TECHNICAL REPORT

IEC TR 62140-3

First edition
2002-10

Fossil-fired steam power stations –

**Part 3:
Steam-temperature control**

Centrales à vapeur consommant des combustibles fossiles –

*Partie 3:
Contrôle de température de la vapeur*

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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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FOSSIL-FIRED STEAM POWER STATIONS –

Part 3: Steam-temperature control

FOREWORD

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IEC 62140-3, 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
65/273/CDV	65/285/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 the 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- withdrawn;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 conventional 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 3: Steam-temperature control

1 Scope

This Technical Report deals with steam-temperature control in fossil-fired power stations with natural or forced circulation.

The application of this report is restricted to temperature control systems in power stations in which superheated steam is controlled at a desired target temperature using steam side control interventions, such as spray coolers or heat exchangers, or flue gas side control interventions such as flue gas reflux. Desuperheating stations are not dealt with in this report.

A description of the controlled system is followed by the formulation of the control task; this is followed by a section containing descriptions of suitable configurations for the control circuits, with a further section devoted to an examination of the measuring equipment and actuators necessary for the realization of the control unit.

2 Controlled system

The desire to maintain turbine efficiency over a wide range of load and to avoid fluctuations in turbine metal temperatures has resulted in a need to maintain constant temperature for superheated and reheated steam over the anticipated operating load range. To satisfy this requirement, a control system is necessary. The following description is based on a spray water control system. Alternative configurations are described in 3.1.

2.1 Description of a controlled system

Where an attemperator is used, the controlled system begins at the steam inlet into the attemperator, and ends after the measurement of the steam temperature at the heating surface outlet. It covers the linear behaviour of the attemperator and the heating surface, including the unheated connecting pipes and the distribution and collector systems. The following input quantities affect this control system.

2.1.1 Heat pick-up

The heat absorption of the heating surface is a disturbing variable with fluid side control interventions (attemperator, heat exchangers) and a manipulated variable with flue gas side control interventions (flue gas reflux, tilting burners).

Experience has shown that changes in heating over time can be measured only with difficulty. They are thus derived from easily measurable regulated variables, such as feeder speeds and fuel and flue gas flows, taking into consideration subsequent linear behaviour (for example, release of heat).

2.1.2 Steam flow

Steam flow is another disturbing variable. In contrast to the rate of heat absorption, it is easily measurable and can thus be used as a disturbing variable using the information as a feed forward signal to improve control performance. It is generally not freely available as a manipulated variable.

2.1.3 Inlet temperature

The temperature of the steam entering the control system is another disturbing variable.

2.2 Design

The design of the superheater is largely conditioned by the boiler structure and the thermal design in connection with the pipe material used. The behaviour of the control system can be influenced from design within certain boundaries by distributing the thermal heat absorption over radiation and convection heating surfaces and by selecting in parallel flow or counter-flow.

Good control is made easier by the following.

2.2.1 Heat pick-up

It is preferable to have a low heat pick-up across the heating surface to be controlled. The heat pick-up, i.e. the temperature increase of the steam in the control system heating surface, should be lower as the control performance requirements are stricter (overshoot width) and the disturbances are greater and faster. If there are no design reasons to the contrary, the aim is a heat absorption in the final superheater of a maximum of 50 K to 70 K with large boilers with superheater steam temperatures above 500 °C. One method is to use several stages of superheater and attemperator.

For modern control devices with integrated linear models, for example, state controllers with observers, the intermediate temperatures of the heating surface are calculated and used as auxiliary controlled values within the control loop. As a result, heating surfaces with heat absorption equivalent to a 120 K temperature increase, can also be controlled with good levels of control quality.

The best control results could be achieved with an attemperator at the outlet of the control system. The controller could then exercise the most rapid control. However, this configuration is not generally possible as it would result in high steam temperatures in the heated and unheated pipes.

2.2.2 Temperature distribution

A small disturbance of the temperature distribution, i.e. small differences between the temperatures at the ends of the individual parallel superheater pipes. Too great an imbalance would restrict the allowable control deviation so as to avoid exceeding the material limit temperature.

2.2.3 Material weight

A low material weight of the controlled system, i.e. as little as possible in the way of unheated pipes and headers, and low material weight of the heating surfaces, to keep delay times in the control systems down (see 2.4). An adequate mixing section for the evaporation of the injection water must nevertheless be guaranteed.

2.3 Steady-state behaviour

The gain factor is the ratio of temperature change at the outlet to that at the inlet in steady state. It is somewhat above 1 due to the decreasing specific heat capacity of the steam during superheating.

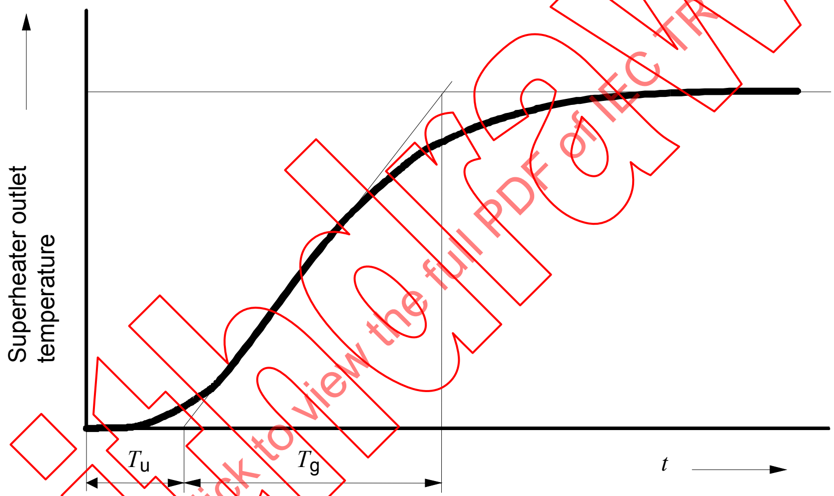
2.4 Transient behaviour

It is advisable to use time response of step changes to characterize the dynamic behaviour of the controlled system. Distinction must be made between the following cases.

2.4.1 Step response of the controlled variable

This is obtained as the time response of the outlet temperature with the fastest possible (i.e. as far as possible in a single step) change in the position of the actuator. Care should be taken during the test that the possible disturbing variables (heat absorption, mass flow and steam inlet temperature) remain as constant as possible. The time response of a superheater outlet temperature after a step change of the inlet temperature (Figure 1) takes the form of a linear delay of high order, and may be approximated by means of a series connection of several first-order lags.

Indication of a time constant and the order of the controlled system is then sufficient to describe the control system. Alternatively, the measured time response can also be characterized using the equivalent initial delay time T_u and the propagation time T_g. The propagation time is the time cut out by the flex tangent of the time response between the X-axis and the asymptote (stationary final value). The initial delay time is the time between the time of adjustment and the point of intersection of the flex tangent referred to with the X-axis (Figure 1). The ratio T_u/T_u has a fixed relationship with the order of the controlled system.



Key

T_u Initial delay time

T_u Propagation time

Figure 1 – Time response of a superheater outlet temperature after a step change of the inlet temperature

2.4.2 Feed forward anticipation

This is obtained as the time response of the outlet temperature with the fastest possible (i.e. as far as possible in a single step) change in the manipulated variable. The disturbances listed in 2.1 are taken into consideration. They are mainly caused by the overall load control and feed forward signals can be anticipated to improve the control behaviour. The delay time with regard to the disturbance step response time is not of interest, except when a feed forward anticipation of the disturbing variable is provided for. It is therefore usually sufficient to characterize the disturbing behaviour using its delay time T_z.

2.5 Calculation of time response (see Figure 2)

The advance calculation of the transfer function of heated pipes assumes the solution of partial differential equations. This leads to transcendent transfer functions and, for a step response, to infinite series of functions with trigonometric parameters. The relatively complicated solutions were replaced by various authors with more simple approximations. The characteristic values T_u, T_g or n, T_z can thus be calculated relatively easily from the design and operational data.

The mathematical order of the controlled system remains constant, almost independently of load, in both constant pressure and floating pressure operation, while equivalent initial delay time and propagation time increase inversely proportional to the steam flow. High-pressure superheaters with good control behaviour have typically, at full load, delay times of approximately 50 s, reheaters approximately 100 s, and values for T_u/T_g of approximately 0,3. The most important characteristic values are brought together in Table 1.

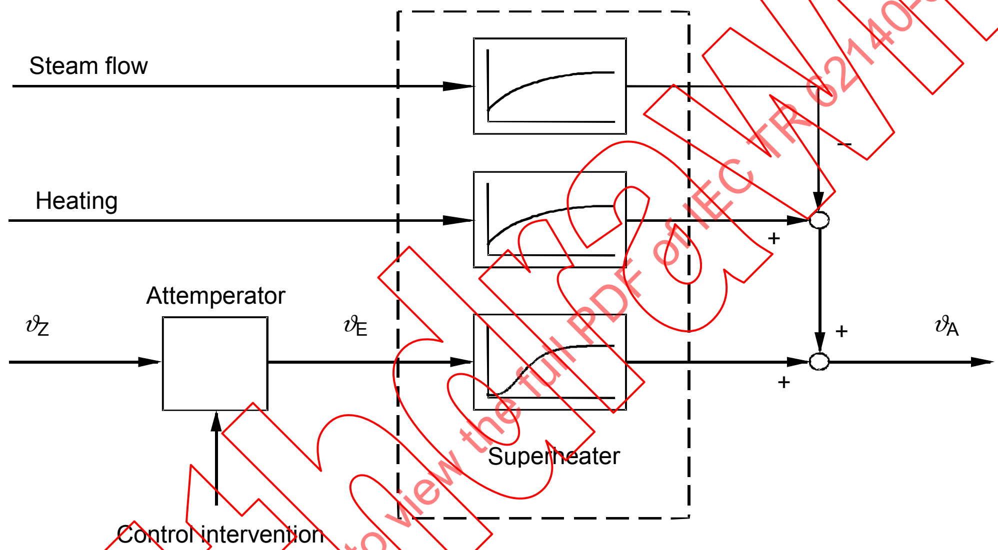


Figure 2 – Block diagram of the controlled system

2.6 Measurement of time response

Measurement of the control transfer function is usually carried out by adjusting the actuator as rapidly as possible (as far as possible in a single step). To keep down the many possible disturbances, the boundary conditions described in 2.4.1 should be complied with. The tests should be carried out from steady-state conditions and only by manipulating one input variable at one time.

Table 1 – Characteristic values of the controlled system

Parameters			Load range			
			100 %	PL 1 [a)]	PL 2 [a)]	40 %
Heat pick-up	Δh	kJ/kg				
Delay time	T_U	s				
Propagation time	T_g	s				
Pipe storage time	T_Z	s				
Injection water enthalpy	h_F	kJ/kg				
a) PL = Part load						

3 Formulation of control task

3.1 Control requirements

The task of steam-temperature control consists of controlling steam temperature in accordance with the reference variable (start-up) or the set point (load operation). The permissible temperature deviations and their transients may not exceed the permissible transients of the stressed thick-walled pressure components at the superheater outlet, in the main steam line and in the turbine.

In general, temperature fluctuations of ±10 K have no significant effect on component exhaustion due to thermal cycling. At high operating temperatures, attention should be paid to the range of use of the material, and to creep stress. If the set point lies at the limit of use of the material, positive control deviations may also contribute to a slight reduction in creep life. Because of the storage capacity of the steam line between superheater outlet and turbine inlet, any oscillation in the temperature at steam generator outlet will become approximately half at the turbine inlet.

At considerable temperature changes of up to 500 K, as occur, for example, during start-up of a power station, care should be taken that the temperature changes take place with the permissible transients. In bypass operation, the steam generator components in the live steam line are limiting, while in turbine operation, the turbine generally limits the permissible temperature transients. Rapid and considerable lasting temperature changes, such as those due to set-point adjustments, are also detrimental to the turbine. In load operation, therefore, set-point adjustments at the superheater outlet should largely be avoided. In accordance with Figure 1, T_u, T_g apply to the control transfer function, T_Z to the time behaviour of the disturbance variables due to heat absorption or mass flow disturbance.

3.2 Control performance

3.2.1 Overshoot

The most important criterion for the assessment of control performance is the overshoot of the controlled variable in case of disturbances. This is the greatest transitory deviation of the controlled variable from the original steady-state condition during the transition to a new steady-state condition. As a criterion, it has the advantage that, with the present control system, it is independent of optimization (i.e. of the course of the control curve) within fairly broad boundaries. The overshoot is dependent on the following quantities.

3.2.1.1 Value of disturbance

Heating fluctuations and changes in steam flow are the disturbances which require particular consideration. Both of these disturbances act (in the region of small changes) proportionately on the heat pick-up. As a result of the opposed direction of action (±), they more or less counterbalance each other in stationary operation.

3.2.1.2 Storage time T_z of the disturbing step function

Time T_z characterizes the gradient of the rise of the disturbance (see 2.4.2). The storage capacity of the superheater prevents the disturbance at the superheater outlet from suddenly acting to its full extent. In addition, heating fluctuations, for example, do not arise suddenly at the superheater with many firing systems, which can be taken into account approximately by extending the calculated storage time T_z.

3.2.1.3 Equivalent dead time of disturbance step response

In the case of considerable equivalent dead time of the disturbance step response, a considerable reduction in the overshoot width can be brought about by feed forward a disturbing variable with suitable time dependence. Attention should be paid here to the fact that, in power operation, both the heating change and mass flow change must be taken into consideration.

3.2.1.4 Equivalent initial delay time T_u and propagation time T_g of the control transfer function

The overshoot is influenced by the equivalent dead time T_u and the ratio T_u/T_g and increases with higher values.

3.2.1.5 Controller setting

It must be taken into consideration with regard to the controller setting that the delay time and compensating time are load-dependent, and thus the controller parameters must also be set load dependent.

4 Configurations of the control circuit

4.1 Control concept

Various methods of controlling steam temperatures are in use. Some designs may use more than one of the methods listed below. It is also possible to combine those methods in one plant.

4.1.1 Injection of feed water before the superheater

The injection water flow can be adjusted using valves, by opening up nozzle cross-sections or by changing the output of a particular pump.

4.1.2 Flue gas bypass (controlled flue)

Flaps are adjusted by the controller which cause part of the flue gas flow to bypass the superheater, so that the latter is only under stress from a partial flow. This type of control has the advantage of lower delay time in comparison with control by cooling (at equal steel weight of the heat surfaces), but a limited control range. This lower delay time applies only to the steam outlet temperature of that part of the superheating which is covered by the flue gas bypass.

4.1.3 Flue gas reflux

Colder flue gases are led from the boiler exit to the inlet of the superheater or into the lower furnace, with the stream of recycled flue gases regulated by flaps or by changing the fan speed. The control intervention usually acts on several heating surfaces at the same time. This process produces low delay times, but requires considerable additional expenditure of energy. The introduction of the flue gases immediately in front of the superheater causes a temperature drop, while introduction into the lower furnace causes a temperature increase.

4.1.4 Tilting burners

These give a low delay time, but have only a limited control range. In addition, the firing control must be taken into consideration. Because of the limited reproducibility of the regulating effect, this method is not included in a control loop, but is carried out only statically.

4.1.5 Additional superheater heating

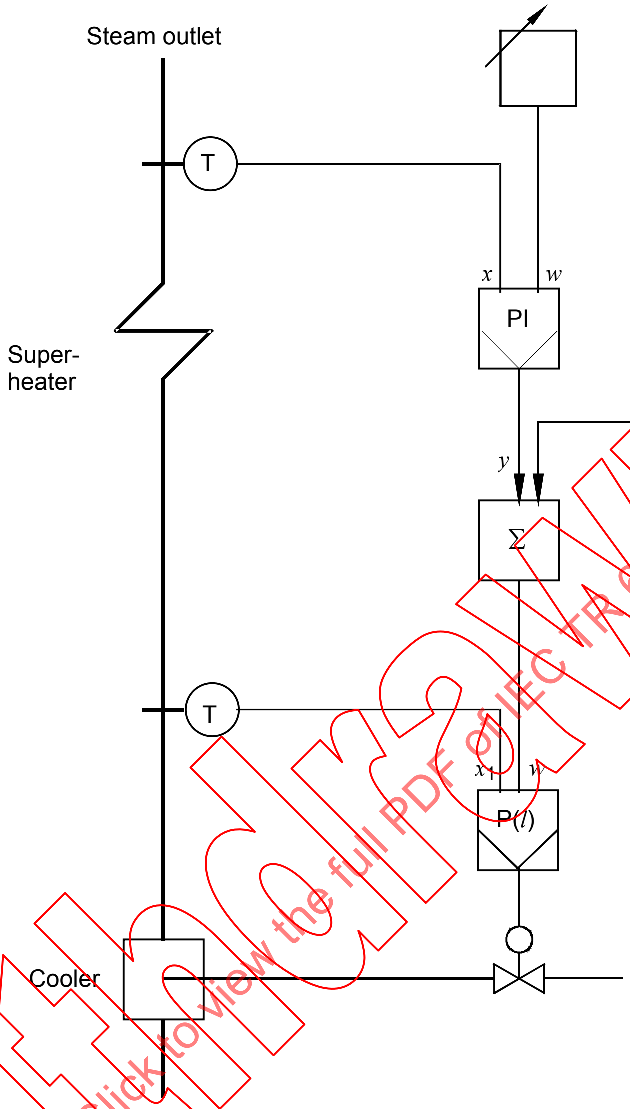
This method has previously been used only infrequently.

4.1.6 Heat exchanger

The heat exchanger is used as an energy shunt system. The hot steam passes energy to a fluid at lower temperature. An actuator operated by the controller leads part of the steam flow to the heat exchanger. In the reheater area, it is used to reduce the injection flow and hence to improve the cyclic process efficiency. In the high-pressure range, the load-dependent heat absorption characteristic is improved.

4.1.7 Feed-water adjustment

In waste heat plants, the live steam temperature is often controlled by adjusting the feed-water flow. This also applies, by analogy, to once-through steam generators if the temperature control circuits are connected through to regulation of the feed-water flow.



NOTE Temperature after the attemperator is the auxiliary controlled variable.

Figure 3 – PI(D)/P(I) cascade control

4.2 Control circuits

Of all different control concepts, the control circuit with an attemperator is mainly used and therefore described in more detail.

4.2.1 Controlled variables

The steam temperature at the superheater outlet is the main controlled variable in nearly every control circuit. The controller must act integrally, in order to be able to control all disturbances. It should be taken into consideration here that the steam temperature after injection (auxiliary control variable) must always be greater than the saturated steam temperature.

PI or PID controllers and state controllers with observers represent the possible controllers. In certain cases it may be necessary to adjust the set point of the steam temperature as a function of load. The load then becomes a reference variable. The controlled system assigned to the steam-temperature controller was described in 2.1.