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Water-tube boilers and auxilliary installations - Part 3: Design and calculation for pressure parts

Wasserrohrkessel und Anlagenkomponenten - Teil 3: Konstruktion und Berechnung für drucktragende Teile

Chaudieres a tubes d'eau et installations auxiliaires - Partie 3: Conception et calcul des parties sous pression

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Water-tube boilers and auxilliary installations - Part 3: Design and calculation for pressure parts

Chaudières à tubes d'eau et installations auxiliaires - Partie 3: Conception et calcul des parties sous pression

Wasserrohrkessel und Anlagenkomponenten - Teil 3: Konstruktion und Berechnung für drucktragende Teile

This European Standard was approved by CEN on 25 July 2001.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

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Foreword

This European Standard has been prepared by Technical Committee CEN/TC 269 "Shell and water tube boilers", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2002, and conflicting national standards shall be withdrawn at the latest by June 2002.

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports safety requirements of the Pressure Equipment Directive (PED) [7].

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this standard.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The European Standard series EN 12952 concerning water-tube boilers and auxilliary installations consists of the following Parts:

Part 1: General
Part 2: Materials for pressure parts of boilers and accessories
Part 3: Design and calculation for pressure parts
Part 4: In-service boiler life expectancy calculations
Part 5: Workmanship and construction of pressure parts of the boiler
Part 6: Inspection during construction, documentation and marking of pressure parts of the boiler
Part 7: Requirements for equipment for the boiler
Part 8: Requirements for firing systems for liquid and gaseous fuels for the boiler
Part 9: Requirements for firing systems for pulverized solid fuels for the boiler
Part 10: Requirements for safeguards against excessive pressure
Part 11: Requirements for limiting devices and safety circuits of the boiler and accessories
Part 12: Requirements for boiler feedwater and boiler water quality
Part 13: Requirements for flue gas cleaning systems
Part 14: Requirements for flue gas DENOX-systems
Part 15: Acceptance tests
Part 16: Requirements for grate and fluidized bed firing systems for solid fuels for the boiler

Although these Parts may be obtained separately, it should be recognized that the Parts are inter-dependent. As such, the design and manufacture of water-tube boilers requires the application of more than one Part in order for the requirements of the European Standard to be satisfactorily fulfilled.

NOTE Part 4 is not applicable during the design, construction and installation stages.

The annexes A and B of this European Standard are normative.

The annexes C, D, and ZA of this European Standard are informative.

1 Scope

This Part of this European Standard specifies the requirements for the design and calculation of water-tube boilers as defined in EN 12952-1.

2 Normative references

This Part of the European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to, or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest editions of the publication referred to applies (including amendments).

prEN 1092-1, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges.*

EN 1591, *Flanges and their joints — Design rules for gasketed circular flange connections — Calculation method.*

prEN 1759-1, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, class designated — Part 1: Steel flanges NPS ½ to 24.*

EN 10025, *Hot rolled products of non-alloy structural steels — Technical delivery conditions (includes amendment A1 : 1993).*

prEN 10266, *Steel tubes, fittings and structural hollow sections — Definitions and symbols for use in product standards.*

prEN 12953-3, *Shell boilers — Part 3: Design and calculation.*

EN 12952 series, *Water-tube boilers and auxiliary installations.*

prEN 13445 series, *Unfired pressure vessels.*

prEN 13480 series, *Metallic industrial piping.*

ISO 7-1, Pipe threads where pressure-tight joints are made on the threads — Part 1: Dimensions, tolerances and designations.

ISO 4287, *Geometrical Product Specification (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters.*

3 Terms and definitions

For the purpose of this standard the terms and definitions given in EN 12952-1 apply.

4 Symbols and abbreviations

For the purposes of this standard, the symbols given in Table 4-1 of EN 12952-1 shall apply. Throughout this European Standard, additional terminology and symbols have been included where necessary to meet the requirements of the specific text concerned.

5 General

5.1 Purpose

Water-tube boiler pressure parts shall be designed in accordance with the requirements of EN 12952-3. The resulting designs shall be reproduced in the form of approved drawings and specifications to ensure the proper application of the design requirements during the manufacturing and inspection stages.

5.2 Dimensions of pressure parts

The wall thickness and other dimensions of pressure parts sufficient to withstand the calculation pressure at calculation temperature for the design lifetime shall be determined in accordance with EN 12952-3 using materials in accordance with EN 12952-2.

The design for loadings arising from the following situations shall also be determined in accordance with this part of EN 12952:

a) the bending of a drum or header as a beam under self weight and imposed loads;

b) local support loads on drums;

c) thermally induced forces and moments within or arising from systems of integral tubing;

d) local loading of tubes by structural attachments;

e) rapid and frequent changes of pressure and temperature.

Methods for calculating stresses caused by external loads applied to nozzles and to attachments shall be in accordance with prEN 13445.

NOTE The purpose of this part is to give specific design rules for common forms of loadings to which boiler parts are normally subjected to and general rules on how other loadings are to be considered. It does not give specific design rules for loadings other than those described in a) to e).

These design rules are adequate for boilers of established construction, installed and operated in accordance with the manufacturer's instructions.

Determination of the dimensions of pressure parts shall be given special consideration not included in this standard, when abnormal conditions are present, such as:

f) abnormally high corrosive products of combustion;

g) highly pressurized products of combustion;

h) poor feedwater.

Deviations from the requirements of this standard by the use of alternative design methods shall be permitted, provided it can be shown that the adoption of such methods does not impair the safety of the component. A record of all deviations shall be recorded in the manufacturer`s dossier. See also clause 7 of EN 12952-1.

5.3 Strength of pressure parts

The strengths of the pressure parts shall be such as to withstand the following loads:

a) internal pressure

b) the weight of all pressure parts and their contents, the weight of components suspended from them and any superimposed slag, fuel, ash or dust;

c) loads caused by gas pressure differentials over the boiler furnace and flue gas passes;

d) loads arising at connections between the boiler system and other parts.

If applicable, the pressure parts shall be adequate to withstand wind and earthquake loads. The conditions applicable for such loads shall be determined by the manufacturer.

5.4 Design by analysis

It shall be permissible to design by analysis provided the safety and functional requirements of the components are not impaired.

The results of any stress calculations carried out for loadings not explicitly covered by equations in this clause shall be determined by using the criteria given in prEN 13445.

5.5 Cyclic loading

Boiler components are deemed to be exposed to cyclic loading if the boiler is designed for more than 500 cold start ups. Where cylindrical or spherical pressure parts with openings are subject to cyclic loading, the following calculation shall be carried out:

$$v_t = \left(550\ \mathrm{N/mm^2} - p_0 \left(\frac{\alpha_m \times d_m}{n_s \times e_{ms}} - 0{,}5\right)\right) \frac{Z}{e_{ms}^2} \qquad (5.5.\text{-}1)$$

where

p_0 is the maximum operating pressure,

d_m is the mean diameter of the shell,

e_{ms} is the minimum wall thickness;

n_s = 2 for cylindrical shells or
n_s = 4 for spherical shells;

α_m = 4 or if there is any doubt that this value is conservative, the exact value taken from Figure 13.4-5 or Figure 13.4-7 shall be used;

Z = 2 K mm^4/(N s) for ferritic steels or
Z = 1 K mm^4/(N s) for austenitic and martensitic steels or

$$Z = -\frac{0{,}5\ D_{th}}{\gamma_{cyl\ sp}\ \alpha_t\ \beta_t\ E/(1-\nu)} \qquad (5.5.\text{-}2)$$

Where exact values D_{th}, β_t, E, ν may be taken from annex D, $\gamma_{cyl\ sp}$ from Figure 13.4-6 or 13.4-9 and α_t from Figure 13.4-8.

If the result of this calculation is smaller than the required temperature transient at start up, or if it is negative, then 13.4 shall apply.

For designs subject to cyclic loading, careful attention shall be paid to the design configuration in order to avoid stress raising features and to ensure good stress distribution. Stamping of materials shall not be done in critical areas.

In considering operating conditions, the design shall make adequate allowance for corrosion and fatigue.

The level of non-destructive testing adopted shall meet the acceptance criteria for main drum welds in EN 12952-6.

5.6 Other design requirements

5.6.1 General

In particular, cognizance shall be taken of the following requirements in EN 12952-5 and EN 12952-6:

a) the design shall be such that manufacturing and welding in accordance with EN 12952-5 and inspection in accordance with EN 12952-6 shall be possible;

b) where partial penetration welds are to be used, the depth of the required weld preparation groove shall be specified on the drawing;

c) the welds attaching branches, nozzles, stubs and supports to drums and headers shall not involve any combination of austenitic and ferritic steel;

d) the requirements covering the attachment of nozzles and branches to drums and headers without strength welding shall be to 9.3 of EN 12952-5;

e) the requirements covering tube connections to drums and headers without strength welding shall be to 9.4 of EN 12952-5;

f) limits of operation for cast iron valves and fittings;

g) where random NDE of welds is permitted by EN 12952-6, it shall be demonstrated that the welding is adequate for the imposed loading when a weld joint factor of 0,85 is applied;

h) the special requirements applicable to coil boilers are given in annex D of EN 12952-5;

i) the special requirements applicable to chemical recovery boilers are given in annex E of EN 12952-5.

For major components operating in the creep range, facilities shall be provided for monitoring the creep in relation to operation.

5.6.2 Access

The boiler shall be designed to ensure adequate access is provided to facilitate the internal examination of the drums and headers. The examination may be either manual or remote in accordance with the physical size of the components. The requirements and limitations of access and inspection openings shall be in accordance with 9.2 of EN 12952-5.

5.6.3 Drainage and venting

The boiler shall be provided with adequate means of drainage and venting in order to avoid water hammer and vacuum collapse, and to enable internal inspections to be carried out.

5.7 Design, calculation and test pressures

5.7.1 Design pressure

For the purpose of EN 12952-3 the design pressure p_d shall be equal to/or greater than the maximum allowable pressure PS.

For each compartment of the water-tube boiler, the design pressure shall be at least the highest set pressure of any safety valve mounted on that compartment.

NOTE A compartment is any pressurized section of plant which can be isolated by shut-off valves.

5.7.2 Calculation pressure

Each compartment might be divided into sections, each with its own calculation pressure p_c and calculation temperature t_c. The design of each section shall be based on one of the following.

a) For parts whose design stress has been derived from tensile strength R_m or minimum yield proof strength $R_{p\ 0,2\ tc}$, the calculation pressure shall be the design pressure increased to the highest pressure possible when the plant is operating at the calculation temperature. Any difference between design pressure and calculation pressure might be caused by hydrostatic pressure and by pressure drop caused by fluid flow. Differences in hydrostatic height less than or equal to 0,05 MPa can be ignored;

b) For parts whose design stress has been derived from the creep rupture stress, the calculation pressure shall be the lowest set pressure of any safety valve at the superheater/reheater outlet, as appropriate, increased by the highest pressure difference possible under continuous rating at the calculation temperature.

A check shall be made of the thickness calculated by method b), using the calculation pressure of a) above with a design stress derived from tensile strength R_m or minimum yield/proof strength $R_{p\ 0,2/tc}$ at the calculation temperature used in b), and the greater thickness used.

If the minimum yield strength data at higher temperatures are not available, linear extrapolation may be allowed.

5.7.3 Calculation pressure for pressure differences

For parts with a design pressure not less than 1 N/mm^2, which are simultaneously subject to both internal and external pressure, e.g. surface type attemperators in boiler drums, and where the design ensures that both pressures always occur together, the calculation pressure shall be the maximum pressure difference, but not less than 1 N/mm^2. The loading occurring during hydrostatic testing shall be taken into account.

5.7.4 Hydrostatic test pressure

5.7.4.1 General

In order to demonstrate, the strength and integrity of individual components and of the completely assembled water-tube boiler, and to establish that no major error or defect has occurred, completely assembled water-tube boilers shall be hydrostatically tested to the test pressure specified in 5.7.4.3 and individual components shall be hydrostatically tested in accordance with 5.7.4.3 without any sign of weakness or defect.

The hydrostatic tests shall be carried out on welded components or the completed water-tube boiler after all welding and heat treatment has been completed, but may be carried out prior to the drilling of holes for expanded tubes in the boiler drum.

5.7.4.2 Hydrostatic tests on individual components

Boiler drums shall be hydrostatically tested to the test pressure specified in 5.7.4.3 before assembly into the water-tube boiler, unless these devices are to be assembled into a water-tube boiler and the assembled water-tube boiler is then to be tested in the manufacturer's workshop to the test pressure specified in 5.7.4.3.

All components which are not reasonably accessible for inspection after assembly into the water-tube boiler shall be individually hydrostatically tested to the test pressure specified in 5.7.4.3 before assembly into the water-tube boiler.

Components other than those specified above shall not require to be individually tested before assembly in the water-tube boiler.

5.7.4.3 Test pressure

A boiler assembly comprises of a number of components each having its own specific calculation pressure and design temperature. The test pressure p_t for components as defined in 5.7.4.2 shall be determined directly in accordance with 5.7.4.4.

As there can only be one hydrostatic test pressure for a boiler assembly or separately isolated compartment as defined in 1.2 of EN 12952-1, it shall be necessary to carry out a series of individual calculations on selected components throughout the assembled boiler or isolated compartment, if applicable, in accordance with 5.7.4.4, to determine the individual apparent test pressure for each selected component. The hydrostatic test pressure for the whole assembly shall be the pressure which ensures that none of the components selected shall be subjected under test conditions to a stress greater than that given in 6.3.4.

5.7.4.4 Calculation of hydrostatic test pressure

The hydrostatic test pressure for a component or completely assembled boiler, shall be determined as follows:

$$p_t = 1{,}43 \times PS \qquad (5.7\text{-}1)$$

or

$$p_t = 1{,}25 \times p_c \times \frac{R_{p0,2\ 20}}{K} \qquad (5.7\text{-}2)$$

which ever is the greater, where

p_c is the calculation pressure of the component under consideration

p_t is the test pressure for the component under consideration

The ratio $R_{p0,2\ 20}/K$ to be used shall be the highest of those permitted for the component under consideration, based on the material properties and the specific calculation temperature and should not be less than 1, see also 6.3.

5.8 Metal wastage

NOTE For the purpose of design in accordance with EN 12952-3 metal wastage includes oxidation, corrosion, erosion and abrasion.

5.8.1 Internal wastage

Internal wastage is normally small and shall not be considered for boilers operated with feedwater in accordance with EN 12952-12. For components exposed to risk of greater than normal wastage (e.g. erosion by turbulence), appropriate countermeasures shall be provided.

The magnetite layer shall be protected in accordance with 13.4.1.1.

5.8.2 External wastage

External wastage of pressure parts not exposed to flue gases is normally small, and the thickness determined by this EN 12952-3 shall be adequate without further addition.

Tubes exposed to flue gases shall experience wastage to a varying extent. If the boiler design data indicates that wastage can be significant, the tubes shall be increased in thickness accordingly. Also other means of tube protection may occur. In this case the wall thickness allowance shall be specified by the manufacturer unless the purchaser has specified a higher allowance.

In the special case of chemical recovery boilers, it shall be permitted to provide for wastage by means of metallurgically bonded, composite materials tubing with corrosion resistant layers.

5.8.3 Requirements

Where an allowance for wastage is made, the amount shall be specified in the design documents stipulating whether this allowance is "internal or external". Strength calculations shall use the dimensions after the wastage allowances are removed.

However, for tubes designed using design strengths derived from creep rupture properties, integration over time of the effects of creep and wastage shall be permitted, so that failure can be predicted at a time not less than the design lifetime. In such cases the tube thickness towards the end of the design life might be less than required by equations (11.2-2 to -5).

5.8.4 Stress corrosion

With boiler water quality controlled in accordance with EN 12952-12, stress corrosion would not be expected to occur in ferritic tubing under normal boiler operating conditions. The risk of such corrosion in austenitic superheater materials can be satisfactorily reduced by ensuring no water droplets are carried over into the austenitic tubing. Carry over can be considered to have been adequately restricted if the steam has an enthalpy of 2 900 kJ/kg or greater, or the enthalpy corresponds to a temperature of 425 °C or higher.

Where it is predicted that exceptional conditions of chemical concentration may occur for prolonged periods of operation, the effects of stress corrosion and corrosion gouging shall be considered, and the materials selected accordingly.

NOTE It is not possible to compensate for stress corrosion by increasing the thickness of components.

5.8.5 Mechanical requirements

Where there is a likelihood of in-service relative movement or fretting between a pressure part and a non-pressure part in contact with it, consideration shall be given to wastage of the components. If necessary wear pads shall be welded to the pressure part, or other equivalent means shall be employed.

5.9 Attachments on pressure parts

5.9.1 Load carrying attachments

Load-carrying attachments shall be defined by the design engineer and indicated as such on the drawing.

Load-carrying attachments are:

a) attachments designed for primary loads which are completely definable and are usually for support purposes, or;

b) attachments which are usually provided for alignment and/or restraint purposes where the loading is not easily defined. Such attachments may be loaded by either primary or secondary loads.

Stresses caused by load-carrying attachments shall be calculated in accordance with prEN 13445.

5.9.2 Non-load-carrying attachments

Non-load-carrying attachments are attachments which carry no significant primary or secondary loads during manufacture, erection, testing or any operating condition.

6 Calculation temperature and nominal design stress

6.1 Calculation temperature

6.1.1 General

For the purpose of EN 12952 the maximum allowable temperature TS shall be that at the steam/hot water outlet.

The reference temperature t_{or} shall the mean fluid operation temperature of the component under consideration, which is to be expected during use.

Where steam or water flows through components in parallel, t_{or} for each component shall take account of variations in heat transfer and fluid flow between the parallel parts.

The calculation temperature t_c of a component shall be calculated by taking account of variations in heat transfer and fluid flow in the boiler. If such calculations are not carried out then the calculation temperature t_c shall be composed of the reference temperature t_{or} and the temperature allowance in accordance with 6.1.2 to 6.1.10. The temperature allowances in Table 6.1-1 shall be regarded as minimum values, except where calculations of t_c are carried out, and is allowed by 6.1.5.

Table 6.1-1 — Reference temperatures and temperature allowances

Physical state	Reference temperature	Temperature allowances			
		Unheated components[a]	Heated components[a]		
			Heating mainly by radiation[b]	Heating mainly by convection	Protected against radiation
Water or water/steam mixture	Saturation temperature at allowable (working gauge) pressure $p_{s\,1}$ or at allowable (total gauge) pressure $p_{s\,2}$	0 °C	50 °C For headers[c] (30 + 3 e_s) °C but not less than 50 °C	(15 + 2 e_s) °C but not more than 50 °C	20 °C
Superheated steam	Superheated steam, see also 6.1.3	15 °C, see also 6.1.5	50 °C	35 °C	20 °C

[a] For definitions of types of heating see 6.1.7 to 6.1.10

[b] Platen type superheaters are treated like convection type superheaters.

[c] For definition of header see 6.1.6

6.1.2 Circulation boilers

For circulation boilers, the reference temperature and the temperature allowance shall be in accordance with Table 6.1-1.

6.1.3 Once-through boilers, superheaters and reheaters

The calculation temperature t_c shall be calculated taking into account of variations in heat transfer and fluid flow in the boiler.

For once-through boilers, superheaters and reheaters the reference temperature shall be the mean temperature expected during service, of the fluid flowing through the various boiler parts.

6.1.4 Hot water generators

For the special case of hot water generators, where the temperature of the contained fluid is limited by thermostats[1)], the reference temperature of the components shall be the fluid temperature.

[1)] Temperature limiters manufactured and tested in accordance with EN 12952-11 are considered to be reliable

6.1.5 Temperature allowances for unheated components

For unheated components carrying superheated steam, the temperature allowance of 15 °C given in Table 6.1-1 shall be reduced to 5 °C (measuring tolerance) if it shall be ensured that the temperature required by the design cannot be exceeded.

This can be achieved by:

a) temperature control upstream of the said components;

b) the arrangement of cooling or mixing points (e.g. by headers through which the fluid flows in a longitudinal direction) upstream of the said components;

c) connection measures for heating surface arrangement or the like.

6.1.6 Headers

Tubular hollow parts with a nominal external diameter greater than 76,2 mm, into which there are three or more non-axial tube entries, shall be considered as headers.

6.1.7 Unheated components

Components shall be considered to be unheated if

a) they are behind refractory brickwork, and an intermeditate space of at least 100 mm is between the brickwork and the components;

b) a gas-tight-welded waterwall is arranged between the components and the furnace or gas pass;

c) the components are protected by a layer of refractory bricks or refractory lining and this layer is not primarily subject to heat absorption due to radiative heat transfer[2)]; in this case, the brickwork or refractory lining shall be attached to the suspended part by means of holding devices. In the case of headers, studding can be provided for this purpose;

d) the highest possible temperature of the flue gas is less than the reference temperature of the component.

6.1.8 Components protected against radiation

Components shall be considered to be protected against radiation[2)] if they are screened by closely spaced tubes (maximum clear distance 3 mm) and no substantial flow of flue gases can occur between the screening tubes and the components.

6.1.9 Components heated by convection

Components shall be considered to be primarily heated by convection if

a) they are not subject to radiation[2)];

b) the components are protected by a layer of refractory brickwork or refractory lining against radiative heat transfer[1)]. In this case, the bricks or refractory lining shall be attached to the suspended part by holding devices, which in the case of headers, can be studding;

[2)] see 6.1.10

c) the components are protected by a row of tubes with a ratio of

$$P_{\Phi} / d_0 \leq 1{,}3\ n^{0{,}63} \qquad (6.1\text{-}1)$$

where

n is the number of rows;

P_{Φ} is the tube pitch;

d_o is the outside tube diameter.

This requires a value of

$P_{\Phi}/d_o \leq 1{,}3$ for one row of tubes in accordance with Figure 6.1-1;

$P_{\Phi}/d_o \leq 2{,}0$ for two rows of tubes in accordance with Figure 6.1-2;

$P_{\Phi}/d_o \leq 2{,}6$ for three rows of tubes in accordance with Figure 6.1-3.

d) the components are provided with closely spaced tubes in accordance with Figure 6.1-4 with a ratio of

$$\frac{P_0\ P_{90}}{\pi\ l^2} \leq 0{,}1 \qquad (6.1\text{-}2)$$

where

P_0 is the longitudinal pitch with ∅ = 0;

P_{90} is the circumferential tube pitch on the external surface with ∅ = 90;

l is the distance between component and furnace envelope.

6.1.10 Components heated by radiation

Unscreened components shall be considered to be primarily heated by radiation, if they are subject to radiation by flue gases with a temperature > 950 °C.

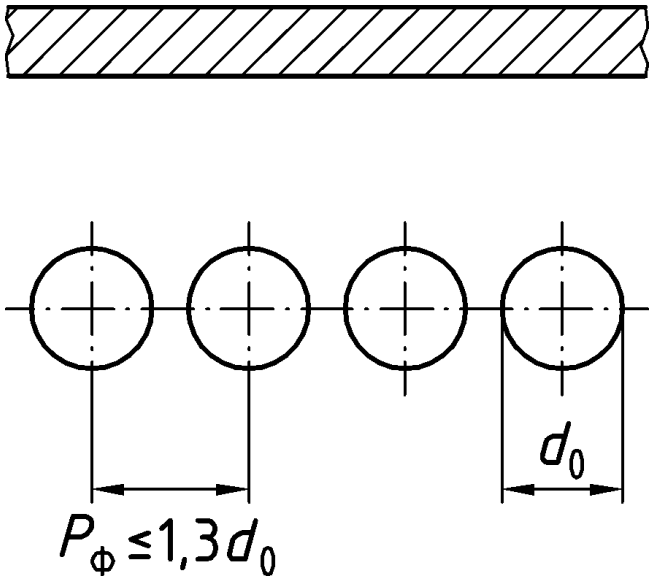

Figure 6.1-1 — Components protected by one row of tubes