TECHNICAL REPORT

IEC TR 62140-2

First edition
2002-10

Fossil-fired steam power stations –

Part 2: Drum-level control

Centrales à vapeur consommant des combustibles fossiles –

Partie 2:
Contrôle du niveau d'eau des ballons

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International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FOSSIL-FIRED STEAM POWER STATIONS –

Part 2: Drum-level control

FOREWORD

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IEC 62140-2, which is a Technical Report, has been prepared by IEC technical committee 65: Industrial-process measurement and control.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
65/272/CDV	65/284/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with ISO/IEC Directives, Part 2.

IEC 62140 consists of the following parts, under the general title *Fossil-fired steam power stations:*

Part 1: Limiting controls

Part 2: Drum-level control

Part 3: Steam-temperature control

The committee has decided that the contents of this publication will remain unchanged until 2007. At this date the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

A bilingual version of this Technical Report may be issued at a later date.

INTRODUCTION

This Technical Report is part of a series of Technical Reports which contain advice on the proper design and operation of control circuits in fossil-fired power stations. They are based on technical solutions used today by some member nations and provide also the background information necessary for proper understanding.

For the time being, all the different national documents tackling the subject are deemed to be at the same level. They always present or imply particular technical solutions which, although finally aimed at satisfying similar functional user needs, are different from country to country and often inconsistent among themselves. Such documents are considered to be actual barriers to international trade.

The need for new standards formalizing an internationally agreed approach to express the functional need of fossil-fired power plant operators and suppliers is clearly identified by all the experts. Such documents could facilitate and develop the international business in this particular domain for the profit of the suppliers and the customers. The IEC 62140 series should consider the existing national documents presenting national solutions as a technical basis and should be consistent with them.

In the absence of an internationally agreed approach, this Technical Report is to be strictly considered as an example of particular technical solutions at a given time. It is only aimed at stimulating the debate in order to encourage the convergence of views on the subject and should not be transformed into an International Standard.

There are two types of technical reports within this series.

The reports of the first type refer to specific control circuits of steam generators, such as drum-level control or steam-temperature control and that under normal operational conditions.

The reports of the second type show special means to ensure proper operation also under restricted conditions, for example, during run-up and run-down or in the event of anomalous operating states, or they deal with super-ordinated control circuits, for example, load control or frequency control systems. These reports refer generally to the power station unit as a whole.

Each of the reports within this series is independent from each other; their contents, however, are largely coordinated. The series is to be supplemented.

FOSSIL-FIRED STEAM POWER STATIONS –

Part 2: Drum-level control

1 Scope

This Technical Report deals with drum-level control of fossil-fired steam power stations with natural or forced circulation.

The report starts with a description of the controlled system, its structure and design, its behaviour in steady, transient and disturbance state. From this, the required control structure may be developed. Consequently, three well-proven configurations of control circuits are shown and the field of application of each is given. The report ends with the requirements for the measuring elements and actuators which are necessary to complete the control circuits. There may be special national legal requirements, for example, regarding drum-level monitoring and safety equipments, and they would have to be considered.

2 Controlled system

2.1 Description of controlled system

Feed water is fed to the circulating system of a steam generator with natural or forced circulation, and saturated steam and eventually demineralization water are removed. If the infed and removed mass flows diverge from one another, the content of the circulating system changes, whereby the change in content is the time integral of the difference between the mass flows. Generally, only the water level in the upper drum of the circulating system is available as a measure of the content of the boiler. Lower drums which may exist in some steam generators are always completely filled with water and therefore not of further relevance in this report. The water level in the upper drum – in the following only referred to as drum – changes as long as there is a difference between the mass flows. The task of the drum-level control is therefore to adjust the feed-water flow to the steam flow in order to keep the drum-level within certain limits. The spray water flow used for steam desuperheating bypassing the drum and the blow-down water flow from the drum – in order to remove impurities – may need to be taken into account here as disturbance variables. The main disturbance variable, however, is the steam flow delivered by the steam generator; in addition, other disturbance variables, such as, for example, steam pressure, feed-water pressure, furnace output also act indirectly.

2.2 Structure and design

The behaviour of the controlled system is influenced by the following technical dimensions.

2.2.1 Size of the drum

The required minimum size of the drum is generally determined by the task of separating the saturated steam from the circulating water. The smaller the drum in relation to the boiler capacity, the more difficult level control becomes. This results from the influence of the maximum rate of change of the water level on control behaviour.

2.3 Position of the water-level set point in the drum

The water-level set point is determined by the design of the drum. As far as possible it should be positioned so that the rate of change of the water level is as small as possible, for example, half-way up a horizontal round drum.

2.3.1 Size and position of economizer

The enthalpy of the water on entry to the drum should be as close as possible to the saturated liquid enthalpy.

2.4 Steady-state and transient behaviour

2.4.1 Ideal control behaviour, definitions

A simple water-level controlled system displays “integral” behaviour as a “compensation-free controlled system” (see Figure 1a). This can be described using integration time T_1.

2.4.2 Deviations from ideal control behaviour

The actual control behaviour of the water level deviates from the ideal control behaviour for various reasons. A more accurate determination, however, is not required, as an approximation is generally sufficient to describe the control behaviour. The deviations are based on the fact that the boiling medium is a mixture of water and steam. The volume of the fluid is pressure- and temperature-dependent. As a result of this, phenomena which are similar to delay-time phenomena may arise.

If preheating does not take place up to boiling temperature in the economizer, an increase in the control flow m_{FW} reduces the void content of the evaporation system. This results in a transitory drop of the water level l (see Figure 1b). This initially anomalous behaviour (non-minimum phase response, with T_{nmpr} as a time constant for non-minimum phase response) cannot easily be described and causes difficulties, both for practical control and for theoretical treatment.

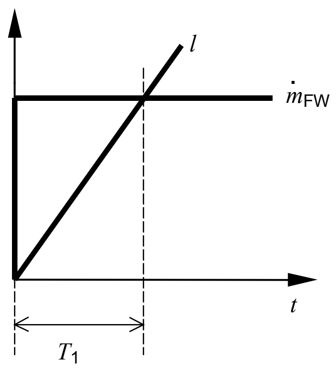

Figure 1a – Ideal behaviour

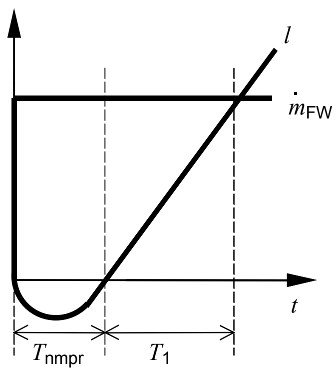

Figure 1b – Real behaviour

Figure 1 – Control behaviour of water level *l*

2.4.3 Disturbance behaviour

In order to design the control structure and equipment and to predict the achievable control performance, it is necessary to know, in addition to the control behaviour, the disturbance behaviour and the fluctuations in the disturbance variables by size, direction and change over time.

The principal disturbance variables are:

– change in steam flow $\dot{m}_S$;

– change in steam pressure p;

– change in furnace output $\dot{m}_F$.

Transfer functions in accordance with Figure 2 may occur as effects of these disturbance variables.

3 Formulation of control task

3.1 Control set point

The desired operational water level forms the set point for the controlled variable (Figure 3), which may be adjusted by the operator. The permissible steady-state and transitory deviations depend on the design of the steam generator. The actual value may not, on any occasion, fall below the licensed minimum water level, nor exceed the designed permissible maximum water level. To avoid unnecessary aggravation of the control task, the distance between the minimum and maximum water levels should be set as large as is permissible in terms of the design. The measuring range of at least one measuring device should always be greater than the range between the maximum and minimum water level, and should include the designed permissible limits.

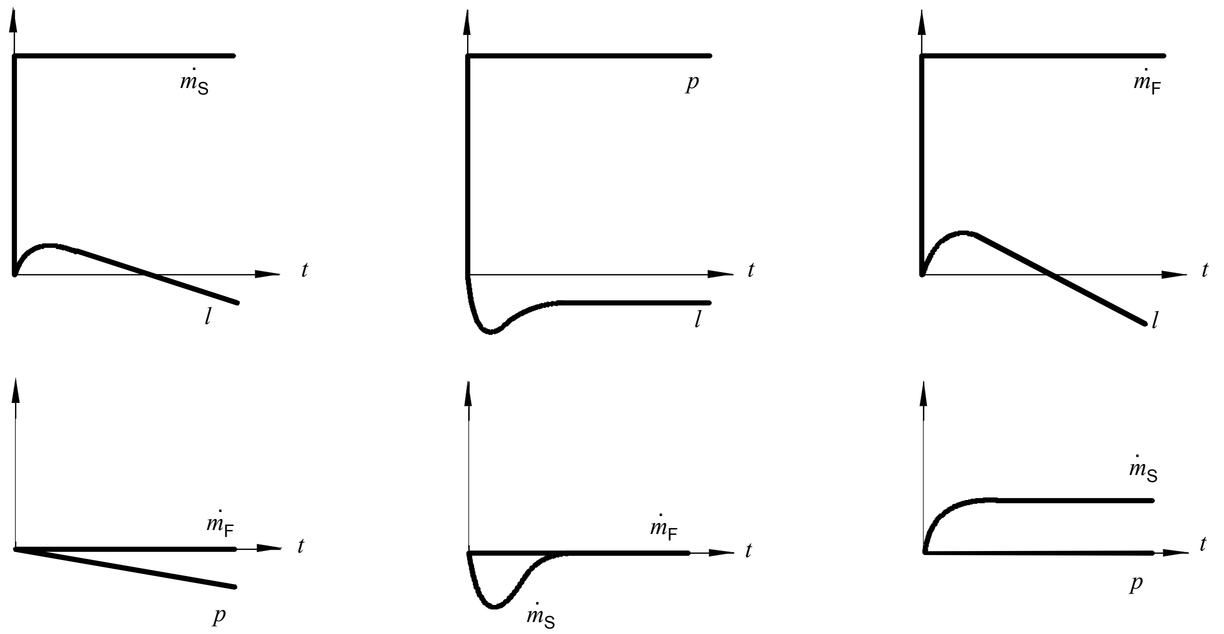

Figure 2a – Single-step change in steam flow m_s	Figure 2b – Single-step change in steam pressure p	Figure 2c – Single-step change in furnace output m_F

Figure 2 – Disturbance behaviour of water level l

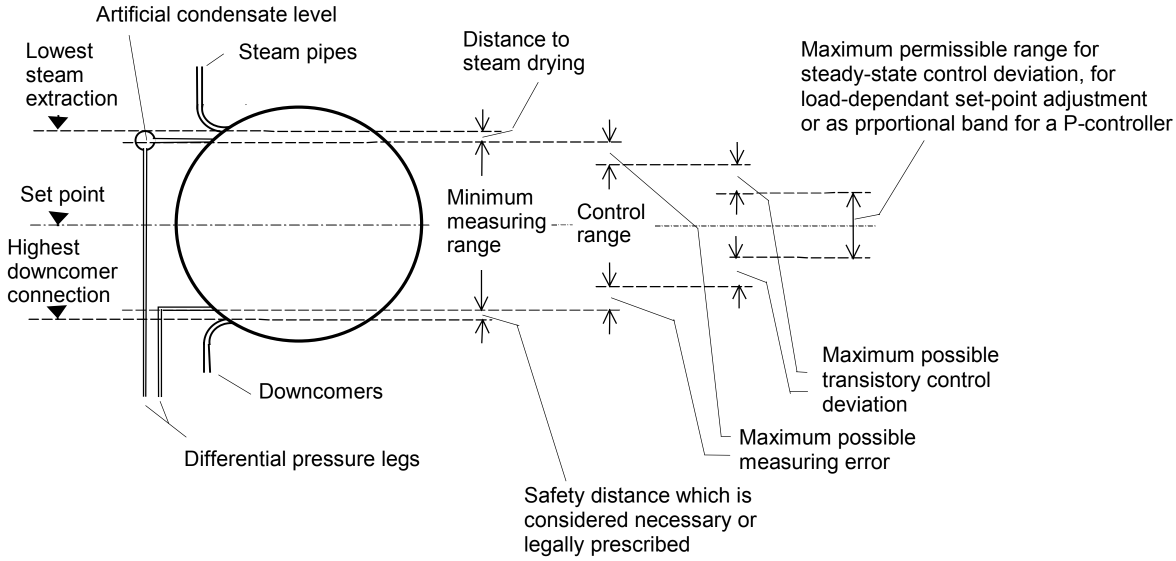

Figure 3 – Measuring and control ranges on the drum

3.2 Control performance requirements

3.2.1 Definition of control performance

In drum-level control, the control performance is principally characterized by the steady-state control difference and the transitory control difference (overshoot width).

3.2.2 Influences on control performance

The control performance is influenced by the selected configuration of the control circuit (see Clause 3), the control transitional behaviour of the controlled system (see 2.3.1 and 2.3.2), by the disturbance transitional behaviour of the controlled system, particularly with large and rapid load changes (see 2.3.3), and by the properties of the measuring devices (see 4.1) and the control devices (see 4.2).

3.2.3 Control performance requirements

Steady-state or transitory control differences may not exceed the limits indicated in Figure 3. This also applies to load changes. More stringent demands do not result in operational advantages. The control behaviour should be sufficiently damped. Stochastic fluctuations, also described as “noise”, should not affect the control flow in the load range between full and minimum load by more than ±2 % related to full-load flow.

4 Configurations of the control circuits

The configuration of the control circuit which it is advisable to select depends on the following conditions.

a) The transfer function of the drum level (see Figure 1).
b) The required speed of the load change of the boiler.
c) The time response of the furnace and the heat transmission through the heating surfaces.
d) The differential pressure fluctuations which occur at the control valve for feed-water flow.
e) The deviations of the actual valve characteristic from that desired (see 5.2.1.3).
f) The requirements of the constancy of the drum level.

Control configurations already applied took up to four variables into consideration:

- Drum level l: controlled variable
- position of actuator y: regulated variable
- feed-water flow $\dot{m}_{FW}$: control flow
- steam flow m: main disturbance variable

The usual control circuits differ in the number of variables used and their coupling structure.

4.1 Single-element control

Only one element, namely the water level, is fed to a P respectively PI controller and compared with the set point (Figure 4a). This simple control circuit will lead to large and possibly non-permissible transitory control deviations with larger and more rapid load changes, and also, if certain limits are exceeded, in the conditions given under 4a) to 4f).

4.2 Three-element control

With three-element control, the feed-water flow, in addition to the water-level control difference and the steam flow, are sent to a PI controller so that a particular feed-water flow is assigned to each steam flow. This assignment is proportionally corrected in the event of a control difference of the water level. In spite of the fact that steady-state control deviations, such as measuring errors in the steam or feed-water flow measurement, may arise as a result of the proportional water-level “correction”, this circuit is predominantly used because of its simplicity (Figure 4b).

4.3 Three element control as cascade circuit

With this circuit, a controller, such as a PI controller, regulates the feed-water flow as a function of the steam flow. By overlaying, for example, a PI water level controller in accordance with 3.1, the assignment of feed water to steam flow is influenced in such a way that no steady-state control deviations arise (Figure 4c).

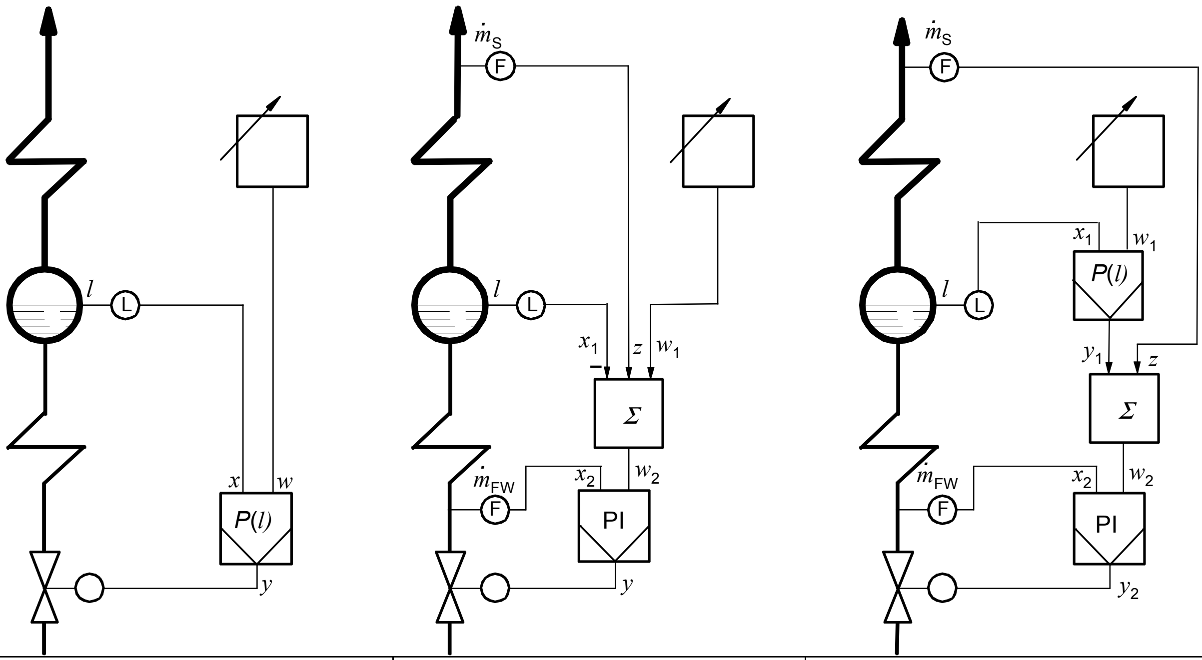

Figure 4a – Single-element control	Figure 4b – Three-element control	Figure 4c – Three-element control as cascade circuit

Figure 4 – Configurations of the control circuit

5 Realization of the control circuit

5.1 Measuring element

The most important measured variable is the height of the drum water level (controlled variable). Because of thermodynamic and flow processes, there is no homogenous water level in the drum. Each measuring device can therefore only display an apparent mean water level. In addition, most measuring techniques are encumbered with systematic errors.

If two parallel local water gauges are present then the tappings for the remote water-level measurements should be positioned between the local ones. If only one local water gauge is present, the remote water measurement should be positioned nearby. An alternative practice is to use the average of two measurements at either end of the drum.

The influence of downcomers, risers and feed-water inlets has also to be considered when designing the location of the tappings.

Even using high-accuracy measuring devices, differences between the internally present and externally measurable water levels will remain due to systematic errors in the individual measuring processes. They have to be taken into account when designing the control range.

5.1.1 Physical measuring techniques

The differential pressure technique has gained broad acceptance as a measuring method in power stations. As a measure of the water level in the drum, the difference in the hydrostatic pressures between the drum level and an artificial condensate level is being used (see Figure 3). The method implies that, also in the steady-state condition, a change in density inside the drum generally causes a measuring error. The artificial condensate level should lie only slightly above the highest water level to be measured, and the lower extraction point only slightly below the lowest water level to be measured. The differential pressure lines must be installed so that they have as steady a temperature as possible from the height of the lower extraction point. If these design specifications are not complied with, even slight changes in the ambient temperature cause marked measuring errors due to change in the densities in the measuring lines. Insulation of the lines is recommended.

Other measuring techniques, such as that according to the buoyancy principle using a displacement body in the drum or in a separate vessel, are used in small plants.

5.1.2 Steady-state behaviour

In general, the measuring errors of the measuring devices used are less than the systematic measuring errors of the drum-level measurement described. If the operating state differs from that for which a measuring device is designed, in particular during start-up of the boiler, or in case of sliding pressure operation, considerable measuring errors arise, due to the deviation of the density from the design state, which cause a widening and shift in the indicating range. In this case, corresponding corrections have to be applied.

5.1.3 Time response

The measuring device should respond to changes in the drum-level with as small a delay as possible. It is recommended that the measuring device be designed in such a way that it shows an error of maximum 10 % of the control range (Figure 3) if this range is run through at the greatest possible rate of change.

5.1.4 Measurement transducer for steam flow and feed-water flow

Usual flow measuring devices can be used. Although systematic errors are of secondary importance for steady-state behaviour, sensitivity must be high and hysteresis low. Under certain circumstances, for example, in case of sliding pressure operation, a state correction should be provided for in the steam flow measurement. The delay times of the steam flow and feed-water flow transducers have to be short, as they can be neglected with respect to the rate of flow changes which may occur during operation

5.2 Actuators for regulating feed-water flow

The delivery pressure required to convey the feed water into the steam generator is generated by one or more full-load or part-load feed-water pumps. The feed-water flow can be regulated by throttling or by changing the feed-water pump speed. In addition to consuming as little energy as possible, the feed-water flow control elements should also be dimensioned so that they comply with the control requirements. All the feed-water system components have to be designed in accordance with the national guidelines.

5.2.1 General properties

5.2.1.1 System and pump characteristics

The following characteristics are definitive for the design of the actuator (Figure 5).

Line a indicates the pressure in the constant pressure point of the steam generator, feed characteristic b shows the pressure at the infeed point of the steam generator as a function of water flow. The difference between lines a and b corresponds to the flow resistance between the infeed point and the constant pressure point. The difference between lines b and c indicates the pressure drop in the feed line and the apparatus between the pump and the infeed point as a function of the water flow. The difference between the lines c and d corresponds to the geodetic height difference between the feed-water pump and the superheater outlet. System characteristic d indicates the pressure required at the discharge nozzle of the feed-water pump as a function of water flow, although it does not contain the pressure drop in the feed-water control valve which is required under certain circumstances.

Pump characteristic e indicates the pressure arising at the discharge nozzle of the feed-water pump under operating conditions as a function of the water flow through the pump (delivery) at a set speed. This pressure results from the pressure at the suction nozzle of the feed-water pump plus the pressure increase in the pump at operating temperature. The feed-water flow results from the delivery of the pump after deduction of the flow which may be diverted through the pump minimum flow valve and the injection water flow. The difference between lines d and e represents the pressure difference at the feed-water control valve.

5.2.1.2 Control range

The control range must include the following limits.

– If special start-up and shut-down control valves are present, the control range of the main actuator, or actuators, should be so designed that the minimum flow to be controlled should lie at approximately 20 % of the minimum load below the minimum boiler load, under certain circumstances also at reduced operating pressure. (The feed-water control elements should, as far as possible, not be determining factors for the lower boiler power limit.)

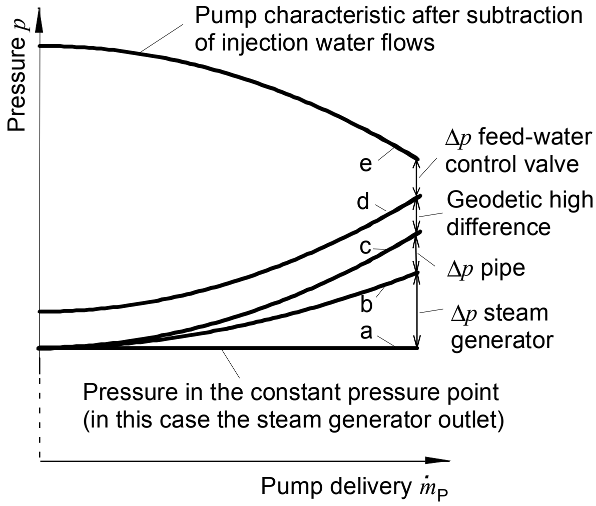

Figure 5 – System and pump characteristic at constant speed and with the pump minimum flow valve closed

- If no additional actuators are present for start-up and shut-down, the actuator must be able to control the feed-water flow down to zero.
- The actuators must be capable of allowing a feed-water flow which is necessary for the highest continuous power of the steam generator at the highest permissible drum pressure.
- The influence of calculated tolerances, wear and allowances for control performance, in addition to legal regulations regarding the required maximum feed-water flow should be taken into consideration in the design of the actuator or actuators.

5.2.1.3 Characteristic of the actuator

The characteristic of the actuator, or the valve trim characteristic, indicates the control flow as a function of the position of the actuator at the differential pressure which arises from the corresponding system and pump characteristics. This characteristic should be as linear as possible in the range between maximum and minimum load of the steam generator. (Where applicable, non-linearities should be taken into consideration within the framework of the instrumentation.)

5.2.1.4 Control time

The control time should be adjusted to the rate of change of the disturbance variables, taking into consideration the travel time. 30 s can be assumed as a standard value.

5.2.2 Control by altering pump speed

The feed-water flow is regulated by altering the speed of the pump, or pumps, so that the pump characteristic $e_1...e_7$ cuts the system characteristic d at the required pump delivery (Figure 6).

5.2.2.1 Drives

There is a series of variable-speed drives which have special properties. Where such a drive is selected, both the control and economic aspects must be taken into consideration.

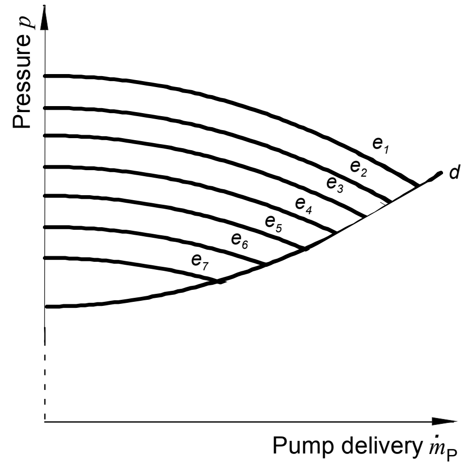

Figure 6 – Family of characteristics with alteration of pump speed

5.2.2.2 Characteristics

The relationship between speed and pump delivery at a preset delivery pressure is constant, but not linear. The relationship between regulated variable and speed of the drive machine at corresponding load is largely non-linear. The whole characteristic regulated variable to pump delivery therefore also generally deviates from the desired linear dependency. An approximation of the linear characteristic is possible by mechanical or electronical linearization between actuator and drive or by feedback of suitable intermediate variables, for example, speed or delivery. (Modern speed variable drives therefore mostly have internal electronic speed controls.)

5.2.3 Control by throttling

The feed-water flow is regulated by changing the flow resistance between the uncontrolled feed-water pump and the inlet of the steam generator by additional throttling of the actuator (feed-water control valve) so that the pump characteristic e cuts the altered system characteristic $d_1, \ldots d_4$ at the required pump delivery (Figure 7).

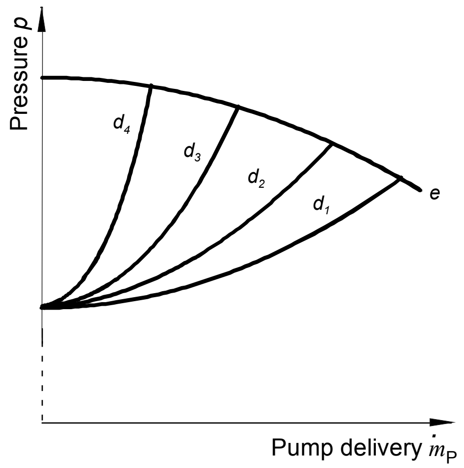

Figure 7 – Family of characteristics with throttling

5.2.3.1 Characteristics

The characteristic of the control valve, that means the ratio between stroke and feed-water flow, should be linear. The basis for the calculation of the aperture cross-section of the valve depending on its stroke is the relationship between the pressure difference and the feed-water flow, given by the pump characteristic (line e in Figure 5) and the system characteristic (line d).

With a number of valve types, a linear characteristic can only be achieved in a limited range. The linear range should include the controlled minimum and maximum continuous load of the steam generator.

If a valve has to be operated under a widely varying differential pressure at equal control flow due to variable operating states, the linear characteristic for each operating state should be determined. The characteristic for the valve design should be formed from the various characteristics of the different operating states so that it satisfies the various requirements and includes the extreme cases.

Where electronic instrumentation systems are used, deviations from desired characteristics may also be corrected electronically, i.e. by using function generators.

5.2.3.2 Required pressure difference

The pressure drop of the feed-water control valve with the valve fully open depends on the design. With a given nominal connection width, the free aperture cross-section cannot be made as large as desired. The characteristics of actual valves deviate considerably from the desired basic form, particularly in the vicinity of the closing point. Below the minimum stroke, at which the permissible gradient tolerance of the characteristic is exceeded, perfect control is no longer possible. The minimum stroke depends on the valve characteristic and the valve design. Checks must be carried out in each case to ensure that the stroke does not operationally fall below the minimum. For this, it is advisable to determine the required valve operating range b_e:

$$b_e = \frac{\dot{m}_{100}}{\dot{m}_{min}} \cdot \sqrt{\frac{\Delta p_{min}}{\Delta p_{100}}} \cdot \sqrt{\frac{\rho_{100}}{\rho_{min}}} = \frac{F_{100}}{F_{min}} \cdot \frac{\beta_{100}}{\beta_{min}}$$

(*ß* is the flow correction value of the valve, ρ the density of the feed water, F the aperture cross-section, Δp the pressure difference). The index 100 refers to the maximum continuous load. The permissible operating range of the valve selected, to be indicated by the valve manufacturer, must be greater than the required valve operating range b_e:

$$b_e < b_{max}$$

In the above equation, while control flow and density ratio are fixed due to the operating conditions, the pressure difference ratio can be influenced by selecting a feed-water pump with a steep or flat flow/pressure characteristic. An adequate pressure difference Δp_{100} for the valve must be assumed here.

The more ample the pressure reserve selected, the easier the control task; however, this does lead to a continually increased energy loss.

5.2.3.3 Reduction of the valve operating range

If small partial loads are to be run with the steam generator, either an actuator with a large operating range is required, or, at full load, a greater pressure drop at the actuator must be permitted, or an additional differential pressure controller installed. In such cases, this controller can be used to keep the pressure difference at the feed-water control valve at as low a value as possible at all loads. As a result, the required valve operating range b_e is reduced (Δp_{min} then becomes Δp_{100}). Because of the lowest possible pressure difference, 5.2.3.2 should be taken into consideration. The possible lowest value, however, usually results from the smallest possible proportional band of the differential pressure controller.

Operation at very low partial loads can be made easier by using an extra-low load control valve, which is installed in parallel to the main control valve. Both valves will be opened or closed in succession.

5.2.3.4 Data for valve dimensioning

In order that the valve can be dimensioned, the following data should be provided for each different operating state (in accordance with 5.2.3.1):

- pressure in front of the valve;
- pressure behind the valve;
- water temperature for $\dot{m}_{min}, \dot{m}_{100}, \dot{m}_{max}$ and at least two intermediate values.

It is advisable to provide the data in diagram form.

The legal specifications should be taken into consideration.

5.2.3.5 Small feed-water flows

If the valve design allows, the valve plug can be shaped, outside the linear characteristic, in such a way that very small feed-water flows can also be regulated at reduced drum pressure, for example, during run-up and run-down.

5.2.3.6 Leak-tight closing

Operationally, leak-tight closing of the valves is desirable. In the long term, absolute leak-tightness can only be achieved with single-seat valves. In general, large drive power is required for these valves. Compensated single-seat valves or double-seat valves require lower power levels, although they do not generally guarantee absolute leak-tightness. In this case, additional isolating valves are to be provided.

5.2.4 Control by a combination of alteration of pump speed and throttling the feed-water control valve

The feed-water flow is regulated by throttling the feed-water control valve, and the feed-water pump sets a constant pressure difference at the feed-water control valve by altering the speed. The position of the feed-water control valve is proportional to the flow if a linear characteristic ($k_V \sim m$) is selected. This solution offers economic operation and is particularly suitable for rapidly controllable heating such as for an oil- or gas-fired steam generator.

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Thank you for your contribution to the standards-making process.

Nicht frankieren
Ne pas affranchir

Non affrancare
No stamp required

A Prioritaire

RÉPONSE PAYÉE

SUISSE

Customer Service Centre (CSC)
International Electrotechnical Commission
3, rue de Varembé
1211 GENEVA 20
Switzerland

Q1 Please report on **ONE STANDARD** and **ONE STANDARD ONLY**. Enter the exact number of the standard: *(e.g. 60601-1-1)*

....

Q2 Please tell us in what capacity(ies) you bought the standard *(tick all that apply).* I am the/a:

- purchasing agent ❑
- librarian ❑
- researcher ❑
- design engineer ❑
- safety engineer ❑
- testing engineer ❑
- marketing specialist ❑
- other...

Q3 I work for/in/as a: *(tick all that apply)*

- manufacturing ❑
- consultant ❑
- government ❑
- test/certification facility ❑
- public utility ❑
- education ❑
- military ❑
- other...

Q4 This standard will be used for: *(tick all that apply)*

- general reference ❑
- product research ❑
- product design/development ❑
- specifications ❑
- tenders ❑
- quality assessment ❑
- certification ❑
- technical documentation ❑
- thesis ❑
- manufacturing ❑
- other...

Q5 This standard meets my needs: *(tick one)*

- not at all ❑
- nearly ❑
- fairly well ❑
- exactly ❑

Q6 If you ticked NOT AT ALL in Question 5 the reason is: *(tick all that apply)*

- standard is out of date ❑
- standard is incomplete ❑
- standard is too academic ❑
- standard is too superficial ❑
- title is misleading ❑
- I made the wrong choice ❑
- other ....

Q7 Please assess the standard in the following categories, using the numbers:
(1) unacceptable,
(2) below average,
(3) average,
(4) above average,
(5) exceptional,
(6) not applicable

- timeliness ....
- quality of writing....................................
- technical contents...................................
- logic of arrangement of contents ....
- tables, charts, graphs, figures...............
- other ....

Q8 I read/use the: *(tick one)*

- French text only ❑
- English text only ❑
- both English and French texts ❑

Q9 Please share any comment on any aspect of the IEC that you would like us to know:

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