



IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators

IEEE Power Engineering Society

Sponsored by the
Energy Development and Power Generation Committee

125TM

IEEE
3 Park Avenue
New York, NY 10016-5997, USA
26 October 2007

IEEE Std 125TM-2007
(Revision of
IEEE Std 125-1988)

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**Energy Development and Power Generation Committee
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Approved 7 June 2007

IEEE-SA Standards Board

Abstract: This recommended practice is intended to assist users with the preparation of procurement specifications for electric-hydraulic speed governors.

Keywords: control, digital, governor, hydraulic, hydroelectric, speed, stability

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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Print: ISBN 0-7381-5637-X SH95699
PDF: ISBN 0-7381-5638-8 SS95699

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Introduction

This introduction is not part of IEEE Std 125-2007, IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators.

This recommended practice assists users with procurement specifications for turbine governing systems for hydroelectric generating units. It is recommended this document be used in conjunction with companion document IEEE Std 1207™.^a This recommended practice is designed to be a reference document for practicing engineers in the hydroelectric industry and offers guidance for what elements of a turbine governing system need to be specified.

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Participants

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David Apps, *Chair*
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J. C. Agee
Terry Bauman
Steven R. Brockschink
Matthew T. Davis
Terry Deckman
Donald Evans

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James H. Gurney
Hans Naeff
Bernard Poulin

Douglas Seely
Chris Shultz
Philip Spotts
Winfried Stach
Wayne Timm
John B. Yale

The following members of the balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

William J. Ackerman
J. C. Agee
S. K. Aggarwal
David B. Apps
Ali Al Awazi
Steven R. Brockschink
Tommy P. Cooper
Luis M. Coronado
Matthew T. Davis
Bostjan K. Derganc

Gary R. Engmann
J. Travis Griffith
Randall C. Groves
James H. Gurney
Gary A. Heuston
David A. Horvath
Innocent Kamwa
Joseph L. Koepfinger
David L. Kornegay
Lawrence D. Long
William Lumpkins

John W. Martin
Don G. McLaren
Gary L. Michel
Michael S. Newman
Bartien Sayogo
Gil Shultz
William W. Terry
Wayne Timm
James W. Wilson
Theodore C. Zeiss

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Jennie M. Steinhagen
IEEE Standards Program Manager, Document Development

Matthew J. Ceglia
IEEE Standards Program Manager, Technical Program Development

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IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators

1. Overview

1.1 Scope

This document recommends performance characteristics and equipment for electric-hydraulic governors for all types of hydraulic turbines intended to drive electric generators of all sizes. This recommended practice is applicable to new governors and rehabilitation of existing governors.

1.2 Purpose

This recommended practice is intended to assist users with the preparation of procurement specifications for electric-hydraulic speed governors.

1.3 Disclaimer

This recommended practice is intended to help users develop the technical portion of procurement specifications for electric-hydraulic speed governors. It does not cover the commercial portion of the procurement specification. It does not cover governor equipment installation procedures.

1.4 Use of IEEE Std 125

This recommended practice should be used in conjunction with IEEE Std 1207™.¹ IEEE Std 125 provides recommendations regarding performance characteristics and equipment specifications relating to turbine governing systems for controlling hydroelectric units. IEEE Std 1207 provides application insight for applying these systems to hydroelectric units and offers experience-based guidance on the impact upon system performance of various specification parameters of turbine governing systems. In addition to providing recommendations regarding performance characteristics, it is the intent of the IEEE Std 125 to provide aid in preparing technical specifications for turbine governing systems for controlling hydroelectric units. Incorporation of the technical specifications contained in IEEE Std 125 into a user organization's specification document is left to the user's discretion with respect to organization and sequence.

Features and tests detailed in Clause 5, Clause 6 and Clause 8 of this document are considered either "recommended" or "optional." The appearance of the words "should" implies this feature, function or test is recommended for all installations. The appearance of the words "may" implies this feature, function or test is optional (at the specifier's discretion). Optional items are often not implemented in the majority of installations, but may be required by some purchasers depending on their operating experience and design philosophy.

The following example shows typical wording for a recommended feature:

"The governor-control system should provide a means for controlling the turbine-control actuators manually." (See 5.2.9.)

The following example shows typical wording for an optional feature:

"A governor-control strategy may be specified in accordance with the anticipated performance requirements of the installation." (See 5.2.1.2.)

This document applies to new governors and governor conversions. IEEE Std 1147™ contains a general overview of governor conversions. Only those paragraphs in IEEE Std 125 that apply to the specific equipment to be purchased should be used when preparing the procurement specification.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1010™, IEEE Guide for Control of Hydroelectric Power Plants.^{2, 3}

IEEE Std 1147™, IEEE Guide for the Rehabilitation of Hydroelectric Power Plants.

IEEE Std 1207™, IEEE Guide for the Application of Turbine Governing Systems for Hydroelectric Generating Units.

¹ Information on references can be found in Clause 2.

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³ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

3. Definitions

For the purposes of this recommended practice, the following terms and definitions apply. The glossary in Annex B and *The Authoritative Dictionary of IEEE Standards* [B17],⁴ should be referenced for terms not defined in this clause.

3.1 control actuator limit: A maximum limit within the governor system which prevents the turbine-control actuator from opening beyond the position for which the device is set. May be operator-adjustable.

3.2 control actuator velocity limiter: A device that functions to limit the control actuator velocity in either the opening, closing, or both directions, exclusive of the operation of the slow closure device. *See also:* **slow closure device.**

3.3 executable code: The software code that resides in the digital controller and executes the control sequence/strategy in real time.

3.4 governor controller: A device or system that compares the turbine speed, along with any applicable intermediate feedbacks, to a reference set point and processes the resultant error signal to produce a command signal to the turbine-control actuator.

3.5 governor conversion: Replacement of the governor controller components of an existing governor, typically with a digital controller and new speed and turbine-control actuator position-sensing equipment.

3.6 grid connected: The condition where the turbine-generator unit is electrically connected to a large power grid consisting of many turbine-generator units operating in parallel.

3.7 hydraulic power unit (HPU): The pumps, means for driving them, sump tank, and associated accessory devices.

3.8 hydraulic pressure supply system (HPSS): The hydraulic power unit (HPU), pressure tank(s), valves, and piping connecting the various parts of the governing system.

3.9 main servomotor: The primary servomotor used to control the primary turbine-control device. For reaction turbines, the main servomotor controls the wicket gates. For impulse turbines, the main servomotor controls the deflectors. For dual-regulated turbines, the main servomotor is typically larger and faster than the secondary servomotor.

3.10 programming computer: The computer that generates and stores the source code. It is also used to download the executable code and operate the various software tools and utilities.

3.11 settings: The various user-adjustable parameters that reside in the digital controller such as time constants, gains, thresholds, etc. These are also known in the industry as tunables or constants.

3.12 slow closure device: A cushioning device that retards the closing velocity of the control actuator from a predetermined control actuator position to zero control actuator position.

3.13 speed-sensing elements: The speed responsive elements that determine speed and influence the action of other elements of the governing system. Included are the means used to transmit a signal proportional to the speed of the turbine to the governor.

3.14 speed error: The algebraic difference between the speed reference and the measured turbine speed.

⁴ The numbers in brackets correspond to those in the bibliography in Annex A.

3.15 turbine-control actuator: A device or system that controls the position of a turbine-control device in response to a command signal from the governor controller. Examples include: electric motor-driven actuator; hydraulic-control actuator and associated distributing valve.

3.16 turbine-control device: An adjustable device that directly affects the operation of the hydraulic turbine. Some examples of turbine-control devices are wicket gates, runner blades, flow-controlling orifices (or “nozzles”), and deflectors.

3.17 turbine-control actuator rating: The turbine-control actuator rating is the flow rate in volume per unit time that the turbine-control actuator can deliver at a specified pressure drop. The pressure drop should be measured across the terminating pipe connections to the turbine-control actuators at the actuator. This pressure drop is measured with the specified minimum normal working pressure of the HPSS delivered to the supply port of the actuator distributing valve.

4. Functions and characteristics

For purposes of this document, the functions and characteristics discussed in 4.1, 4.2, and 4.3 apply. IEEE Std 1207 should be referenced for functions and characteristics not defined in this clause.

4.1 Control actuator position

The instantaneous position of the turbine-control actuator measured from its zero position expressed as a percentage of the control actuator stroke. This is commonly referred to as gate position, nozzle position, blade position, or deflector position, although the relationship between control actuator stroke and the position of the controlled device may not always be linear.

4.2 Control actuator stroke

Travel of the turbine-control actuator (in inches or mm) from minimum (zero without squeeze) position to maximum position (without overtravel). This is sometimes referred to as “effective control actuator stroke.” For a gate or nozzle control actuator this is defined as the travel of the control actuator required to change the gate or nozzle position from no discharge to maximum discharge. For a blade control actuator this is defined as the travel of the control actuator required to change the blade position from “flat” to “steep.” For a deflector-control actuator this is defined as the travel of the control actuator required to change the deflector position from the “no deflection” position to the “full flow deflected” position with maximum discharge under maximum specified head, including overpressure due to water hammer.

4.3 Control actuator time

The elapsed time for one full control actuator stroke (either opening or closing) at maximum control actuator velocity. The control actuator time is equal to 100 divided by the maximum control actuator velocity (velocity expressed in units of percent per second) and is typically measured over a reduced range (for example, 25% to 75%) to eliminate the effect of cushioning.

5. Equipment specifications

5.1 General specifications

5.1.1 Interface to other plant equipment

For new unit supply, the manufacturer of the governor equipment should cooperate to the fullest extent possible with the manufacturers of the turbine and generator equipment to ensure that the purchaser is furnished with a complete and properly coordinated governor-control system capable of functioning to properly regulate the speed and power output of the turbine and generator.

For governor replacements and conversions, the manufacturer of the governor equipment is responsible for ensuring that the equipment will interface both mechanically and electrically to the existing plant equipment. Visits to the site by the manufacturer may be required to confirm compatibility between existing and proposed equipment and to confirm dimensions shown on existing plant equipment drawings.

5.1.2 Governor operation

Unless otherwise specified, the governor-control system should be supplied as a complete system, including speed-sensing elements, governor-control cabinet, governor hydraulic-control valve, HPSS, and all specified parts and accessories required to control the speed and generation of the hydroelectric generating unit. The rating of the governor hydraulic-control valve should be sufficient to operate the turbine-control actuators within the specified control actuator timing parameters.

This recommended practice primarily focuses upon using hydraulic turbine-control actuators, which are very commonly used for hydroelectric turbines. However, the functional characteristics specified also apply to any other type of turbine-control actuator that may be used in a particular application (e.g., electric actuators).

5.1.3 Governor cabinet construction

The governor-control equipment should be housed in a cabinet that provides physical protection, electrical shielding and protection from contaminants such as dust and oil. The specification writer may include detailed requirements related to cabinet size, material, paint type and color, grounding, cable access, seismic withstand, wiring and wire termination. Steel and aluminum are commonly specified cabinet materials. The governor electronic control cabinet may either be mounted on the hydraulic power unit, or it may be mounted at a separate location.

5.1.4 Nameplate

A permanent metal nameplate should be provided on each governor-control cabinet, clearly marked or stamped to indicate the following information:

- Manufacturer's name and address
- Serial number of the governor-control system
- Model number and type number of the governor-control system
- Date of manufacture

- Maximum working hydraulic supply pressure
- Minimum normal working hydraulic supply pressure
- Rated hydraulic fluid flow at the minimum normal working hydraulic supply pressure

5.1.5 Electrical power

The purchaser will make available uninterruptible direct current (dc) or alternating current (ac) control power from the station's battery or UPS system within a specified range of voltage. All critical control devices including solenoids, relays, electronic controls, and power supplies used within the governor-control system should be operable within the stated control power voltage range.

The purchaser will also make available three-phase and single-phase station service ac (SSAC) power within stated voltage ranges. These SSAC power sources will be subject to transient overfrequency and overvoltage conditions following a separation of the station from the interconnected power system. All governor-control system components utilizing the SSAC power sources should be designed to withstand these transient conditions without damage and without mis-operation.

Assuming that adequate hydraulic pressure exists and control power is available, it should be possible to start the turbine generator without SSAC power.

5.1.6 Power supplies

A reliable power supply system should be provided for powering the governor electronic control circuitry. The preferred power supply system should include redundant power supplies connected to separate power sources within the station such that the failure of any one regulated output voltage should cause instantaneous transfer to a redundant supply without affecting normal governor operation in any way. Alarm indication should be provided to indicate the failure of one of the redundant power supplies. If non-redundant power supplies are specified, proper fail-safe operation of the governor control in the event of a power supply failure should also be specified. The manufacturer of the governor system should provide full details of the proposed power supply system for approval by the purchaser. A common design philosophy for redundant power supply systems powers one redundant power supply from the station service ac source, and one redundant power supply from the station dc battery system. This approach accommodates the fact that the ac power source is not considered secure, and the dc power source is always available to act as a backup to the ac power source.

5.1.7 Test facilities

5.1.7.1 Isolation and test switches

The specifier may specify isolation and test switches to facilitate testing during commissioning or maintenance. The quantity, circuit location and physical location should be clearly indicated.

5.1.7.2 Signal monitoring

If a digital controller is specified, analog outputs may be provided for purposes of monitoring internal variables with the purchaser's recording device. The bandwidth of each analog output should be specified (10 Hz or higher typical). Alternatively, this capability may be provided by way of having the governor controller automatically record the internal variables. The recording rate should be user adjustable. The fastest recording rate (10 samples per second typical) and the minimum number of samples (1000 typical) should be specified.

It should be possible for the user to select any combination of variables for recording from a preset menu or list. The quantity and variable names should be clearly indicated. The following variables are typical:

- Main turbine-control actuator (gate or deflector) position
- Main turbine-control actuator (gate or deflector) set point
- Blade or nozzle servomotor position (if applicable)
- Blade or nozzle servomotor set point (if applicable)
- Speed
- Speed error (input to damping element)
- Turbine-control actuator limit setting

5.1.7.3 Signal injection

A specified quantity (typically two) of analog inputs may be specified for purposes of external live-signal injection for test purposes. The bandwidth of the analog inputs should be a minimum of 10 Hz. It should be possible to sum the injected signal at various user-selectable points inside the governor controller. Typical injection points include the following:

- Speed-error summing point
- Active-power summing point (if applicable)

5.2 Governor and auxiliary functions

5.2.1 Governor control

5.2.1.1 Speed error

Measurement of turbine speed is a basic requirement of a speed-governing system. The governors specified in accordance with this recommended practice should measure the speed of turbine rotation and compare this measured speed with the governor speed reference to produce a speed error. The speed error is used to develop a controlling output to the turbine-control devices according to the chosen governor-control strategy in order to regulate the speed and power output of the hydraulic turbine/generator to satisfy the specified performance criteria.

NOTE—The term “speed reference” is also commonly known as a speed changer or speed set point.⁵

5.2.1.2 Governor-control strategy

A governor-control strategy is a basic requirement of a speed-governing system. A governor-control strategy may be specified in accordance with the anticipated performance requirements of the installation. The strategy consists of processing the speed error signal (see 5.2.1.1), applying speed droop and finally

⁵ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

applying a suitable damping scheme, which is used to control the turbine-control actuator(s). The strategy may include switching between different control modes (see 5.2.3).

Some common damping strategies are:

- Temporary droop controller
- Proportional, integral, derivative (PID) controller
- Double derivative controller
- Lead/lag controller

For details regarding damping and control strategies, see Agee et al. [B1] and Eilts et al. [B6] in Annex A and IEEE Std 1207.

Some manufacturers may offer only one of the above damping strategies whereas others many offer more than one strategy. Specifying one particular damping strategy may reduce the competitiveness of the tendering process.

5.2.2 Speed droop

Speed droop is a basic characteristic of a speed-governing system. The speed droop for the governor-control system should be adjustable over the range specified for the application. This adjustment should be adjustable at the governor-control cabinet, and it may be specified to be adjustable from a remote location. The range adjustability is typically 0 to 10%

The speed droop parameter may be derived by control actuator position feedback (historically referred to as simply “speed droop”), in terms of active power feedback (historically referred to as “speed regulation” or sometimes “power droop”), or in terms of flow feedback. For the remainder of this recommended practice, the historical terms will be dropped in favor of the following more precise terms:

- Speed droop-position (speed droop derived via position feedback)
- Speed droop-power (speed droop derived via power feedback)
- Speed droop-flow (speed droop derived via flow feedback)

5.2.3 Control modes

5.2.3.1 Position control

For projects where position control is required, the governor should compare the measured to the desired turbine-control actuator position, multiply this error signal by the droop parameter, and inject the resultant signal into a summing point to adjust the turbine-control actuator(s) accordingly. The measured position typically comes from an analog or digital actuator position-measuring transducer.

5.2.3.2 Power control

For projects where power control is required, the governor should compare the measured to the desired power, multiply this error signal by the droop parameter, and inject the resultant signal into a summing point to adjust the turbine-control actuator(s) accordingly. The measured power typically comes from watt

transducers. The user should specify what automatic actions the governor will take if the power signal is lost.

NOTE—An alternate method of achieving power control is to implement position control via an inner loop and apply the power error signal to an outer loop.

5.2.3.3 Flow control

For projects where flow control is required, the governor should compare the measured to the desired flow, multiply this error signal by the droop parameter, and inject the resultant signal into a summing point to adjust the turbine-control actuator(s) accordingly. The measured flow typically comes from flow meters or from a look-up table that uses total head along with either wicket gate position or power output to determine the actual flow. The user should specify what automatic actions the governor will take if the flow signal is lost.

NOTE—An alternate method of achieving flow control is to implement position control via an inner loop and apply the flow error signal to an outer loop.

5.2.3.4 Head pond and tail pond control

For projects where head pond or tail pond level control is required, the governor controller should compare the measured pond level to the desired pond and inject this error signal into a summing point to adjust the turbine-control actuator(a) accordingly. The control process should take into account the physical layout of the water system and time delays due to water passage. Due to the critical nature of the feedback from the pond, care should be taken to ensure the reliability of the pond level signal. The user should specify what automatic actions the governor will take if the pond level signal is lost.

5.2.3.5 Pumped storage

A pumped storage facility has additional requirements that should be accurately described in the specification. The following is a list of some of the items that may be required:

- A means of manually controlling gate position while in pump mode
- Gate control actuator positioning as a function of operating head
- Separate control actuator velocity adjustments for pumping operation

For further details of pumped storage controls, see IEEE Std 1010.

5.2.4 Speed reference

The speed reference should be operator-adjustable over the range specified for the application. Typically, the specified range is from 85% of rated speed at no load and zero speed droop to 110% rated speed at maximum control actuator position/power and maximum speed droop. If remote control of the speed reference is required, the time to change the power output setting from maximum to zero or vice versa should be specified. An adjustment range of 20 s to 60 s is typical.