BRITISH STANDARD

BS EN
60308:2005

Hydraulic turbines — Testing of control systems

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

ICS 27.140

British Standards

National foreword

This British Standard is the official English language version of EN 60308:2005. It is identical with IEC 60308:2005.

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;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English version

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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Foreword

The text of document 4/199/FDIS, future edition 2 of IEC 60308, prepared by IEC TC 4, Hydraulic turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60308 on 2005-05-01.

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– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2006-02-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2008-05-01

Annex ZA has been added by CENELEC.

Endorsement notice

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

CONTENTS

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	

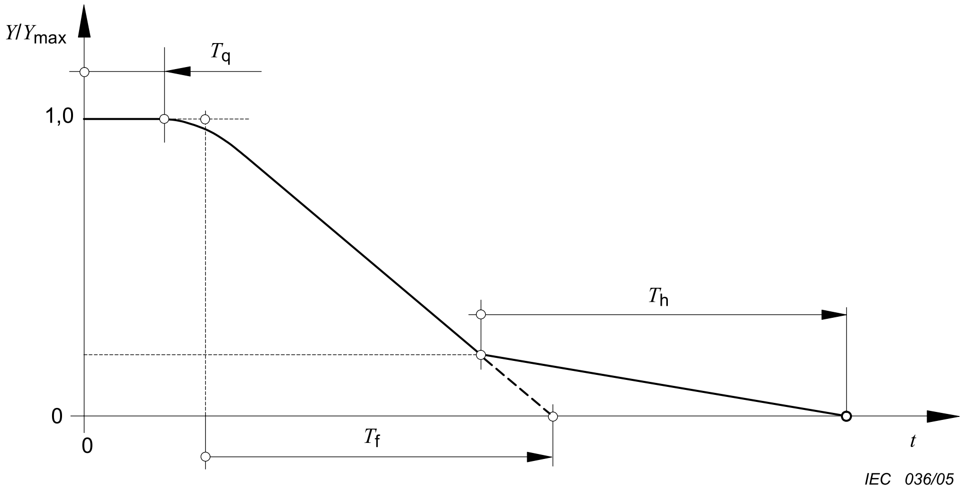
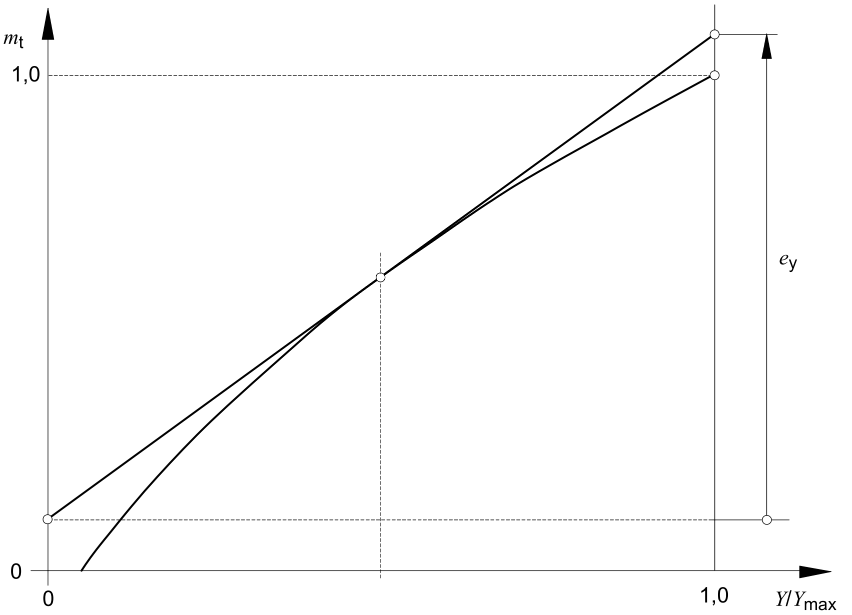


Figure 1 – Servomotor cushioning time T_h

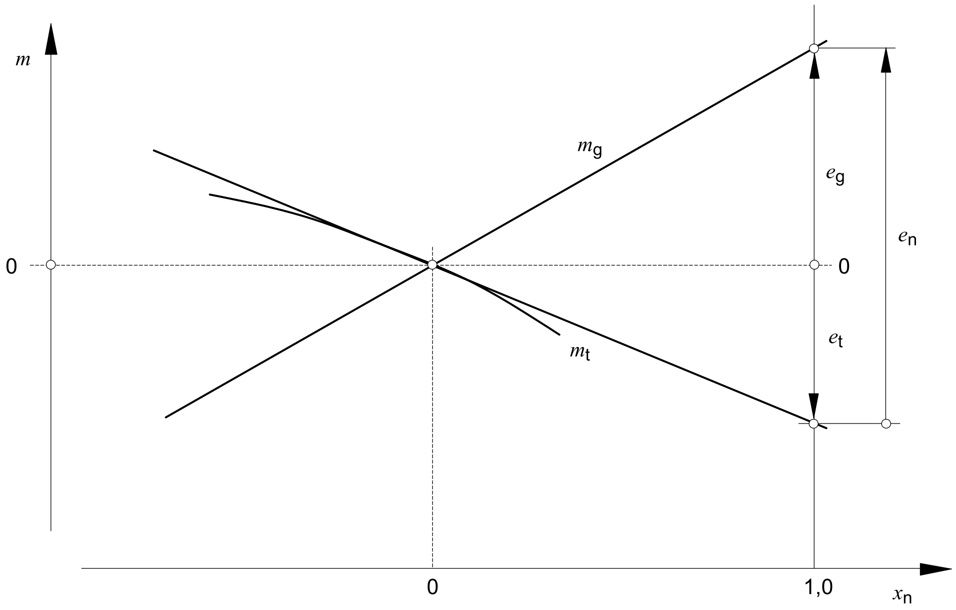
Sub-clause	Term	Definition	Quantity	Unit	Relative quantity
3.3	Terms relating to the controlled system				
3.3.1	controlled system	system controlled by the governing system consisting of the hydraulic turbine, its water supply and discharge passages, the generator with voltage regulator and the electric 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			



IEC 037/05

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 $e_p = -\frac{\mathrm{d}x_n}{\mathrm{d}x_p}$			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 $e_t = \frac{\mathrm{d}m_t}{\mathrm{d}x_n}$ 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 $e_g = \frac{\mathrm{d}m_g}{\mathrm{d}x_n} = \frac{\omega_r}{P_r} \times \frac{\mathrm{d}(P/\omega)}{\mathrm{d}x_n}$ 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: $T_W = \frac{Q_r}{gH_r} \sum_{i=1}^{n} \frac{L_i}{A_i}$ 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)	Δn_{max} $\Delta \omega_{max}$ Δf_{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)	ΔH_{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

The primary modes are the following:

	Standard	**Subclause**
– 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/electronical 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

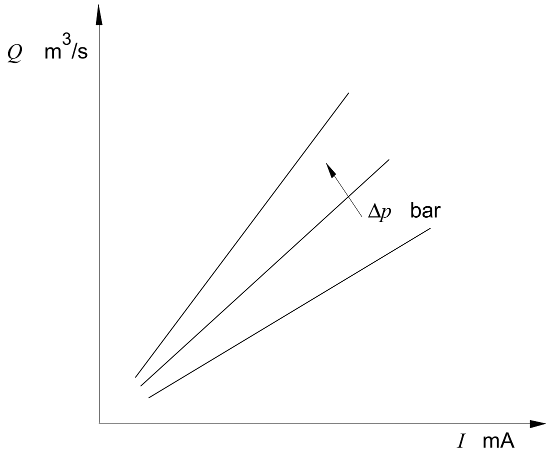
6.5.1.1 General

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.



IEC 039/05

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.

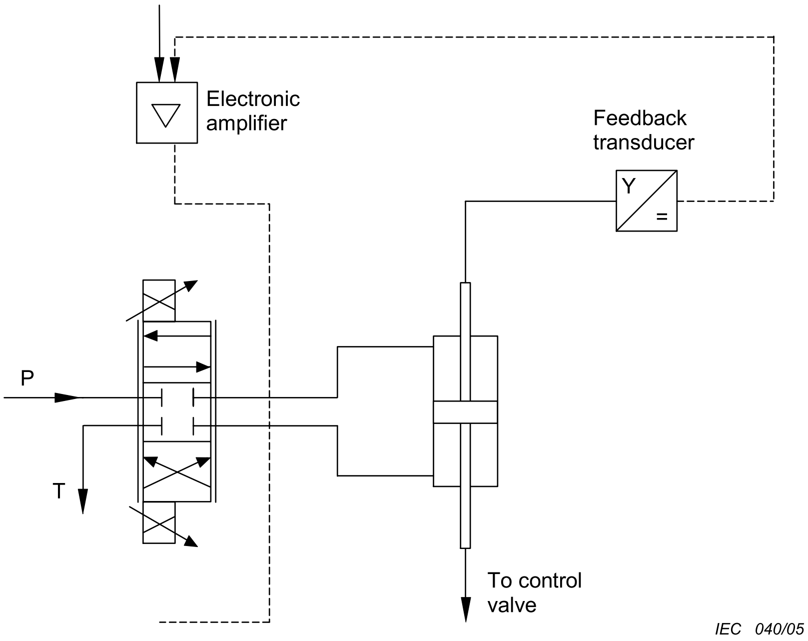


Figure 5 – Electro hydraulic converter for high grade control system

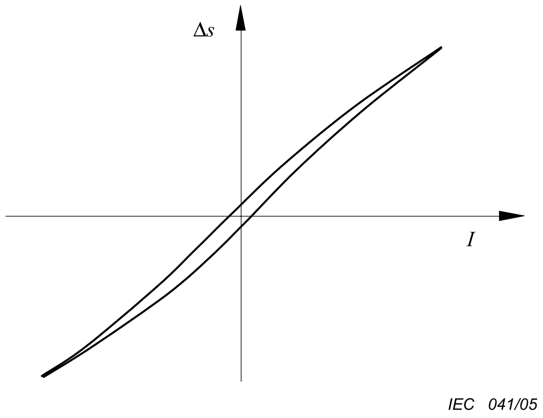


Figure 6 – Output stroke Δs of a converter versus input current I

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.

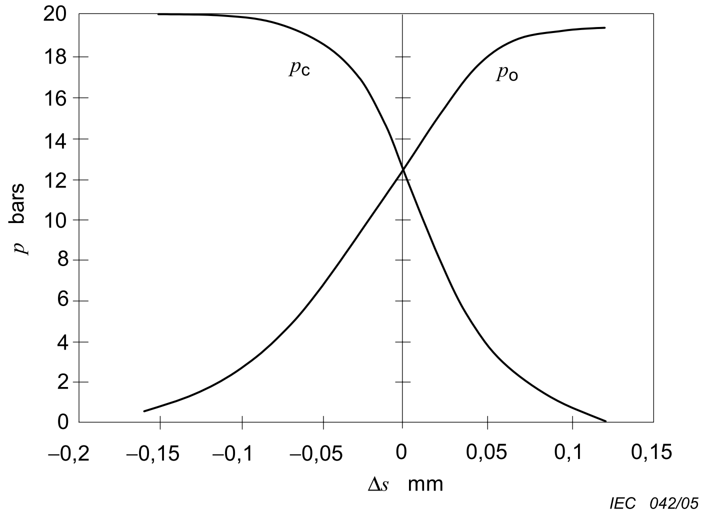


Figure 7a) Pressure p curves in closed pipes versus displacement Δs of the valve spool (typical)

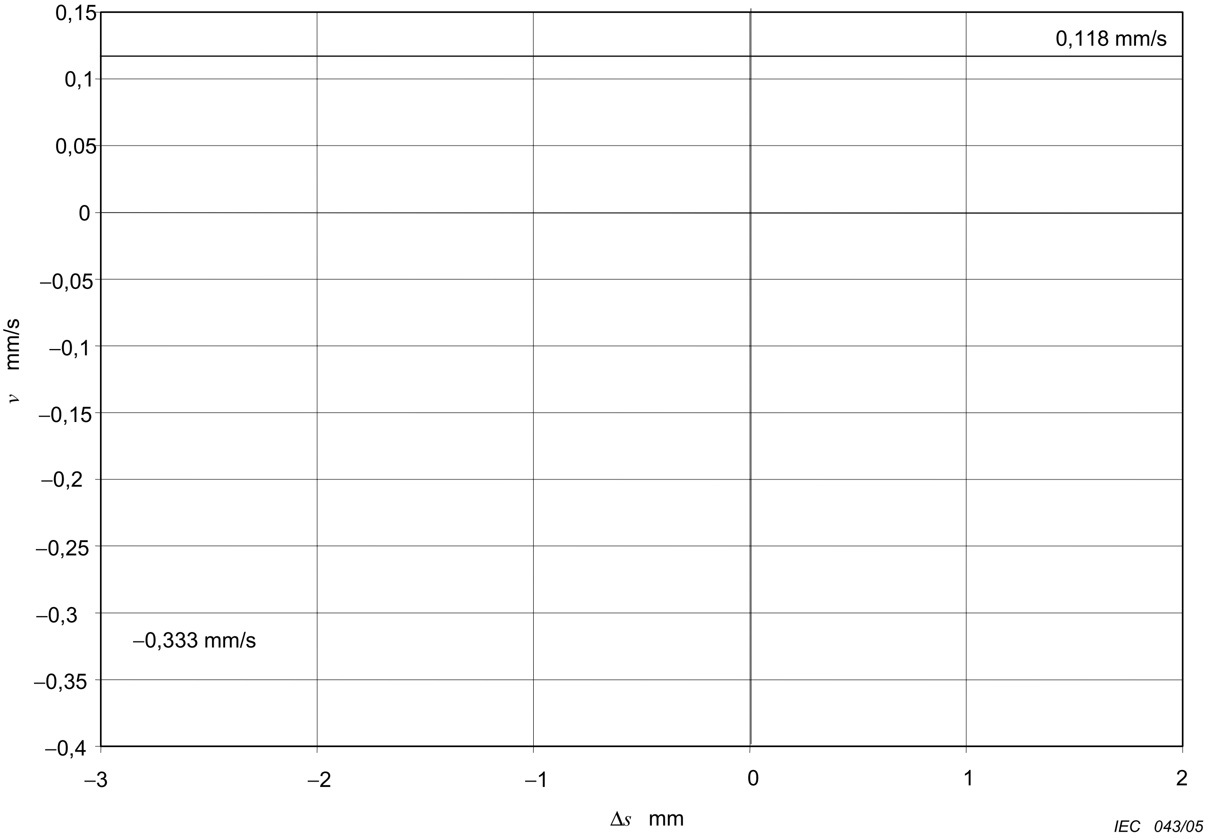


Figure 7b) –Servomotor speed versus displacement Δs of the valve spool (typical)

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.

- Limit values:
    - water level;
    - surge and suction waves in the event of flow changes.

6.6.2 Functional test of the control system

Tests shall be carried out with an undisturbed control system. The most important steps are:

- activation of the respective control mode;
- input of defined test signals, i.e.:
    - command variables;
    - set-point changes of the follow-up controls;
    - auxiliary and disturbance variables.

  Each of the above defined operating points shall be within the control range maintaining limits (for example with respect to pressure range, servomotor speed etc.).
- determining the criteria for evaluating the results achieved by optimisation of the controller settings;
- according to specified criteria of control quality (for example determining the damping ratio 0,8 < D < 1,1 for a time response, measuring the control area (integral criterion) etc.);
- adhering to the admissible limit values and loads (for example minimum system deviation, limitation of speed changes, pressure surge, and surge and suction waves);
- using recommended uncertainties in measurement according to Clause 7.

NOTE For the damping ratio D (or sometimes denoted as ζ) the formula $D = 0{,}5\ (T_1/T_2)$ applies, whereby T_1 and T_2 are the time constants of an element of second order delay; $D = 0$ is zero damping and $D \geq 1$ is aperiodic damping.

6.6.3 Determination of control system's parameters

6.6.3.1 Step responses, transient functions

Prior to the test, the following is important:

- determination of operating states;
- selection of step amplitudes. The input signals shall be such that they cannot be invalidated by possible disturbing influences;
- choice of the evaluation criteria of the results for determination of the parameters, particularly if non-linearities occur during the tests (for example actuating speed limitations).

6.6.3.2 Frequency response characteristics

Since the control behaviour can usually be better evaluated on the basis of transient functions and since, on the other hand, measurements and evaluations are costly, frequency response measurements should only be made in special cases. The execution of such measurements is to be stipulated in special agreements. Type test results should be acceptable.

6.6.3.3 Insensitivities

Insensitivity testing is only to be carried out on control systems in peak load power plants and in power plants with respect to accuracy of frequency control. Suitable input and output parameters (one variable for each) should be agreed within selected opening ranges.

For power control, the actual power value cannot be used as a measuring variable. As an input parameter, the frequency, which via the power frequency droop is always available as an additional input variable, or the power set-point are chosen.

6.6.3.3.1 Localisation of insensitivities

The localisation of insensitivities is the following:

- The tests are started with the servomotor position as an output variable. In some instances, for example with individual wicket gate control, the mean value can be chosen as output variable.
- If sensitivity is insufficient, step by step measurement of output variables against the signal flow, up to the controller output.

6.6.3.3.2 Insensitivity test with X-Y recording

The controller shall have a short reset time since otherwise the insensitivity appears to be increased. For instance, the quotient of integral action time T_i and proportional-action gain K_P should be as low as possible (ideally, proportional action only). It is therefore necessary to change during the test the parameters of the controller to carry out the test.

The most important steps are

- recording of the interdependence between output variable and input variable for selected operating openings;
- determination of insensitivity $i_\mathrm{x}/2$ from the dead band.

6.6.3.3.3 Insensitivity test by means of transient response functions (time characteristics)

The controller shall have a short reset time since otherwise the insensitivity appears to be increased. For instance, the quotient of integral action time T_i and proportional-action gain K_P should be as low as possible (ideally, proportional action only). It is therefore necessary to change during the test the parameters of the controller to carry out the test.

The main steps include:

- recording of input and output variables with small defined changes of the input variable for selected operating openings;
- determination of the insensitivity $i_\mathrm{x}/2$ from the dead band. If the input variable is superposed by stochastic fluctuations, often only the sensitivity of response can be measured.

For the recommended insensitivity, see 4.3.2 of IEC 61362. Acceptable measuring uncertainties are given in Clause 7.

6.6.3.3.4 Flutter tests of 2 mechanical or hydraulic variables with X-Y recording

The flutter tests are carried out with synchronous operation of positioners and serve to record mechanical and/or hydraulic discontinuities. It is assumed that in the steady-state condition the absolute positions are in accordance with each other.

The tests may for instance include:

- the position of 2 pump turbine guide vanes during load operation (admissible deviation with slow adjustment usually <1 %);
- the position of one guide vane against the mean value of all guide vane positions with individual guide vane control (admissible deviation usually <0,5 %).

The most important steps are

- selection of a suitable input variable;
- recording of the movement of both output variables when changing the input variable in both directions by the same amount for selected openings;
- determination of mechanical or hydraulic deviations from synchronous operation (flutter disturbances) from the hysteresis.

6.6.4 Characteristic parameters of controlled systems

If the control performance does not meet expectations without deficiencies of the control system being noted, the characteristic parameters of the controlled system shall be checked.

6.7 Safety tests

6.7.1 General

The function and the scope of the safety devices are described under IEC 61362, 4.14. In addition to the facilities mentioned there, such as:

- trip (rapid shut down);
- emergency shutdown;
- overspeed safety device;
- interlocking;

systems for monitoring the control system and braking of the unit may be mentioned, which in a broader sense also belong to the safety system.

The safety test is meant to prove that the protection devices of the plant and the personnel fulfil their tasks. Apart from the interests of the manufacturer and the user, there may be obligations of public authorities and insurance companies which shall be taken into consideration.

Usually, the tests put more load on the plant than under normal operating conditions (overspeed, load rejection, pressure surges). Therefore, the manufacturer, user and, if required, public authorities should be in agreement on what kind of tests are to be carried out.

6.7.2 Test strategy

Generally, all signal routes shall be checked. In order to limit the number of load rejections necessary for the testing, the monitoring and protection equipment can be checked in sections. This may be necessary when testing complex protection systems. Testing of the complete signal route is to be ensured by choosing the least possible number of overlapping sections.

6.7.2.1 Sensor test

For the calibration of measuring and limit value transmitters, their function is to be checked under the most realistic conditions possible (for example real pressure reduction in the accumulator tank (pressure vessel) down to the tripping value).

6.7.2.2 Functional check

Interlocking conditions and the various tripping possibilities are to be checked during standstill (dry test) as far as possible.

6.7.2.3 Checking of the safety actuators

The function of the individual safety actuators (trip, emergency shutdown) shall be proven by specific tests on the unit – if necessary during operation.

6.7.2.4 Trips for the generating unit

In order to limit the number of actual trips of the generating unit to a minimum, proper functioning of the complete safety equipment including the braking device, if any, is to be tested by live trips with representative trip criteria.

6.7.3 Test performance

The scope, sequence and procedure of the tests as well as the responsibility are to be fixed beforehand in a test programme. In addition, the initial and boundary conditions (for example head, power, flow) have to be specified for the individual tests.

If necessary, additional measuring and recording facilities shall be installed. This may include equipment to measure:

- valve switching times;
- delay times of emergency and safety shutdown valves;
- actuating pressures in brake cylinders;
- pressures in the water ways;
- actuator openings;
- control oil pressures;
- turbine speed, power and flow.

The test signals can be generated either internally or externally corresponding to the possibilities from the controller.

6.8 Test conditions to be fulfilled

6.8.1 Electrical sources

If the measuring and/or damping systems are arranged as electrical impedance networks fed from a shaft driven, fixed excitation generator, the generator can be replaced for the tests by an AC-source whose frequency and voltage correspond to those of the fixed excitation generator at normal speed. The voltage deviation shall be less than 5 % of the fundamental unless otherwise specified by contract.

Other auxiliary voltages shall be maintained during the test within ±10 % of their rated values.

6.8.2 Turbine

For acceptance tests performed on speed control systems installed at site, except as may be noted hereinafter or otherwise permitted by mutual agreement.

- Operating head on the turbine shall be within the limits specified in the turbine contract, otherwise the method of correction should be agreed upon.
- Tailwater elevation and power output of the turbine shall be such that the cavitation factor (σ) is not less than the lower limit of the turbine manufacturer’s guarantee or recommendation.
- Steady-state power output of the turbine shall not deviate from the specified value by more than ±1,5 % of rated output.

6.8.3 Fluctuations during individual test runs

For tests performed under conditions of constant speed and constant oil pressure, the fluctuations of the speed source and supply oil pressure shall not exceed the following limits during an individual run:

a) speed ±0,1 % for measurements under steady-state conditions,

b) pressure ±10 % of average oil pressure,

except as may be noted hereinafter or otherwise permitted by mutual agreement.

6.8.4 Adequate provision for test

It is recommended that when the plant is being designed, attention be given to provisions for testing. The test conditions should be considered when the intending purchaser, or his engineers, submit an inquiry to possible suppliers. The extent to which tests are to be performed in accordance with the requirements of this code shall be stated in the contract.

6.8.5 Permissible deviation from specified values

It is important that specified values stated in the contract, upon which stated guarantees are based, be adhered to as closely as possible. The relative deviations from specified values under which it is permissible to make a control system acceptance test are specified in 6.8.6.

6.8.6 Deviation of average values from specified operating conditions

6.8.6.1 Speed

If acceptance tests cannot be performed at the specified speed, the permissible deviation from the specified speed and its effect on the acceptance test results shall be agreed upon prior to tests.

6.8.6.2 Oil hydraulic system

The acceptance tests of oil hydraulic systems pertain to the following parameters:

a) Pressure

   Acceptance tests, performed on a control system installed on site with the turbine running or at a standstill, shall be performed with the oil pressure as specified in the contract; for tests performed in the shops of the control system manufacturer, because of the absence of regulating force required by the turbine, the oil pressure of the last amplification stage of the controller system may be reduced correspondingly after demonstrating satisfactory operation at the specified pressure. This reduction in oil pressure shall be mutually agreed upon prior to the conduct of the tests.

b) Oil quality and temperature

   Acceptance tests shall be performed with an oil quality prescribed by the supplier or provided by the purchaser with the approval of the supplier.

   Oil temperatures during the tests shall correspond to normal sustained operating conditions and lie within a range indicated by the manufacturer.

   The oil temperature herein referred to is that of the high pressure oil supply measured within or as close as possible to the control system.

   The prescriptions of the manufacturer regarding absence of foam and foreign matters in the oil shall be strictly observed.

6.8.7 Provisions of instruments

Unless otherwise specified by contract, the purchaser shall be responsible for obtaining the necessary instruments. The final report shall state the manufacturer and manufacturer's serial number of the instruments and completely describe special devices or modifications to standard instruments used in connection with the acceptance test.

6.8.8 Calibration of instruments

All instruments which cannot be calibrated on site shall carry calibration certificates, valid on the date of the tests, issued by an official institution which is acceptable to both parties. The provision of calibration certificates shall be the responsibility of the party providing the test instruments. Unless omitted by agreement, repeat calibrations shall be made after completion of the tests. Either one or both parties may, if they so wish, witness calibration and recalibration tests.

6.9 Isolated network field tests

6.9.1 Preconditions

NOTE Isolated grid tests should not be considered mandatory.

The decision whether to perform an isolated grid test and the type of testing to be performed should be stated by station owner/operator at the time of tender. The following factors should be considered by the owner/operator when defining the scope of isolated grid testing:

- the performance constraints of the turbine, for example due to maximum opening and closing rates;
- the intended role of the machines in the network management philosophy;
- cost implications like direct costs (for example cost of test and equipment) and indirect costs (for example lost generation revenue);
- the details of the test should be based on the predicted isolated grid conditions;
- the owner/operator shall co-ordinate with the network managing body to determine the details of the test. It should be remembered that the response of the control system is affected by the characteristics of the isolated network and the generator.

Three methods to investigate the behaviour of the plant operating on an isolated network can be considered: numerical simulation of all components (see Clause 8), field tests by simulated isolation and field tests on a real isolated grid.

6.9.2 Tests by simulated isolation

A very practical test method is on-line simulation and is usually sufficient for most cases. The stability of isolated grid operation depends essentially on the optimum selection of the dynamic parameters of the speed control system which are used for this mode. Before the field tests, the suitable values of these parameters are generally calculated with optimisation specific software, based on more or less accurate models of water passages, turbine, generator and load.

However, real power plants are sometimes different from mathematical models, data can be erroneous, and equipment subject to contingencies and modifications during their lifetime: therefore, the quality of numerical calculations may appear relatively inadequate in certain cases.

For this reason, it is often desirable, before or in place of carrying out real isolated grid field tests, to develop an intermediate method, based on an «on-line isolated grid simulator».

Figure 8 represents the principle scheme of such a simulator (the variables are in relative values): the generating unit is operating in parallel with the interconnected power system at different values of power output (corresponding to the different operating points desired for the isolated network operation). Therefore, the speed of the unit is held constant (or nearly constant) by the power system.

The principle of the simulator can be described as follows: a signal, representing the speed/frequency variations which would occur if the unit were supplying an isolated load, is developed by calculation from the measured electrical power output of the generator. This simulated speed/frequency signal is then delivered to the controller in place of (or in addition to) the actual speed/frequency signal.

The simulated frequency is obtained by integration of the difference between the power output measurement and an adjustable power reference (sum of the initial value of the power and of a test signal); it takes into account:

– the inertia of the unit (unit acceleration constant T_a);

– the inertia of the load (load acceleration constant T_b; this constant is often taken equal to zero);

– the controlled system self-regulation factor (e_n), which is the difference between the load self-regulation (e_g) factor and the turbine self-regulation factor (e_t).

One typical simulated isolation test is the step-response test: a step signal is applied to the adjustable power reference, and the simulated speed/frequency signal following this step change is recorded in the time domain. Attention should be paid to the magnitude of the step signal, which shall be significant, but with a typical maximum value corresponding to 10 % of the rated power output.

In this on-line simulation, the dynamic effects of the real components of the hydraulic system are included, i.e. the water column, the turbine (for simplicity, its dependence on the speed can also be taken into account by the turbine self-regulation factor), the controller, including all non-linearities.

The effect of the simulated unit speed change to turbine flow in these tests is neglected as the actual unit speed is held constant, therefore the inaccuracy will be increased by this simplification.

One particular point is the behaviour of the generator, which is different in inter-connected network and isolated networks. In interconnected network operation, the generator can be represented as a second-order system (natural frequency typically between 0,8 Hz and 1,5 Hz); the power output is affected by electromechanical oscillations at this natural frequency. In most cases (except in cases with fast acting deflector control of Pelton turbines) the response time of the speed control is longer, so that the influence of this phenomenon can usually be neglected and the power output of the generator can be assumed equal with the mechanical power of the turbine (losses of the generator neglected).

Moreover, the isolated network can be modelled very simply, neglecting the complex dynamical behaviour of the loads.

As a precautionary measure, for safety reasons, it is necessary that the simulator allows the controller to quickly revert back to normal operating conditions of the control system, i.e. to the measured frequency of the interconnected grid in place of the simulated frequency; these precautions are essential in case of divergent oscillations during the test, for example due to un-adapted values of parameters of the speed control system.

Figure D.16 presents a field recording of such a step-response by on-line isolated grid simulation with a Francis turbine.

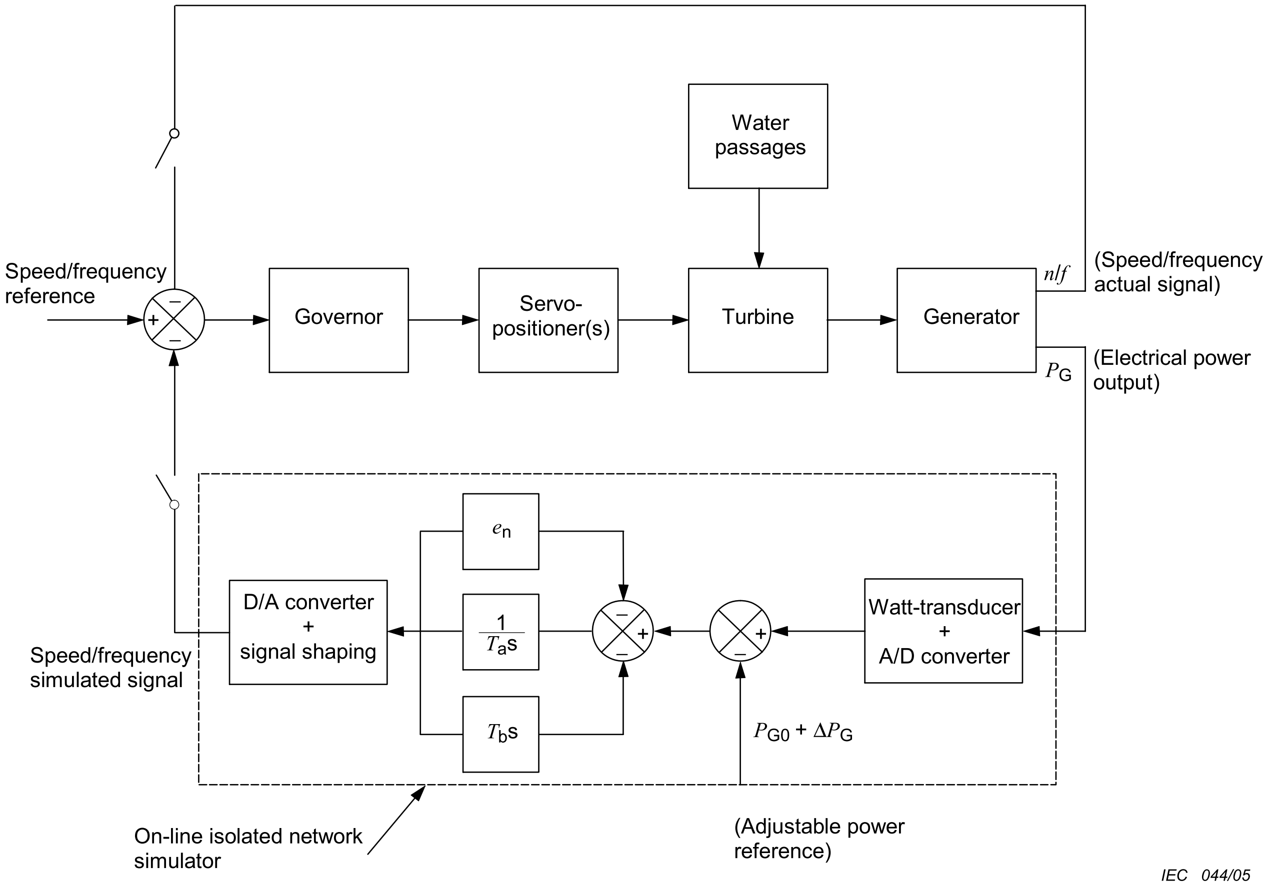


Figure 8 – Example of on-line simulated isolated grid test

6.9.3 Tests on real isolated grid

Real isolated grid tests are usually carried out only if the grid operator requires them specifically. They can be costly, with the involvement of numerous parties (the operators of the power plant, of the transmission grid and of the distribution or of the industrial consumer to be supplied in isolation mode). They require careful planning and execution in order to prevent unacceptable disruption to the isolated network.

The amplitude of the load change when transferring from the interconnected grid to the isolated one should be initially relatively small. This amplitude and the dynamic parameters of the speed control system can be pre-determined by calculation and/or on-line simulation.

The amplitude of the load changes can be gradually increased to determine the point at which the frequency variations become unacceptable.

6.10 Role of controller for stability in interconnected power systems

The fluctuations of shaft torque in a hydraulic machine can be induced by:

a) variations of the pressure forces acting on the runner/impeller blades;

b) variations of the electro-magnetic forces acting on the generator/motor.

Pressure fluctuations are a natural occurrence in hydraulic machinery. Refer to 4.3.1.1 of IEC 60193 for a full description. The pressure fluctuations generally occur typically between 0,2 and 3 times the runner peripheral frequency.

The torque fluctuations induced by the natural frequency of an electric generator can also occur.

Normally the frequency of these oscillations is in the region of 0,8 Hz to 1,5 Hz and is dependent upon characteristics (topology, frequency, etc.) of the interconnected power system, operation point of the generator (active and reactive power), and parameters of the voltage regulation.

A resonance can result at partial loads of a Francis turbine due to the interaction of the pressure fluctuations and/or the natural oscillations of the penstock and the natural frequency of the generator, connected to an inter-connected power system. This phenomenon results in the fluctuation of the speed and/or power output of the hydro-generating unit.

The hydro turbine controller may not be able to suppress these power swings. This can be easily checked by operating the hydro-generating unit under gate (wicket gate, runner blade or nozzle) limit control, with the servomotor(s) in the steady-state condition. Any speed and/or power fluctuation is due to the turbine or generator and interconnected power system.

The aim of the modern power system control is to provide power at constant frequency and voltage. However power swings with associated frequency swings can be experienced due to the complex nature of generation and transmission systems. Power system stabilisers are provided, as part of the excitation system, to reduce the power swings. The turbine controller can also help in reducing the power swings.

In other cases, the turbine controller can cause or worsen local hydro turbine oscillation involving its water conductor system, that could influence or deteriorate the power system. An example is the turbine controller power output control, based on “frequency versus power” permanent speed droop characteristics, on hydro power installations with surge tanks.

Overall power swings can be experienced if the adjustable parameters of Automatic Voltage Regulator (AVR) and /or Power System Stabiliser (PSS) are not optimised. The acceptable power swings on a hydro generation unit, operating in an inter-connected power system, should not be more than 5 % (peak to peak) of the rated power.

7 Inaccuracies in controller tests

Generally, all tests have errors up to a certain extent. Systematic errors cannot be eliminated by repetition of measurements, as they are defined by the characteristics of the measuring instruments and by the measuring arrangement. However, random errors can be reduced by repeated measurements. With controller measurements, random errors can only seldomly be determined since these measurements are hardly ever repeated several times. When recording static characteristic curves, it is at best possible to establish an equalising curve and then determine the mean random error. Therefore, systematic uncertainties are dealt with in the following subclauses. If no random errors are determined, the real uncertainty of measurements is larger by an unknown but generally small random portion.

Basically, the uncertainty of the applied measuring instruments and measuring chains as well as of the measurement evaluation should correspond to the importance of the measurements to be carried out and their results. Often it results from the contractual specifications.

In the following, recommendations are given for the admissible, systematic uncertainties with respect to the most important measured variables dependent on the task to be carried out. The uncertainties always cover the complete measuring chain from the transmitter to the display and/or recording including telecontrol transmission, if any. Superimposed, disturbing oscillations of the measured variables can be filtered out. During this process, neither a perceptible damping nor a major phase shift of the signal to be determined are permissible; the cut off-frequency of the filter should surpass the essential frequency of the control process by at least 10 times.

For all measured variables, the difference is to be made between plants grouped in the categories shown in Table 1. Tables listing the specific test programs are presented in Annex B.

Table 1 – Unit and plant categories

Level	Description	Remarks
I	Units for peakload operation	
II	Units for base load operation Units in big grids Small units for isolated load operation	
III	Small units with induction generators (position control and run of the river projects with gate limiter operation)	Turbine-generator sets in separate networks having major frequency oscillations due to permanently varying load

In many plants, uncertainties ranging between the above categories are allowed. Very often, the industrial measuring instruments are sufficient. Prior to each measurement, the admissible measuring uncertainty should be agreed upon dependent on the particular measuring task. The admissible values of the instrument uncertainties for the different categories are shown in Table 2.

Table 2 – Admissible measuring instrument uncertainties

Item No.	Description	Level I	Level II	Level III
7.1	Frequency, speed			
7.1.1	Insensitivity measurements $\| f_\mathrm{n} \| \leq$ $\| \Delta f \| \leq$ (with f_r = 50 Hz)	0,002 % 0,001 Hz	0,002 % 0,001 Hz	0,1 % 0,05 Hz
7.1.2	Frequency/speed when measuring static curves $\| f_\mathrm{n} \| \leq$ $\| \Delta f \| \leq$ (with f_r = 50 Hz)	0,1 % 0,05 Hz	0,1 % 0,05 Hz	0,4 % 0,2 Hz
7.1.3	Speed during start-up and switching-off processes $\| f_\mathrm{n} \| \leq$ $\| \Delta f \| \leq$ (with f_r = 50 Hz)	0,5 % 0,25 Hz	0,5 % 0,25 Hz	2 % 1 Hz
7.2	Strokes			
7.2.1	Insensitivity measurement $\| f_\mathrm{y} \| \leq$	0,05 %	0,05 %	0,5 %
7.2.2	Flutter test (synchronous operation) measurements (guide vane – guide vane) $\| f_\mathrm{y} \| \leq$	0,05 %	0,05 %	0,5 %
7.2.3	Strokes during start-up and shut down processes, network and isolated operation $\| f_\mathrm{y} \| \leq$	1 %	1 %	2 %
7.3	Power All percentage data refers to maximum power $\| f_\mathrm{P} \| \leq$	0,5 %	0,5 %	2 %
7.4	Pressure/heads			
7.4.1	All data refer to the pressure p_o or the head h_o in steady state, calculated for the horizontal centre line elevation. Pressure/heads during start-up and shut-down processes, network and isolated operation $\| f_\mathrm{p} \| \leq$ In special cases, greater values can be permitted	2 %	2 %	2 %
7.4.2	Oil pressures All data refers to the nominal pressure p_1 of the pressure accumulator $\| f_\mathrm{p} \| \leq$	2 %	2 %	2 %
7.5	Water levels			
7.5.1	Water level control [a)] $\| \Delta H \| \leq$	–	0,5 cm	2 cm

[a)] Proper protection of transducer from influence of waves.

Table 2 *(continued)*

Item No.	Description	Level I	Level II	Level III
7.5.2	Water level fluctuation in surge tanks. All data refer to the difference between the highest and lowest water level, Δh_o in the surge tank $\vert f_h \vert \leq$	1 %	1 %	1 %
7.6	Time			
7.6.1	Dead times $\vert \Delta t \vert \leq$	0,05 s	0,05 s	0,05 s
7.6.2	Actuating, synchronising and transient times $\vert \Delta t \vert \leq$	0,2 s	0,2 s	0,2 s
7.7	Flow			
	Absolute flow	5 %	5 %	5 %
	$\vert f_Q \vert \leq$	1 %	1 %	1 %
	Resolution			

[a] Proper protection of transducer from influence of waves.

8 Simulation of governing and control operations

8.1 General remarks

The simulation of physical processes is not a test, properly speaking. However, since the tests can be substituted and/or simplified to a greater or lesser extent by simulations, it is useful to include them into the present standard.

Generally, the simulation of the behaviour of component parts, plants or parts thereof involve costs. The more complicated the simulated parts and the higher the precision with which their behaviour is to be determined, the higher the expenses. Therefore, the scope and task of a simulation is to be agreed upon contractually, in advance. As a rule, a plant simulator is a separate device. However, it can also be designed as a separate programme section within the digital controller. The advantage of the separate device is that the interfaces between the control system and the plant simulator can be designed just like in the plant itself.

The following tasks can be assigned to simulation.

- Pre-examination of the complete plant including the control system for selection and optimisation of the controller set-point values (parameters) and – if necessary – of the controller algorithms and for the testing of operating conditions which cannot easily be produced in the plant (for example isolated operation). The computing time needed for this is of no importance.
- Parameter studies on the influence of unpredictable plant characteristics, for example the power system (grid) self regulating factor. The computing time again is of no importance.
- Workshop acceptance test of the control system together with the simulated controlled system (unit acceleration time constant T_a, water inertia time constant T_W, etc.). In this test, those parts of the control system which cannot be included in the acceptance test shall be simulated, such as for example the oil pressure system for actuators and servomotors. For this, a real time simulator is required.

- Personnel training in plant operation either in the workshop or on site. If training is to be carried out on the original control system, here again a real-time simulator shall be used for the plant.

8.2 Simulator characteristics

The simulator is meant to reproduce all important physical properties of the part to be simulated as exactly as possible. Besides the steady-state behaviour, above all the dynamic properties shall be reproduced correctly, including, in detail, the following.

- In plant simulations, all the significant components of the water passage system shall be determined. For pipe sections subjected to a high degree of dynamic pressure variations, the water compressibility and the pipe wall flexibility shall be taken into account. Surge tanks shall be carefully modelled, particularly if extreme water levels are to be determined, whereas distribution pipes and similar short pipe sections can often be simplified.
- Characteristic diagrams of hydraulic machines and other relevant characteristic curves shall be entered as accurately as possible, at least for all relevant areas (model characteristic diagrams and curves).
- Adjusting devices should contain all non-linearities, for example servomotor speed limitations or graded actuating laws.
- In separate networks, the load characteristics are seldom known. Therefore, it shall be made sure that even the most unfavourable cases are considered in the simulation.
- In order to avoid damage due to incorrect interlocking or control times during start-up, the influence of the forces on the servomotor times should be taken into account when testing oil and water hydraulic control systems with important interlocking functions (for example headrace- and tailrace spherical valve control systems in connection with difficult pressure surge conditions).
- When simulating electronic control functions in work shop tests, important interlocking functions which shall operate reliably right from the beginning during start-up, are also to be implemented.

8.3 Inaccuracy of plant simulators, calculations of pressure surge and control parameters

8.3.1 General

All simulations are prone to inaccuracies. This applies to plant simulators, calculations of pressure surge and control parameters all of which have the same elements. There are different reasons for the inaccuracies. In the following Subclauses, the unavoidable inaccuracies are listed according to their origin.

8.3.2 Inaccuracy of input data

Distinction must be made between

- unforeseeable inaccuracies of the input data, and
- specific simplifications made in input data processing.

Examples of unforeseeable uncertainties of the input data are

- deviations of model characteristic diagrams and curves of the turbines and valves from those of the plant;
- deviations of the unit's moment of inertia;
- deviations of the friction resistances and the resistance coefficients of individual components;
- deviations of the actuator speeds of wicket gates and valves due to hydraulic forces and moments.

These factors cannot be measured and can result in significant differences between simulation and reality.

When preparing the input data, the following systematic simplifications are for instance made:

- simplification of distributing conduits, branches, cones;
- adjustment of the partial sections or wave velocities of staggered conduit systems to the computed time intervals;
- greatly simplified consideration of the mass inertia of the water masses in the units.

Generally, the effects of these systematic simplifications can be maintained in reasonably confined limits when being dealt with carefully.

8.3.3 Inaccuracy of computing programmes

The programmes are based on the actual knowledge of the mathematical description of the relevant physical processes and the numerical methods for solving the equation systems. Here are some examples of computing simplifications which result in computing inaccuracies:

- using the streamline theory thus neglecting multi-dimensional influences;
- neglect of the speed energy;
- using steady-state characteristic diagrams and curves;
- cycle time of non-stationary processes which in reality are continuous.

Experience has shown that these influences are so small in these relatively slowly evolving processes that they can actually be neglected.

8.3.4 Conclusions

In summary, it can be said that

- the results of computational simulations including plant simulators are generally prone to faults;
- a lot of experience is required to decide on the simplifications and to judge the documents and results available;
- experience gained from calculations of pressure surge and control processes, using the same elements and simplifications as plant simulators, have shown that when being dealt with carefully the deviations from the behaviour in the plant remain within acceptable limits so that the simulation results can be used for dimensioning the plant parts, for judging the control systems and for pre-setting the control parameters.

Annex A
(informative)

Test procedures

A.1 Insensitivity test procedure

(Speed control)

a) Test in the workshop

Measuring values to be recorded:

- ordinate: actual value of speed;
- abscissa: actual value of servo motor stroke.

Test procedure:

The desired value of speed has to be changed in steps (with a disturbance signal) with defined plus/minus steps. From step to step, the amplitude of speed change becomes reduced until the servo motor shows no more movement.

The corresponding value of amplitude of speed change shows the insensitivity from the unit control.

b) Test in the field

Measuring values to be recorded:

- ordinate: actual value of speed or frequency;
- abscissa: servo motor stroke.

Test procedure:

One possible test procedure is to use the unit connected to the grid without additional disturbance signal. In the range of insensitivity, where only the speed signal is changing, the record shows the insensitivity as a band with accumulated, partly vertical lines.

The inclination from the band of insensitivity corresponds to the adjusted permanent speed droop.

A.2 Dead time test procedure

a) Test in the workshop

Measuring values to be recorded:

- ordinate: disturbance signal, actual value of speed and servomotor stroke;
- abscissa: time.

Test procedure:

The speed has to be changed in steps within ±10 % of the rated speed. The time between the change in steps of actual value of speed and the beginning from the movement of servomotor is the dead time. The stepwise speed change of value equal to 4 times the specified dead band will be suitable.

b) Test in the field

The same tests as in the workshop can be carried out, or as follows.

Measuring values to be recorded:

- ordinate: actual value of speed and servomotor stroke;
- abscissa: time.

Test procedure:

The dead time can be derived from a load rejection. It is the time between the beginning of speed increase and the beginning of the movement of the servomotor.

The dead time test can also be carried out with triangular input signals instead of steps.

A.3 Test procedure for the pressure indication from servomotors

a) Objective of the test

To determine the size and direction of the hydraulic and frictional moments (opening and closing) for refurbishment purposes.

These sizes depend on:

- machine size;
- head and/or flow rate;
- maximum opening angle of the blades;
- friction;
- geometric form of wicket gate and runner.

Measuring values to be recorded:

- ordinate: the pressures prevailing on the opening and closing sides of the servomotor p_o and p_c;
- abscissa: the servomotor's stroke and/or the value of the corresponding indicating scale (it shall be precisely defined what is 100 %);
- additional parameters to be noted:
  - the correlation and/or the relevant attached scales for
    servomotor stroke Y_{ga} versus guide vane angle $\varnothing$;
    servomotor stroke Y_{ru} versus runner blade angle β_2 and/or turning angle on the plate;
  - the static head H;
  - the tail race level;
  - the generator power at fully opened turbine.

b) Test procedure

If possible, the measurements shall be plotted with a recorder.

In general, the wicket gate and/or the runner shall be moved slowly and uniformly, on the one hand, to take the inertia of the measuring instruments into account, and on the other hand to guarantee sliding friction. At the same time, the pressures in the opening and closing sides should be measured, taking care that the servomotor moves during reading (sliding friction).

The test shall be carried out in 2 stages:

- generator unsynchronised and wicket gate from no-load position to closed position and vice versa;
- generator parallel to grid from full open position to no-load position and vice versa.

A measurement shall always be made in the opening and the closing direction.

c) Pressure and stroke measurement

Measuring instruments (manometers) to measure oil or water pressures shall be connected directly to the servomotors and not to a supply piping.

On control devices with water closing cylinders, the water pressure shall also be measured or recorded over the whole stroke, since the pressure is not constant because of the varying penstock pressure.

If the measurements are not carried out with a recorder, the following shall be observed.

- The pressures should be read at intervals of a least every 10 % of the stroke. Care shall be taken to see that the servomotor moves slowly at the time of reading.
- The pressure cannot be read in the reversal points (i.e. end positions OPEN and CLOSED). Therefore, it shall be measured at 2 % and 98 %. The openings, where the pressures shall be read, should be marked on the indicator at the beginning.
- The measuring instruments should be calibrated before and after the measurement.
- To check whether no excessive friction exists, indexing shall first of all be carried out with an empty spiral case.

A.4 Procedure for the measurement of the pressure and flow characteristics of control valves

a) Pressure characteristic (see Figure 7a))

Measuring values to be recorded:

- ordinate: pressure in the working ports for opening and closing;
- abscissa: valve position.

Test procedure:

The working ports shall be closed or the servomotor shall be in the corresponding end position, where the servomotor piston cannot move, when the control valve opens. The inclination from the pressure curve depends on the internal leakage of the control valve or from the control valve and the servomotor.

b) Flow characteristic (see Figure 7b))

Measuring values to be recorded:

- ordinate: servomotor speed (flow);
- abscissa: valve spool position.

Test procedure:

The valve spool becomes displaced by a defined stroke. The inclination from the curve of the servomotor stroke is proportional to the flow under a specified pressure drop. The flow can be calculated with the formula:

$Q = A \times v$ with the servomotor area A and the velocity v of the servomotor piston.

$v = \frac{Y}{t}$ with the servomotor stroke Y and the measuring time t.

The test shall be repeated for several values of valve position.

The flow also depends on the pressure difference Δp at the control valve. The relation is shown by the formula:

$$Q \approx \sqrt{\Delta p}$$

Annex B
(informative)

Recommendation for testing of turbine controllers

B.1 General

Some of the tests, as per the following tables, shall be conducted during the pre-start stage prior to filling waterways, commonly referred to as dry condition. Refer to Annex C.

The term NOC means "Normal Operating Conditions". Some of the tests may be required to be performed on an existing hydro-generating unit for rehabilitation studies, etc.

The following checks shall be made for normal operating conditions:

- for an adjustable blade type turbine, the blade control mechanism shall be in normal operation;
- if a relief valve or synchronous bypass is present, they shall be set for normal operation.

Plant control by ordinary operating, recording or integrating instruments or station meters, 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.

The following Tables B.1 to B.12 provide indicative test programmes for use in the factory or on site for the different categories of groups.

B.2 Level 1 – Units for peak load operation

B.2.1 Workshop tests

Table B.1 – Normal test programme

Functional group	Part	Test	Test conditions
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions 4) Servo/proportional valve test	Actual or dummy servomotor
	Turbine controller	1) Opening control 2) Multi servo control 3) Supervision/alarms 4) Other functions	Simulated servo-systems
Sub-modules	Oil pressure system	1) Pressure control 2) Pump capacity 3) Power supply range 4) Alarm/trip signals	Oil quality and temperature within "normal" range
	Speed monitor	1) Speed levels 2) Supervision/alarms	

Table B.2 – Comprehensive test programme

Functional group	Part	Test	Test conditions
Overall system	Assembled system	1) Sensitivity/dead band 2) Dead time 3) Closed loop control (frequency step, load step) 4) Full load rejection	Actual or dummy servomotor Simulated unit, hydro and grid system
Subsystems	Servosystem 1 Servosystem 2	1) Static characteristic and accuracy 2) Dynamic test (step or harmonic response)	Actual or dummy servomotor
Main modules	Hydraulic control unit	1) Distributing valve characteristic 2) Shut down functions 3) Opening/closing speed 4) Manual functions	Actual or dummy servomotor
	Turbine controller	1, Opening control 2) Permanent droop and other control functions 3) Sequences 4) Multiservo control 5) Optimisation 6) Supervision/alarms 7) Other functions	Actual or simulated servosystems Simulated unit, hydro and grid system
Sub-modules	Oil pressure system	1) Pressure control 2) Pump capacity 3) Energy storage capacity 4) Power supply range 5) Alarm/trip signals	Oil quality and temperature within "normal" range
	Speed monitor	1) Speed levels 2) Supervision/alarms	

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B.2.2 Field tests

Table B.3 – Normal test programme

Functional group	Part	Test	Test conditions
Overall system	Complete system	1) No-load stability 2) Load stability 3) Load rejections	Normal operational conditions (NOC)
Subsystems	Servosystem 1 Servosystem 2	1) Static characteristic and accuracy 2) Dynamic test (step or harmonic response[a])	Dry test
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions	NOC
	Turbine controller	1) Opening control 2) Multiservo control 3) Supervision/alarms 4) Other functions	
Sub-modules	Oil pressure system	1) Pressure control 2) Alarm/trip signals	NOC
	Speed monitor	1) Speed levels 2) Supervision/alarms	

[a] Normally only for type test.

Table B.4 – Comprehensive test programme

Functional group	Part	Test	Test conditions
Overall system	Complete system	1) No-load stability 2) Load stability 3) Load rejections 4) Isolated operation stability test	NOC NOC (isolated) or parallel operation with simulated speed deviation
Subsystems	Servosystem 1 Servosystem 2	1) Static characteristic and accuracy 2) Dynamic test (step or harmonic response[a])	Dry test
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions	NOC
	Turbine controller	1) Opening control 2) Permanent droop and other control functions 3) Sequences 4) Multiservo control 5) Optimisation 6) Supervision/alarms 7) Other functions	
Sub-modules	Oil pressure system	1) Pressure control 2) Alarm/trip signals	NOC
	Speed monitor	1) Speed levels 2) Supervision/alarms	

[a] Normally only for type test.

B.3 Level 2 – Units for base load operation

NOTE Units in big grids. Small hydro units for isolated load operation.

B.3.1 Workshop tests

Table B.5 – Normal test programme

Functional group	Part	Test	Test conditions
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions 4) Servo/proportional valve test	Actual or dummy servomotor
	Turbine controller	1) Opening control 2) Multiservo control 3) Supervision/alarms 4) Other functions	Simulated servosystems
Sub-modules	Oil pressure system	1) Pressure control 2) Pump capacity 3) Alarm/trip signals	Oil quality and temperature within "normal" range
	Speed monitor	1) Speed levels 2) Supervision/alarms	

Table B.6 – Comprehensive test programme

Functional group	Part	Test	Test conditions
Overall system	Assembled system	1) Sensitivity/dead band 2) Dead time 3) Closed loop control (frequency step, load step)	Actual or dummy servomotor Simulated unit, hydro and grid system
Subsystems	Servo system 1 Servo system 2	1) Static characteristic and accuracy 2) Dynamic test (step or harmonic response[a])	Actual or dummy servomotor
Main modules	Hydraulic control unit	1) Distr. valve characteristic 2) Shut down functions 3) Opening/closing speed 4) Manual functions	Actual or dummy servomotor
	Turbine controller	1) Opening control 2) Permanent droop and other control functions 3) Sequences 4) Multiservo control 5) Optimisation 6) Supervision/alarms 7) Other functions	Actual or simulated servosystems Simulated unit, hydro and grid system
Sub-modules	Oil pressure system	1) Pressure control 2) Pump capacity 3) Energy storage capacity 4) Power supply range 5) Alarm/trip signals	Oil quality and temperature within "normal" range
	Speed monitor	1) Speed levels 2) Supervision/alarms	

[a] Normally only for type test.

B.3.2 Field tests

Table B.7 – Normal test programme

Functional group	Part	Test	Test conditions
Overall system	Complete system	1) Load rejections	NOC
Subsystems	Servosystem 1 Servosystem 2	1) Static characteristic and accuracy 2) Dynamic test (step or harmonic response[a)])	Dry test
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions	NOC
	Turbine controller	1) Opening control 2) Multiservo control 3) Supervision/alarms 4) Other functions	
Sub-modules	Oil pressure system	1) Pressure control 2) Alarm/trip signals	NOC
	Speed monitor	1) Speed levels 2) Supervision/alarms	

a) Normally only for type test.

Table B.8 – Comprehensive test programme

Functional Group	Part	Test	Test conditions
Overall system	Complete system	1) Load rejections 2) Isolated operation stability test	NOC NOC (isolated) or parallel operation with simulated speed deviation
Subsystems	Servosystem 1 Servosystem 2	1) Static characteristic and accuracy 2) Dynamic test (step or harmonic response[a])	Dry test
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions	NOC
	Turbine controller	1) Opening control 2) Permanent droop and other control functions 3) Sequences 4) Multiservo control 5) Optimisation 6) Supervision/alarms 7) Other functions	
Sub-modules	Oil pressure system	1) Pressure control 2) Alarm/trip signals	NOC
	Speed monitor	1) Speed levels 2) Supervision/alarms	

[a] Normally only for type test.

B.4 Level 3 – Units with induction generators

B.4.1 Workshop tests

Table B.9 – Normal test programme

Functional group	Part	Test	Test conditions
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions 4) Servo/proportional valve test	
	Opening control device	1) Opening control 2) Supervision/alarms	
Sub-modules	Oil pressure system	1) Pressure control 2) Alarm/trip signals	Oil quality and temperature within "normal" range
	Speed monitor	1) Speed levels 2) Supervision/alarms	

Table B.10 – Comprehensive test programme

Functional group	Part	Test	Test conditions
Subsystems	Servosystem 1 Servosystem 2	1) Static characteristic and accuracy 2) Dynamic test (step or harmonic response)	
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions	
	Opening control device	1) Opening control 2) Supervision/alarms	
Sub-modules	Oil pressure system	1) Pressure control 2) Pump capacity 3) Energy storage capacity 4) Power supply range 5) Alarm/trip signals	Oil quality and temperature within "normal" range
	Speed monitor	1) Speed levels 2) Supervision/alarms	

B.4.2 Field tests

Table B.11 – Normal test programme

Functional group	Part	Test	Test conditions
Overall system	Complete system	1) Shut down	NOC
Main modules	Hydraulic control unit	2) Shut down functions 3) Opening/closing speed 4) Manual functions	NOC
	Opening control device	1) Opening control 2) Supervision/alarms	
Sub-modules	Oil pressure system	1) Pressure control 2) Alarm/trip signals	NOC
	Speed monitor	1) Speed levels 2) Supervision/alarms	

Table B.12 – Comprehensive test programme

Functional group	Part	Test	Test conditions
Overall system	Complete system	1) Shut down	NOC
Subsystems	Servosystem	1) Static characteristic and accuracy	Dry test
Main modules	Hydraulic control unit	1) Shut down functions 2) Opening/closing speed 3) Manual functions	NOC
	Opening control device	1) Opening control 2) Supervision/alarms	
Sub-modules	Oil pressure system	1) Pressure control 2) Alarm/trip signals	NOC
	Speed monitor	1) Speed levels 2) Supervision/alarms	

Annex C
(informative)

Field test of control systems

NOTE This annex presents a number of on-site test application elements within the framework of the commissioning of hydraulic turbine components in accordance with IEC 60545.

C.1 Data on operating conditions

The following data shall be made available for satisfactory commissioning of the control system:

- guide vane opening (or needle opening of impulse turbines) for no-load, starting and cavitation limits, as function of headwater and tailwater levels also, where appropriate, runner blade or deflector opening;
- turbine control system (controllers, etc.) and servomotor characteristics;
- adjustment of overspeed protection device;
- characteristics of the fluid for the oil pressure system, filter specifications and information on purification frequency and method;
- maximum steady-state runaway speed and maximum speed and pressure variations at various operating heads;
- information on oil pressures and levels at which the pumps and accumulator should be normally operated;
- maximum and minimum pressures of the oil pressure system.

C.2 Pre-start tests prior to filling waterways

Step No. 1 is as follows:

- calibration of scales and feedback devices for wicket gate opening and where applicable, for runner blades, needles and deflectors;
- operation of the oil pressure system consisting of pumps, accumulator, automatic and manually operated starting and stopping devices (control valves, isolating valves etc.) and signalling devices;
- check oil levels and pressures of the oil pressure system;
- check protective devices, such as oil level, pressure and temperature alarms and trips, with final adjustments;
- calibration of power transducer;
- check operating times of the servomotors, independently of the control systems, if possible.

Step No. 2 is as follows:

- operation of converters (servo-valve, proportional valve, etc.), check of input electrical signal versus servomotor speed;
- operation of electronic controllers, analogue electronic interface devices and electrical control systems.

C.3 Test after filling waterways

Automatic protection devices which actuate the wicket gate (or needles/deflectors for impulse turbines) shall be checked.

C.4 Initial run

The operation of a hydro generating unit, under the control system (controller, etc.), shall be performed in agreement with the test/commissioning co-ordinator.

C.5 No-load tests

The generating unit shall be kept under manual control at or above the starting speed (depending on the design of thrust bearing and other bearings). Increase the machine speed to the rated value, ensuring that the generator has been balanced by the commissioning engineer responsible for generator and turbine commissioning.

Initiate shutdown by operating the stop, first by manual operation and then by automatic operation by simulating a fault.

After the bearing run, the generating unit shall be started under automatic control. Check that the control system controls the gate (wicket gate or needle) as per the specified control sequence and that the steady state speed is attained without excessive speed overshoot.

Optimise the controller parameters for unsynchronised speed no-load operation. Check the performance by varying the speed by at least 5 % followed by the automatic control system to stabilise the speed at the rated value.

Carry out control system tests as per the agreed procedure.

Perform machine trips, either by simulating faults or by creating faults, ensuring that the faults created are not detrimental to the generating unit.

C.6 Load and load rejection tests

Check the function of the control systems (controller, etc.) for load acceptance, load variation, and optimise the controller parameters for stable operation in the grid.

Re-check the operating times of the servomotors.

Determine the momentary speed rise and pressure rise during load rejection tests, to be performed at 25 %, 50 %, 75 % and 100 % of the rated load.

For safety testing, extrapolate results as a function of load in diagrams during testing. That makes it possible to see the trend before next load step.

C.7 Measurement and recordings

The commissioning engineer shall measure and record the following variables during the above mentioned tests:

- headwater and tailwater levels;
- power output;
- servomotor opening;
- pressure at turbine inlet;
- pressure in draft tube;
- unit speed;
- pressure of the oil pressure system;
- any additional control system variables useful for interpretation.

Annex D
(informative)

Control system test examples

Overview

The following examples refer to special plants with different control systems and requirements. Therefore, they cannot be transferred directly to other plants. The test scope, the admissible values as well as the type and extent of the representation may differ considerably in individual cases. The examples show how to proceed in determining the values of the various parameters.

D.1 Insensitivity test under speed control with X-Y recording
(example referring to 4.1 and 6.6.3.3.2)

6-jet Pelton turbine, H_r = 1 260 m, P_{Gr} = 260 MW; electronic PI speed controller; machine in network operation; minimum controller reset time, maximum amplification; insensitivity of a jet needle to frequency variations.

a) Measuring recording, see Figure D.1

- Ordinate: power system frequency, taken from wall socket, filtered (low-pass filter, frequency 55 Hz).
- Measuring instrument: cycle measuring instrument with 0,000 25 Hz resolution within 2 s[1] integration time.
- Measuring uncertainty:

  $|f_n| = 10^{-5}$ = 0,001 %, $|\Delta f|$ = 0,000 5 Hz.
- Abscissa: needle stoke Y_{nz} in percent.
- Measuring instrument: capacitive angular transmitter, resolution approximately 0,01 mm needle stroke.
- Measuring uncertainty:

  $|f_y|$ = 0,01 % needle stroke.

b) Result and evaluation

- Dead band (vertical distance of the envelope line): 0,011 1 Hz or related to 50 Hz it gives $2{,}2 \times 10^{-4}$.
- Insensitivity: $1{,}1 \times 10^{-4}$ (setpoint value according to IEC 61362: 2×10^{-4}) corresponding to 0,005 5 Hz.
- Permanent speed droop:

$$b_p = \frac{\Delta f[\text{Hz}]/50}{\Delta Y_{nz}/Y_{nz\,max}} \times 100\ \% \sim 4\ \%.$$

- The guarantee for a peak-load power plant is fulfilled.

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[1] Possible in a smooth grid/must be reduced in a rough grid.

D.2 Insensitivity test under power control with time characteristics (example referring to 4.1 and 6.6.3.3.3)

6-jet Pelton turbine, H_r = 1 260 m, P_{Gr} = 260 MW; electronic PI power controller; machine in network operation; superimposed speed droop switched off; insensitivity of a jet needle with abrupt power set-point step change; minimum step amplitude ±3 mV corresponding to 160 kW or 0,06 % of total load.

a) Measuring recording, see Figure D.2

- Ordinate: needle stroke Y_{nz} in mV as unit step response.
- Measuring instrument: capacitive angular transmitter, resolution approximately 0,01 mm.
- Measuring uncertainty: $|f_y|$ = approximately 0,01 % needle stroke.
- Abscissa: time.

b) Result and evaluation

- Clear response to a set-point step change of ±0,06 % of full load.
- Insensitivity: $i_X/2 < 6 \times 10^{-4}$ (set-point value according to IEC 61362: $i_X/2 < 1 \times 10^{-2}$).
- The guarantee for a peak-load power plant is fulfilled.

D.3 Flutter test of 2 regulated quantities with X-Y recording (example referring to 6.6.3.3.4)

Pump turbine, H_r = 350 m, P_{Gr} = 275 MW.

Electronic speed and power controller with power pre-control characteristic curve in transfer circuit.

Individual guide vane control.

Slow adjustment of gate limiter in the range between 50 % and 80 % guide vane opening.

a) Measuring recording, see Figure D.3

- Ordinate: in each case, stroke of guide vane No. 12, Y_{12ga} in percent.
- Abscissa: stroke of guide vanes Nos. 2 and 20, Y_{2ga}, Y_{20ga} in percent.
- Measuring instruments for ordinate and abscissa:

  Angular transmitter (feedback transducer), resolution approximately 0,005 % of full guide vane angle.
- Measuring uncertainty: $|f_y|$ = 0,01 % of full guide vane angle.

b) Result and evaluation

- Flutter performance: largest deviation approximately 0,12 % between guide vanes 12 and 20, and approximately 0,15 % between guide vanes 2 and 12.
- The synchronous operation of the guide vanes is good.
- The real differences can be a little smaller due to the effect of the amplifiers' delay.

D.4 Measurement of a unit step response with PID speed controller (example referring to 4.1; 6.6.1.2; 6.6.3.1)

Pump turbine, H_r = 430 m, P_{Gr} = 154 MW.

Electronic PID speed controller with permanent speed droop, individual guide vane control, actuator laws are preset electronically at the controller output.

Unit in grid operation, controller speed input open, controller mode “isolated operation“.

Input of a fictitious speed step of +1 %.

a) Measuring recording, see Figure D.4

- Ordinate 1: percentage scale for speed controller output Y_1, amplifier input Y_2, (according to actuator laws), mean value of servomotor stroke Y_{ga}, generator actual power value P_G, trigger signal (without scale).
- Ordinate 2: head on pressure side ΔH in m.
- Measuring instruments: industrial measuring instruments.
- Measuring uncertainty (estimation):

  For all percentage values related to the nominal range, approximately ±1 % absolute; for the head ±2 m.
- Abscissa: time.

b) Result and evaluation

- The speed controller output shows a clear PID behaviour.
- Due to the limitation of the actuating speed, the derivative action at the amplifier input can hardly be recognised. The same applies to the servomotor movement. The derivative D-term mainly serves for compensating delays and insensitivities.
- The average servomotor movement starts delayed by $T_q \approx$ 0,25 s.
- The power characteristic clearly shows the influence of the pressure surge; power only starts changing in the correct direction after approximately 3,6 s (non minimum phase behaviour).

D.5 Measurement of a unit step response with speed control for determination of PID controller parameters (example referring to 4.1; 6.6.1.2; 6.6.3.1)

2-jet Pelton turbine, H_r = 714 m, P_{Gr} = 30 MW; digital speed controller with PID algorithm and permanent speed droop; unit in grid operation; speed controller input open; mode of speed controller - “isolated operation“; input of a fictitious speed step of –0,42 %.

a) Measuring recording, see Figure D.5a)

- Ordinate 1: speed n in percent.
- Ordinate 2: penstock pressure H in m.
- Ordinate 3: percentage scale for speed controller output Y, needle stroke Y_{nz} and generator power output P_G.

- Measuring instruments for ordinates: industrial measuring instruments.
- Measuring uncertainty (estimation):

  For all percentage values related to the nominal range, approximately ±1 % absolute; for the head ±2 m.
- Abscissa: time.

b) Measuring recording, see Figure D.5b)

The controller output Y and the needle stroke Y_{nz} are plotted scaled up.

c) Result and evaluation

- The speed controller output shows PID behaviour.
- Considering the sudden frequency change of x_{i} = –0,21 Hz = –0,42 % the following controller parameters result with reference to the controller output:
  - proportional gain: $K_{\mathrm{p}} = \frac{1}{0{,}004\,2} \times 0{,}012\,5 = 3$ (servomotor stroke: 1,25 %);
  - integral action time: $T_{\mathrm{i}} \sim 6{,}5$ s (sub-tangent);
  - permanent speed droop: $b_{\mathrm{p}} = \frac{0{,}004\,2}{0{,}106} \times 100\,\% = 4\,\%$ (servomotor stroke: 10,6 %).
- The uncertainty of the evaluation – mainly due to reading errors – is estimated to be

  $| \Delta K_{\mathrm{p}} | \approx 0{,}2$; $| \Delta T_{\mathrm{i}} | \approx 0{,}5$ s; $| \Delta b_{\mathrm{p}} | \approx 0{,}16$ % (4 % of b_{p} = 4 %).
- The D-part at the speed controller output can be clearly recognised; it is practically eliminated by the limitation of the positioning speed of the servomotor.

D.6 Measurement of a unit step response in isolated operation (example referring to 4.1; 6.6.1.2; 6.6.3.1)

2-jet Pelton turbine, H_{r} = 714 m, P_{Gr} = 30 MW.

Digital speed controller with PI – algorithm and permanent speed droop; isolated grid operation with load from pumps.

Load step –4,6 MW = –15,3 % P_{Gr}.

a) Measuring recording, see Figure D.6

- Ordinate 1: speed n in percent.
- Ordinate 2: percentage scale for penstock pressure H and deflector stroke Y_{de}.
- Ordinate 3: percentage scale for speed controller output Y, needle stroke Y_{nz} and generator power P_{G}.
- Measuring instruments for ordinates: industrial measuring instruments.
- Measuring uncertainty (estimation):

  For all percentage values related to the nominal range approximately ±1 % absolute; for the head ±2 m.
- Abscissa: time.

b) Result and evaluation

- The frequency rises temporarily by approximately 3 % causing the deflectors to engage. After a short undershoot, the frequency reaches the new final value after approximately 45 s.
- The speed controller output overrides in the closing direction.
- The needles close for about 7 s with maximum velocity until speed decreases again and reaches the new final value after about 30 s.
- The pressure variations die out relatively quick, a small pressure oscillation remains corresponding to a respective power fluctuation, double amplitude ~0,5 %. Frequency variations can hardly be noticed.
- The control circuit is stable.

D.7 Measurement of unit step responses with power control (example referring to 4.1; 6.6.1.3; 6.6.3.1)

2-jet Pelton turbine, H_r = 714 m, P_{Gr} = 30 MW.

Digital power controller with PI algorithm and permanent speed regulation without power pre-control characteristic; unit connected to the grid with power controller.

Input of fictitious frequency steps of ±0,42 % at the power controller frequency input.

a) Measuring recording, see Figure D.7

- Ordinate 1: speed n in percent.
- Ordinate 2: penstock pressure H in m.
- Ordinate 3: percentage scale for controller output Y, needle stroke Y_{nz} and generator power P_G.
- Measuring instruments for ordinates: industrial measuring instruments.
- Measuring uncertainty (estimation):

  For all percentage values related to the nominal range approximately ±1 % absolute; for the head ±2 m.
- Abscissa: time.

b) Result and evaluation

- The power controller output shows PI behaviour.
- The limitation of the closing velocity can clearly be noted.
- In each case, the new load is reached after approximately 35 s.
- Permanent speed droop referred to the power $b_p \approx 3$ %.

D.8 Measurement of unit step responses with power control (example referring to 4.1; 6.6.1.3; 6.6.3.1)

Pump turbine, H_r = 350 m, P_{Gr} = 275 MW.

Electronic power controller with power pre-control characteristic.

Individual guide vane control.

Unit connected to the grid with power control.

Abrupt change of the power set-point.

a) Measuring recording, see Figure D.8

- Ordinate 1: penstock pressure H in bars.
- Ordinate 2: percentage scale for guide vane position Y_{ga} and generator power P_{G}.
- Measuring instruments for ordinates: industrial measuring instruments.
- Measuring uncertainty (estimation):

  For all percentage values related to the nominal range approximately ±1 % absolute; for the head, ±0,2 bar.
- Abscissa: time (feeding from right to left).

b) Result and evaluation

- Under the effect of the pre-control curve, the wicket gate movement is almost linear up to the final position. Since power is delayed, the wicket gate overrides a little.
- Under the influence of the pressure surge, this power changes in the first movement by approximately 1 % to the opposite side and subsequently follows the wicket gate position with a time delay of ~1,5 s when closing and ~3 s when opening.

D.9 Measurement of a unit step response with power control for determination of PI-controller parameters

(example referring to 4.1; 6.6.1.3; 6.6.3.1)

Pump turbine, H_{r} = 430 m, P_{Gr} = 154 MW.

Electronic PI power controller with power pre-control characteristic.

Individual guide vane control.

Actuating laws are pre-set electronically at the controller output.

Unit connected to the grid, controller inputs for the actual speed and power values are open; input of a fictitious sudden power variation at an additional controller input (power pre-control curve not active).

a) Measuring recording, see Figure D.9

- Ordinate 1: percentage scale for power controller output Y, mean value of the servomotor strokes Y_{ga}, generator power P_{G}, (trigger signal without scale).
- Ordinate 2: change of penstock pressure ΔH in m on pressure side.
- Measuring instruments for ordinates: industrial measuring instruments.
- Measuring uncertainty (estimation):

  For all percentage values related to the nominal range approximately ±1 % absolute; for the head ±2 m.
- Abscissa: time.

b) Result and evaluation

- The power controller output has an almost pure PI behaviour.
- The average servomotor movement starts with a delay of T_{q} = 0,27 s; the limitation of the closing velocity can clearly be seen. The real servomotor dead time is probably less since the controller output signal initially goes in the wrong direction when switching over because of the short interruption of the input signal.
- Considering a fictitious, relative, 5 % power variation on the actual power value, the following controller parameters result related to the controller output:

- Proportional gain: $K_\mathrm{P} = \dfrac{1}{0{,}05} \times 0{,}024\,7 = 0{,}49$ (servomotor stroke = 2,47 %).
- Integral action time T_i = 4,2 s (sub-tangent).
- The measuring uncertainty is estimated to be: $|\ \Delta K_\mathrm{p}\ | \approx 0{,}1$; $|\ \Delta T_\mathrm{i}\ | \approx 0{,}5$ s.
- The power curve clearly shows the influence of the pressure surge.

D.10 Measurement of a unit step response with head race level control
(example referring to 4.1; 6.6.1.4; 6.6.3.1)

Plant with 2 Francis and 2 Pelton turbines, H_r = 190 m.

For each turbine P_Gr = 6 MW, Q_r = 3,5 m^3/s.

Equalising basin of approximately 2 000 m^2 surface.

Mechanical turbine speed controller with superimposed digital level controller acting on the opening limiters of the 4 mechanical turbine controller via a three-position controller; input of a 0,5 m set-point step change when operating a Pelton turbine with P_G ~ 4,9 MW.

Limits: minimum load 1 MW,
maximum load 5,9 MW.

a) Measuring recording, see Figures D.10a) and D.10b)

Figure 10a)

- Ordinate: head race level set-point and actual value in m.
- Abscissa: time.

Figure 10b)

- Ordinate 1: variation of penstock pressure ΔH in m.
- Ordinate 2: generator power P_G in MW.
- Abscissa: time.

Measuring instruments: industrial measuring instruments, digital recorder.

Measuring uncertainty (estimation): level ±0,02 m; load ±0,1 % of nominal load.

b) Result and evaluation

The actual level value moves into the new position by way of damped oscillation; the largest overshoot is approximately 0,1 m, thus remaining below the admissible deviation of 0,2 m. In order to keep the ice of the basin as low as possible in winter time (one-unit operation) a slight tendency to level oscillation is welcome.

Temporarily, the turbines are reaching both load limits.

D.11 Measurement of the unit step responses with head race level control, in multi-unit operations
(example referring to 4.1.2; 6.6.1.4; 6.6.3.1)

Plant with 2 Francis and 2 Pelton turbines, H_r = 190 m.

For each turbine P_Gr = 6 MW, Q_r = 3,5 m^3/s.

Equalising basin of approximately 2 000 m^2 surface.

Mechanical turbine controller with superimposed digital level controller acting on the opening limiters of the 4 mechanical turbine controllers via a three-position controller.

Plant operating 2 Francis and 1 Pelton turbine.

11:20 h – input of a –0,5 m set-point step change,

12:03 h – input of a +0,5 m set-point step change,

12:50 h – unit 3 switched off from level control and machine load reduced to 1 MW.

Limits: minimum load – Francis turbine – 2 MW,
minimum load – Pelton turbine – 1 MW,
maximum load – 5,5 MW.

a) Measuring recording, see Figure D.11a) and Figure D.11b)

Figure D.11a)

- Ordinate: head race level set-point and actual value in m.
- Abscissa: time.

Figure D.11b)

- Ordinate 1: variation of penstock pressure ΔH in m.
- Ordinate 2: turbine loads in MW.
- Abscissa: time.
- Measuring instruments: industrial measuring instruments, digital recorder.
- Measuring uncertainty (estimation): level ±0,02 m; load ±0,1 % of nominal load.

b) Result and evaluation

- The actual level value reaches the new set-point value after an overshoot. The overshoot is approximately 0,1 m, thus remaining below the admissible deviation of 0,2 m.
- Small control movements of the unit are guaranteed.
- Temporarily, the turbines are reaching both load limits.

D.12 Measurement of a load rejection with transition into no-load operation (example referring to 4.2; 6.6.1.2)

Kaplan turbine, H_r = 2,75 m, P_Gr = 1 395 kW.

Electronic PID speed controller.

Generator separated from the grid at P_G = 1 360 kW.

a) Measuring recording, see Figure D.12

- Ordinate 1: runner servomotor position Y_ru in percent.
- Ordinate 2: wicket gate servomotor position Y_ga in percent.
- Ordinate 3: speed n in percent.
- Measuring instruments for ordinates: industrial measuring instruments assigned voltage signals from the speed controller.
- Measuring uncertainty (estimation): for all percentage parameters approximately ±1,5 % in relation to the nominal range.
- Abscissa: time.

b) Result and evaluation

- In order to avoid a speed undershoot after the overshoot, the wicket gate closes stepwise, in each case at maximum velocity.
- At approximately 103 % speed, the wicket gate reopens without having reached the closed position.
- The runner closes at the value determined by the wicket gate/runner correlation. In the no-load range, it does not interfere with the control to achieve better stability.
- The speed reaches the nominal value almost aperiodically.

D.13 Measurement of a load rejection with limit control of surge and suction waves and with transition into no-load operation

(example referring to 4.2; 6.6.1.2)

Kaplan turbine, H_r = 2,75 m, P_{Gr} = 1 395 kW.

Electronic PID speed controller.

Generator is disconnected from the system at P_G = 1 300 kW.

a) Measuring recording, see Figure D.13

- Ordinate 1: runner servomotor position Y_{ru} in percent.
- Ordinate 2: wicket gate servomotor position Y_{ga} in percent.
- Ordinate 3: speed n in percent.
- Measuring instruments for ordinates: industrial measuring instruments assigned voltage signals from the controller.
- Measuring uncertainty (estimation): for all percentage parameters approximately ±1,5 % in relation to the nominal range.
- Abscissa: time.

b) Result and evaluation

- Contrary to example D.12, the runner is fixed at the so-called “surge-opening“ for limitation of flow change and thus surge and suction waves. When this state is reset (released, removed, cancelled), the runner slowly closes to the normal cam position.
- Initially, the wicket gate closes at the maximum positioning speed, but is then stopped at a relatively large opening. So when, for instance, reaching the nominal speed, the wicket gate increases the opening up to the larger no-load position corresponding to the runner position.
- Due to the turbulent surge operation (draft tube vortex), the wicket gate performs large control movements in order to be able to maintain a steady speed. The speed shows slight variations.
- The maximum speed increase is, due to the larger runner opening, smaller than in example D.12.

D.14 Measurement of a start-up process under load

(example referring to 4.2)

6-jet Pelton turbine, H_r = 1 260 m, P_{Gr} = 260 MW. Needle No. 6 is controlled to open for start-up, when reaching 20 % of nominal speed the needles 1 to 5 open temporarily in addition for faster acceleration of the unit.

a) Measuring recording, see Figure D.14

- Ordinate 1: head change ΔH in m.
- Ordinate 2: percentage scale for needle positions 1 to 6 Y_{nz}, setpoint generator load $P_{G\ set}$, actual generator load $P_{G\ act}$, speed n.
- Measuring instruments for ordinates: industrial measuring instruments.
- Measuring uncertainty (estimation): for all percentage parameters approximately ±1 % absolute in relation to the nominal range; for head change ±4 m.
- Abscissa: time.

b) Result and evaluation

- 80 % of the nominal speed is reached after $t_{0,8}$ = 38 s (IEC 61362).
- Readiness for synchronising reached after $t_{SR} \approx 70\ s = 1{,}84 \times t_{0,8}$.
- Synchronisation after $t_s \approx 71\ s = 1{,}87 \times t_{0,8}$ (set-point according to IEC 61362 $t_s/t_{0,8}$ = 1,5 to 5,0).
- Readiness for synchronisation and synchronisation perfectly fulfils the requirements.
- The load increase in the upper load range could be faster if the power controller was equipped with a power pre-control characteristic.

D.15 Measurement of changeover from full turbine load to synchronous condenser operation

(example referring to 4.2)

6-jet Pelton turbine, H_r = 1 260 m, P_{Gr} = 260 MW.

The 6 needles close at maximum positioning speed.

a) Measuring recording, see Figure D.15

- Ordinate 1: head change ΔH in m.
- Ordinate 2: percentage scale for needle stroke Y_{nz}, actual generator load $P_{G\ act}$, speed n.
- Measuring instruments for ordinates: industrial measuring instruments.
- Measuring uncertainty (estimation): for all percentage parameters approximately ±1 % absolute in relation to the nominal range; for head change ±4 m.
- Abscissa: time.

b) Result and evaluation

- Linear change of needle and load set-point values (not shown in Figure D.15).
- The needle movement in the upper opening range is non-linear as a result of the effect of the hydraulic forces.
- Closing in steps for small needle openings is necessary due to the pressure surge. Needle No. 6 closes somewhat faster (see start-up process in Figure D.14).
- The maximum head increase is 112 m, far below the admissible value.

D.16 Measurement of a power step-response in on-line simulated isolation test (example referring to 6.9)

Francis turbine, H_r = 90 m, P_{Gr} = 13 MW; servomotor stroke Y_{max} = 273 mm.

Electronic PID speed controller; generator in parallel with the interconnected grid, controller connected to the on-line isolated grid simulator.

Simulation of a power step-response with the following characteristics of the simulated isolated grid:

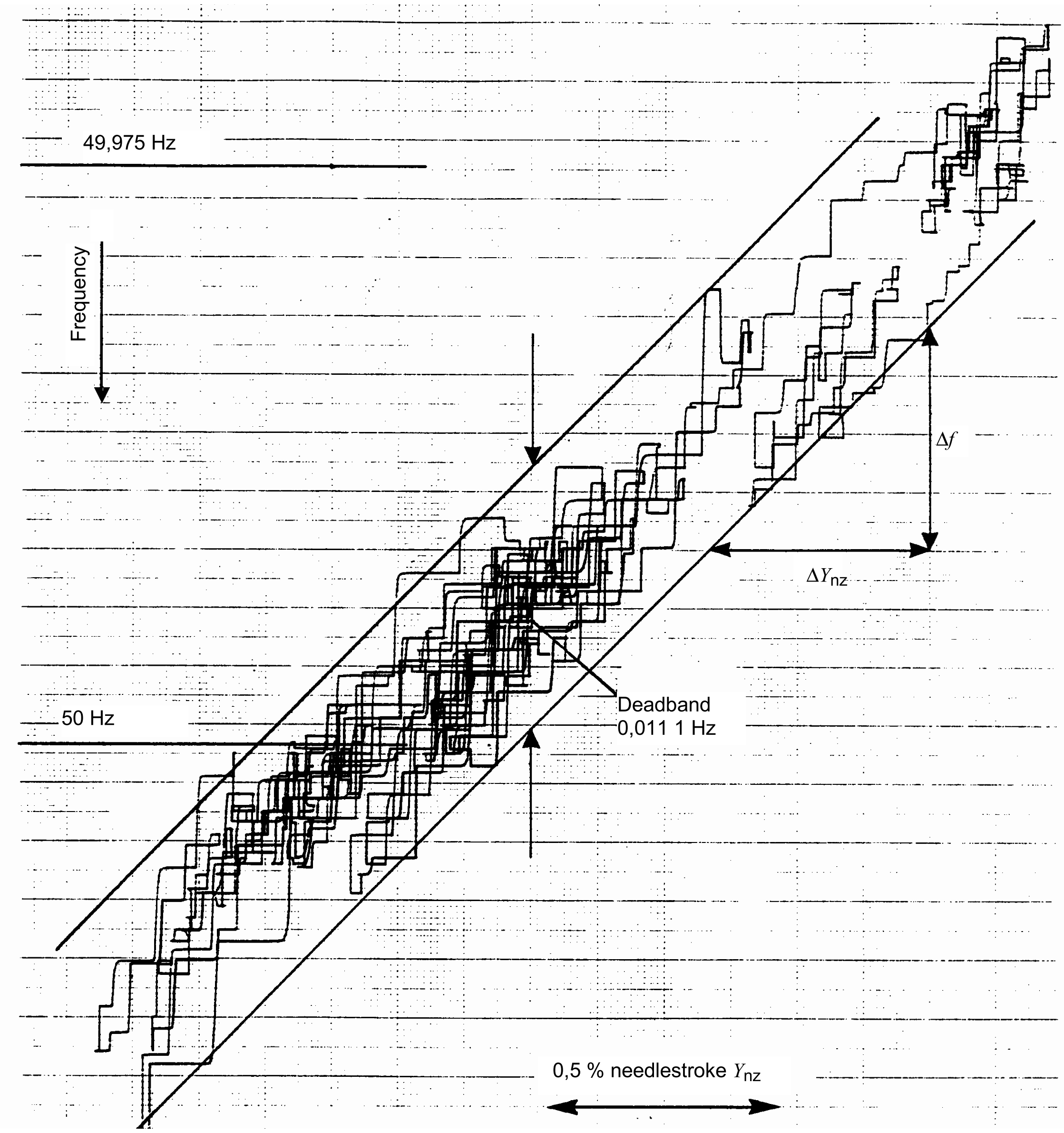
- initial power output P_{G0} = 10,5 MW,
- unit acceleration time constant T_a = 7,2 s,
- load acceleration time constant T_b = 0,
- controlled system net self-regulation factor e_n = 1 (with power and frequency expressed in "per unit"),
- incremental power ΔP_G = 2 % P_{Gr}.

a) Measuring recording, see Figure D.16

- Ordinate 1: simulated frequency.
- Ordinate 2: electrical power output.
- Ordinate 3: servomotor position.
- Ordinate 4: mechanical power.
- Abscissa: time.
- Measuring instruments for ordinates: industrial measuring instruments (excepted the torque meter combined with a remote transmission for the measurement of the mechanical power), digital recorder.
- Measuring uncertainty (estimation): less than ±1 % for all variables related to the nominal range.

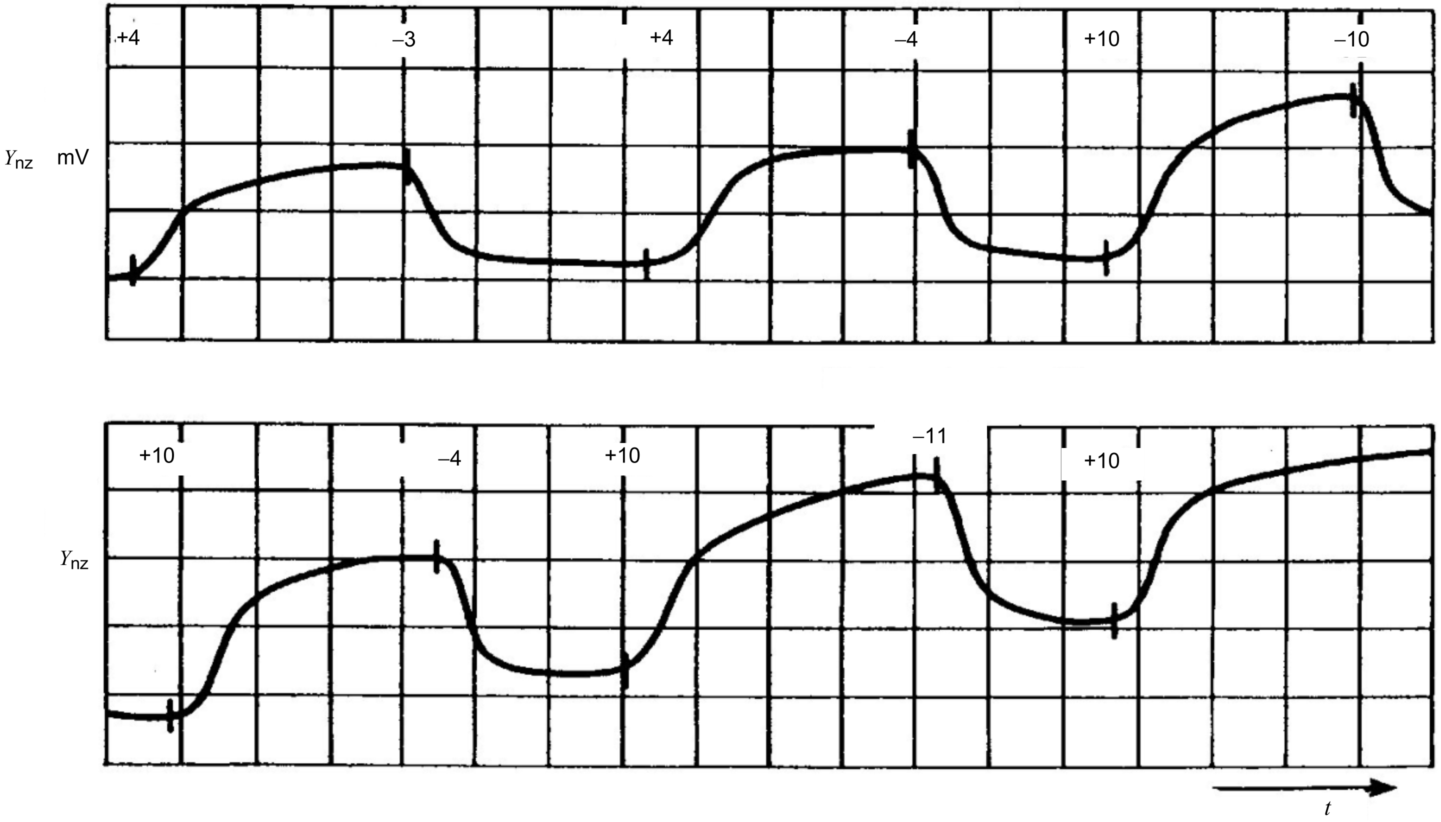
b) Result and evaluation

- The simulated frequency has a stable behaviour, similar to the result of numerical simulation; the undershoot reaches about 0,8 % of the nominal frequency for a power step of 2 % of the rated output.
- The servomotor opening, the mechanical power and the electrical power comes close to their final values in less than 3 s.
- The electrical power output is affected by electromechanical oscillations at a natural frequency between 1 Hz and 2 Hz; the amplitude of these oscillations is relatively small, and with an adapted filter on this measurement of power, the calculation of the simulated frequency is not disturbed.



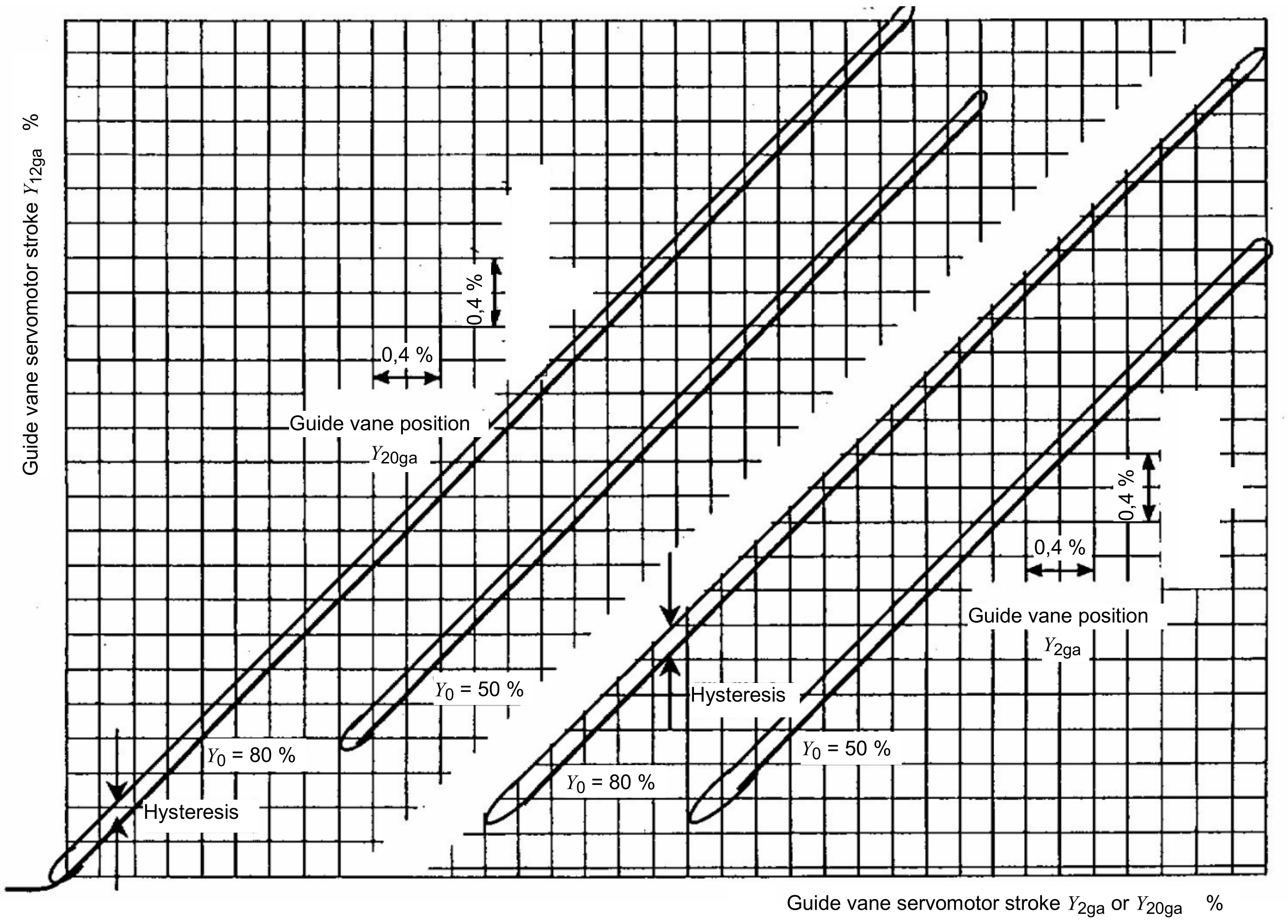
IEC 045/05

Figure D.1 – Insensitivity test under speed control with X-Y recording



IEC 046/05

Figure D.2 – Insensitivity test under power control with time characteristics



IEC 047/05

Figure D.3 – Flutter test of 2 regulated quantities with X-Y recording

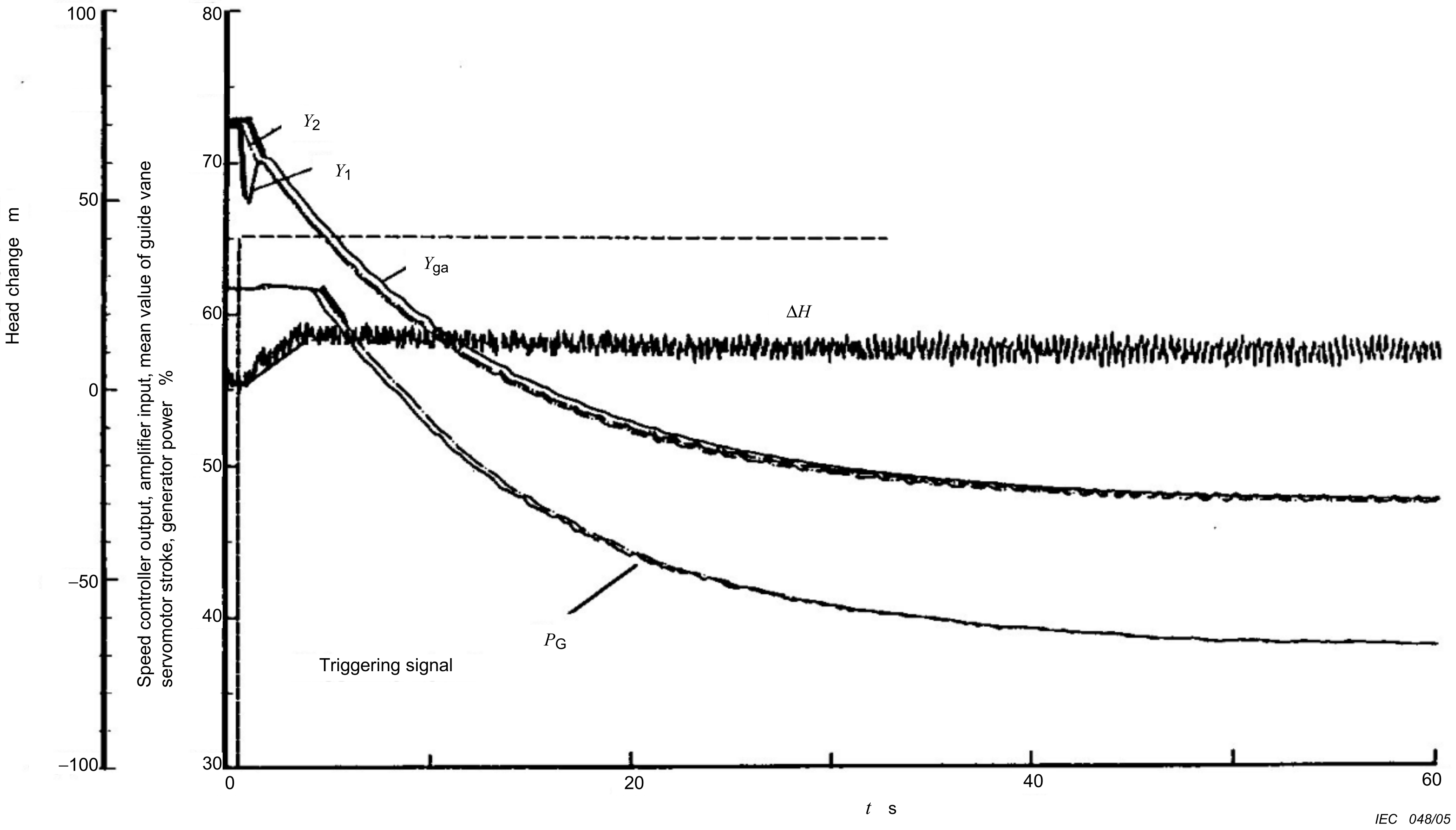
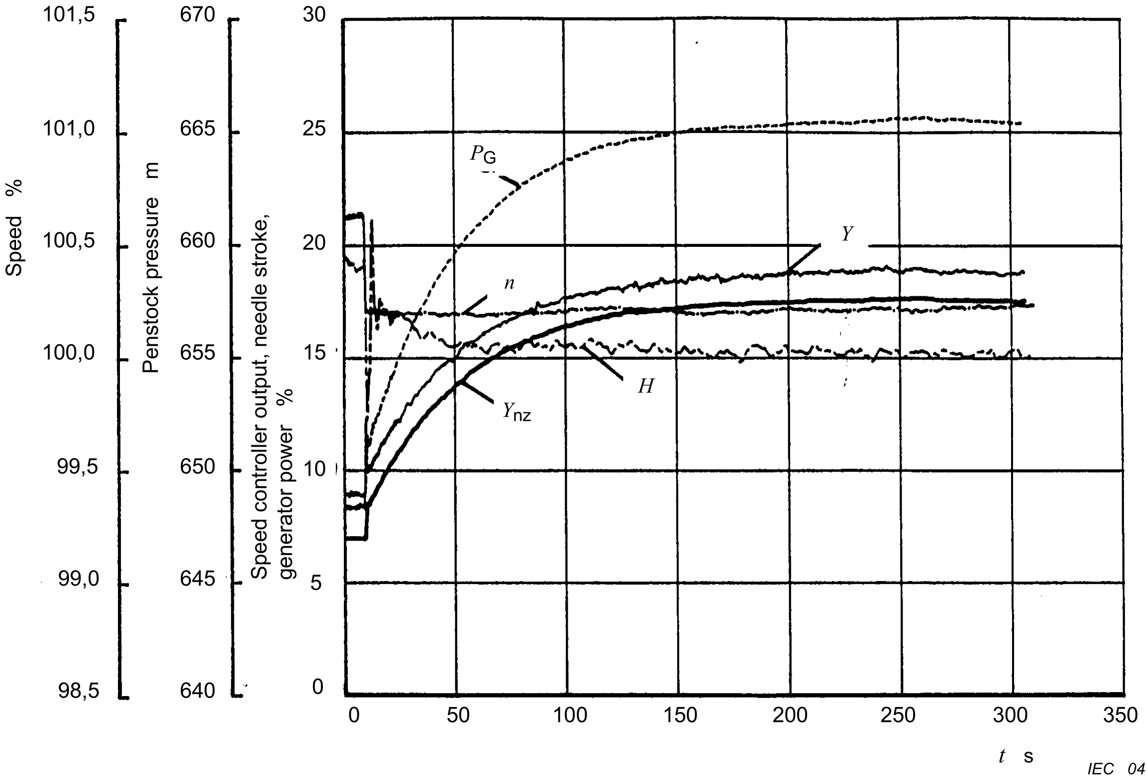
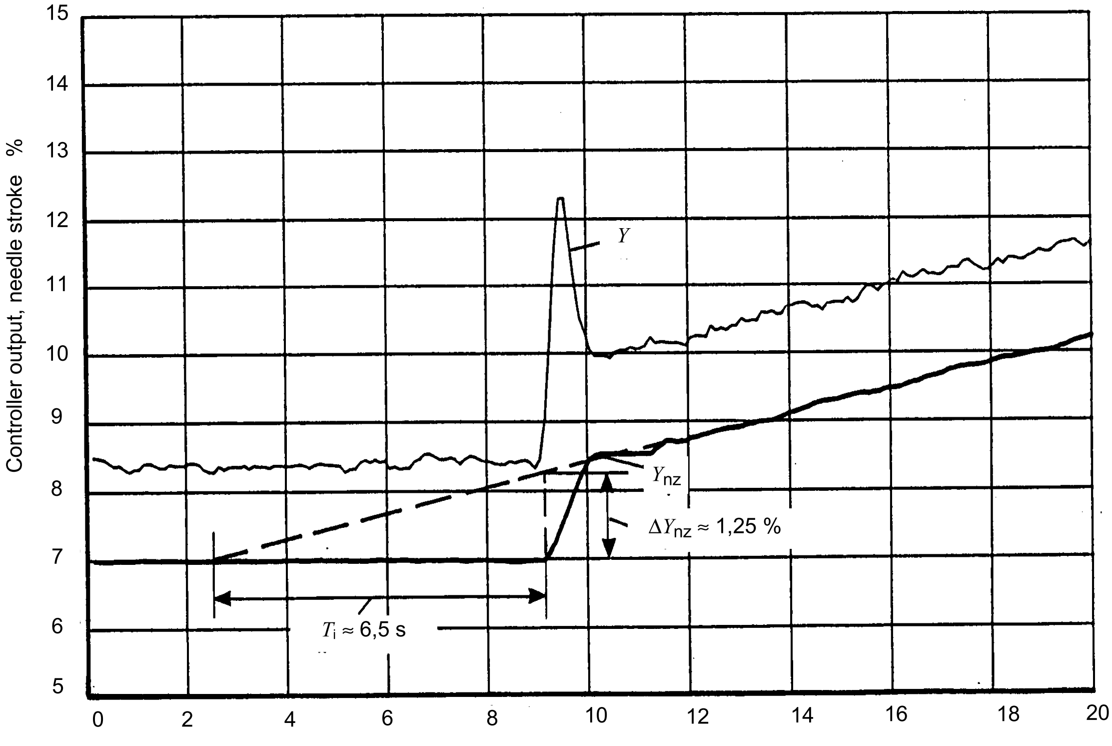


Figure D.4 – Measurement of a unit step response with PID speed controller



IEC 049/05

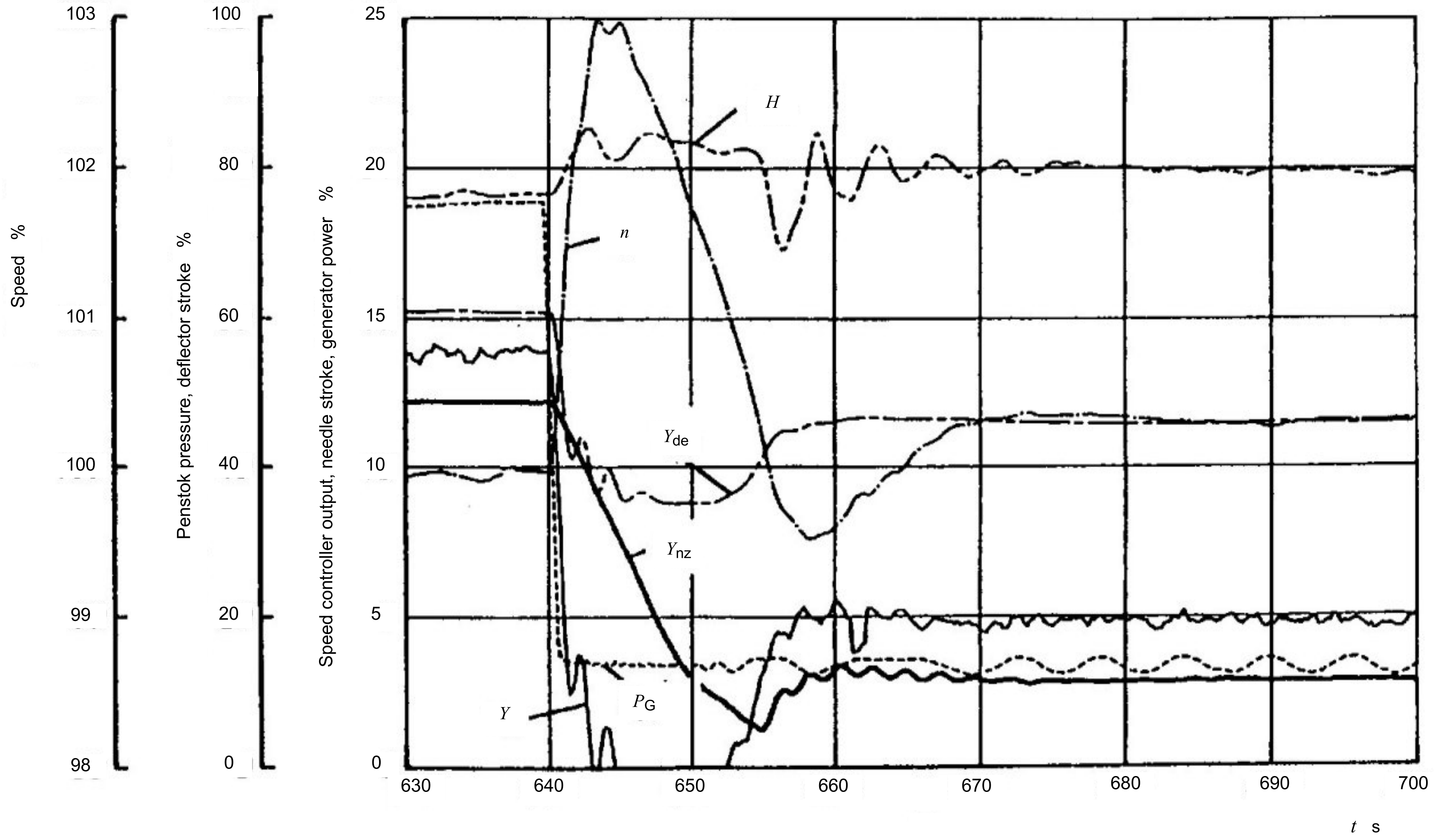
Figure D.5a)



IEC 050/05

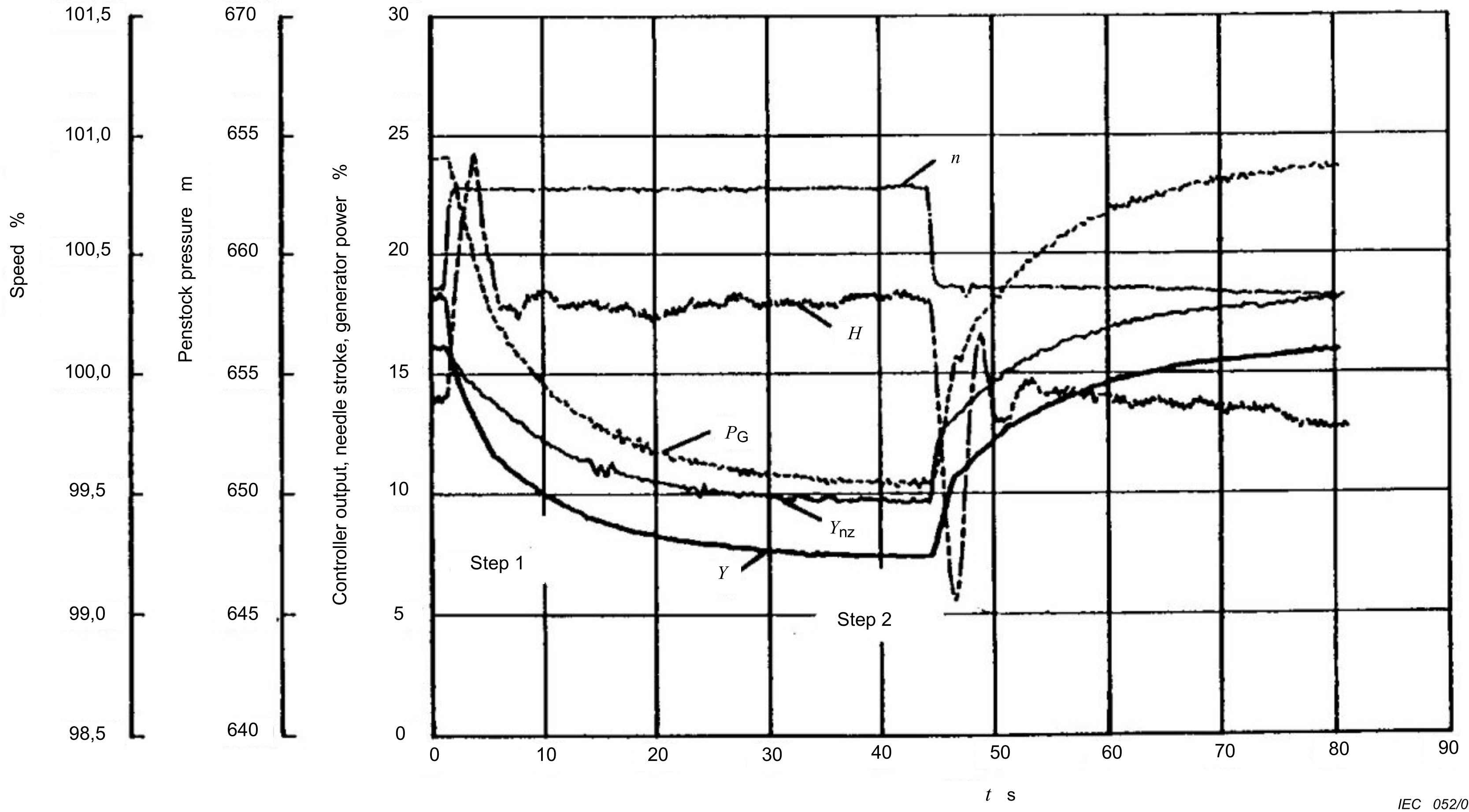
Figure D.5b)

Figure D.5 – Measurement of a unit step response with speed control for determination of PID controller parameters



IEC 051/05

Figure D. 6 – Measurement of unit step response in isolated operation



IEC 052/05

Figure D.7 – Measurement of a unit step responses with power control (Pelton turbine)

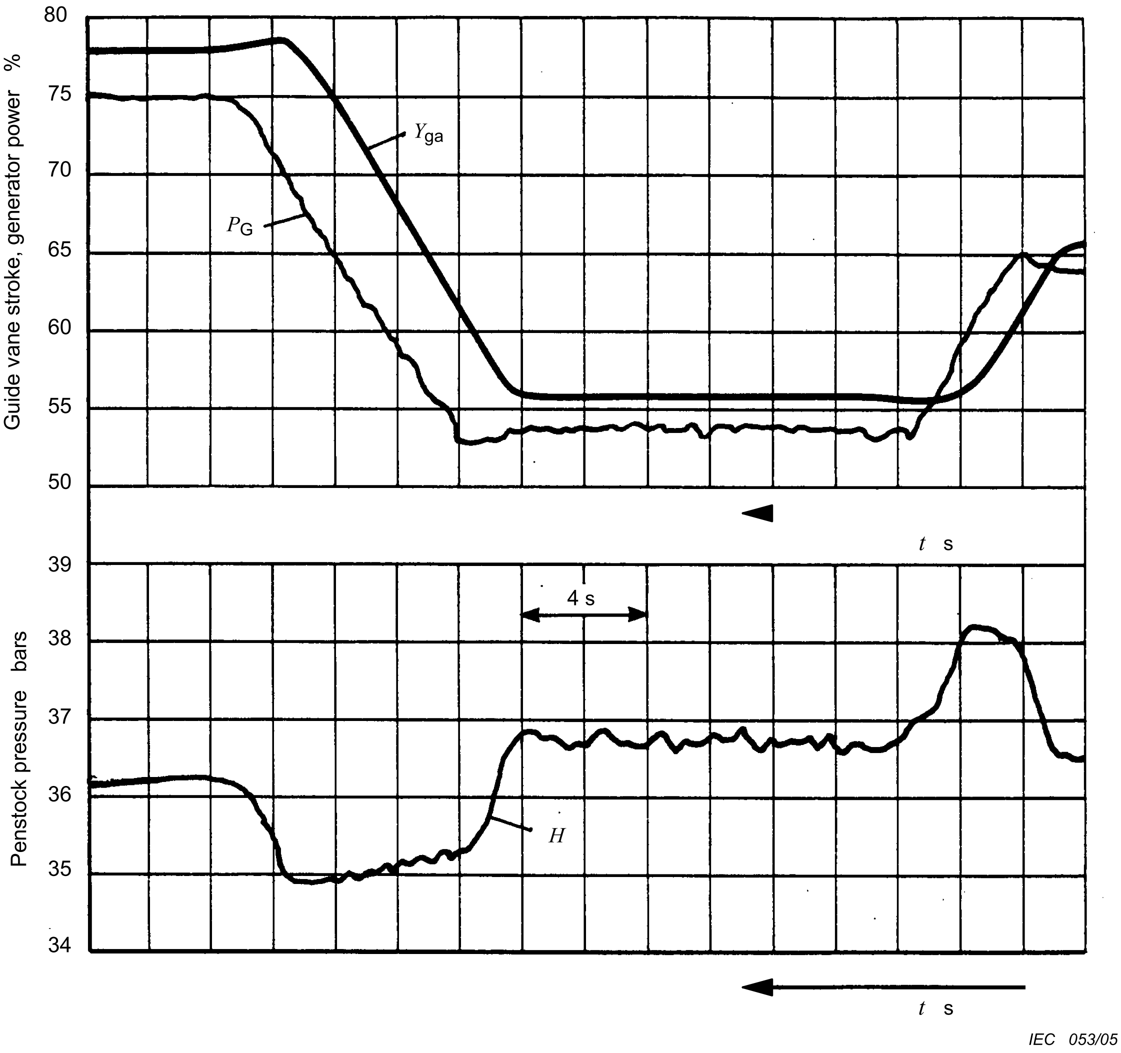


Figure D.8 – Measurement of unit step responses with power control (pump turbine)

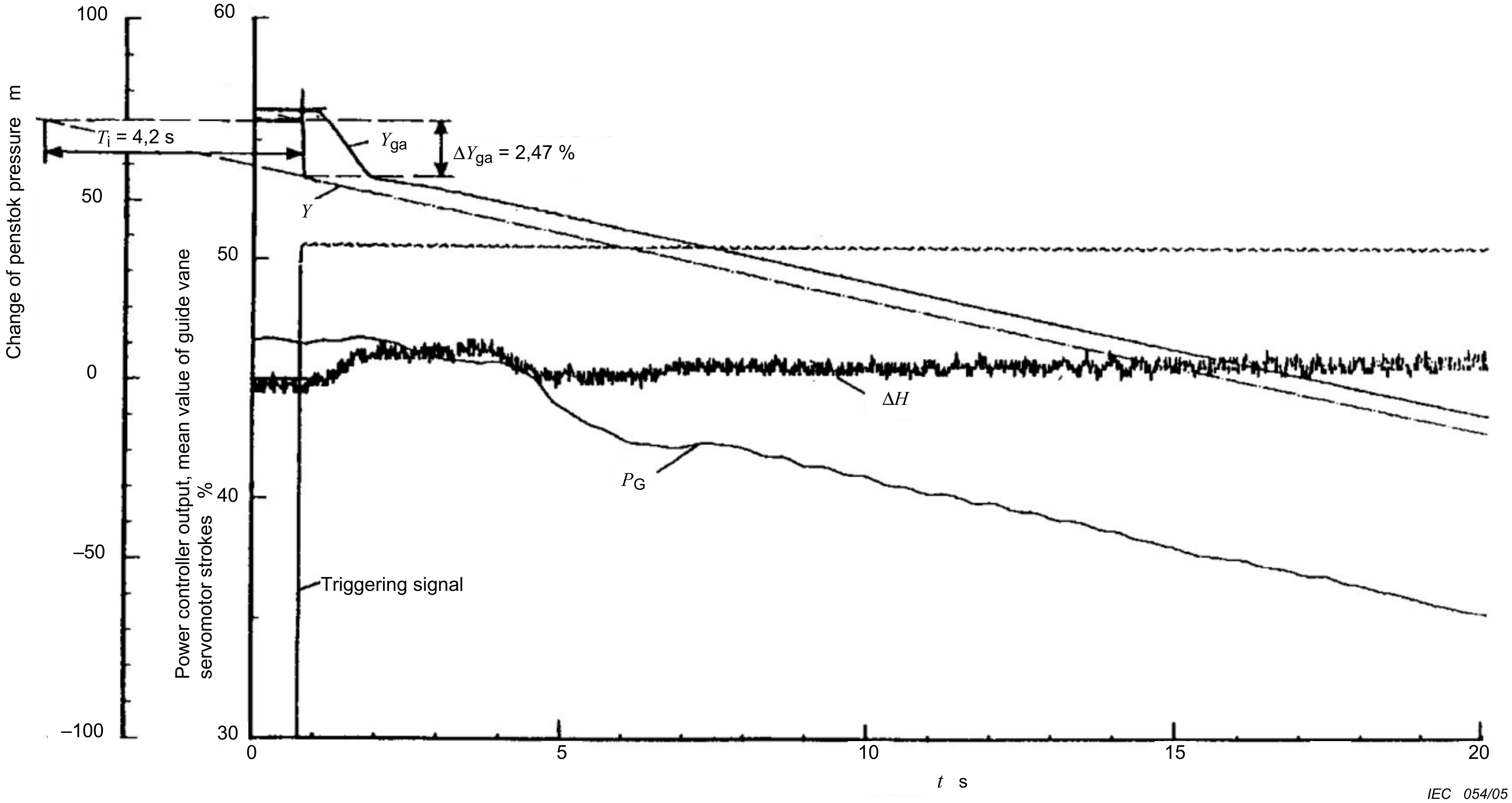


Figure D.9 – Measurement of a unit step response with power control for determination of PI-controller parameters

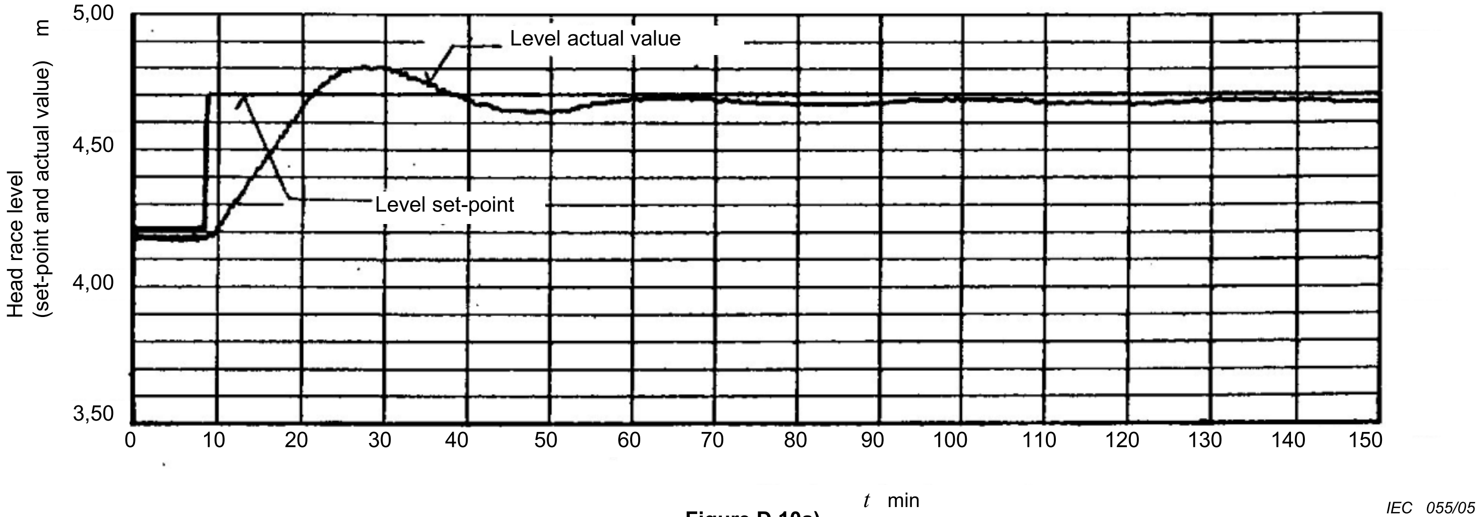


Figure D.10a)

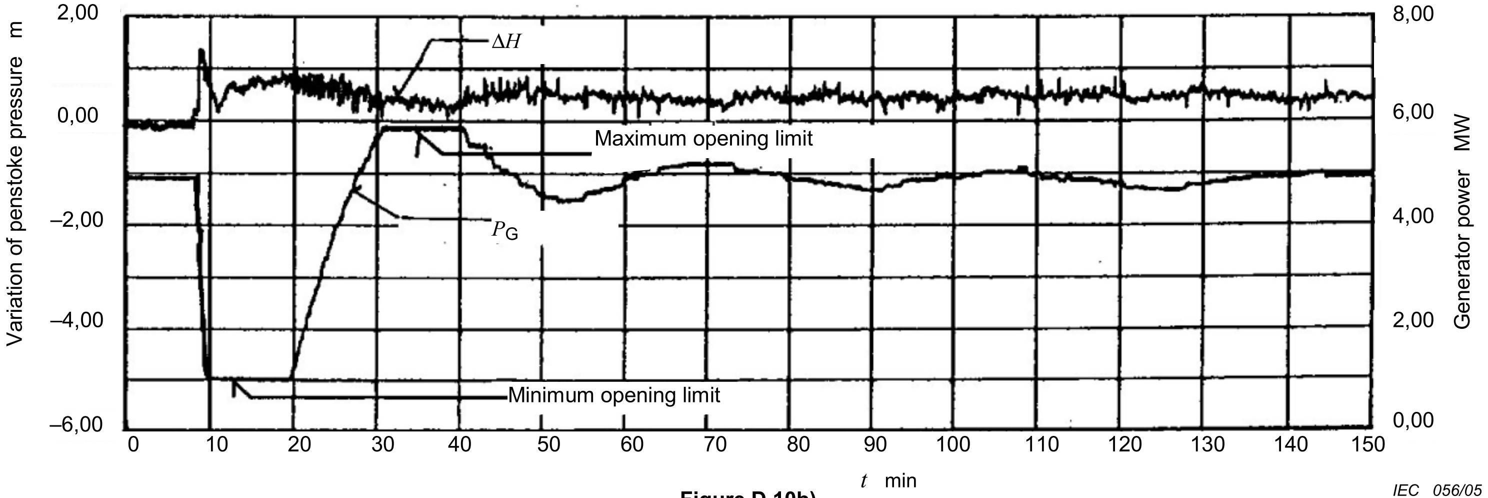


Figure D.10b)

Figure D.10 – Measurement of a unit step response with head race level control

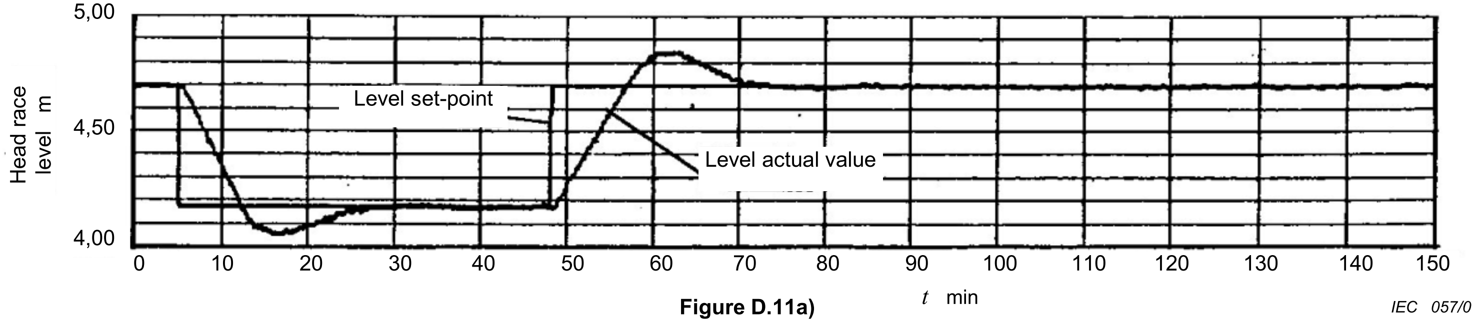


Figure D.11a)

IEC 057/05

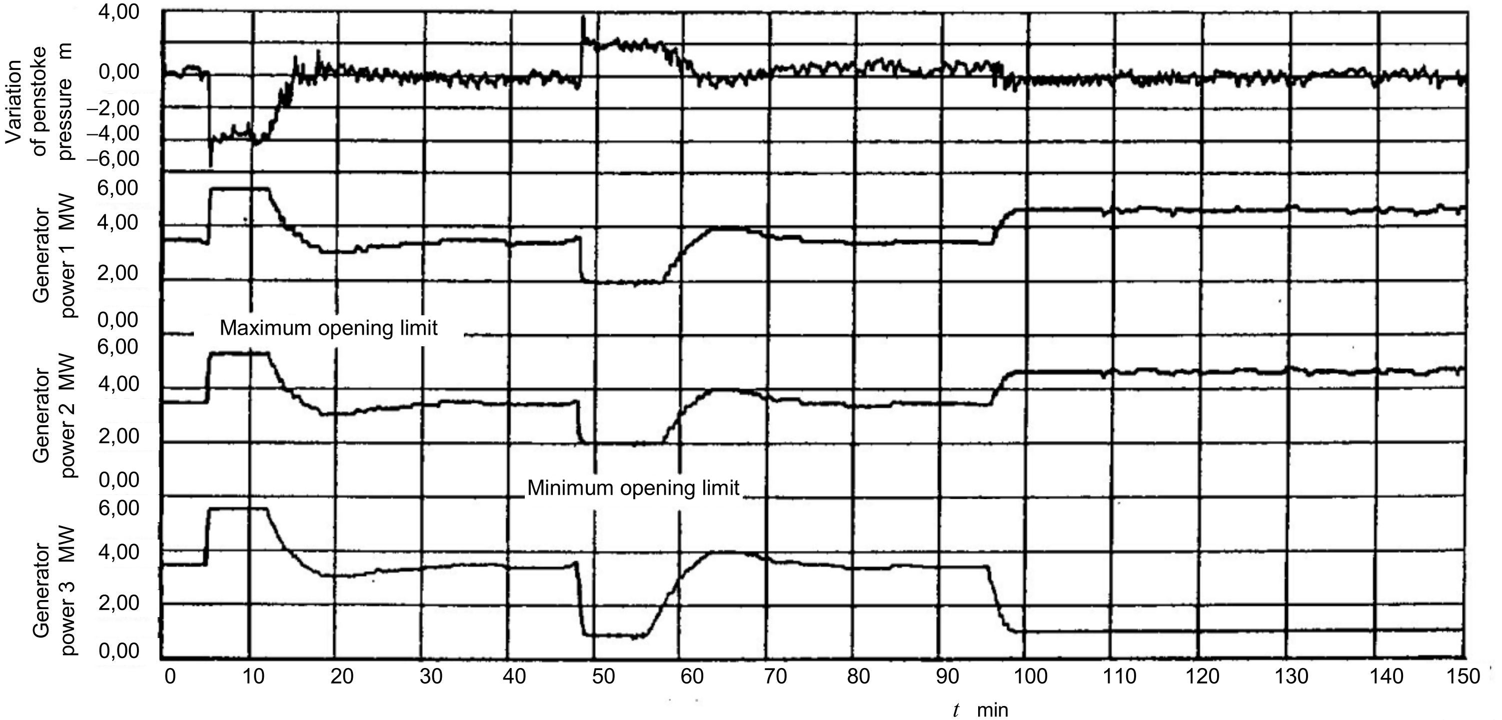


Figure D.11b)

IEC 058/05

Figure D.11 – Measurement of the unit step responses with head race level control in multi-unit operations

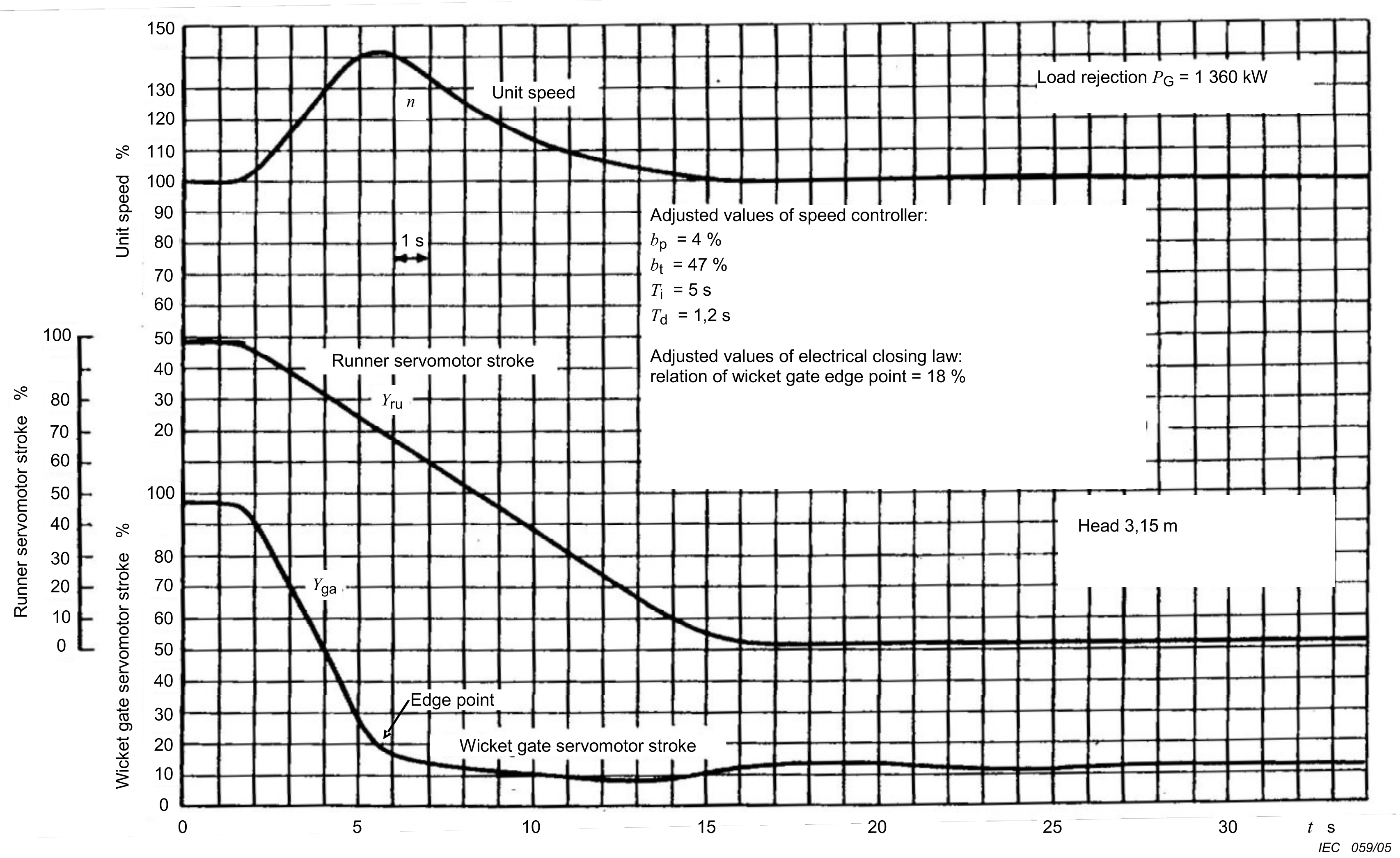
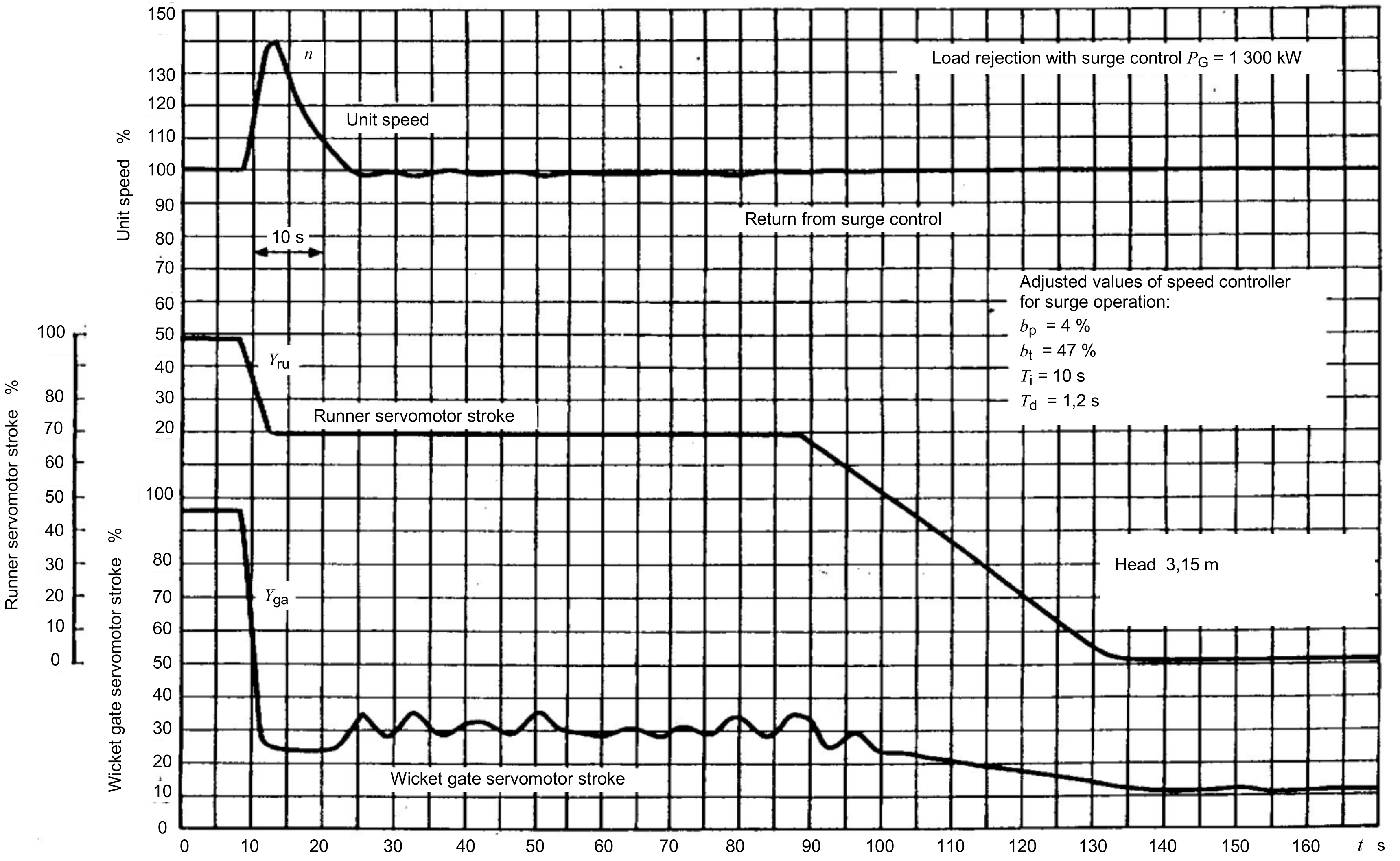
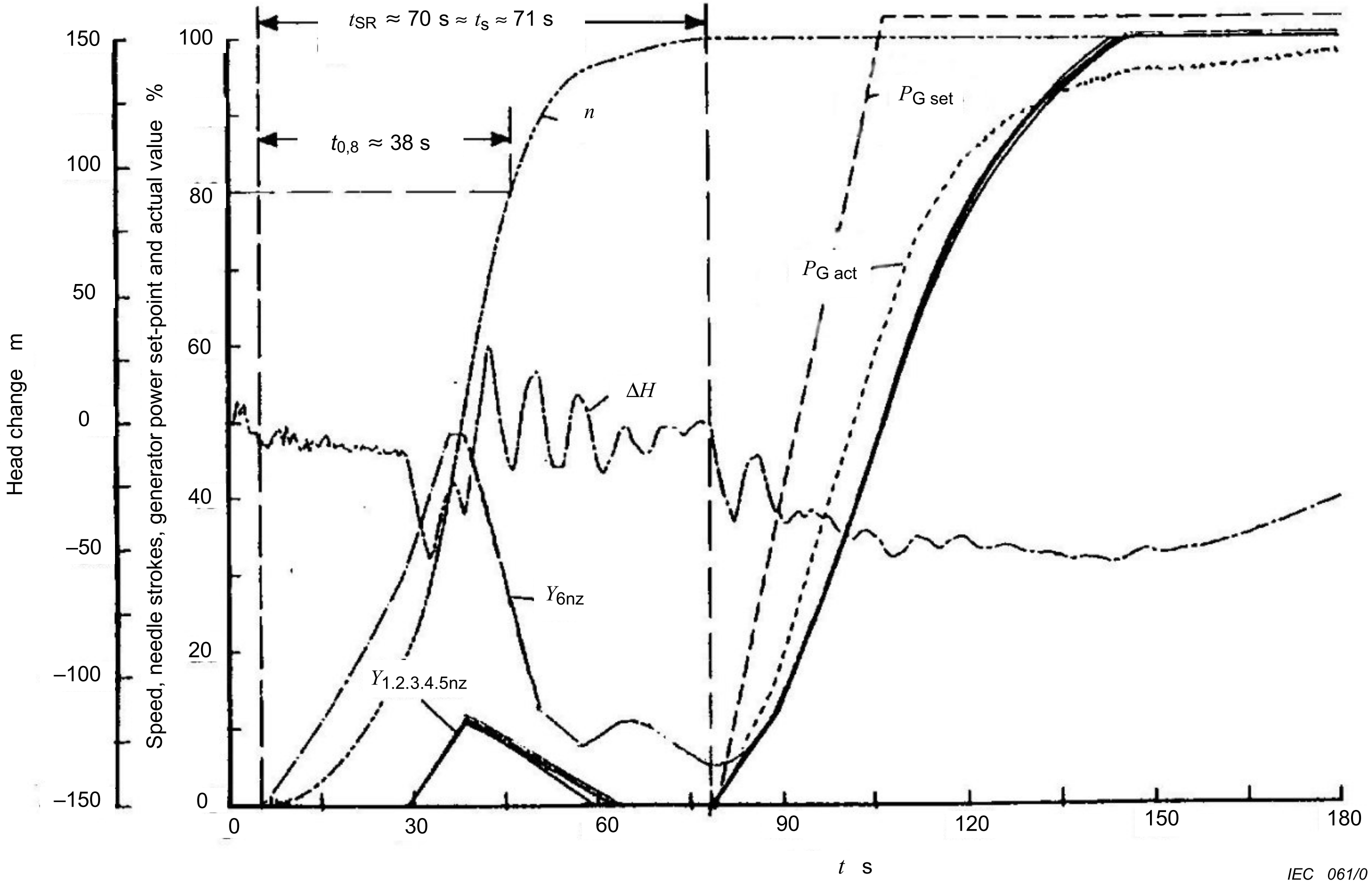


Figure D. 12 – Measurement of a load rejection with transition into no-load operation



IEC 060/05

Figure D.13 – Measurement of a load rejection with limit control of surge and suction waves and with transition into no-load operation



IEC 061/05

Figure D.14 – Measurement of a start-up process under load

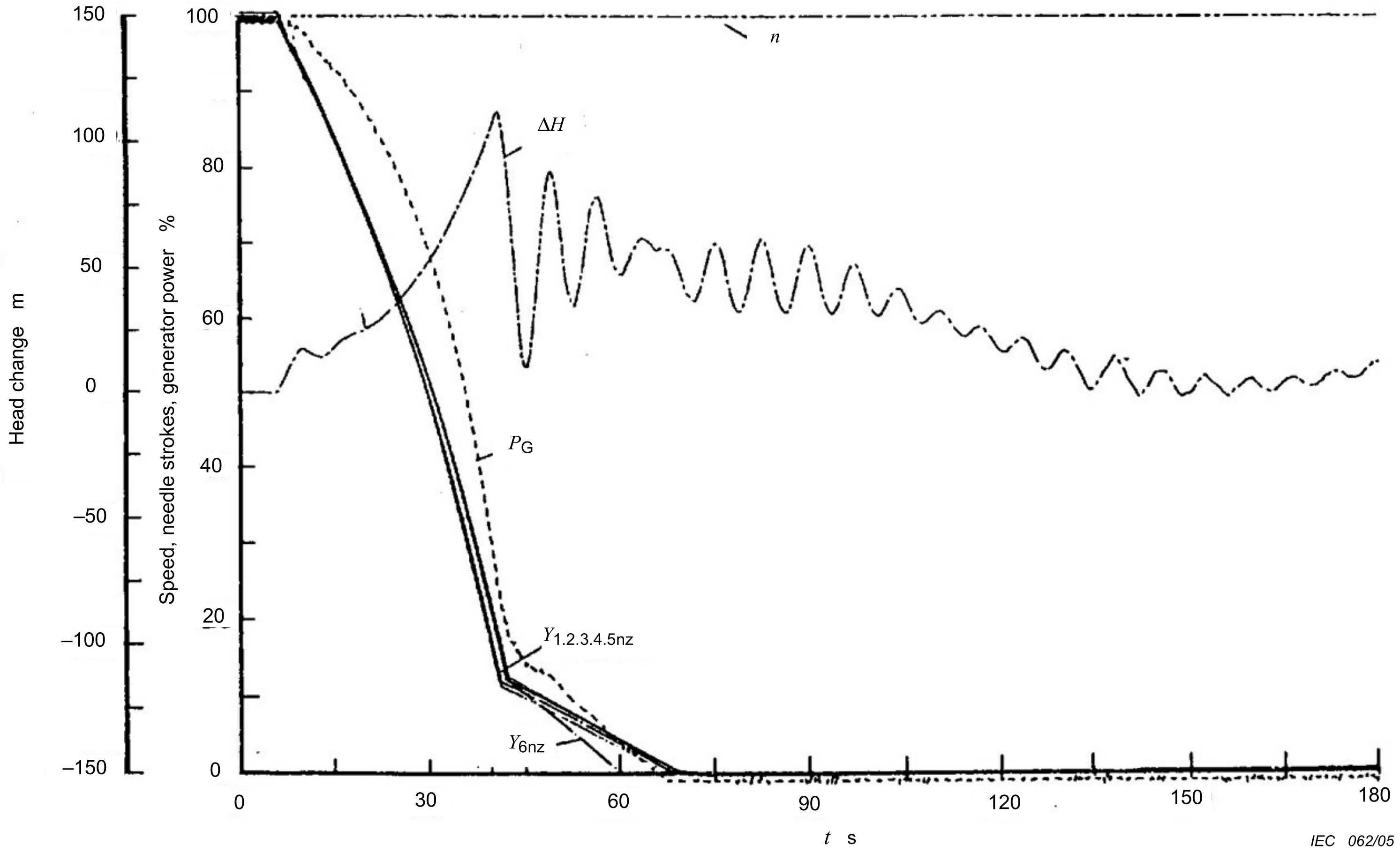


Figure D.15 – Measurement of changeover from full turbine load to synchronous condenser operation

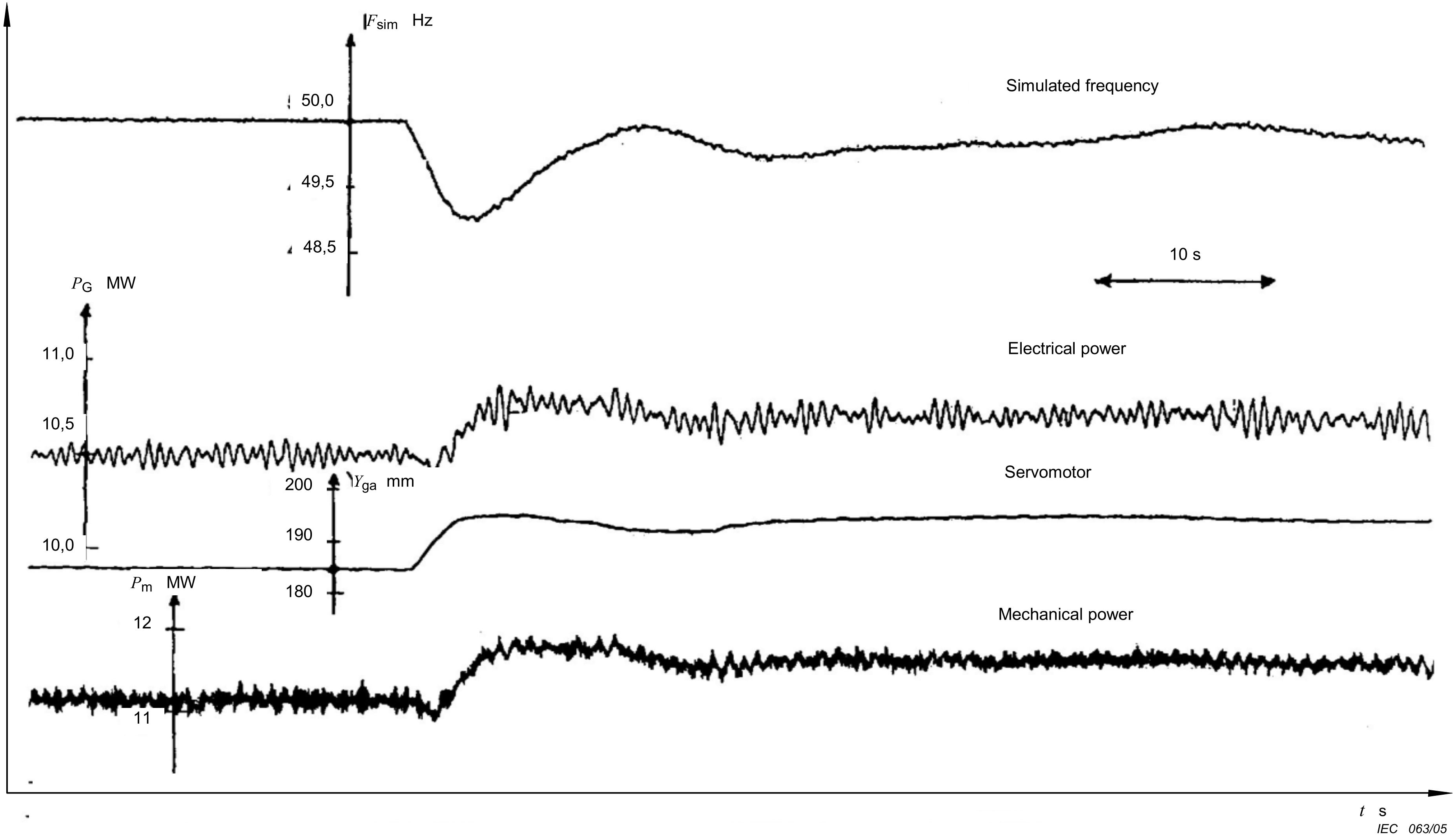


Figure D.16 – Measurement of a power step response in on-line simulated isolation test

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE Where an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60041 (mod)	1991	Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines	EN 60041	1994
IEC 60193	1999	Hydraulic turbines, storage pumps and pump-turbines - Model acceptance tests	EN 60193	1999
IEC 60545	- 1)	Guide for commissioning, operation and maintenance of hydraulic turbines	-	-
IEC 61362	1998	Guide to specification of hydraulic turbine control systems	EN 61362	1998
IEC 61000-4-2	- 1)	Electromagnetic compatibility (EMC) Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test	EN 61000-4-2	1995 2)
IEC 61000-4-3	- 1)	Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test	EN 61000-4-3	2002 2)
IEC 61000-4-6	- 1)	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	-	-

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1) Undated reference.

2) Valid edition at date of issue.

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