2. For the sake of mathematical simplicity, the data set has been translated to place the middle data point at the origin. This translation is possible because the slope of a line through a set of points is data set translation independent.

The slope of the best least squares fit line through the points on the graph in Fig. A-2 will then be the uncer-

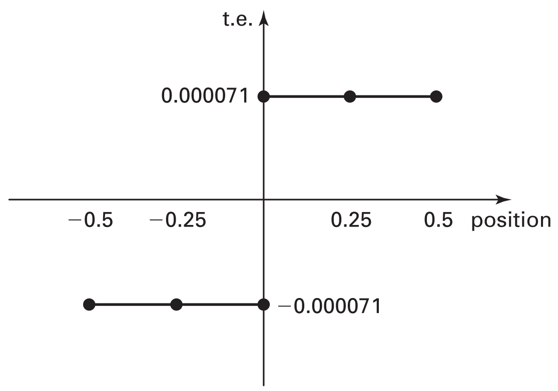

Fig. A-2 Total Error

tainty in the calculated value of speed droop and is given to be

$$b = \frac{\Sigma(X_n)\,(Y_n)}{\Sigma\,(X_n)^2}$$

$$= \frac{(-0.5)(-0.000071) + (-0.025)(-0.000071) + (0.25)(0.000071) + (0.5)(0.000071)}{(-0.5)^2 + (-0.25)^2 + (0.25)^2 + (0.5)^2} = 0.00017$$

The uncertainty on droop, whether expressed as an absolute percentage of ±0.017% or ±0.34% when referred to the set droop of 5%, is now proven to exceed (by a factor of 3) the functional engineering expectations tabulated in para. 1-3 of this Code. Since the selected instruments were general purpose, it is concluded that retaining instrumentation accuracy is sufficient evidence of para. 1-3 measurement confidence conformance.

A-3 CONCLUSION

This Appendix serves as a sample calculation of uncertainty. It is applied to the governor parameter permanent droop. Two separate analyses are included, the first being the conventional methodology, with the second computing the deviation in the measurement of droop assuming all data to be at maximum error with respect to testing equipment's reading accuracy.

For sample 5% permanent droop data, the conventional computation indicates a ±0.25% measurement, while the maximum data dislocation method reports 0.34%, each referenced to the 5% base. These results are in close agreement, the methods lending credence to one another.

While not included in the Code due to the large number of governor parameters considered, each parameter was examined using the instrument-accuracy based analysis, to assure that all meet Code para. 1-3 engineering uncertainty expectations.

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PERFORMANCE TEST CODES (PTC)

(continued)

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