

Hydraulic turbines — Testing of control systems

The European Standard EN 60308:2005 has the status of a
British Standard

ICS 27.140

National foreword

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The UK participation in its preparation was entrusted to Technical Committee MCE/15, Hydraulic turbines, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
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**Hydraulic turbines –
Testing of control systems
(IEC 60308:2005)**

Turbines hydrauliques –
Essais des systèmes de régulation
(CEI 60308:2005)

Wasserturbinen –
Prüfung von Regelsystemen
(IEC 60308:2005)

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CENELEC

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Foreword

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Endorsement notice

The text of the International Standard IEC 60308:2005 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

The control functions of water turbines have undergone far-reaching changes and at the same time gained in importance during the last few decades. This is shown in the fact that a new standard has been developed: i.e. IEC 61362.

HYDRAULIC TURBINES – TESTING OF CONTROL SYSTEMS

1 Scope and object

This International Standard deals with the definition and the characteristics of control systems and is the basis for tender documents and technical tenders. It is not limited to the actual controller tasks but also include other tasks which may be assigned to a control system, such as for instance sequence control tasks, safety, provision for the actuating energy.

The testing of control systems for hydro turbines can generally fulfil the following tasks:

- verification of system characteristics as per contract specification;
- verification of general proper functioning in the workshop and/or on site;
- tests to prove the fulfilment of guarantees;
- assessment of the actual state of an existing control system with regard to the question of repair or replacement.

This standard covers the following systems:

- speed, power, opening, water level and flow control for all turbine types;
- electronic, electrical and fluid power devices;
- safety devices;
- start-up, shutdown devices etc.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60041:1991, *Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines*

IEC 60193: 1999, *Hydraulic turbines, storage pumps and pump-turbines – Model acceptance tests*

IEC 60545, *Guide for commissioning, operation and maintenance of hydraulic turbines*

IEC 61362: 1998, *Guide to specification of hydraulic turbine control systems*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

ISO 4406: 1999, *Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles*

3 Terms and definitions, symbols and units

For the purposes of this document, the following terms and definitions, symbols and units, as well as the terms and definitions, symbols and units given in IEC 61362, apply.

Sub-clause	Term	Definition	Quantity	Unit	Relative quantity
3.1	General definitions				
3.1.1	speed deviation	at a considered instant, the difference between the actual speed of rotation and a reference speed	Δn $\Delta \omega$ Δf	rev/min rad/s Hz	x_n
3.2	Performance under major disturbances				
3.2.1	servomotor cushioning time	elapsed time during which the rate of servomotor travel is retarded beginning at a specified servomotor position to full closed position (see Figure 1)	T_h	s	
3.2.2	servomotor force	net opening and/or closing force generated by the servomotor when supplied with oil at the minimum specified pressure NOTE When penstock water pressure is used to provide the closing force, the head at which the servomotor shall be rated should be stated. For spring operated servomotors it is the net force exerted by the servomotor when the spring is at its maximum extended position	F	N	
3.2.3	servomotor capacity	product of the maximum servomotor stroke and the force as described under 3.2.2	$F \times Y_M$	J = N · m	

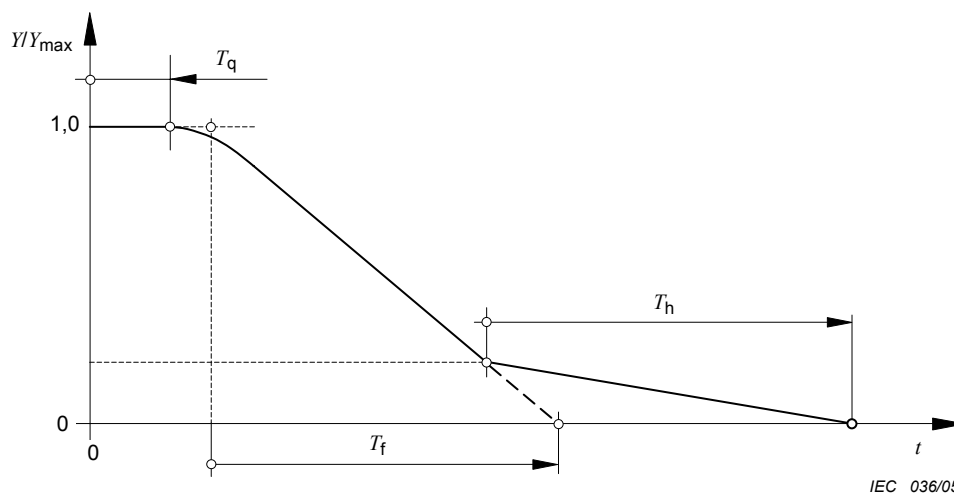


Figure 1 – Servomotor cushioning time T_h

Sub-clause	Term	Definition	Quantity	Unit	Relative quantity
3.3	Terms relating to the controlled system				
3.3.1	controlled system	system controlled by the governing system consisting of the hydraulic turbine, its water supply and discharge passages, the generator with voltage regulator and the electric power network to which it is connected			
3.3.2	torque deviation	power output deviation divided by instantaneous angular speed	ΔM	N·m	m
3.3.3	unit acceleration constant	ratio of the angular momentum of the unit to the guarantee torque	T_a	s	
3.3.4	load acceleration constant	ratio of the angular momentum, caused by the network referred to the guaranteed torque of the unit	T_b	s	
3.3.5	turbine control transmission ratio	At a considered servomotor position, the slope of the graph relating to the turbine torque m_t at constant speed and head to servomotor movement y (see Figure 2) $e_y = \frac{d(M_t/M_r)}{dy} = \frac{dm_t}{dy}$			e_y
3.3.6	speed regulation graph	graph showing the relative speed as a function of the relative power $p = \frac{P}{P_r}$, when the controller is in equilibrium and the command signal is constant			

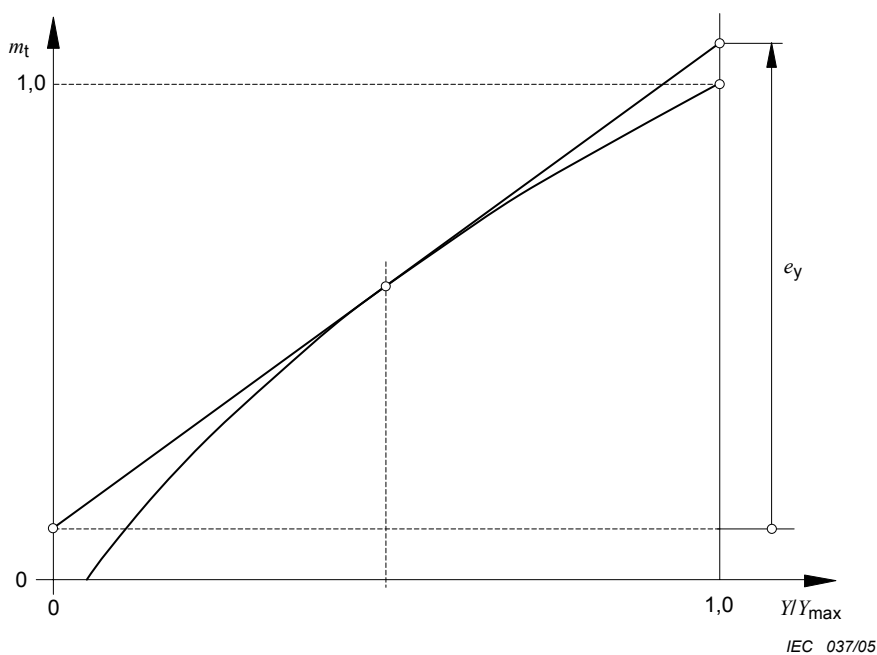
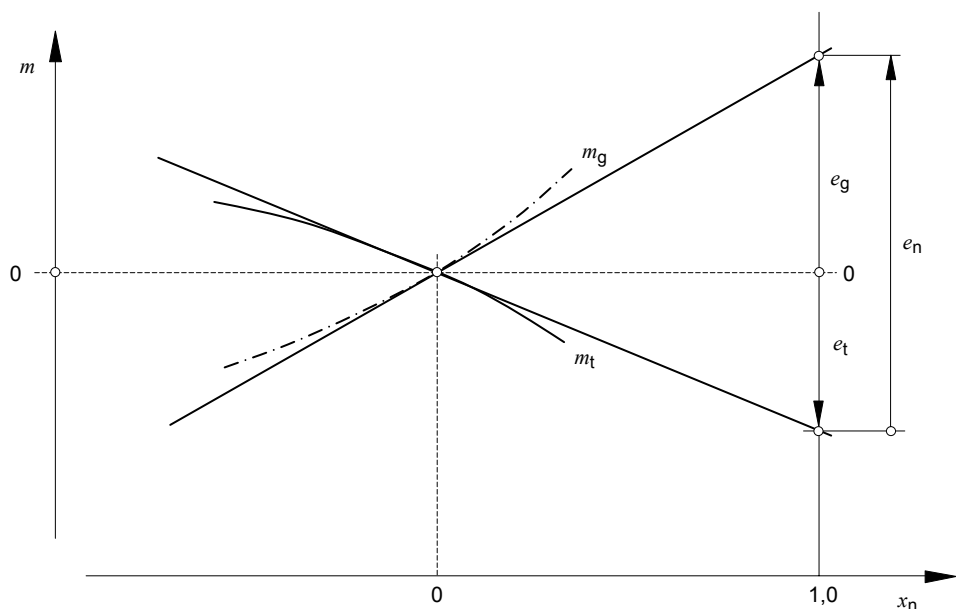


Figure 2 – Turbine control transmission ratio

Sub-clause	Term	Definition	Quantity	Unit	Relative quantity
3.3.7	permanent speed regulation	slope of the speed regulation graph at a specific point of operation $e_p = -\frac{dx_n}{dx_p}$			e_p
3.3.8	maximum power change speed regulation	difference between the relative speeds read from the speed regulation graph at zero power and rated power			e_s
3.3.9	controlled system self-regulation factor	at the speed considered, the slope of the graph relating to the torque deviation to the speed at a specified servomotor position and a specified load condition of the network. The torque should be referred to the rated torque P_r/ω_r and the speed referred to the rated speed ω_r (see Figure 3)			e_n
3.3.10	turbine self-regulation factor	component of e_n due to the turbine $e_t = \frac{dm_t}{dx_n}$ P_r and ω_r are the same values as used to determine e_n (see Figure 3)			e_t
3.3.11	load self-regulation factor	component of e_n due to the load $e_g = \frac{dm_g}{dx_n} = \frac{\omega_r}{P_r} \times \frac{d(P/\omega)}{dx_n}$ P_r and ω_r are the same reference values as used to determine e_n (see Figure 3)			e_g



IEC 038/05

Figure 3 – Controlled system self-regulation factor

Sub-clause	Term	Definition	Quantity	Unit	Relative quantity
3.3.12	network load characteristic	coefficient expressing the ratio of relative torque variation of the load to the relative speed variations. The value to which the power variations, ΔP , to be referred is the actual power, P_1 , absorbed by the network. For practical purposes, the constant, e_b , is obtained from the formula: $e_b = \frac{\Delta P / P_1}{x_n} - 1$			e_b
3.3.13	penstock reflection time	time required for the pressure waves to travel 2 lengths of the penstock: $T_r = 2 \sum_{i=1}^n \frac{L_i}{a_i}$ where a_i is the velocity of wave propagation in each section of the penstock; L_i is the length of each penstock section	T_r	s	
3.3.14	water inertia time	characteristic time at rated ^{a)} condition due to inertia of the water in the water passages defined as: $T_W = \frac{Q_r}{g H_r} \sum_{i=1}^n \frac{L_i}{A_i}$ where A_i is the area of each section; L_i is the corresponding length; Q_r is the rated discharge; H_r is the rated head; g is the acceleration due to gravity	T_W	s	
3.3.15	water hammer number (Allievi constant)	ratio of water inertia time, T_W , to penstock reflection time, T_r at guaranteed conditions. $h_W = \frac{T_W}{T_r}$			h_W
3.3.16	maximum momentary speed variation	maximum momentary change of speed, when a specified load is suddenly changed (see IEC 60041)	$\Delta n_{\max}$ $\Delta \omega_{\max}$ $\Delta f_{\max}$	rev/min rad/s Hz	
3.3.17	maximum momentary pressure variation	maximum momentary pressure variation, when a specified load is suddenly changed (see IEC 60041)	$\Delta H_{\max}$	Pa	
^{a)} Can be calculated for different conditions.					

4 Functions and components of hydro control systems

In this clause, the functions and components are listed, which may be subjected to tests and verifications.

NOTE Again reference is made to IEC 61362 for explanation and definition.

4.1 Control systems proper

4.1.1 Primary modes

	Standard	Subclause
The primary modes are the following:		
– speed control (no-load and synchronising, isolated operation)	IEC 61362	3.1.1
– power control	IEC 61362	3.1.2
– opening control	IEC 61362	3.1.3

4.1.2 Secondary modes

The secondary modes are the following:

– water level control or positioning (opening) control	IEC 61362	3.1.3
– flow control	IEC 61362	4.15.4
– optimisation control (station control)	IEC 61362	4.9

4.2 Other control systems and transitions

The other control systems and transitions are the following:

– surge control	IEC 61362	4.15.2
– pressure control	IEC 61362	4.15.1 and 4.15.3
– start up and synchronisation	IEC 61362	4.13.1
– shutdowns and load rejections	IEC 61362	4.13.2
– transitions between different control modes		

4.3 Control system components

The control system components are the following:

– electro-hydraulic and electro-mechanical converters		
– control valves		
– servomotors		
– pressure oil supply systems and energy storage mechanisms (accumulators, weights, springs)	IEC 61362	4.11
– auxiliary power supply for electrical/electronic systems		

4.4 Safety functions, 4.14 of IEC 61362

The safety functions are the following:

- safety shutdown
- overspeed protection
- interlocks
- creep detection

4.5 Environmental protection, 4.16 of IEC 61362

For control systems, the following aspects are relevant:

- vibrations
- climatic conditions

4.6 Electromagnetic compatibility (EMC)

For control systems, the following aspects are relevant:

- electromagnetic compatibility IEC 61362 4.17
- electrical interference sources

5 Contractual stipulations

5.1 Guarantees and acceptance tests

In the process of verifying guarantees set up according to IEC 61362, the following is recommended in case of new control systems for new plants as well as for existing power plants:

- establish the characteristics of the controlled system;
- establish scope of control system tests to verify guarantees and scope of documentation (see 5.2);
- stipulate measures to be taken in the event of failure to comply with guarantees.

In the process of verifying the actual state of an existing control system, only measurements which allow the assessment of the most important basic properties, for example isolated network operation will be performed.

A test manager is to be made responsible for the test procedure, the recording and documentation of results. The extent and the format of the documentation are to be agreed upon beforehand.

5.2 Documentation

For every test, the following shall be documented:

- instrument parameters;
- list of measured variables;
- limit values;
- test conditions;
- test procedure;
- test results.

Careful documentation is particularly important if certain tests are to be repeated at given time intervals (for example for authorities, insurance companies, restarts after revision, etc.). Care has to be taken in order to avoid environmental hazards.

The measured values can be recorded and processed either:

- by using suitable recording instruments with subsequent manual evaluation, or
- on line by a directly connected computer with the printouts forming an integral part of the documentation.

In the case of initial start-ups, a final report should demonstrate that

- the unit is operating according to specification;
- the safety requirements are fulfilled;
- the specific contractual guarantees are fulfilled.

6 Control system tests

6.1 General

In order to keep the commissioning period as short as possible, it is recommended that the largest part possible of the required contractual tests be carried out in the manufacturer's works (workshop tests). The on site tests should be limited to the demonstration of such characteristics, which:

- are indispensable for the safety, and
- which cannot be carried out without the generating unit and the pressure supply system.

In the following subclauses, some basic aspects are summarised.

6.2 Recommendations on workshop tests

The scope of the tests, the best set up and the extent of the documentation should be stipulated in the contract in accordance with requirements. Thereby type tests, including EMC type tests with certificates shall be considered. It should be stipulated, who will witness the tests.

For workshop tests, it is not necessary to set up all components in a complete loop, the following subsystems (which may be different makers' responsibility) can rather be tested separately:

- cabinet with plug-in units for control;
- servo-positioners, control valves with a test servomotor if necessary;
- oil pressure supply systems.

In this case, signals at interfaces between separately tested equipment shall be clearly defined and measurable.

It is appropriate to arrange for the simulation of simple circuits to test subsystems and/or to employ a plant simulator if available to test the complete control process for overall performance.

Individual testing of components and/or subsystems may not be needed in case the complete system is assembled.

6.3 Recommendations on field tests

6.3.1 New control systems

For control systems, the following measures and steps apply.

- Safety devices, displays, alarms and trip settings should be verified prior to conducting field tests of control systems.
- Commissioning of the complete generating unit has to be performed including load rejection tests as per IEC 60041:1991 and the testing of control systems shall be co-ordinated with the commissioning of Hydro generating equipment. Refer to IEC 60545.

For the actual control system tests:

- The relevant mode to be checked is set, such as no-load, isolated network operation, frequency-power control or level control; subsequently defined test signals are superimposed and resulting changes for the specified values through the entire operating range are observed/recorded, whereby control settings can be optimised during the process. The results of such tests can be used as baseline values in order to be compared with the results of maintenance tests which are carried out during the life of the equipment.
- The insensitivity of the controller can be checked; this test is only needed when the power station will be participating in primary regulation of network frequency, especially in peak load power stations, also in power stations with a distinct requirement for high control accuracy (for recommended insensitivities, see 4.3.2 of IEC 61362, acceptable measuring uncertainties are given in Clause 7).
- Controller parameters can be determined. If the guaranteed behaviour is not achieved and the reason for this has to be identified, then other functions influencing the control system behaviour shall be examined. These functions may include: masses, generator-load characteristics and the influence of regulator forces on actuating times. In certain cases, the determination of the controller parameters and of the turbine transfer function may be used to provide models of the power plant, in order to carry out analytical studies of the dynamic behaviour of the power system.
- The turbine characteristics of pump turbines may need to be determined in detail in order to provide a basis for a reliable control strategy.

6.3.2 Existing control systems

6.3.2.1 Indication of control deficiencies

Deficiencies in existing control systems may have the following effects:

- long settling times of the controlled variable;
- long synchronisation times, excessive damping;
- drifting operating points;
- changes in actuator speeds;
- unusual oscillations (in no-load and/or isolated operation, etc.);
- excessive insensitivities and/or hysteresis effects;
- excessive leakages (pumping period, oil temperature, etc.).

6.3.2.2 Identification of deficiencies

The following checks can be made:

- measurement of the insensitivity;
- recording of step responses/transient functions (unit step responses) by applying defined signals at the input (command signal, controlled variable, frequency, etc.);
- indexing the servomotors;
- checking the runner/guide vane relationship in Kaplan turbines;
- checking the deflector/nozzle relationship in Pelton turbines;
- identifying possible resonances (draft tube, generator etc.);
- measurements to check the plant parameters;
- checking of the overall safety of the hydraulic conduit and the pipe-installation.

6.3.2.3 Deciding whether to replace or to repair existing control systems

The above-mentioned checks will in almost all cases give information on the reasons why the deficiencies occur, allowing to decide on the measures to be taken, such as for instance:

- verification of the reliable operation of existing equipment for retention;
- overhauling of individual components;
- replacement of components or of complete control systems;
- changes in the configuration;
- risks and consequences of oil leakage.

Besides the above-mentioned points, the following facts may also influence the decision to replace or repair existing elements or systems:

- the assessment of operating costs;
- the assessment of repair costs;
- the operating and efficiency improvement potential of replacement versus repair;
- general safety and any demands required by authorities.

6.4 Electrical checks

6.4.1 General

Whereas the electrical components of the mechanical turbine controller include control valves, servomotors, pump and pendulum (ballhead) drives, the electronic controller already carries out all control functions including pilot control.

Electronic systems are sensitive to electrical-magnetic interference. Therefore, the following shall be given special attention:

- quality of the power supply;
- overvoltage protection;
- filter and shielding measures;
- immunity of the components to interference.

If certain basic safety measures are taken and guidelines adhered to, testing can concentrate on checking the control systems for proper functioning. Electrical checking is expensive and requires qualified personnel as well as special testing equipment (for example for measuring transient overvoltages, storage oscilloscopes with an upper cut-off frequency of 100 MHz are required). Electrical checking is usually performed in the form of type tests. For specifications of the electromagnetic compatibility (EMC) tests refer to IEC 61000-4-2, IEC 61000-4-3 and IEC 61000-4-6.

6.4.2 Selection of test center

To carry out the functional checks on site, a centrally located, quiet place (control room) should be selected where all important signals of the process are available.

If the controller is not located near the generating unit, provision for local emergency operation should be made.

6.4.3 Power supply

The check of the power supply with volt- and amperemeter, oscilloscope or transient recorder should normally be carried out in the workshop and is generally limited to

- tolerance limits and ripple factor;
- current input;
- test of switch-over of the supply voltage and set-in of a redundant voltage of stored energy time after power failure and re-closing behaviour (for small and simple systems, these tests can be reduced);
- failure monitoring.

6.4.4 Overvoltage protection and suppression of interference voltage

The following may be checked:

- certification of the electronic equipment with respect to EMC;
- the electric isolation of the power supply unit for withdrawable electronic parts;
- the contact separation of the binary and analogue signals during take-over and/or transfer;
- shielding of the cables to the peripheral devices;
- the physical separation of the signal cables from power lines;
- earthing of inactive metal parts;
- protection of the peripheral devices against overvoltages by protective elements;
- wiring of inductive devices (relay coils, solenoid valves) with extinguishing elements (free-wheeling diode, RC combination, etc.).

Ground connections are to be tested with ohmmeters. In the event of interferences, a measurement is to be carried out at the ends of the signal cables with an oscilloscope.

6.4.5 Test of the process interface system

The electrical signals for actuator position, speed, power, flow, head (up-stream and tail race) shall be checked for:

- open circuit characteristic and hysteresis (actuator position);
- zero drift and temperature sensitivity;
- interference;
- filtering (power, flow, water level);
- limit value acquisition;
- fault monitoring, if available.

6.5 Test of converters, amplifiers and actuators

6.5.1 Electrohydraulic and electromechanical converters

6.5.1.1 General

The converters dealt with here are the connecting element between the electronic and the hydro-mechanical part of the control system. They are of great importance for the overall behaviour of the control system. Therefore, sensitivity, precision (including temperature stability) and also the dynamic behaviour shall exceed the corresponding properties of the subsequent amplifier stages.

6.5.1.2 Electro hydraulic converters

(Examples: servo-valves, proportional valves.)

The most important characteristic is to establish the oil flow rate as a function of the command signal and of the pressure drop.

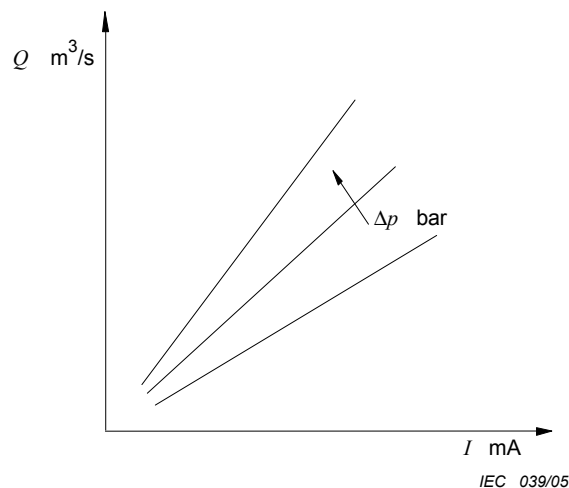


Figure 4 – Oil flow Q function of input current I and pressure drop Δp

The curves of Figure 4 should be measured with various pressure differences and, in addition, oil temperature and type of oil (viscosity grade) should be noted. The flow can be measured by tank measurement or by using a test servomotor.

Further measurements may be taken to verify the dead time and the dynamic characteristics.

NOTE 1 Multi-stage servo- and/or proportional valves often have an additional position controller for the second stage and can therefore only be tested as a system including the corresponding electronic device.

NOTE 2 If an emergency trip and failsafe (for example shutdown in the event of power failure) are available, their function should also be tested.

NOTE 3 Generally, to achieve the specified performance, a vibration (dither) signal is applied, which must also be checked.

6.5.1.3 Electromechanical converters

In principle, these converters are electro-motor driven (rotating or linear). For hydro turbines controlled by such electric actuators, they consist of electric motor, gearbox and operating mechanism. These converters are, for instance, used for the direct actuation of the regulating elements (guide vanes, runner blades, nozzle, deflector) or to drive control valve systems.

This type of actuator does not depend on the oil pressure system. It is generally suitable for small hydro turbines, designed to withstand sustained runaway operation, in the event of the total failure of electric supply. Suitable back-up protection shall be provided, to reduce the turbine discharge to an acceptable level. Some examples of the protection are

- closing of guide vanes by self-closing characteristics;
- closing of inlet valve, with guide vanes open;
- counter weight or spring.

For testing purposes, measurement of current input and actuating times is usually sufficient.

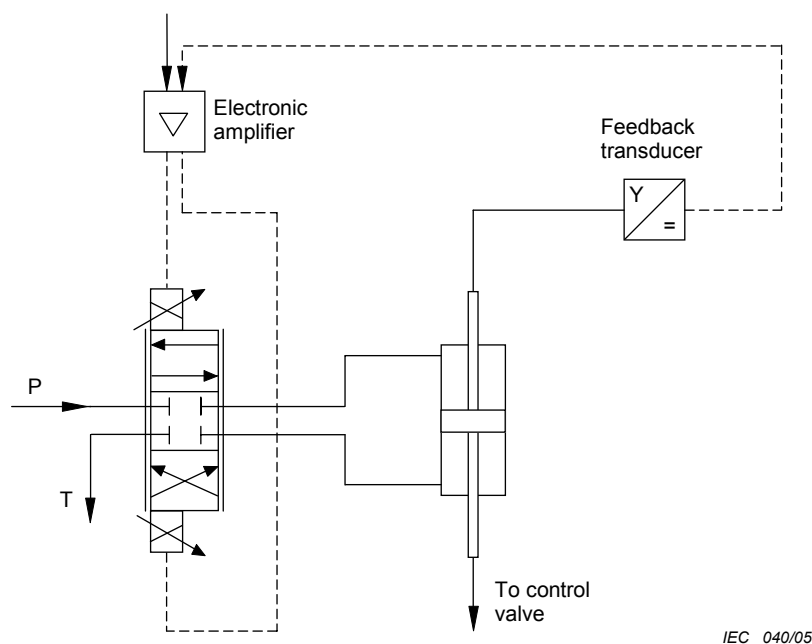
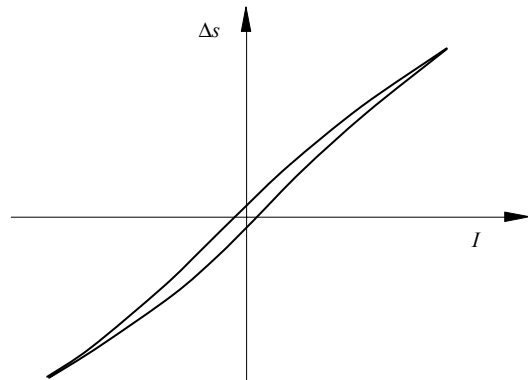


Figure 5 – Electro hydraulic converter for high grade control system



IEC 041/05

Figure 6 – Output stroke Δs of a converter versus input current I

It is furthermore possible to check

- the dead time;
- the actuating forces as a function of the oil pressure;
- the dynamic characteristics.

During these checks, the corresponding vibration (dither) signal, oil losses, oil temperature and oil viscosity should be recorded.

6.5.1.4 Two stage electromechanical/hydraulic control

In some control systems, electro mechanical/hydraulic converters can be composed of an electro hydraulic converter (see 6.5.1.2), a small pilot servomotor and a position feedback, (see Figure 5), the pilot servomotor will then actuate the main control (distributing) valve. For measurement, no additional aspects have to be considered.

If these converters are designed as a compact device (for example as a plunger coil design) with integrated hydraulic amplification, the correlation between output stroke and input current shall be established or shall be proven by type test from which the hysteresis can also be seen, see Figure 6,

It is furthermore possible to check

- the dead time;
- the actuating forces as a function of oil pressure;
- the dynamic characteristics.

During these checks, the corresponding vibration (dither) signal, oil losses, oil temperature and oil viscosity should be recorded.

6.5.2 Hydraulic amplifiers

Hydraulic amplifiers consist of the main distributing valve, servomotor and feedback.

6.5.2.1 Control valves

For workshop checks, it is recommended to connect the main distributing valve with the servomotor. If the servomotor is not available, a test servomotor can be used in its place.

In addition to testing the shortest actuating times, the friction, and the tightness, the characteristics of the main distributing valve should be established. They are recorded as a function of the valve spool stroke and consist of the pressure gain curve (pressure build-up in the control lines with the flow to the servomotor blocked) and the flow curve (actuating speed of the servomotor), see Figure 7.

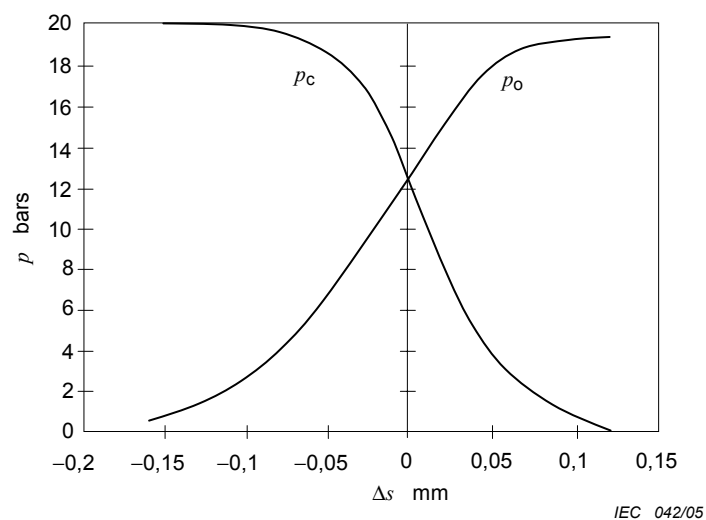


Figure 7a) Pressure p curves in closed pipes versus displacement Δs of the valve spool (typical)

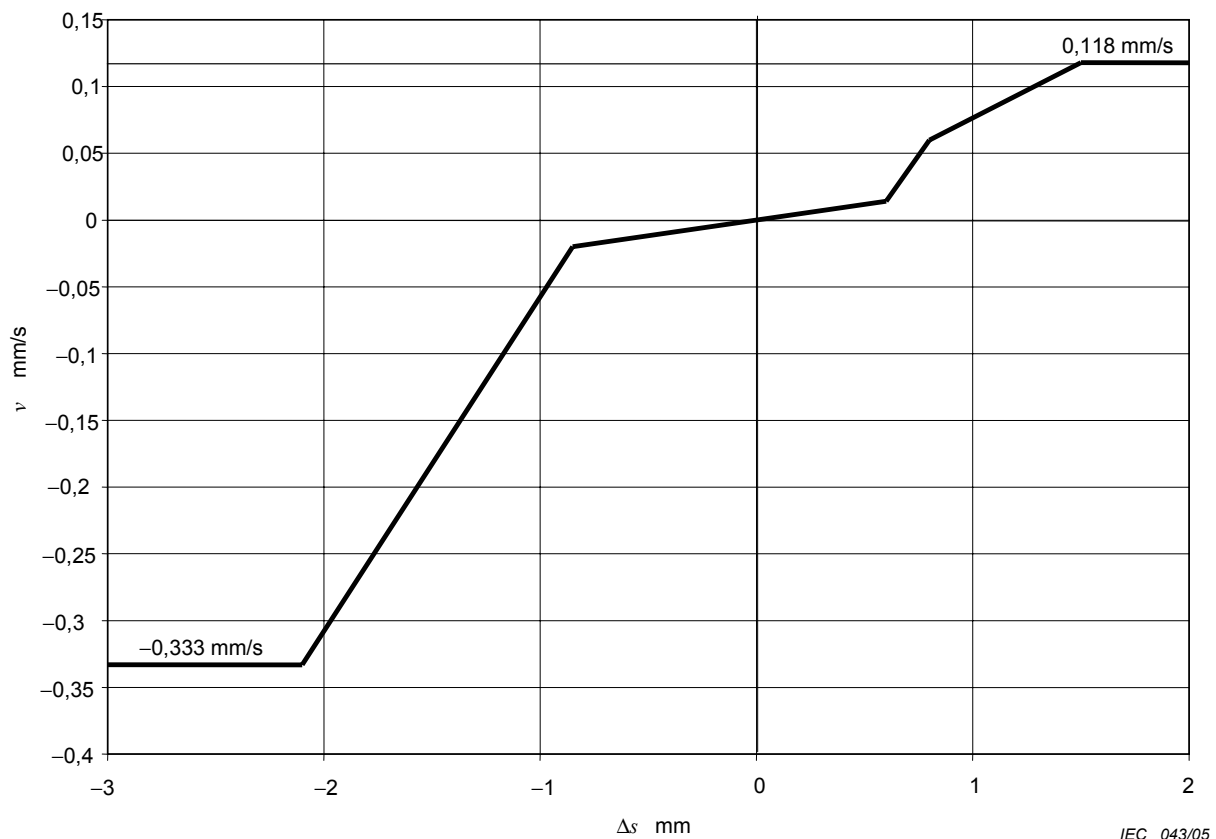


Figure 7b) –Servomotor speed versus displacement Δs of the valve spool (typical)

Figure 7 – Performance curves of control valves

These measurements are especially important for valves provided with pre-opening notches on the control edges. From the pressure curve which is only affected by the internal overlap, the displacement necessary to produce the required actuating force of the servomotor can be derived. The flow curve shows the size of the overlap in the individual notches. The widths of the notches are determined on the basis of the chosen time constants. For checking, these can be re-calculated from the inclination of the characteristic curves. The time constants are of importance for the stability and the dynamic performance (overshoot and settling time when positioning), whereas the overlaps are responsible for the control system insensitivity and/or positioning accuracy.

In some Kaplan turbines, the lubrication and cooling of the runner oil supply takes place via the runner control valve. When checking the valve, it has to be made sure that there is sufficient lubrication in the steady state center position of the piston.

If the hydraulic amplifier stage of the plant is to be checked in more detail, here too, the amplifier characteristics may be recorded as shown in Figure 7. The behaviour of the pressure build-up in Figure 7a) is determined in the servomotor end positions. Figure 7b) shows the speed behaviour as a function of the valve displacement. However, this measurement can only be made with spiral casing or distributor isolated from water conductor system. The control valve spool may be overlapped, zero-lapped (critical centered) or underlapped.

6.5.2.2 Servomotors

Generally, the servomotor is tested together with the main distributing valve. However, it can also be tested without a control valve with separate pressurisation. The measurement of the friction forces, for example via a pressure measurement during no-load (indexing) is important.

6.5.2.3 Servomotor opening and closing laws

In many cases, the closing and opening movements of the servomotors are not continuous but take place in 2 or more speed steps.

For safety reasons, the actuating times and actuating laws are pre-checked at maximum supply oil pressure of the plant prior to filling waterways during dry testing.

Upon commissioning, the plant shall in any case be retested and adjusted, if necessary, in order to be sure that unacceptable pressure variations are avoided.

Relatively long actuating times can be determined with the stopwatch whilst it is recommended to record short actuating times and actuating laws.

6.5.2.4 Dead time, insensitivity

For dead time measurement, the control valve and/or the control valve spool or the pilot spool is displaced abruptly into both directions from the center position. The time between displacement and the beginning of the servomotor movement is recorded. It is recommended that this measurement be carried out in connection with a dead time measurement of the complete control system.

Measurement of the control systems insensitivity is of particular interest for units which are used for primary control. The various possibilities are described in 6.6.3.3.

The insensitivity of the amplifier stage is determined by the valve overlap, the servomotor friction and frictional forces of positioning mechanism; to overcome these, a corresponding pressure difference and the corresponding valve displacement (see Figure 7a) are required. Oil leakages also have a considerable influence.

6.5.2.5 Oil leakage

It is difficult to measure the oil leakage from the control valve and from the servomotor separately. The servomotor losses in the end positions can be measured approximately as follows: the control valve spool is displaced into the maximum opening or closing position while the servomotor is in the end position. The oil discharged from the control valve then mainly originates from the servomotor leakage, because the displaced valve itself has hardly any oil losses in this position since its movements in normal operation are around center position only and most of the abrasion occurs near the control edges.

6.5.3 Provision of actuating energy

6.5.3.1 Systems without accumulator

a) Availability of actuating energy

The characteristics of the system required for achieving the amount of the actuating energy are described in IEC 61362, 4.11.2.

b) Flow

The flow is best checked by measuring the selected opening and closing times.

6.5.3.2 Systems with accumulator

6.5.3.2.1 Availability of actuating energy

The amount of actuating energy available can be measured on the basis of the specifications as per IEC 61362, 4.11.1.

6.5.3.2.2 Leakage

When using a fixed displacement pump, the shutoff or unloading period should be considered during steady state operation, as a measure for increased losses.

When using a pressure-controlled adjustable pump, for example an axial or radial piston pump, the increase in no-load electric power consumption of the motor can be taken as a measure for increased losses.

6.5.3.2.3 Rules for measurements on pressure accumulators

Generally, the available effective oil volume within the specified pressure range is measured as follows:

The check should be carried out at operating temperature, i.e. at 30 °C to 40 °C. The gas pressure should be adjusted according to the gas temperature which mainly depends on the ambient temperature, in such a way that the fixed displacement pump is pressureless or switched off at the level specified by the design.

With piston accumulators, the piston friction which occurs when pressure oil is discharged, shall only cause a pressure drop as specified by the manufacturer of low friction sealing.

The check shall be carried out at an oil flow corresponding to the operating conditions. Pressure oil may be drained via a drain valve.

6.5.3.3 Filtering (see ISO 4406)

For a reliable and safe operation from oil hydraulic control systems, it is necessary to check that:

- the total oil volume is very well cleaned with off line or in-line filters, as specified by the equipment supplier;
- the electro hydraulic converters (servo valves, proportional valves) are protected by in-line filters directly in front of their supply port as specified by the equipment supplier.

6.6 Site tests of controller characteristics

The different technical designs and operational tasks of Hydro Generating plants shall be taken into account without limiting the freedom of choice regarding the test procedures.

6.6.1 Main controller tasks

In the following paragraphs, some additional information to IEC 61362 is given, not directly connected with the tests.

6.6.1.1 Opening control (primary mode)

The opening control serves to position the servomotor, either as a follow-up control in master control operations (for example speed control) or as an operating mode in network control.

The control equipment consists of the elements: opening controller, electro hydraulic converter and servomotor.

- Input signals: opening set-point value, if necessary speed dependent with permanent droop, actual opening value.
- Output signal: servomotor opening.
- Limit values:
 - servomotor opening ramp,
 - servomotor closing ramp,
 - opening limiter.

A special design of the turbine control is the provision of individual guide vane servomotors and electro hydraulic controls requiring synchronisation, to maintain all guide vanes at the same position. The synchronisation is achieved with the help of mechanical linkages or electronically, depending on the system adopted.

6.6.1.2 Speed control (primary mode)

The control equipment either consists of:

- a) the elements: speed controller, converter, hydraulic amplifier, or
- b) a series arrangement of speed controller and opening controller
 - Input signals:
 - speed set-point value;
 - actual speed value;
 - if necessary auxiliary and/or disturbance parameters (for example spiral pressure, water level, head, power, servomotor position).
 - Output signal: servomotor position.
 - Limit values: admissible speed changes in the event of load rejection; surge, suction wave and pressure changes in the event of loading, unloading and load rejections; maximum frequency changes in isolated operation with defined load changes.

6.6.1.3 Power control (primary mode)

The control equipment either consists of:

- a) the elements: power controller, converter, hydraulic amplifier, or
- b) a series arrangement of power controller and opening controller
 - Input signals:
 - desired power value;
 - actual power value;
 - speed dependent on permanent droop;
 - if necessary, auxiliary and/or disturbance parameters (for example spiral pressure, water level, head).
 - Output signal: servomotor opening.
 - Limit values: upper and lower power limitation and banned regions dependent on head, cavitation, partial load and dynamic condition of the system (for example surge-tank situation).

6.6.1.4 Water level control (secondary mode)

The control equipment either consists of:

- a) the elements: water level controller, converter, hydraulic amplifier, or
- b) a series arrangement of water level controller and opening controller, or
- c) a series arrangement of water level controller, flow controller and opening controller
 - Input signals:
 - desired water level value;
 - actual water level value;
 - if necessary, auxiliary and/or disturbance variables (for example gate position, discharge of station, locking).
 - Output signal: servomotor opening.
 - Limit values:
 - maximum value of head race water level;
 - minimum value of tail race water level.

6.6.1.5 Flow control (secondary mode)

The control equipment either consists of:

- a) the elements: flow controller, converter, hydraulic amplifier or
- b) a series arrangement of flow and opening controller
 - Input signals:
 - desired flow value;
 - actual flow value (mostly calculated);
 - if necessary, auxiliary and/or disturbance variables (for example gate position, water level).
 - Output signal: servomotor opening.