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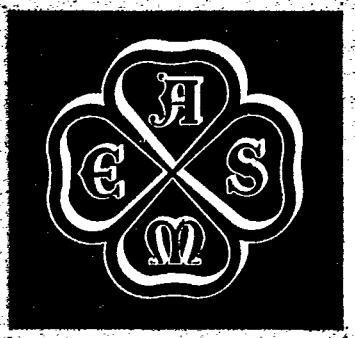
Speed-Governing Systems for Hydraulic Turbine-Generator Units



POWER TEST CODES

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Speed-Governing Systems for Hydraulic Turbine-Generator Units

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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 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 code 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 on Codes and Standards on December 9, 1964.

The members of PTC Committee No. 29 wish to record with sincere appreciation the important service rendered in the development of this code by the late Chairman, Mr. C. L. Avery. He was instrumental in its organization and served as its Chairman from November, 1955, until his untimely death on July 6, 1962.

July, 1965

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TEST CODE FOR SPEED-GOVERNING SYSTEMS FOR HYDRAULIC TURBINE-GENERATOR UNITS

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SECTION 0, INTRODUCTION

0.01 This code provides standard procedures for routine, commercial and acceptance tests either at site or in the shops of the manufacturer for determination of the speed-governing performance characteristics of governing systems for hydraulic turbine-generator units. It includes those tests which are required to determine the performance characteristics specified in the AIEE-ASME (IEEE-ASME) Recommended Specification for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators (AIEE (IEEE) publication No. 605) as necessary for satisfactory speed governing and which are capable of measurement by test with acceptable precision.

0.02 Unless otherwise specified, all references to other codes refer to ASME Power Test Codes. The Code on General Instructions (PTC 1) should be adhered to in detail when formulating the procedure for testing speed-governing systems. Attention is directed to the Code on Definitions and Values (PTC 2) which defines certain technical terms and numerical constants used throughout this code. These auxiliary documents, together with other related ASME Power Test Codes and Supplements on Instruments and Apparatus, where and to the extent applicable, form a part of this code.

0.03 An appendix to this code includes discussion of test methods for determination of certain optional or supplementary data.

SECTION 1, OBJECT AND SCOPE

1.01 The purpose of this Code is to establish rules and procedure for the conduct of tests to determine the following commonly specified speed-governing characteristics of turbine-generator-unit governor systems:

(a) Speed droop
(b) Deadband
(c) Blade-control deadband
(d) Dead time
(e) Time element
(f) Servomotor cushioning time
(g) Stability indexes
(h) Speed-changer governing range
(i) Speed-changer synchronizing range
(j) Speed-changer load-reducing time
(k) Hand-control gate closing time
(l) Oil-pump capacity.

1.02 This code is applicable to the testing of governor systems for hydraulic turbine-generator units furnished with hydraulic turbines which are classified as follows:

(a) Impulse turbines with governor control of
  (1) Deflectors
  (2) Deflectors and jets
(b) Francis turbines
(c) Fixed-blade-propeller turbines
(d) Adjustable-blade-propeller turbines with governor control of wicket gates and runner blades.

1.03 Included within the scope of this code are rules and procedures for shop tests to determine the following characteristics of hydraulic-turbine governors:

(a) Speed droop
(b) Deadband
(c) Speed-changer governing range
(d) Speed-changer synchronizing range
(e) Speed-changer load reducing time
(f) Oil-pump capacity.

1.04 The testing of various protective and supervisory devices is not within the scope of this code.

1.05 The appendix to this code includes discussion of test methods for determination of the following optional or supplementary data:

(a) Overspeed
(b) Pressure rise

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(c) Steady-state speed regulation
(d) Incremental speed droop
(e) Steady-state incremental speed regulation
(f) Servomotor force requirements
(g) Lost motion
(h) Frequency response.

SECTION 2, DESCRIPTION AND DEFINITION OF TERMS

TABLE 1. TYPES OF HYDRAULIC TURBINES

Par. No.	Term	Description
2.01	Impulse turbine	Water is supplied through one or more free jets and impinges on the buckets of the runner.
2.02	Francis (reaction) turbine	Water is supplied in a whirling, radial direction to a runner with a multiplicity of fixed buckets.
2.03	Fixed-blade-propeller (reaction) turbine	Water is supplied in a whirling axial direction to a runner with a number of blades which are rigidly fixed to the runner hub.
2.04	Adjustable-blade-propeller (reaction) turbine	Water is supplied in a whirling axial direction to a runner with a number of blades, which are angularly adjustable in the runner hub.

TABLE 2. TYPES OF HYDRAULIC-TURBINE CONTROL MECHANISMS

Par. No.	Term	Description
2.05	Turbine-control mechanism	Includes those elements of the turbine which control the energy input to the turbine and the system of connected linkage which is actuated by the governor-control mechanism.
2.06	Needle control	On an impulse turbine, a system arranged to control the position of the needle (s) which regulate (s) the size of the jet (s) impinging on the runner buckets.
2.07	Deflector control	On an impulse turbine, a system arranged to control the deflector (s) which are devices located within the turbine housing and actuated to quickly deflect all or part of the water away from the runner buckets, thus regulating the power output.
2.08	Water-wasting control	A system where only the deflector movement is under governor control.

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Table 2. Types of Hydraulic-Turbine Control Mechanisms (Cont'd)

Par. No.	Term	Description
2.09	Water-saving control	A system where both the deflector and needle movements are under governor control and arranged so that water is deflected away from the runner buckets only during rapid load reduction.
2.10	Gate control	A system to control the position of the wicket gates of a reaction turbine and thereby regulate the quantity of water supplied to the runner.
2.11	Blade control	A system arranged to control the position of the runner blades of an adjustable-blade-propeller turbine.
2.12	Hand control	A system for manually operating the turbine gates or deflector(s) by either mechanical or hydraulic devices independently from the speed controlled mechanism.
2.13	Pressure regulator	A bypass valve connected to the penstock or spiral case that opens as the turbine-control mechanism closes and then closes slowly upon completion of such closing movement of the turbine-control mechanism thus reducing pressure rise in the penstock.
2.14	Synchronous bypass valve	A bypass valve connected to the penstock or spiral case that opens as the turbine-control mechanism closes and closes as the turbine-control mechanism opens to maintain a substantially constant total discharge within specified limits.
2.15	A pressure regulator may be arranged to be selectively operated as a synchronous bypass valve.	

TABLE 3. GOVERNOR SYSTEM COMPONENT PARTS

Par. No.	Term	Description
2.16	Governor system	Includes the governor head drive, the governor head, the governor control mechanism and the hydraulic-pressure supply system.
2.17	Governor-head drive	The means used to transmit a signal proportional to the speed of the turbine to the governor head. It may be mechanical, either through belts or gearing, or *electrical,* either through potential transformers in the driven generator leads or through an independent generator which is coupled to the main generator shaft.
2.18	Governor head or speed-sensing circuit	Includes only those elements which are directly responsive to speed, which determine speed error and influence the action of other elements of the governing system.

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Table 3. Governor System Component Parts (Cont'd)

Par. No.	Term	Description
2.19	Governor-control mechanism	Includes all equipment such as relays, servomotors, pressure- or power-amplifying devices, levers and linkages between the governor head and the turbine-control mechanism. Includes, in the case of adjustable-blade turbines, gate and blade-control equipment and in the case of impulse turbines, deflector- and/or needle-control equipment.
2.20	Hydraulic-pressure supply system	Includes the pumps, means for driving them, the pressure and sump tanks, the valves and piping connecting the various parts of the governing system and associated and accessory devices.
2.21	Governor	Refers to the assembly comprised of the distributing valve (s) and other control elements in combination with the governor cubicle when it is furnished. For impulse-turbine governors, the needle-distributing valve (s) and for adjustable-blade turbine governors, the blade-distributing valve may be included. The hydraulic-pressure supply system or portions thereof may also be included in the governor assembly.
2.22	Governor-control console or board	Supports certain electrical elements of the governing system and may be located remotely from the distributing valve assembly.
2.23	Type of governor	Refers to the arrangement of the component parts of the governor system.
2.24	Gate-shaft type governor	The gate- or deflector-distributing valve, servomotor, hand-control mechanism and other associated parts of the governor-control mechanism are mounted on a single base. The turbine-control mechanism is operated through a gate shaft.
2.25	Actuator type governor	The gate- or deflector-distributing valve, hand-control mechanism and associated parts of the governor-control mechanism are mounted on a single base or stand. The gate or deflector servomotor (s) are mounted remotely from the governor and adjacent to or integral with the hydraulic turbine.
2.26	Cabinet type governor	The governor structure includes a cabinet which encloses specified governor-control and/or hydraulic-pressure supply mechanisms.
2.27	Distributing valve	The element of the governor-control mechanism which controls the flow of hydraulic fluid to the turbine-control servomotor (s).

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Table 3. Governor System Component Parts (Cont'd)

Par. No.	Term	Description
2.28	Turbine-control servomotor	The amplifying element of the governor-control mechanism which moves the turbine-control mechanism in response to the action of the distributing valve. Turbine-control servomotors are designated as: *(a)* Deflector servomotor *(b)* Needle servomotor *(c)* Gate servomotor *(d)* Blade servomotor
2.29	Slow closure device	Retards the rate of servomotor closing travel from a predetermined servomotor position to zero effective servomotor stroke.
2.30	Restoring connections	Includes those elements of the governor-control mechanism which feed back the motion of the turbine-control mechanism.
2.31	Compensating mechanism	Includes those elements of the governor-control mechanism which modify the motion of the turbine-control mechanism to prevent over-travel, thus producing stability. Stability is obtained by modifying the speed-error signal with a signal which is a function of the derivative (s) of speed. Derivative of speed may 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.
2.32	Stops	Blocking devices which limit the distributing-valve travel and thereby limit the rate of travel of the turbine-control servomotor.
2.33	Speed changer	A device by means of which the governor system may be adjusted to change the speed or power output of the turbine while the turbine is operating.
2.34	Speed-droop changer	A device by means of which the speed droop may be adjusted while the turbine is operating.
2.35	Gate limit	A device which acts on the governor system to prevent the turbine-control mechanism from opening beyond the position for which the device is set.

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TABLE 4. FUNCTIONS AND CHARACTERISTICS

Par. No.	Term	Symbol	Definition or Description	Unit
2.36	Effective servomotor stroke	L_t	Travel of the turbine-control servomotor required to control the turbine discharge from zero to maximum without overtravel or squeeze at the maximum or minimum position. For a deflector servomotor this shall be established on the basis of full flow deflected from the runner from "no deflection" position (deflector(s) and needle(s) at maximum jet) to full flow deflected with maximum discharge under maximum specified head including overpressure due to waterhammer.	in.
2.37	Servomotor rated-power stroke	L_p	Travel of the turbine-control servomotor corresponding to the change from zero to rated power output of the turbine at rated speed with rated head.	in.
2.38	Servomotor time element	T	The elapsed time for one effective servomotor stroke corresponding to the maximum rate of servomotor travel when the stops are set to give maximum permissible rate of servomotor piston travel. Designated as *opening* or *closing*, depending on the direction of servomotor travel, time element can be qualified as	sec
		T_D	*(a)* Deflector	sec
		T_N	*(b)* Needle	sec
		T_G	(c) Gate	sec
		T_B	*(d)* Blade	sec
2.39	All measurements of servomotor stroke shall be referred to the servomotor position corresponding to zero turbine discharge without servomotor overtravel or squeeze.			
2.40	Cushioning time	T_c	The elapsed time during which the slow closure device acts.	sec
2.41	Speed droop	D_s	The change in steady-state speed expressed in per cent of rated speed, corresponding to the effective servomotor stroke with no-change in setting of any governor adjustments. $D_s = \frac{(N_1 - N_2) \times 100}{N_r}$	per cent
			D_s = Speed droop	per cent

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Table 4. Functions and Characteristics (Cont'd)

Par. No.	Term	Symbol	Definition or Description	Unit
			N_1 = Extrapolated speed corresponding to zero effective servomotor stroke.	rpm
			N_2 = Extrapolated speed corresponding to one hundred (100) per cent effective servomotor stroke.	rpm
			N_r = Rated speed	rpm
2.42	Steady-state speed regulation	R_s	The change in steady-state speed expressed in per cent of rated speed, when the power output of the unit is reduced from rated power output to zero power output under rated head and with identical settings of all governor adjustments.	per cent
			$R_s = \frac{N_o - N}{N_r} \times 100$	
			R_s = Steady-state speed regulation	per cent
			N_o = Speed at zero power output	rpm
			N = Speed at rated power output	rpm
			N_r = Rated speed	rpm
2.43	The speed droop and steady-state speed regulation may vary with different settings of the speed changer. The percentages derived from either formula above are based upon the speed-changer setting which gives rated speed with rated power output at rated head.			
2.44	Incremental speed droop	D_i	The rate of change of the steady-state speed with respect to the effective servomotor stroke at a given steady-state speed and servomotor position. It is the slope of the tangent to the per cent steady-state speed versus per cent effective servomotor position curve (speed droop characteristic curve) at the servomotor position under consideration. It is expressed in per cent of rated speed when the difference in steady-state speed expressed in per cent of rated speed for any two points on the tangent is divided by the corresponding difference in servomotor stroke expressed as a fraction of effective servomotor stroke.	per cent
2.45	Steady-state incremental speed regulation	R_i	The rate of change of the steady-state speed with respect to the power output at a given steady-state speed and power output. It is the slope of the tangent to the steady-	per cent

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Table 4. Functions and Characteristics (Cont'd)

Par. No.	Term	Symbol	Definition or Description	Unit
			state speed versus power-output curve at the point of power output under consideration. It is expressed in per cent of rated speed when the difference in steady-state speed expressed in per cent rated speed for any two points on the tangent is divided by the corresponding difference in power output expressed as a fraction of the rated power output at rated head.	
2.46	The determination of incremental speed droop or incremental steady-state speed regulation for any specific power output is based on rated speed obtaining under rated head for the specific power output under consideration.			
2.47	Speed droop and speed regulation are considered positive when speed increases with decrease in power output. All definitions concerning speed droop or speed regulation are based on zero deadband. Speed droop relates speed to gate position whereas speed regulation relates speed to generator output.			
2.48	Speed-changer	SC_s	Under specified maximum head with specified adjustment of the speed-droop changer, the minimum steady-state speed at zero power output with the speed changer set at its low limit and the maximum steady-state speed at maximum power output with the speed changer set at its high limit, both expressed in per cent of rated speed.	per cent
2.49	Speed-changer synchronizing range	SC_s	With specified adjustment of the speed droop changer, the minimum steady-state speed at zero power output under specified maximum head with the speed changer set at its low limit and the maximum steady-state speed at zero power output under specified minimum head with the speed changer set at its high limit, both expressed in per cent of rated speed.	per cent
2.50	Speed-changer load reducing time	SC_t	With specified adjustment of the speed-droop changer, the time required to reduce the power output from rated power output to zero power output, at rated head, by operating the speed-changer motor continuously at its normal speed.	sec
2.51	Deadband	DB_s	The total magnitude of the change in steady-state speed within which no measurable change in the position of the turbine-control mechanism results from change of	per cent

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Table 4. Functions and Characteristics (Cont'd)

Par. No.	Term	Symbol	Definition or Description	Unit
			speed. Deadband is the measure of the insensitivity of the speed-governing system and is expressed in per cent of rated speed. The total magnitude of the change in steady-state speed referred to above is the change required to change the direction of travel of the turbine-control servomotor during slow reversals.	
2.52	Blade-control deadband	DB_B	For an adjustable-blade-propeller turbine, the total magnitude of the band of blade servomotor travel, expressed in per cent of effective blade-servomotor stroke, over which no measurable change in the position of the blade servomotor results from a movement of the gate servomotor when under the control of the blade-control cam. The determination of blade-control deadband is based upon the blade-control-cam follower being positioned within the middle third of its control range. The total magnitude of the band referred to above is that corresponding to the change in gate-servomotor position required to change the direction of travel of the blade servomotor during slow reversals.	per cent
2.53	Dead time	DT_s	Dead time is the elapsed time from the initial speed change to the first corrective movement of the turbine-control mechanism.	sec
2.54	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 of the governor system introduced to reduce friction are excluded.	
2.55	Speed-stability index	I_S	The peak-to-peak magnitude of sustained oscillation of turbine speed (expressed in per cent of rated speed) produced by the governor system when the unit is operating independently and under steady-state load demand.	per cent

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Table 4. Functions and Characteristics (Cont'd)

Par. No.	Term	Symbol	Definition or Description	Unit
2.56	Power-stability index	I_c	The peak-to-peak magnitude of sustained oscillation of power output (expressed in per cent of rated power output) produced by the governor system when the generator is operating in parallel with other generators and under steady-state load demand.	per cent
2.57	Steady-state speed or power		Having a constant mean value with limited random deviations. Random deviations of speed are considered to be limited when they do not exceed plus or minus one-tenth (± 0.1) per cent of rated speed (N_r). Random deviations of power output are considered to be limited when they do not exceed plus or minus one-fourth (± 0.25) per cent of rated power output (P_r).	
2.58	Oscillations		The alternate increase and decrease, with respect to time, of speed, head, pressure or power output within finite limits.	
2.59	Damped oscillations		Those in which the amplitude of oscillations decreases with time.	
2.60	Sustained oscillations		Those in which the amplitude of oscillation does not decrease to zero as a final value.	
2.61	Overspeed	N_t	The maximum *increase* in speed (expressed in per cent of rated speed) from a stated speed, following a sudden reduction of load demand. For an adjustable-blade turbine this definition is based on the blade-control mechanism functioning normally (on-cam operation).	per cent
2.62	Rated head	H_r	The value stated on the turbine name plate.	ft
2.63	Steady-state pressure	p_s	The average pressure in the water passages measured at the entrance to the turbine when the unit is operating under steady-state conditions.	psi
2.64	Overpressure	p_t	The maximum *increase* in pressure measured at the entrance to the turbine (expressed in per cent of steady-state penstock pressure) following sudden closure of the turbine-control mechanism.	per cent
2.65	Load dump		The sudden and total removal of load demand from the generator.	

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Table 4. Functions and Characteristics (Cont'd)

Par. No.	Term	Symbol	Definition or Description	Unit
2.66	Cavitation factor		A function of water barometric height, static draft head and effective head indicating liability of turbine runners to cavitation (See Test Code for Hydraulic Prime Movers, PTC 18)	
2.67	Normal operating conditions		Steady-state operation of the unit with all stop valves and hand gates open and with specified or agreed headwater and tailwater elevations.	
2.68	Independent operation		When the unit is the only source of electrical energy supplying the connected electrical network.	
2.69	Parallel operation		When the unit supplies a connected electrical network which is supplied by other sources of electrical energy.	
2.70	Free-governor control		Control of turbine speed without restriction to the normal action of the governor system.	
2.71	Rated speed	N_r	The value stated on the unit name plate.	rpm
2.72	Power output	P	The electrical output of the turbine generator as measured at the generator terminals.	kw
2.73	Rated power output	P_r	The value stated on the generator name plate.	kw
2.74	Maximum power output	P_{max}	The maximum output which the unit is capable of developing at rated speed under normal operating conditions.	kw
2.75	Frequency response		Graphical or mathematical description of the dynamic behavior of a physical device. This description is found in terms of the response of the various elements of the device to a sinusoidally varying input signal.	
2.76	Input signal		A sine wave signal injected at any point into a control system.	
2.77	Output signal		The physical reaction of any element of a control system to an input signal injected at any point ahead of the element under observation.	
2.78	Linear system		A system in which the output signal is sinusoidal when excited by a constant amplitude, constant frequency, sinusoidal input signal. It may be assumed that a system is linear even though slight deviations occur.	

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Table 4. Functions and Characteristics (Cont'd)

Par. No.	Term	Symbol	Definition or Description	Unit
2.79	Phase angle		Referring to a simultaneous vector diagram of the input and output against time, the angle by which the output signal lags or leads the input signal.	
2.80	Magnitude ratio		The ratio of the peak magnitude of the output signal to the peak magnitude of a constant frequency, constant amplitude, sinusoidal input signal.	
2.81	Feedback control system		A closed-loop or feedback control system is a control system in which the controlled quantity is measured and compared with a standard representing the desired performance. Any deviation from the standard is fed back into the control system in such a sense that it will reduce deviation of the controlled quantity from the standard. See ASA C42.25 – American Standard Definitions of Electrical Terms (C42.25.05.041 – Closed-loop or Feedback Control System). (NOTE: The restoring connections of compensating mechanisms of hydraulic-turbine governor systems is a feedback control system.)	
2.82	Open-loop control system		An open-loop control system is a control system in which the controlled quantity is permitted to vary in accordance with the inherent characteristics of the control system and the controlled power apparatus for any given adjustment of the controller. See ASA C42.25 – American Standard Definitions of Electrical Terms (C42.25.05.036 – Open-loop control system). (NOTE: A control system devoid of feedback.)	

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SECTION 3, GUIDING PRINCIPLES

3.01 When an acceptance test performed at site under the rules of this code is required, it should be undertaken shortly after the turbine-generator unit is first put into commercial service, provided no serious operating difficulty exists. In any event, except with written agreement to the contrary, the acceptance test should take place within the warranty period specified in the contract.

3.02 For an at site acceptance test, if the turbine-generator unit does not meet the full requirements of the contract, a separate agreement will be required between the various interested parties, outlining the departures from guaranteed 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 unit performances. These corrections will be applied to the test observations to establish reported performances of the governor system.

3.03 This code does not consider any over-all tolerances or margins. Any allowances for instrument calibrations or for variations in precision of measurements shall be agreed to by parties to the test, prior to the testing, and shall be clearly stated in the test report.

3.04 The test results shall be reported as calculated from the test observations, only such allowances agreed upon prior to the testing having been applied.

3.05 Items on Which Agreement Shall Be Reached. The object of the test should be clearly defined and stated in writing prior to the preparation for and the conduct of the test.

3.06 The scope of an acceptance test depends on the guarantees stipulated in the specifications. 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. The specific test procedure to be followed will depend on the specified guarantees to be verified and on the nature of the installation. On the other hand, particular guarantees may require tests which are not described in this code. Therefore, prior to any test, there shall be agreement between the parties to the test on the exact method of testing and the methods of measurement. Unless modified by written agreement, the procedure prescribed in this code for procuring various measurements and handling other details incidental to the formal testing shall be mandatory.

3.07 Among the items not covered in this code, upon which agreement should be reached, are the following:

(a) Intent of the contract of specifications if ambiguities or omissions appear evident

(b) Apportionment of cost of test and allocation of responsibility

(c) Procedure for calibration of instruments

(d) Method of operating any auxiliary equipment, the performance of which may influence the test results

(e) Methods of maintaining constant operating conditions as nearly as possible to those specified

(f) Duration of operation under test conditions before test readings are started

(g) Duration of test runs

(h) Frequency of observation

(i) Test agenda, including definite values of test loads and rotating speeds of the unit at which each individual test run is to be conducted.

3.08 Preparation for Test. The plan of test and procedure shall be agreed upon in advance by the interested parties and shall be confirmed in writing, definitely covering the methods and procedures to be used in measuring all major factors. If experts are retained to take charge of one or more measurements, their responsibilities should be stated in the agreement.

3.09 Details of test procedures shall include statements of the manner in which the unit will be operated and the provisions that are to be made in the power station for transfer of load to other units, and definite agreed values of loads required in the discharge of the tests.

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3.10 Indisputable records shall be made to identify and distinguish the equipment to be tested. Descriptions, drawings or photographs may all be used to give a permanent, explicit record.

3.11 Any dimensions or information regarding the physical condition of parts of the equipment to be tested, which may be required for calculation purposes or which are to be included in the report, should be obtained and recorded before the test is made. This will include the conditions of any equipment or accessories affiliated with the unit and its governor system which might influence performance when the test is made. Serial numbers and any plant data should be recorded to identify all equipment related to the test.

3.12 **Test Personnel.** Agreement shall be reached in advance as to the personnel required to conduct the test. The parties to the test shall be entitled to have present such members of their staffs as may be required for them to be assured that the tests are conducted and the observations taken in accordance with this code and with the agreements made prior to the test.

3.13 Personnel shall include a sufficient number of competent observers to take and record the various readings. No observer shall be required to take so many readings that lack of time may result in insufficient care and accuracy.

3.14 The parties to the test may designate a person to direct the test and serve as arbitrator in the event of any dispute regarding precision of observations, test conditions or methods of operation. Intercommunication arrangements between observers and the person in charge should be established.

3.15 **Equipment Inspection.** Careful inspection and checks shall be made before, during, and after the tests to insure that the turbine-generator unit is operating properly.

3.16 The governor system and all of its associated equipment shall be carefully checked and properly adjusted prior to the test. This shall be done as mutually agreeable to the parties to the test and with due consideration to operating requirements, so that the time required to check the mechanical conditions and make the necessary adjustments of the governing mechanism will not impose an unwarranted interruption of the normal operation of the unit.

3.17 Equipment and instruments should be examined thoroughly to assure acceptability for purposes of the test. Duplicates for those instruments liable to failure or breakage in service should be provided and calibrated as part of the preparation for the test.

3.18 **Operation During Test.** The parties to the test shall have agreed in advance as to what conditions will be permissible with respect to the safety of a unit, including

(a) Permissible acceleration rate

(b) Maximum speed

(c) Adverse vibrations

(d) Adverse pressure fluctuations.

3.19 Control by ordinary operating, indicating, recording or integrating instruments, preparation of graphical logs and close supervision shall be established to assure that the equipment under test is operating in accordance with the intended conditions.

3.20 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 report of the test.

3.21 Any points of disagreement as to the conduct of the test shall be settled to the satisfaction of both parties and sufficient results of the test shall be computed and agreed upon as acceptable before the testing personnel shall have left the field and before the test shall be considered terminated or the test equipment removed. All results shall be agreed upon by both parties before they are embodied in the final report.

3.22 **Adjustments.** The adjustment of instruments, recording devices or other test apparatus, to the unit or to the governor system shall be made only after full agreement is reached between the parties to the test, with due consideration for the safety and performance of the unit. The equipment or conditions shall not be altered or adjusted for test purposes in such a way that specified stipulations are altered or voided. Adjustments to the equipment for test purposes that may prevent immediate continuous and reliable operation at all

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capacities or outputs and under all specified operating conditions should not be made.

3.23 No corrections or changes in setting of the governor system shall be permitted during the test except as otherwise set forth in the agreement of Par. 3.06.

3.24 Operating Conditions. The operating conditions shall be maintained within limits prescribed in this and other appropriate ASME Power Test Codes. Unless otherwise permitted by agreement between parties of the test,

(a) Operating head on the turbine shall be within the limits specified in the turbine specifications.

(b) Tail water elevation and test power outputs shall be such that the specified or agreed limits of the cavitation factor (σ) are not exceeded.

3.25 Power-output determinations, when used in calculating governor performance, shall be corrected to the specified or agreed head in accordance with the procedure specified under the Test Code for Hydraulic Prime Movers (PTC-18).

3.26 Except as noted hereinafter, all tests are to be performed under normal 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.

(a) The normal variations from specified values of voltage and power factor have negligible effects on governor-system characteristics and may be adjusted to suit station conditions.

(b) Steady-state speed shall not deviate from the specified value by more than plus or minus fifteen-hundredths (±0.15) per cent of rated speed (N_r).

(c) Steady-state power output shall not deviate from the specified value by more than plus or minus one and one-half (±1.5) per cent of rated power output.

3.27 Preliminary Tests. Prior to acceptance tests, the parties to the test shall have reasonable opportunity to examine the equipment, to correct defects, and to render the equipment suitable to undergo test. They may make such reasonable preliminary test runs as may be deemed necessary.

3.28 Preliminary test runs with log records are recommended to determine whether equipment is in condition to undergo test, to check instruments and methods of measurement, and to train personnel. Observations during these preliminary test runs should be carried through to the calculation of results as an over-all check of procedure, layout, and organization. If mutually agreed, a preliminary test may be considered an acceptance test, provided it has complied with all the necessary requirements of this code.

3.29 Records. Complete written records of the test should be included in the Test Report. The test observations shall be entered on carefully prepared original log sheets which shall be signed by the observers. The original log sheets, being the only documents of validity, should, therefore, be such as to permit facsimile reproduction as, for example, by carbon copies or by photographic process. Copying is not permissible. A complete set of unaltered log sheets shall become the property of each of the two principal parties to the test, and of such others as may be agreed upon. The observations shall include the date and time of day. They shall be the actual readings without application of any instrument corrections. The log sheets should constitute a complete record including details that at the time may seem trivial or irrelevant. Particular care should be taken to record any adjustments made to any equipment under test whether made prior to a run or between the runs. The reason for each adjustment shall also be stated in the test record. Erasures on or destruction of any log sheet or of any reading on any log sheet shall not be permitted under any circumstances. If correction is needed, the alteration shall be entered so that the original entry remains legible, and an explanatory note should forthwith be attached.

3.30 Alternate methods are presented in this code for certain tests and for computing their results. In these instances, the Test Report shall state which alternative has been employed.

3.31 Rejection of Test Results. If the test results show malfunctioning of the unit and any of its accessories, the defects shall be corrected be-

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fore the test series is repeated.

3.32 If, during the conduct of a test, or during the subsequent analysis or interpretation of observed data, an obvious inconsistency is found, the parties should make every reasonable effort to adjust or eliminate the inconsistency by mutual agreement. Failure to reach such an agreement should require repetition of the test.

SECTION 4, INSTRUMENTS AND METHODS OF MEASUREMENT

1 – Selection of Instruments

4.01 This section describes the instruments required to determine the performance characteristics of a governor system. Unless otherwise specified herein, the instruments and their calibration shall be in accordance with the appropriate Power Test Code Supplements on Instruments and Apparatus (hereinafter referred to as I & A) (PTC 19).

4.02 To determine the performance characteristics of the governor system, it is necessary to measure the following:

(a) Head

(b) Pressure

(c) Power output or electrical load

(d) Speed or frequency

(e) Motion or travel

(f) Time.

4.03 Head and Power-output Measurements. With respect to head and power-output measurements, it is desirable, but not mandatory, that the measurements conform with the requirements of the Test Code for Hydraulic Prime Movers (PTC 18). Such measurements shall be recorded during the governor system tests for record purposes. Upon agreement or if they have been calibrated by means of a previous test, the normal station operating instruments and gages may be used.

4.04 For a determination of power-stability index, a recording wattmeter should be used having an error not exceeding 1 per cent of the rated power output of the unit and a span step-response time not in excess of 1 second. The chart speed should be 3 in. per minute minimum.

4.05 Pressure Measurements. Servomotor differential pressures at various positions may be obtained by use of one of the following instruments:

(a) Calibrated pressure gages

(b) Calibrated differential-pressure indicator or recorder.

High instrument accuracy is not required for these measurements. An instrument error of plus or minus two (2) per cent of normal hydraulic supply pressure will give satisfactory results.

4.06 Speed or Frequency Measurements. Any direct-reading speed-measuring device may be used to determine speed or frequency, provided it meets the requirements hereinafter prescribed.

4.07 The measurement of frequency is considered equivalent to the measurement of speed.

4.08 The use of graphic speed-recording instruments is highly desirable for determination of deadband, overspeed, stability index, and for the simultaneous measurements of speed and power output, speed-changer travel or turbine-control servomotor travel. The chart speed of the instrument should be at least 3 in. per minute.

4.09 Speed measuring instruments shall meet the following requirements:

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Application	Suggested range, per cent of rated speed	Maximum error, per cent of rated speed	Maximum deadband, per cent of rated speed
Speed droop and steady-state speed regulation	80 to 115	0.50	0.10
Overspeed	80 to 200	0.50	0.10
Range of speed-changer adjustment	80 to 115	0.50	0.10
Deadband	99 to 101	0.02	0.01
Stability index	99 to 101	0.02	0.01

4.10 For the determination of the speed-stability index, use of a graphic speed-recording instrument is essential. In addition to meeting the requirements of Pars. 4.08 and 4.09, the instrument should have a span step-response time of 1 second maximum.

4.11 For the determination of overspeed, use of a graphic speed-recording instrument is preferred. In addition to meeting the requirements of Pars. 4.08 and 4.09 the instrument should have a span step-response time of 2 seconds maximum. For convenience, the governor tachometer may be used for this purpose and if desired, calibrated at site.

4.12 Motion or Travel Measurements. Measurement of motion will generally be limited to measurement of the distance traveled by the speed changer or turbine-control servomotor from a point of reference.

4.13 For the purpose of this code, the position of the turbine control servomotor may be measured by piston stroke, or any other characteristic of the speed-control mechanism such as electrical potential which is available to indicate the position of the turbine-control-mechanism. The measuring device shall measure the position of the turbine-control servomotor within plus or minus five-tenths (± 0.5) per cent of full travel.

4.14 For measurement of motion or travel over a distance in excess of 3 in., a scale graduated in divisions of $\frac{1}{64}$ in. may be used.

4.15 For measurement of motion or travel over a distance not exceeding 3 in., use of a dial indicator with scale divisions of 0.001 in. is preferred.

4.16 The position or travel of the speed changer may be established by means other than those described in Pars. 4.14 and 4.15, provided comparable accuracy is obtained. For this purpose, a suitable position indicator, if provided with the speed changer, may be used. If the positioning of the speed changer is effected by a screw, its position may be established by counting the number of turns and fractions of turns as measured from either end of its travel.

4.17 Time Measurements. For the determination of time element, speed-changer or hand-control load-reducing time, etc. a stop watch may be used. For the determination of dead time, a graphic device for recording time history of servomotor travel and speed or frequency is required. Oscillographic devices or equipment of equivalent accuracy is mandatory since accurate determination of elapsed times of the order of magnitude of one-quarter (0.25) seconds is required.

4.18 Alternately, for the determination of time element an electric timer or cycle counter arranged to be operated from contacts at one-quarter (0.25) and three-quarters (0.75) effective servomotor stroke or suitably calibrated recording equipment may be used. Accuracy should be of the same order as for servomotor travel measurement.

4.19 Special Instruments. Determination of the performance of governor systems is facilitated by the simultaneous measurement of two variables. Special instruments are available which can measure two variables simultaneously and record one as a function of the other as X-Y coordinates. Use of such instruments is highly desirable provided they conform to the requirements with respect to range, sensitivity, rate of response and accuracy, as hereinbefore prescribed.

4.20 For determination of deadband, use of a recording instrument designed to produce an X-Y diagram of speed or frequency as a function of the position of the turbine-control servomotor is recom-

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mended. The *X-Y* instrument should be capable of producing a diagram with a slope of 15 to 45 deg with the speed or frequency axis.

4.21 For determination of blade control deadband and lost motion, a recorder arranged to produce an *X-Y* diagram of one mechanical motion as a function of another mechanical motion is recommended.

II – Methods of Measurement

4.22 The methods of measurement specified in this section apply to code tests of governor systems for hydraulic turbine-generator units with impulse, Francis, fixed-blade-propeller or adjustable-blade-propeller turbines. Unless otherwise specified or agreed, measurement of servomotor position is considered equivalent to measurement of position of the turbine control mechanism.

4.23 Hereafter throughout this code, the unqualified term "servomotor" refers to:

(a) The deflector servomotor, when the unit has an impulse turbine with water-wasting control.

(b) A needle servomotor, when the unit has an impulse turbine with water-saving control.
If the needles of a multiple-jet turbine are not mechanically linked together, the time elements of each individual servomotor shall be determined independently.
Upon agreement, the servomotor travel of one specified servomotor may be used for the determination of speed droop, deadband and dead time. It may be required to determine how closely the positioning of the various needles correspond.

(c) The gate servomotor, when the unit has a Francis, fixed-blade or adjustable-blade-propeller type turbine.

4.24 Shop Tests. When specified or agreed, tests performed at the governor manufacturer's plant to determine certain specific characteristics of the governor, conforming in all regards to the requirements of this code, shall constitute bona fide acceptance tests under this code in so far as they shall apply to the requirements of contract specifications. Specifically, these characteristics are:

(a) Speed droop

(b) Deadband

(c) Speed-changer governing range

(d) Speed-changer synchronizing range

(e) Speed-changer load reducing time

(f) Oil pump capacity.

4.25 In so far as possible the governor-head-drive components shall be used in conjunction with the governor during shop testing. Except as noted hereinafter, a suitable test stand capable of maintaining speed within the defined steady-state limits (Par. 3.26) and of being controlled by the governor over the specified range of operating characteristics is required for determining steady-state characteristics.

4.26 An actuator-type governor shall be connected to a suitable pressure-supply system and to a test servomotor of not less than 1000 cubic inches displacement. The connection between the governor and the servomotor shall include a suitable restoring mechanism.

4.27 Determination of Speed-droop. The test procedure described may be performed at a specified or agreed fixed setting of the speed-droop changer. For an acceptance test, unless otherwise specified or agreed, the speed-droop changer shall be adjusted to its maximum value.

4.28 Instruments.

(a) Speed or frequency indicators. (Pars. 4.06 through 4.11.)

(b) Servomotor and speed-changer position-indicators (Pars. 4.12 through 4.16.)

4.29 Procedure.

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

(b) Operate the unit at steady-state rated speed (N_r) at the servomotor position corresponding to rated power output (P_r) under rated head (H_r) (The procedure for establishing a curve relating power output to servomotor position is described in Par. 7.16.) Record the corresponding speed-changer position and servomotor position, (L_r).

(c) By adjustment of the speed-changer and power

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output operate the unit and record the corresponding speed changer positions and steady-state servomotor positions at steady-state rated speed for:

(1) The highest permissible servomotor position (L_3) under the prevailing operating conditions, but not higher than nine-tenths (0.9) effective servomotor stroke.

(2) A minimum of two (2) servomotor positions (L_1) and (L_2) approximately equally spaced between the rated-power-output position (L_r) of Par. 4.29 (b) and zero-power-output position (L_o).

(d) Reduce the power output to zero and separate the unit from the system.

(e) Reset the speed changer to the position recorded in Par. 4.29 (b) and record the steady-state servomotor position (L_{or}) and speed (N_{or}).

(f) Reset the speed changer to the positions recorded in Par. 4.29 (c) and record the steady-state speeds (N_{o1}) (N_{o2}) and (N_{o3}) corresponding to servomotor positions (L_1) (L_2) and (L_3) respectively.

4.30 Shop Test Procedure.

(a) Adjust the speed changer for nine-tenths (0.9) effective servomotor stroke at the governor speed corresponding to rated speed (N_r) of the unit.

(b) Record the servomotor position.

(c) Without changing the speed-changer adjustment, change the servomotor position by approximately four equal increments of servomotor stroke to one-tenth (0.10) effective servomotor stroke by changing the speed of the test stand used to drive the governor under test.

(d) Record the servomotor position and governor speed at each test point.

4.31 Upon agreement, it may be desirable to make supplementary shop checks of the speed droop characteristic curves – as determined in Par. 4.30 at nine-tenths (0.90) effective servomotor stroke corresponding to rated speed (N_r) – for other speed-changer positions corresponding to rated speed (N_r) at the four (4) servomotor positions indicated under Par. 4.30 (c).

4.32 Determination of Deadband of the Governor System. To determine the deadband of the governor system, simultaneous measurements of speed or frequency and position of the turbine-control mechanism are required, while the unit is in normal operation and carrying loads. Generally, the normal load variations will produce sufficient frequency changes for the purpose of this test. Readings taken when the frequency is changing too rapidly for the speed-governing system to follow should be discarded. The use of indicating instruments is not recommended.

4.33 Instruments.

(a) *X-Y* Recorder (Par. 4.20).

(b) For shop test, Method B, see Par. 4.37 (a) and (b).

4.34 Procedure.

(a) Operate the unit under load with a speed-droop setting of not less than two (2) per cent. It may be desirable to test for deadband at several different power outputs between zero (P_o) and maximum (P_{max}).

(b) The *X-Y* instrument is used to establish a diagram of speed or frequency as a function of servomotor travel. Each test chart should be run long enough to give a well defined diagram including closed loops of short servomotor movements.

4.35 Shop Test. A test for governor deadband shall be made with the governor control mechanism, including the test servomotor, responding to but not controlling the speed of the governor-drive test facility; with a speed-droop setting of not less than two (2) per cent and with the compensating mechanism inoperative.

4.36 Procedure – Method A. With the governor arranged to be driven from the available local power supply and subject to its random deviations, the procedure of Par. 4.34 applies.

4.37 Procedure – Method B.

(a) The governor head shall be arranged to be driven by a suitable power source capable of maintaining the speed-sensing signal within a band of five-thousandths (0.005) per cent of normal. The power source shall have provision for plus or minus step-signal changes of known

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magnitude in increments equivalent to one-hundredth (0.01) per cent of normal speed of the unit (N_s) or less.

(b) Provision shall be made for recording test-servomotor position and speed-sensing signal preferably by means of oscillographic devices.

(c) From steady-state normal value of speed sensing signal make alternate positive and negative step changes of varying increments. A minimum of eight (8) step changes is required to establish the governor deadband.

(d) Record simultaneously the steady-state servomotor position and speed-sensing signal.

4.38 Blade-control Deadband. For this test, operate the unit under load under control of the gate limit.

4.39 Instruments.

(a) *X-Y* Recorder (Par. 4.21) arranged to produce a trace of blade-servomotor position versus gate-servomotor position. Used only for Method A (Par. 4.40).

(b) Gate-servomotor and blade-servomotor position indicators (Pars. 4.12 through 4.16).

4.40 Procedure – Method A.

(a) Calibrate the *X-Y* Recorder against blade-servomotor travel.

(b) Using the gate limit, set the load on the unit so that the blade-control-cam follower is positioned at approximately one-third (⅓) of its control range.

(c) Slowly move the gate servomotor in the opening direction by a series of small increments of travel. Pause between each increment until the blade servomotor stops. The total range of gate-servomotor travel shall be so limited that the blade-control-cam follower remains within the middle third of its control range.

(d) Repeat this procedure in the closing direction until the gate servomotor approximately returns to the original position of Par. 4.40 (b).

4.41 Procedure – Method B.

(a) Using the gate limit, set the load on the unit so that the blade-control-cam follower is positioned within the middle third (⅓) of its control range and note the gate-servomotor position (L_G).

(b) Raise the gate limit until the blade servomotor moves. By adjusting the gate limit downward, return the gate servomotor to its original (L_G) position. Read the corresponding steady-state blade-servomotor position (L_{B1}) in inches from zero (0) position.

(c) Repeat this procedure in the opposite sense, first lowering the gate limit and then adjusting it upward to return the gate servomotor to its original (L_G) position.
Read the corresponding steady-state blade-servomotor position (L_{B2}) in inches from zero (0) position.

(d) Several tests should be performed to establish consistency of the determination at any one load point. Tests at several load points within the middle third (⅓) of the control range of the blade-control-cam should be made to establish a maximum value.

4.42 Determination of Dead Time. Dead time is determined from the servomotor closing characteristic after a load dump. Unless otherwise specified or agreed a load dump of ten (10) per cent or more of turbine rated power output shall be used.

4.43 Instruments. Speed or frequency and servomotor travel recording equipment (Par. 4.17).

4.44 Procedure.

(a) Install the recording speed or frequency measuring apparatus so that it will record the off-line speed of the unit.

(b) Start the recording equipment at least ten (10) seconds before the unit power circuit breaker is opened to establish that steady-state conditions exist.

4.45 If supplementary overspeed tests are made it is more convenient to make the determination of dead time simultaneously.

4.46 Determination of Time Element. The time elements of the various functionally designated turbine control servomotors shall be determined individually. Except as noted below, the time element shall be determined with the turbine unwatered. If supplementary tests of overspeed are

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made the closing time elements may be verified at that time. In the case of spring-loaded needle servomotors for impulse turbines, the springs may have to be removed. In the case of certain single acting servomotors, it may be impossible to determine the time element with the turbine unwatered in which case the closing time elements can be determined only by a series of load dumps.

4.47 Instruments.

(a) Servomotor position indicator (Pars. 4.12 through 4.15)

(b) Timing device (Pars. 4.17 and 4.18).

4.48 Procedure.

(a) With governor oil pressure at high limit of its normal operating range operate the servomotor through its full stroke by manually manipulating the pilot valve so that the distributing valve travel is limited by the appropriate stop. Time the servomotor travel between one-quarter (0.25) and three-quarters (0.75) effective servomotor stroke. This shall be determined for both opening and closing strokes.

(b) If the time element is determined after a load dump test (Par. 7.03) a load dump corresponding to not less than nine-tenths (0.9) effective servomotor stroke shall be mandatory.

4.49 By specification or agreement, the time elements of gate-shaft governors may be determined by shop test.

4.50 Determination of Servomotor Cushioning Time. This determination shall be made with the turbine unwatered.

(a) Usually the determination can be made sufficiently accurate with a stop watch.

(b) If, due to severe water hammer effects, a more accurate determination is required, a recording of servomotor travel time history should be made.

4.51 Instruments.

(a) Servomotor position indicator (Pars. 4.12 through 4.15)

(b) Stop watch (Par. 4.17), or

(c) Servomotor travel recording equipment (Par. 4.17).

4.52 Procedure. With governor oil pressure at high limit of normal operating range operate the servomotor from half stroke position to full closure by manually manipulating the pilot valve so that the distributing valve travel is limited by the closing stop. Time the servomotor travel from the beginning of slow closure to zero effective servomotor stroke.

4.53 By specification or agreement, the servomotor cushioning time of gate shaft governors may be determined by shop test.

4.54 Determination of Stability Indexes. The degree of stability achieved by a governor system is judged by the magnitude of the sustained oscillations of speed and of power output of the turbine which are produced by the governing system.

4.55 For the speed-stability test it will be necessary to operate the unit off the line and under independent operation at steady-state power output. For the power-stability tests it will be necessary to operate the unit in parallel with other units. Records made for these determinations should include at least (10) consecutive sustained oscillations of speed or of power output to demonstrate that they represent truly sustained oscillations.

4.56 Instruments.

(a) Recording speed or frequency meter (Pars. 4.08 through 4.10)

(b) Recording wattmeter (Par. 4.04) operated simultaneously with the recording speed or frequency meter. (Par. 4.56 (a).)

4.57 Procedure – Speed-Stability Index. The speed-stability index (I_s) is the larger of the two values determined when operating the unit at rated speed with the generator either disconnected from the line or under independent operation and carrying load.

(a) Install the recording speed or frequency meter so that it will record the off-line speed of the unit.

(b) Operate the unit at zero-power output, at rated speed and with the generator disconnected from the line. The generator should be excited with normal field current.

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(c) Take a record and observe the peak-to-peak amplitude of oscillations in speed if present. Records shall be taken at steady-state normal speed (N_r) after sudden readjustments of the speed changer and after sudden manual upsetting of the governor system consistent with safe operation. To determine if there are sources of speed instability outside the governor system, repeat this test at steady-state speed with the governor system under control of the gate limit at the position corresponding to zero power output. Neglect any slow drift in speed.

(d) Operate the unit under normal operating conditions and independent operation at rated speed (N_r) and at steady-state power output (P). If the generator is equipped with an automatic voltage regulator, the test should be made with this regulator inoperative. Generally, the largest value of this index will be found at the power output corresponding to the lowest steady-state incremental regulation.

(e) Take records of speed and power output (P) simultaneously. Use only portions of the speed record obtained during periods when steady-state power output prevails.

4.58 Procedure – Power-Stability Index.

(a) Operate the unit in parallel with other units under normal operating conditions and with the generator under manual voltage control, if possible.

(b) Read the recording wattmeter to determine the oscillations of power output over a period when the fundamental component of the power output deviates from the mean by less than three (3) per cent of rated power output (P_r).

(c) To determine if there are sources of instability outside the governing system place the governor system under control of the gate limit at the position corresponding to the same power output. Read the recording frequency meter over a period of time.

4.59 Determination of Speed-Changer Governing and Synchronizing Ranges. Strictly, the upper limit of the speed-changer governing range can be determined only by a shop test; or, if the unit is operating on load independently and it is permissible to raise the frequency of the system.

4.60 Instruments.

(a) Gross head indicator (Par. 4.03)

(b) Speed indicator (Pars. 4.06 through 4.09)

(c) Servomotor- and speed-changer-position indicators (Pars. 4.12 through 4.16).

4.61 Procedure. Set the speed droop changer to the specified or agreed values.

(a) Operate the unit disconnected from the line and with zero power output.

(b) Set the speed changer to its low limit and read the minimum governed speed with zero power output. Record the gross head and servomotor position.

(c) Set the speed changer to its high limit and read the maximum governed speed with zero power output. Record the gross head and servomotor position.

(d) Operate the unit at maximum permissible power output, proceeding as follows (Pars. 4.64 (e) and 4.64 (f)):

(e) If on independent operation and if it is permissible, set the speed changer to its high limit and read the maximum governed speed at maximum power output.

(f) Otherwise, set the speed changer to just move the servomotor to maximum effective stroke or maximum permissible power output. Read the speed-changer position, gross head and servomotor position. From this information the maximum governed speed at maximum power output can be estimated.

(g) To determine the data required to estimate the maximum governed speed at maximum power output reduce the power output to zero (0) and disconnect the unit from the line. Set the speed changer to the position determined under Par. 4.61 (f) and record the governed speed.

(h) Set the speed changer to its high limit and record the governed speed.

4.62 Shop Test. In the absence of other specifications or agreements, it is customary to measure:

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(a) The minimum governed speed with zero power output at zero effective servomotor stroke and maximum speed droop.

(b) The maximum governed speed with zero power output at zero effective servomotor stroke and zero speed droop.

(c) The maximum governed speed with maximum power output at maximum effective servomotor stroke and maximum speed droop.

4.63 Determination of Speed-changer Load Reducing Time. This determination is made with the unit disconnected from the line.

4.64 Instruments.

(a) Stop watch (Par. 4.17).

(b) Speed-changer-position indicator (Pars. 4.12 through 4.16).

4.65 Procedure.

(a) With the speed-droop changer set to the specified or agreed setting, accurately determine the position of the speed changer corresponding to rated power output (P_r) and to zero power output (P_o) at rated head. (The procedure for establishing a curve relating Power output to servomotor position is described in Par. 7.16.)

(b) Measure with a stop watch the elapsed time required for the speed changer to travel from the position corresponding to rated power output (P_r) to the position corresponding to zero power output (P_o) while the speed-changer motor is operated continuously at its maximum speed.

4.66 Determination of Hand Control Gate Closing Time. This test shall be performed with the turbine unwatered, most conveniently at the time that servomotor time elements are determined. (Par. 4.47.)

4.67 Instruments.

(a) Stop watch (Par. 4.17).

(b) Servomotor position indicator (Pars. 4.12 through 4.16).

4.68 Procedure.

(a) Position the servomotor at maximum stroke.

(b) Transfer control of the unit to the hand-control mechanism.

(c) With governor oil pressure at high limit of normal operating range, reduce the servomotor stroke to zero in the fastest possible time using hand control and measure the time of closure.

4.69 Determination of Oil-Pump Capacity. This determination is made with the unit shutdown and all connections to the pressure tank shut off except (1) the inlet line from the pump, (2) the pressure connection to the pump unloader valve or device and (3) the oil level gage.

4.70 Instruments.

(a) Scale (Par. 4.14)

(b) Stop watch (Par. 4.17).

4.71 Procedure.

(a) Install the scale on the pressure tank oil level gage.

(b) Measure the outside circumference (C) of the pressure tank in inches and determine its wall thickness (W) from the inspection data stamped on its exterior wall.

(c) Charge the tank with air for normal maximum oil pressure or pump unloading pressure with normal static oil level in the pressure tank.

(d) Check that the sump tank has sufficient oil so that the pump will not draw air at the end of the pumping cycle.

(e) Shut off the pump and lower the oil level in the pressure tank sufficiently to provide a reasonable drop in oil level in the gage glass and shut all valves as specified in Par. 4.69.

(f) Start the pump and measure the time (T_p) in seconds for the oil level to rise in the gage glass over a measured distance of (Z) inches.

(g) The measured distance (Z) must be located along the gage glass so that the acceleration and deceleration of the oil column in the glass at the beginning and end of the pumping cycle do not affect the determination of the time (T_p).

(h) A minimum of three (3) readings of the time (T_p). (Par. 4.71 (F) shall be made to determine oil-pump capacity.

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SECTION 5, COMPUTATION OF RESULTS

5.01 Symbols not defined in this section of the code are explained in Section 2 (Pars. 2.36 through 2.81), or in Section 4, (Pars. 4.22 through 4.71).

5.02 Speed Droop. The speed droop is given by the formula:

$$D_s = \frac{(N_1 - N_2)\,100}{N_r} \text{ (for } (N_1)\ (N_2)\ (N_r) \text{ in rpm)}$$

$$= N_1 - N_2 \text{ (for } (N_1)\ (N_2) \text{ in \% of } N_r)$$

The values to be substituted in this formula are derived as follows:

5.03 From the data of Par. 4.29:

(a) Convert the servomotor positions (L_r) of Par. 4.29 (b); (L_1), (L_2), (L_3) of Par. 4.29 (c); and (L_{or}) of Par. 4.29 (e); to per cent effective servomotor stroke (L); and the speed (N_{or}) of Par. 4.29 (e); and (N_{o1}), (N_{o2}), and (N_{o3}) of Par. 4.29 (f) to per cent normal speed (N_r).

(b) Compute the coordinates of points on the speed droop characteristics curve, which is the graph of per cent steady-state speed versus per cent effective servomotor stroke, from the percentage values of Par. 5.03 (a) as follows:

Servomotor stroke, %	Speed, %
L_o	N_{or}
L_1	$N_{or} - N_{o1}$
L_2	$N_{or} - N_{o2}$
L_3	$N_{or} - N_{o3}$
L_n	$N_{or} - N_{on}$
L_r	O

(c) Using the data computed in Par. 5.03 (b), plot a graph per cent speed (N) versus per cent servomotor stroke (L) oriented on the origin – ($N = 100$), ($L = 0$) – as shown on Fig. (1).[1] Extend the curve to zero (0) stroke and read (N_1); to one hundred (100) per cent stroke and read (N_2).

(See Fig. 1)

[1] The figures included in this code are to some extent distorted to illustrate the text and are not necessarily typical of governor construction.

5.04 From the data of Par. 4.30:

(a) Convert the servomotor positions to per cent effective servomotor stroke and governor speeds to equivalent per cent rated speed (N_r) of the turbine, and plot a graph of per cent speed versus per cent servomotor stroke. Extend the graph to zero (0) stroke and read (N_1); to one hundred (100) per cent stroke and read (N_2) (See Fig. 4).

(b) The value of speed droop determined by graph of Par. 5.04 (a) is arbitrarily based on the speed-changer setting which gives rated speed at nine tenths (0.9) effective servomotor stroke.

5.05 From the data of Par. 4.31 and following the procedure of Par. 5.04 (a), plot the family of speed droop characteristic curves determined by these data as shown in Fig. 4.

5.06 Determination of Deadband. The deadband of the governor system is determined as follows from the charts obtained by the procedure of Par. 4.34 or Par. 4.36 (Shop test – Method A). A typical chart is illustrated by Fig. 2.

(a) From the diagrammed charts obtained under Par. 4.34 or Par. 4.36: If the changes in speed have been slow enough so that the speed-governing system could follow them, the diagrams take the form of ellipsoidal parallelograms centered on a line whose slope corresponds to the incremental speed droop at the specific servomotor position (L_x) at which the diagram was taken. To determine the deadband, measure the length of the trace which is parallel to the frequency axis and convert to change in speed (δN). The per cent deadband will then be:

$$DB_s = \frac{\delta N}{N_r} \times 100$$

(b) As the acceleration or deceleration of the unit increases, the diagrams tend to swell in the center. Such lines should be disregarded in determining the deadband or if they must be used, consider only the points of inflection at the ends of the figures.

(See Fig. 2)

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5.07 From the chart obtained by the procedure of Par. 4.37 (Shop test – Method B), the determination of the deadband is as follows. Figure 3 illustrates a typical chart.

(a) Over the portion of the chart between the points (T_1) and (T_2), where the changes in speed are less than the deadband, the servomotor movements are random and erratic.

(b) Over the portion of the chart between the points (T_o) and (T_1) where the changes in speed exceed the bounds of the deadband the proportional return of the servomotor to normal will stop at the boundary of the deadband.

(c) Measure the envelope (A) of the points on the servomotor trace which indicate the limits of the deadband as stated in Pars. 5.07 (a) and 5.07 (b).

(d) Measure the width of the servomotor trace (B) corresponding to a measured variation in speed (ΔN) expressed as per cent of normal speed (N_r).

(e) To determine the value of the deadband substitute the values of (A) and (B) of Pars. 5.07 (c) and 5.07 (d) in the formula:

$$DB_s = \frac{A}{B}(\Delta N)$$

(See Fig. 3)

5.08 Determination of Blade-Control Deadband. The blade control deadband is determined as follows:

5.09 For Method A (Par. 4.40), it is the maximum width (referred to the axis of the blade-servomotor travel and expressed as per cent of effective blade-servomotor or stroke) of the envelope of the unmarked central portion of the diagram produced by the X-Y instrument.

5.10 For Method B (Par. 4.41) it is determined by the formula:

(a)
$$DB_B = \frac{(L_{B1} - L_{B2})}{L_{BT}} \times 100$$

where

L_{BT} = Effective blade-servomotor stroke in inches.

(b) To determine the value of ($L_{B1} - L_{B2}$) to be used in the formula of Par. 5.10 (a), at each point corresponding to a specific gate position (L_g) (after discarding those readings which are obviously inconsistent) determine the arithmetic average of (L_{B1}) and (L_{B2}) as determined by the procedure of Pars. 4.41 (b) and 4.41 (c) respectively and using these average values compute ($L_{B1} - L_{B2}$).

5.11 Determination of Dead Time. Dead time is determined from the oscillographic traces of speed and servomotor travel after a load dump. It is the elapsed time in seconds from the instant the speed commences to deviate from steady-state normal speed (N_r) to the instant the servomotor commences to close from its steady-state position which prevailed before the load dump occurred.

5.12 Determination of Time Element. The time element of the servomotor is determined by doubling the values determined by the test procedure of Par. 4.48 (a).

5.13 Determination of Servomotor Cushioning Time. The servomotor cushioning time is the value determined by the test procedure of Par. 4.52.

5.14 Determination of Stability Indexes.

(a) The off-line speed stability index is determined by deducting the peak-to-peak amplitude of the oscillations of speed found under Par. 4.57 (c) with the governor system under control of the gate limit from the peak-to-peak amplitude found under Par. 4.57 (c) with free governor control to obtain the amplitude of oscillations of speed produced by the governor system.

(b) The on-line speed stability index is determined from the selected record of speed obtained under Par. 4.57 (e). Read the amplitude of each half cycle oscillation. If these amplitudes do not vary greatly use the average value obtained to determine the peak-to-peak amplitude of the oscillations. If the variations in speed are random and it can be established from the output record that they are truly corrective, and if no oscillations of more or less constant period can be observed, the index is zero(0).

(c) The speed-stability index is obtained by converting the largest amplitude obtained under

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Par. 5.14 (a) or 5.14 (b) to per cent rated speed.[2]

5.15 The power-stability index is determined as follows:

(a) Deduct the peak-to-peak amplitude of the oscillations of power-output found under Par. 4.58 (c) with the governor under control of the gate limit from the peak-to-peak amplitude of the selected record of power-output found under Par. 4.58 (b).[3]

(b) To determine the peak-to-peak amplitude, read the amplitude of each half cycle oscillation. If these amplitudes do not vary greatly, use the average value obtained. If the variations in output are random and it can be established from the frequency record that they are truly corrective and if no oscillations of more or less constant period can be observed, the index is zero (0).

5.16 Determination of Speed-Changer Governing and Synchronizing Ranges. Convert the values of speed determined under Pars. 4.61 or 4.62 to per cent of rated speed (N_r).

(a) In addition, under Pars. 4.61 (b), (e), and (f), if the test-servomotor positions under the prevailing head at which the several tests are made differ from the servomotor positions corresponding to the specified head and load values, the test speeds shall be corrected to the specified conditions using the following formula:

$$N_c = N_t + (L_t - L_s)\, D$$

where

N_c = Corrected speed

N_t = Test value of speed

L_t = Test servomotor position

L_s = Specified servomotor position

D = Mean value of incremental speed droop between L_t and L_s (rigorously) or the speed-droop setting (if the speed-droop characteristic is linear)

and

speeds are dimensioned in per cent of normal speed N_r; servomotor positions, in per cent of effective servomotor stroke.

(b) To estimate the maximum governed speed at maximum power output from the speed determined in Par. 4.61 (f), add the difference between the speeds recorded under Par. 4.61 (h), and Par. 4.61 (g), in terms of per cent of normal speed (N_r), to the corrected speed recorded under Par. 4.61 (f).

5.17 The limits of the speed-changer governing range are (1) the corrected speed recorded in Par. 4.61 (b) and either the speed recorded in Par. 4.61 (e) or the speed determined under Par. 5.16 (b); or (2) the speeds determined under Pars. 4.61 (b) and (c).

5.18 The limits of the speed-changer synchronizing range are (1) the corrected speeds recorded in Pars. 4.61 (b) and (c); or (2) the speeds determined under Pars. 4.62 (a) and (b).

5.19 Determination of Speed-Changer Load-Reducing Time. Use the time determined under Par. 4.65 (b).

5.20 Determination of Hand-Control Gate-Closing Time. Use the time determined under Par. 4.68 (c).

5.21 Determination of Oil-Pump Capacity. The discharge capacity of the oil pump as determined by the data of Par. 4.71 will be:

$$Q = 0.816 \frac{Z}{T_p} \left(\frac{C}{6.283} - W \right)^2$$

where

Q = Capacity of the oil pump, U.S. gpm

C = Mean outside circumference of the measuring section of tank, in.

W = Thickness of tank wall, in.

Z = Distance measured on gage glass, in.

[2] In some cases operating experience may dictate a change in the compensation adjustments from those prevailing during these tests. For the determination of the speed-stability index, optimum setting of the compensating mechanism should be used.

[3] The principal source of oscillations of power output which are external to the governor is draft-tube surges. These oscillations are usually easily identified and are generally of a frequency such that the magnitude ratio of the frequency response of the governing system is very low and they are usually not amplified by governor action.

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T_p = Time for the oil level to rise in the gage glass over the measured distance (Z) (arithmetic average of data of Par. 4.71), sec.

SECTION 6, REPORT OF RESULTS

6.01 General. The Report of Test shall be prepared for the purpose of formally recording observed data and computed results. It shall contain sufficient supporting information to prove that all objectives of any tests conducted in accordance with this code have been attained.

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

6.03 The complete Report of Test may 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.

6.04 Test Report Form. Tests shall be reported in accordance with the applicable portions of the form presented herewith and shall include the following parts in the order given:

I Title page
II Table of contents
III Conclusions
IV Description of equipment tested
V Objects of test
VI Contract and agreed test conditions and corrections
VII Test methods
VIII Observed data and computed results
IX Test performance
X Supporting data

6.05 Part I, Title Page.

Test of speed-governing system .....
Report No. .....
Unit designation (No.) .....
Location (Plant) .....
Owner (Purchaser) .....
Turbine manufacturer .....
Type .....
Serial Number .....
Governor manufacturer .....
Type .....
Serial Number .....
Date System ready for test .....
Representative of the first party to the test .....
Representative to the second party to the test .....
Test conducted by .....
Report prepared by .....
Date of report .....
Report approved by ..... for the first party to the test .....
Report approved by ..... for the second party to the test .....
Statement that testing, computing, and reporting have conformed to the ASME Test Code for Hydraulic Turbine Governing with the exceptions as noted in Part VII, Test Methods, Pars. 6.11–6.13.

6.06 Part II, Table of Contents. This part aids in finding subdivisions of the report devoted to different objectives.

6.07 Part III, Conclusions. This part shall include conclusions concerning the results of the test and any recommendations or supplementary comments.

6.08 Part IV, Description of Equipment Tested. This part should include complete nameplate data or rated conditions specified by the manufacturer for the turbine-generator unit and the governing system. Diagrams, drawings and photographs should be used where advantageous.

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6.09 Part V, Objects of Test. This part shall include an explicit statement of the objects of the tests covered in the report as set forth in Par. 3.05.

6.10 Part VI, Contract and Agreed Test Conditions and Corrections. Operating conditions specified in the contract as well as other agreements made prior to the test shall be reported.

6.11 Part VII, Test Methods. This part shall include a detailed description of the instruments and apparatus used to measure the quantities from which the primary objects are determined.

6.12 In the determination of secondary objectives, description of methods of measurement shall be included if different from the prescribed rules of Section 4, Instruments and Method of Measurement.

6.13 The following additional information shall be included:

(a) Statement of departures from the rules of this code which have been agreed to by the parties to the test, including any extensions of permissible deviations from operating conditions of the test from those specified in this code.

(b) Description of calibration methods if not carried out by a recognized authority or if methods have been used other than those prescribed in Section 4 of this code or in ASME Supplements of Instruments and Apparatus.

6.14 Part VIII, Observed Data and Computed Results. This section shall include a general log of the test recording the ambient conditions, the operating conditions of the turbine-generator unit, adjustments of the governor, chronological records of the procedure, notes regarding deviations from procedure, etc. It shall include facsimiles of charts and recordings used in the computations of results. It shall also include record of observations, corrected for instrument calibrations and average conditions prevailing, correction values and calculations for each test run.

6.15 Part IX, Test Performance. In this part, final results of tests are reported in the form of graphs and tabular summaries, as specified in Section 5, Computation of Results.

6.16 Part X, Supporting Data. In this part shall be included pertinent material supplementing data presented elsewhere in the test report, whereby an independent verification of the reported results can be made. This material should include:

(a) Instrument calibration records, including identification of individuals responsible for calibrations

(b) Detailed log sheets

(c) Sample calculations, curves used in cross plotting, etc.

(d) Data other than log sheets. (These may include pressure, temperature, flow charts, etc.)

(e) Blueprints, photographs, etc.

APPENDIX I – OPTIONAL AND SUPPLEMENTARY TESTS

7.01 Overspeed. Overspeed is not strictly a characteristic of governor performance. If the governor system is acceptable with respect to deadband, dead time, and time element, the maximum overspeed for full load dump will depend on the mechanical and hydraulic inertias of the unit and its water supply passages.

However, overspeed determinations should be made before the unit is placed in service to check the operation of the overspeed switch and other protective and relay devices. The unit should not lock out on normal full load dump.

7.02 Pressure Rise. Maximum allowable pressure rise in the water passages of the turbine dictates the time element setting of the governor

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system. The time element must be set long enough so that excessive pressure rise in the supply penstock or water separation in the draft tube does not occur. With long penstocks maximum pressure rise could be produced by closure from a partial servomotor position. This condition can be alleviated by the use of a slow closure device.

7.03 Load Dump Tests for Determination of Overspeed and Overpressure. Maximum overspeed and maximum overpressure can be determined by a series of load dumps from progressively increasing gate openings under maximum head permissible for this condition. If these conditions cannot be met during test, the test values may be corrected to maximum permissible head as follows:

$$r_s = (r)\ C_1$$

$$r_h = (r)\ C_2$$

where r = ratio of maximum head to test head

r_s = ratio of $(N_{max})/N_r$ at maximum permissible head to $(N_{max})/N_r$ at test head

r_h = ratio of $(p_{max})/ps$ at maximum permissible head to $(p_{max})/ps$ at test head

C_1 & C_2 = correction factors based on field tests of model test results.

If the head varies by ten (10) per cent or less from maximum permissible, then C_1 and C_2 may be considered equal to unity.

7.04 Servomotor action may be observed and the test for determination of dead time can be made simultaneously with the tests for overspeed and overpressure.

7.05 Instruments. Usually it is undesirable to make more load dumps than are absolutely necessary. Therefore, to reduce the necessity of repeating tests, it is desirable to use recording instruments (as specified in Section 4, Part I) to determine overspeed, overpressure, and servomotor operation. If dead time is determined at this time, the rules of Pars. 4.42 through 4.45 are mandatory. Furthermore, it is recommended that visual reading may be made on indicating instruments (also specified in Section 4, Part I) of maximum values attained in order to supplement recordings in case of these being inadvertently missed. The use of a pressure transducer and oscillograph is preferred if the maximum value of pressure rise is critical.

7.06 Procedure.

(a) Prior to the test, the entire turbine control mechanism should be checked to assure that it is in proper adjustment and in good working order. The setting of the overspeed shutdown device should be checked to make sure that it will operate within the specified limits. This can be done while running at zero output, off the line, on hand control.

(b) After preparations have been completed for this test, it is advisable first to dump load not in excess of one-quarter (¼) rated power output and then at no less than two intermediate loads before full load dump is performed. Thereby, trends of overspeed and overpressure with increasing values of load dumped may be observed. Thus, dangerous conditions can be anticipated and corrected for in advance of the fact.

(c) Install speed-measuring instruments so that turbine speed can be determined at all times.

(d) With the unit operating preferably in parallel with other units at rated speed (N_r) set the speed changer to the position corresponding to the power output specified for this test with steady-state penstock pressure (p_s).

(e) Start recording instruments a few seconds before the generator power circuit breaker is opened. Open the generator power circuit breaker and record the maximum speed (N_{max}) and maximum penstock pressure (p_{max}).

7.07 The per cent overspeed is computed from the formula:

$$N_t = \left(\frac{N_{max}}{N_r} - 1\right) \times 100$$

7.08 The per cent overpressure is computed from the formula:

$$p_t = \left(\frac{p_{max}}{p_s} - 1\right) \times 100$$

In this formula, per cent overpressure is referred to steady-state penstock pressure under steady-

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state conditions prevailing at the time of the load dump. If desired it may be referred to rated head. However, for considerations of safety the absolute value (p_{max}) is most significant.

7.09 The procedure described above gives the maximum overpressure for normal full load rejection and it should be noted that unless the turbine control mechanism closes completely, this value may be exceeded on emergency shutdown. To obtain the maximum overpressure corresponding to emergency shutdown conditions follow the same procedure but dump load by tripping the shutdown solenoid (and simultaneously or subsequently opening the breaker to prevent motoring).

7.10 Determination of Steady-State Speed Regulation. The steady-state speed regulation will always be somewhat lower in value than the speed droop. It can be determined as follows:

7.11 Instruments.

(a) Head (Par. 4.03)

(b) Speed Indicator (Pars. 4.06 through 4.09)

(c) Speed-changer and servomotor position indicators (Pars. 4.12 through 4.16)

(d) Power-output meter (Par. 4.03).

7.12 Procedure.

(a) Operate the unit at rated speed (N_r) and steady-state rated power output (P_r) under rated head. If rated head cannot be obtained, the position of the speed changer should be adjusted to correspond to the position of the servomotor under rated conditions for rated power output (P_r). (The procedure for establishing a curve relating power output to servomotor position is described in Par. 7.16). Accurately establish the position of the speed changer for these conditions.

(b) Operate the unit off the line at zero power output and adjust the speed changer to the position determined under Par. 7.12 (a). When operating conditions become stabilized, record the speed which is the speed (N_o) at zero power output.

(c) The steady-state speed regulation is determined by the formula:

$$R_s = \left(\frac{N_o}{N_r} - 1\right) \times 100$$

7.13 Determination of Incremental Speed Droop.

(a) If the speed droop characteristic graph is a straight line, the incremental speed droop will be constant and equal in value to the speed droop.

(b) If the speed droop characteristic graph is not a straight line the incremental speed droop can be determined from the data obtained by the procedure of Par. 4.31 and the speed droop characteristic graph plotted therefrom as described in Par. 5.05. On each characteristic speed droop line plot the tangent to the curve at rated speed (N_r) as shown on Fig. 4 at fifty (50) per cent servomotor stroke. The mirror method[4] of establishing these tangents is recommended. Extend each tangent so that the end points correspond to zero effective servomotor stroke (L_o) and full effective servomotor stroke (L_t). The difference in the speeds at the end points of each tangent is the incremental speed droop (D_i) corresponding to servomotor position at the point of tangency.

(c) Plot the values of incremental speed droop (D_i) obtained from Par. 7.13 (b) against corresponding values of servomotor position and draw a graph of incremental speed droop versus servomotor position. This is the Incremental Speed-Droop Characteristic Graph (Fig. 5 – Graph I).

(d) If the complete data of Par. 4.31 are not available, generally a graph of incremental speed droop characteristic can be approximated reasonably accurately from several

[4] The mirror method of establishing a tangent (or normal) to a continuous curve requires the use of a flat first-surface mirror with a square, straight bottom edge. It must be supported in a holder which can be easily shifted about and so arranged that the mirror will be perpendicular to the surface of the graph with its straight edge firmly resting thereon, in such a manner that the straight edge may be used in tracing a line on the graph. It should be long enough (3 to 6 in.) so that a reasonable length of line can be established. Place the mirror in its holder on the graph so that the reflecting surface cuts the line of the curve at the point where the tangent (or normal) is to be established, and in a position such that the reflection of the line in the mirror visually appears as a continuous extension of the portion of the line of the curve without a break at the mirror's edge. The trace of the edge of the mirror in contact with the surface of the graph is the normal to the curve at the point of intersection. For the tangent erect a line perpendicular to the normal at the point under consideration.

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tangents plotted on the single speed droop characteristic curve obtained from the data of Pars. 4.29 or 4.30 and calculated as described in Pars. 5.03 or 5.04. (See Fig. 4)

7.14 Determination of Incremental Steady-State Speed Regulation.

(a) Incremental steady-state speed regulation is of significance during parallel operation. For this type of operation it determines the manner of steady-state distribution of load between units and the steady-state response of the unit to supervisory adjustment of loading. Therefore its determination may be desirable to assist in establishing operating procedures and loading schedules. Usually, for reaction turbines it will not vary greatly until the turbine becomes overgated. For impulse turbines, due to the discharge characteristics of the needles it may change continuously over the full range of turbine output.

(b) Steady-state incremental speed regulation is determined from two graphs: (See Fig. 5)

I – Incremental Speed-Droop Characteristic (Par. 7.13)

II – Per cent Power Output versus Per cent Servomotor Position

These graphs relate incremental speed droop and power output to the servomotor position as a parameter thus permitting the determination of steady-state incremental speed regulation as a function of power output. Procedure for the determination of Graph I is given in Pars. 4.29 through 4.31 and 7.13. Procedure for the determination of Graph II and calculation of incremental steady-state speed regulation is to be found in Par. 7.16.

7.15 Instruments.

(a) Head (Par. 4.03)

(b) Speed Indicator (Pars. 4.06 through 4.09)

(c) Servomotor Position Indicator (Pars. 4.12 through 4.15)

(d) Power-Output Meter (Par. 4.03).

7.16 Procedure.

(a) With the unit in parallel with other units under normal operating conditions place the unit on hand control or, with the speed changer set for maximum speed, place the governing system under the control of the gate limit. Starting at maximum power output (P_{max}) move the servomotor by approximate increments of one-tenth (0.1) effective servomotor stroke until zero power output (P_o) is reached. At each setting with rated speed (N_r) obtaining, take readings of head, servomotor position and power output (P).

(b) The power output readings should be corrected to rated head (See PTC No. 18 for Hydraulic Turbines). Plot the corrected values of power-output, expressed as per cent of rated capacity, against the corresponding values of servomotor position, expressed as per cent of effective servomotor stroke. The curve drawn through these plotted points is Graph II (Fig. 5). Data obtained from an acceptance test of the turbine under PTC No. 18 may be used to determine Graph II.

(c) If a linear relationship held between power output and servomotor position, the steady-state incremental speed regulation would be identical to the incremental speed droop as plotted on Graph I. On Fig. 5, this condition is satisfied by the line ($P = L$) and at any point on Graph II for which the tangent to the curve has the same slope as line ($P = L$). Otherwise on Graph II the steady-state incremental speed regulation can be determined from the incremental speed-droop and for this determination the values of Graph I must be modified in accordance with Graph II as follows:

(d) At any assumed point on Graph II (Fig. 5) the deviation of the power output versus servomotor position curve from the linear relationship can be expressed mathematically by a slope factor which is, for equal increments of power output, the ratio (a/b) of the servomotor stroke intercepted by the tangent to the test curve at the point under consideration to the servomotor stroke intercepted by the line ($P = L$). The mirror method of determining a tangent to the curve is recommended (see footnote (4) to Par. 7.13).

(e) For any assumed point on Graph II, for a

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specific servomotor position, there is a corresponding incremental speed droop (D_i) on Graph I. For each point assumed, the incremental steady-state speed regulation is the product of the value of incremental droop (D_i) on Graph I. For each point assumed, the incremental steady-state speed regulation is the product of the value of incremental droop (D_i) from Graph I and the corresponding slope factor determined from Graph II and plotted on Fig. 5 versus servomotor position.

(f) The selection, on the load curve, of points for computation of the slope factor should be made so as to reflect change in slope. Where the slope is changing rapidly, the points should be close together. From these computed data, a graph of steady-state incremental regulation (R_1) versus power output (expressed in per cent rated power output or kilowatts as desired) can be plotted.

(g) Alternately, the incremental steady-state regulation can be determined from the slopes of diagrams produced by an X-Y recorder arranged to read speed as a function of power output. The method to be followed is similar to the deadband measurements of Pars. 4.32–4.34 and the same precautions should be used (see also Par. 5.05).

(h) At any assumed power output, the steady-state-step response of a unit (ΔP) expressed in per cent rated power output, to a sustained supervisory adjustment of the speed changer equivalent to a per cent speed change of (ΔN_{rr}) will be:

$$\Delta P = \frac{\Delta N_{rr}}{R_i}$$

to a sustained speed change of (ΔN_r):

$$P = \frac{\Delta N_r}{R_1}$$

7.17 Servomotor Force Requirements. Governors are rated by foot-pound capacity which is one twelfth ($\frac{1}{12}$) of volume in cubic inches swept by the servomotor(s) for a single effective servomotor stroke multiplied by the governor oil pressure (psi). For purposes of rating, either a specified minimum oil pressure or the normal oil-pump loading pressure is used. The rated foot-pound capacity is the maximum working capacity of the governor at the stated pressure. For satisfactory governor control, the work capacity required to move the turbine control mechanism through its total travel will be considerably less than the governor capacity. The differential pressure across the servomotor piston(s) is a measure of the force requirements. Its determination is described in Par. 7.19.

7.18 Instruments.

(a) Head (Par. 4.03)

(b) Pressure Measuring Instruments (Par. 4.05)

(c) Servomotor Position Indicator (Pars. 4.12 through 4.15)

7.19 Procedure.

(a) Operate the unit under load at permissible maximum head. If permissible maximum head cannot be attained, the values of servomotor differential pressure should be increased to equivalent values for permissible maximum head following procedure recommended by the turbine manufacturer.

(b) Using the gate limit, move the servomotor slowly from zero to maximum effective servomotor opening and take simultaneous readings of servomotor opening and closing pressures or differential pressures across the servomotor piston(s) and gate position (usually at approximately one-tenth (0.1) servomotor stroke intervals).

(c) Repeat the test of Par. 7.19(b) moving the servomotor from maximum to zero effective stroke.

(d) Plot the corrected servomotor differential pressure against servomotor stroke in the opening and closing direction.

(e) Draw the median line between the opening and closing differential pressure line. Assuming that friction forces in the opening and closing directions of travel are the same at any assumed servomotor position, the median line indicates the net servomotor pressure differential required to overcome the hydraulic forces on the turbine and the pressure intercepts between the median line and the opening or closing differential pressure lines, the differential pressure required to overcome

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friction in the turbine-control mechanism and the servomotor.

7.20 Determination of Lost Motion. The tests described heretofore are designed to include the effects of any lost motion in the governor system and it is assumed that lost motion in the turbine-control mechanism does not affect the governor control. Generally, this assumption is valid if the hydraulic loading of the servomotor does not reverse direction. It may be desirable to determine to what extent lost motion between the governor- and turbine- control mechanism contributes to the measured deadband. This check may be incorporated in the inspection procedure (Par. 3.15).

7.21 Instrument. *X-Y* Motion Recorder (Par. 4.21).

7.22 Procedure.

(a) Set up the recorder to measure servomotor piston movement and gate level motion, choosing the wicket gate judged to be most affected by lost motion.

(b) Operate the unit under control of the gate limit and move the servomotor slowly in one direction approximately five (5) per cent effective servomotor travel and return to the original setting.

(c) Take several diagrams at different positions of the turbine-control mechanism.

(d) From the width of these diagrams the percentage of total effective servomotor travel corresponding to lost motion can be determined. This percentage should be largest at the point where the net hydraulic torque on the wicket gates is zero. This point is usually near zero output.

7.23 Periodic Testing. For the purpose of scheduling maintenance, routine checking of deadband, servomotor differential pressures and lost motion is desirable in order to record if there has been deterioration of the equipment and the extent of the same.

7.24 Frequency-Response Approach. In the study of the control of a physical device one is generally concerned with inputs and outputs to the device. As the inputs are varied, the outputs are affected. Inputs and outputs are simply physical variables. Thus turbine speed and servomotor position may be taken to be respectively the input and output of the governing system of a hydraulic turbine.

The test procedures heretofore described have been concerned with steady-state input conditions and the determination of the variation in outputs produced by step changes in inputs.

The frequency-response approach is concerned with dynamic input conditions as exemplified by the variations in outputs produced by sinusoidal variations in inputs.

The two approaches are inextricably related. If the transfer function of the unit and its governor system is known, it is possible to determine the response to step or sinusoidal input signals analytically. However, the experimental approach automatically evaluates all of the physical variations and inaccuracies which are difficult to analyze mathematically.

It is recommended that information obtained from frequency-response tests be presented in the form of frequency-response curves as described in ASME Paper No. 53-A-11 "Frequency Response Data Presentation, Standards and Design Criteria."

These curves, once obtained, provide more readily usable information than the equivalent differential equations. Moreover, they afford a means of evaluating the performance of a system without detailed analysis of its design and construction.

Except for errors in measurements, the experimental frequency-response curves of a physical device truly represent the dynamic functioning of the device. They are valuable for predicting the stability of physical systems.[5]

7.25 Determination of Frequency Response. Although the frequency-response characteristics of the governing system can be independently determined in some cases, frequency-response tests of the installed equipment are recommended as more accurately descriptive and useful.

7.26 Instruments.

(a) Oscillograph with accurate timing means and

[5] For further discussion of the frequency-response approach the reader is referred, especially to:
"A Simplified Technique of Control System Evaluation," by G. K. Tucker and D. M. Wills –
"Frequency Response," Rufus Oldenburger Ph.D., editor – ASME

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a minimum of two (2) recording channels.[6]

(b) A sinusoidal input-signal device with adjustments for independently varying the amplitude and frequency.

(c) Motion transducers to transmit the motion of specified governor elements to the oscillograph.

(d) Necessary instrument apparatus between the signals to be recorded and the oscillograph consisting in most cases of instrument signal amplifiers and required electric cable leads.

7.27 Procedure.

(a) The frequency response of each component of a control system may be measured. However, it is recommended that measurement be limited to two governing functions:

(1) Open-loop frequency response between input and output of the governor (servomotor).

(2) Open-loop frequency response between governor input and final energy-input control element(s) of the turbine (wicket gate, needle or deflector).

(b) Arrange the sine wave input device to drive the governor pilot valve or the ballhead drive, depending upon whether an electrical or mechanical input device is available. Attach motion transducers to measure movement of (1) the servomotor(s) and (2) the final control element of the turbine-wicket gate(s), needle(s), deflector(s). Record on the oscillograph the sinusoidal input signals and the governor system output signals (1) and (2).

(c) During the test, open all feedback signals from the turbine-control mechanism. Neutralize the effect of governor dashpot action or similar devices. Unless otherwise agreed the frequency response will be determined for open-loop operation.

(d) On parallel operation at normal speed (N_r) adjust the turbine to 50 per cent of rated power output. Unless otherwise specified or agreed, this will be considered the steady-state base around which the frequency response will be determined.

(e) Adjust the sinusoidal input signal to obtain a peak to peak turbine output of 10 per cent of rated output at a very slow input signal frequency such that further decrease in frequency of the input signal produces no increase in amplitude of the output signals (1) or (2) (Par. 7.27(b)) while maintaining constant input signal amplitude. Adjust the peaks to obtain 5 per cent of rated capacity above and 5 per cent below the steady-state value. This initial frequency of the input signal shall be of a value that allows all components of the control system, including the turbine-control mechanism to follow exactly the input signal without time lag.

(f) When transient conditions have died out and steady oscillations are obtained, record several cycles of the input and output signals with the oscillograph. Under these conditions the magnitude ratio is the steady-state gain and has a relative value of unity.

(g) Increase the frequency of the input signal, maintaining constant amplitude of input signal equal in magnitude to the amplitude read under Par. 7.27(f). When transient conditions have died out make another recording of several cycles of input and output signals.

(h) Repeat the procedure of Par. 7.27(g) for progressively increased frequencies of input signal maintaining constant amplitude of input signal equal in magnitude to that read under Par. 7.27(f).

(i) As the frequency of input signal is increased, the amplitude of the output signal(s) will decrease and the phase angle between input and output signals will increase. Continue the testing until the input-signal frequency has been increased to a value such that no change in the output signal(s) occurs.

(j) From these data the magnitude ratio and phase angle lag can be determined and should be presented in the form of curves as described in ASME Paper No. 53-A-11, "Frequency Response Data Presentation Standards and Design Criteria," by Rufus Oldenburger, Trans. ASME, Vol. 76, Nov. 1954, pp. 1155–1176.

[6] An oscillograph with a minimum of three (3) channels allows the simultaneous determination of the frequency-response curves recommended in Par. 7.27.

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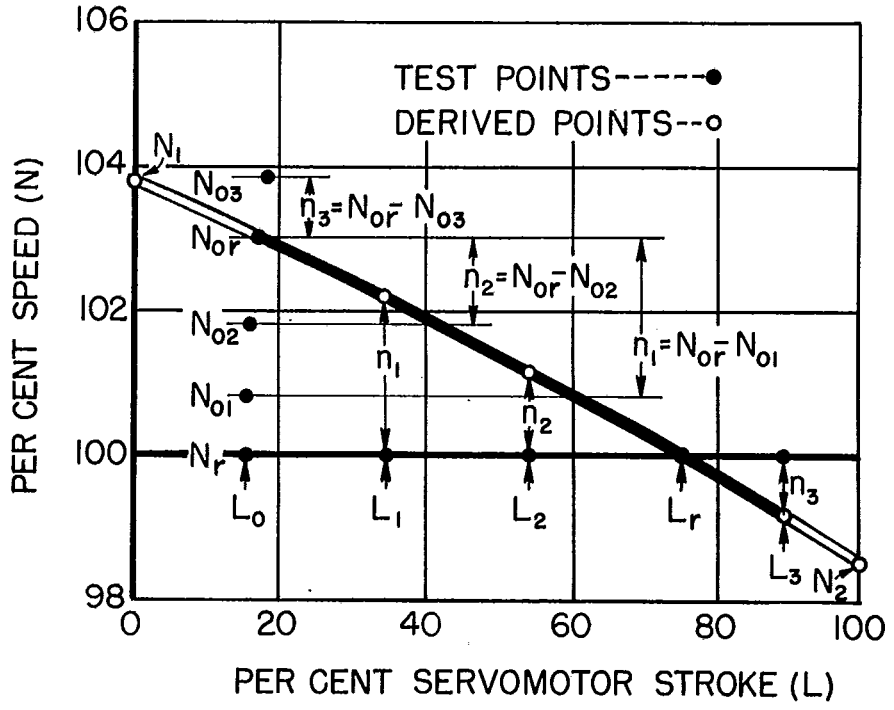

FIGURE 1

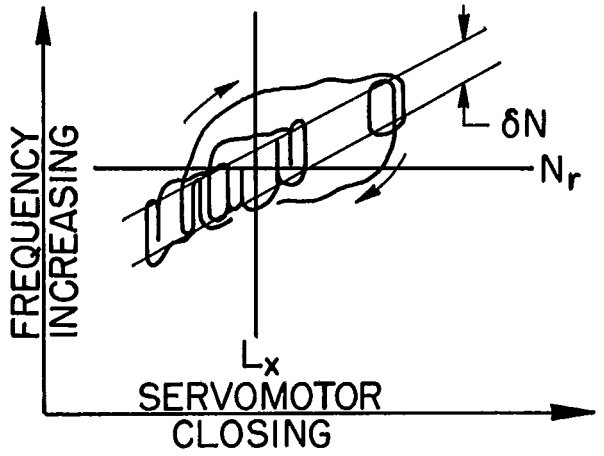

FIGURE 2

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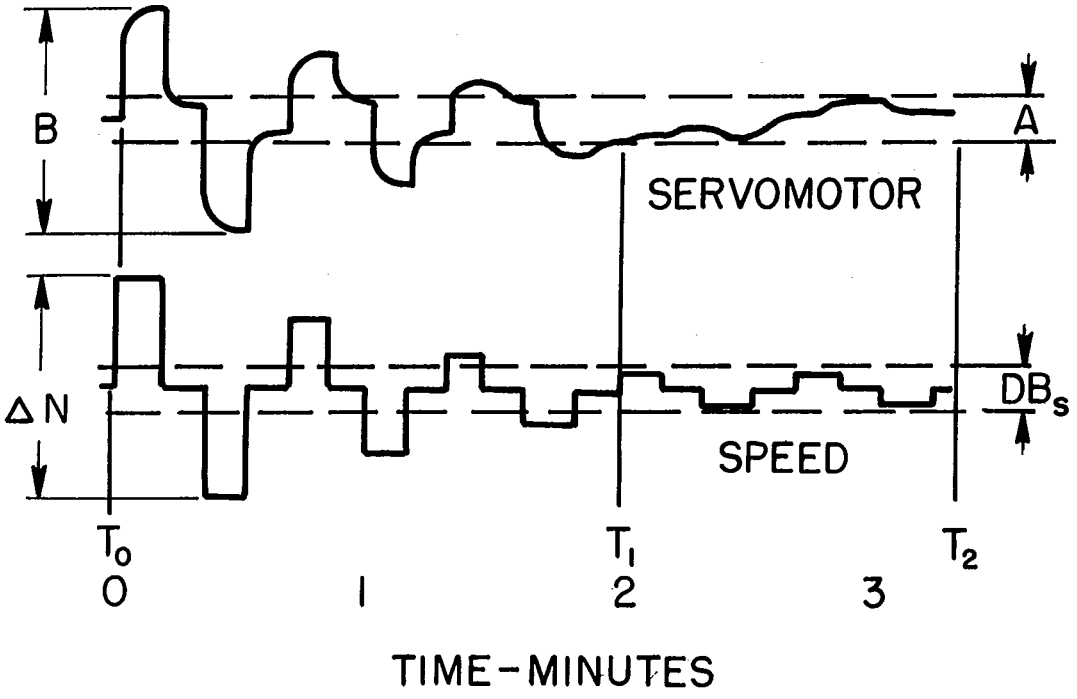

FIGURE 3

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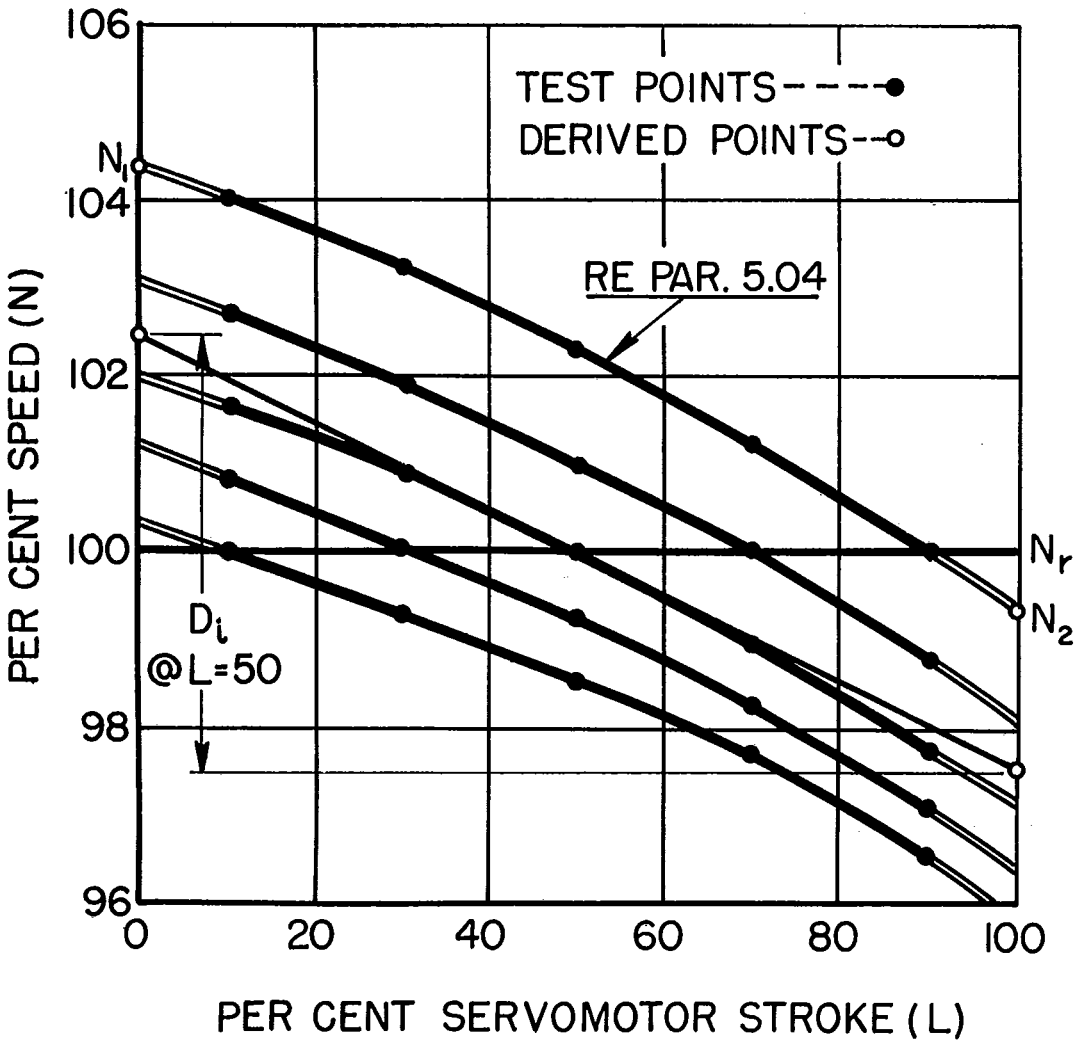

FIGURE 4

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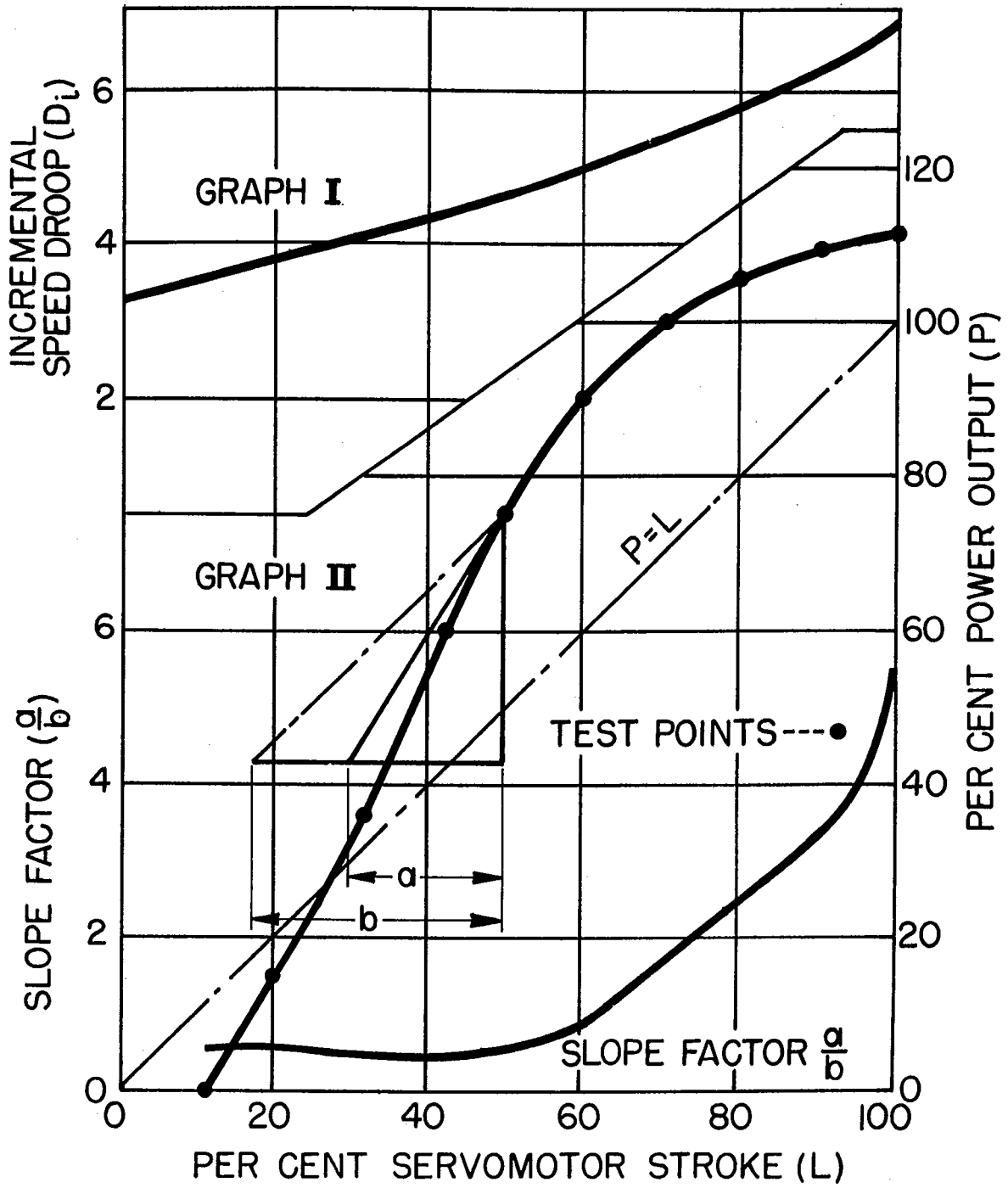

FIGURE 5

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While providing for exhaustive tests, these Codes are so drawn that selected parts may be used for tests of limited scope.

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