Open Access Journal

Journal of Power Technologies 94 (2) (2014) 1–8

journal homepage:papers.itc.pw.edu.pl

Analysis to speed up of the start-up of steam boiler OP-380

Jan Taler*[,a], Bohdan Węglowski[a], Piotr Dzierwa[a], Piotr Czupryński[b], Paweł Madejski[b], Daniel Nabagło[b], Cezary Żyrkowski[b]

[a] *Institute of Thermal Power Engineering, Cracow University of Technology*
24 Warszawska Street, 31-155 Cracow, Poland
[b] *EDF Polska S.A., Research and Developmen*
1 Cieplownicza Street, 31-587 Cracow, Poland

Abstract

During operation of the OP-380 boiler under transient conditions, for example during start-up and shutdown of the power unit, on the circumference of horizontal pressure elements like a drum, inlet and outlet headers, considerable temperature differences are observed. The duration of each start-up and shutdown is relatively long because is limited by thermal stresses caused by temperature changes. The paper presents the method of the maximum stresses arising during operation in transient states determination, based on the measurement of temperature on the outer surface of the thick-walled pressured element. The presented measuring system, including the described method has been implemented in the OP-380 boiler at EDF Krakow. This system will act as a thermal constraints system, whose main task is to protect the equipment against exceeding the maximum allowable thermal stress. This method will also allow assessment of the viability of thick-walled components based on the values of the stresses that occur during long-term operation of the boiler.

Keywords: Boiler, Thermal stresses, Thick-walled elements

---

1. Introduction

Thermal stresses can limit the heating and cooling rates of temperature changes. The largest absolute value of thermal stresses appears at the inner surface. Direct measurements of these stresses are very difficult to take, since the inner surface is in contact with water or steam under high pressure. For that reason, thermal stresses are calculated in an indirect way based on measured temperatures at selected points, located on an outer thermally insulated surface of a pressure element.

The major limiting factor relevant to fast steam boiler start-ups are the maximum allowable thermal stresses in thick-walled components such as headers of superheaters and reheaters, boiler drum and T and Y shaped junctions in steam pipelines [1–4]. Optimization of heating and cooling of thick boiler components is the subject of many studies [5–7], since too rapid heating or cooling element causes high thermal stresses. The heating rates: v_{T1} for pressure p_1 and v_{T2} for pressure p_2 can be determined in accordance with the German TRD 301 boiler regulations [8], or the European Standard EN 12952-3 [9].

The quasi-steady distribution of temperature occurs in the wall of the component after heating the component for a long period of time at the constant rate. Both standards do not allow for abrupt changes in fluid temperature which is their major drawback.

This paper formulates the problem of determining

---

*Corresponding author

Email address: `taler@mech.pk.edu.pl` (Jan Taler*,)

the transient temperature in a drum and live steam headers of boiler OP-380, as an inverse transient heat conduction problem. A computer system for thermal load monitoring in thick-walled components during the boiler start-up and shut-down is implemented in pulverized coal fired boiler OP-380 in EDF CHP in Cracow.

2. Thick-walled components of boiler OP-380

The presented computer system calculates and displays the following data: instant rate of temperature variations in the component walls, thermal stresses at the inner surface of the pressure components, stresses caused by fluid pressure and the total equivalent stresses due to thermal and pressure loads. The cylindrical components such as boiler drum and superheater outlet headers (Fig. 1), will be analyzed.

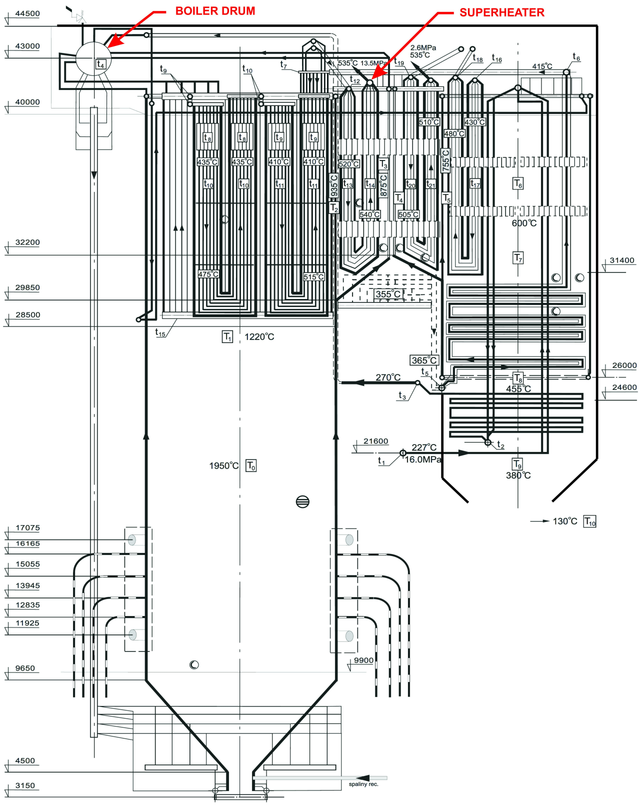

Figure 1: The boiler OP-380 scheme and the analyzed thick-wall components (boiler drum and superheater header)

The boiler OP-380 is a pulverized coal fired boiler with the tangential burners configuration (Fig. 1). The time changes of boiler parameters during a start-up are shown in Figs 2, 3 and 4.

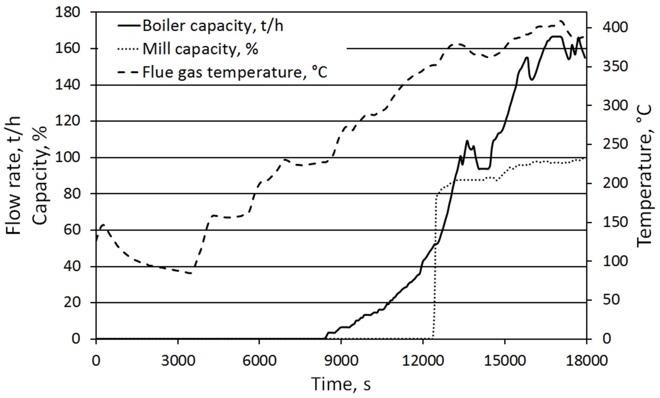

Figure 2: Star-up of the OP-380 steam boiler: live steam mass flow rate, mill capacity

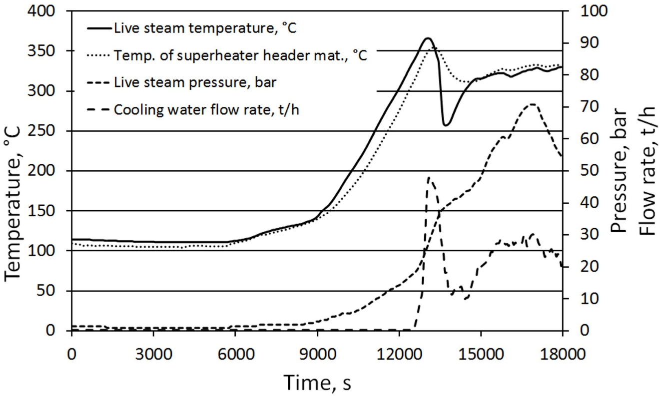

Figure 3: Star-up of the OP-380 steam boiler: live steam parameters

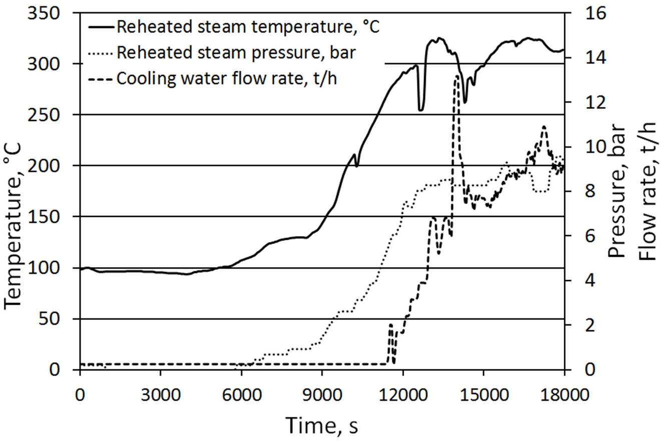

Figure 4: Star-up of the OP-380 steam boiler: reheated steam parameters

From the analysis of the measurements results shown in Figs 2, 3 and 4 it can be seen that fast and sudden temperature changes occur during the start-up of the boiler which cause large thermal stresses.

The drum of boiler OP-380 is the thick-walled, pressurized component made of steel 18CuNMT. The last thick-walled element before the steam supply to the turbine, is the live steam outlet header made of 10CrMo910.

The main geometrical parameters and material properties are presented in Table 1.

$$v_t = \Delta T \cdot \frac{D_{th}}{\phi_w \cdot e_{ms}^2} \tag{1}$$

where: ΔT—the permissible temperature difference between the mean integral temperature in the wall and inner wall surface temperature, K; $D_{th} = \frac{k}{\rho_m c_p}$—metal thermal diffusivity, m^2/s; k—thermal conductivity, W/(m·K); ρ_m—density, kg/m^3; c_p—specific heat, J/(kg·K); e_{ms}—average wall thickness of the pressure element, m; ϕ_w—shape factor for cylindrical pressure element which is a function of outer to inner radius ratio.

3. Permissible heating rate and temperature differences thick-walled components of boiler OP-380

The permissible rate of temperature changes *vt* in boiler pressure parts can be calculated assuming quasi-steady state temperature distribution in the pressure element:

The calculation of temperature differences in the boundary wall of the pressure elements, during heating and cooling processes to be carried out assuming a total permissible range of stress change. The temperature differences limits can be determined using the following formula:

$$\frac{f_{tang,min} - f_{tang,p}}{W} \leq \Delta t \leq \frac{f_{tang,max} - f_{tang,p}}{W} \tag{2}$$

where

$$W = \frac{\alpha_t \cdot \beta_{Lt} \cdot E_t}{1 - \nu} \tag{3}$$

α_t—stress concentration coefficient for circumferential thermal stress, β_{Lt}—linear expansion coefficient at the design temperature T, 1/K, E_t—Young's modulus at the design temperature T, MPa, ν—Poisson's ratio, $f_{tang,min}$, $f_{tang,max}$—the minimum and maximum allowable circumferential stress at the inner surface for the stress which takes into account the stress from the pressure and from thermal load, MPa, $f_{tang,p}$—the allowable circumferential stress form pressure, MPa.

Using formulas (1) and (2), the limit values can be calculated: the difference in temperature and heating rate, taking the pressure $p = p_{min}$ for the beginning of start-up and $p = p_{max}$ for the end of startup.

In the case of shutdown, the beginning is assumed for $p = p_{max}$, and the end for $p = p_{min}$.

Calculated in this way, the heating rate and the permissible limit temperature differences in thick-walled, pressure parts of boilers, are allowed to run riot, and are exempt from service, so as to not exceed the allowable stress. This contributes to improving the life of boiler pressure parts.

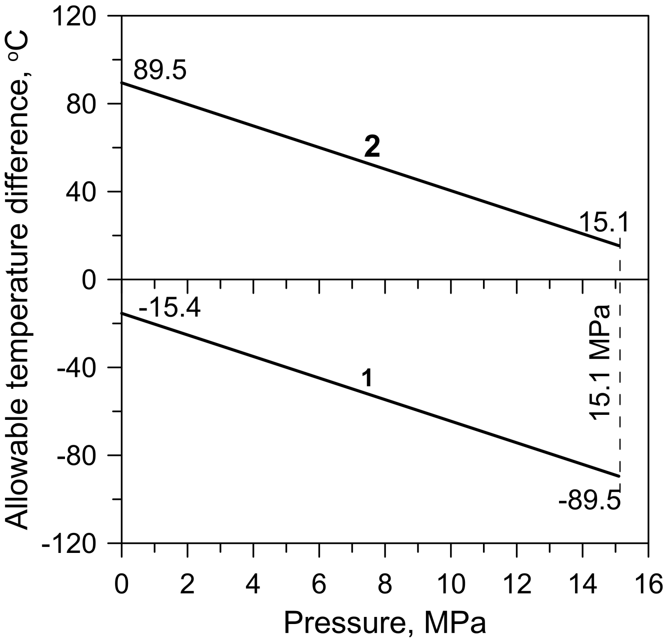

Figure 5: The allowable temperature differences in the wall of the boiler drum during start-up (1) and shutdown (2), from cold state

The calculated allowable temperature differences and heating rates for the boiler drum and superheater outlet header (OP-380) during start-up and shutdown, from a cold state are shown in Figs 5, 6, 7 and 8.

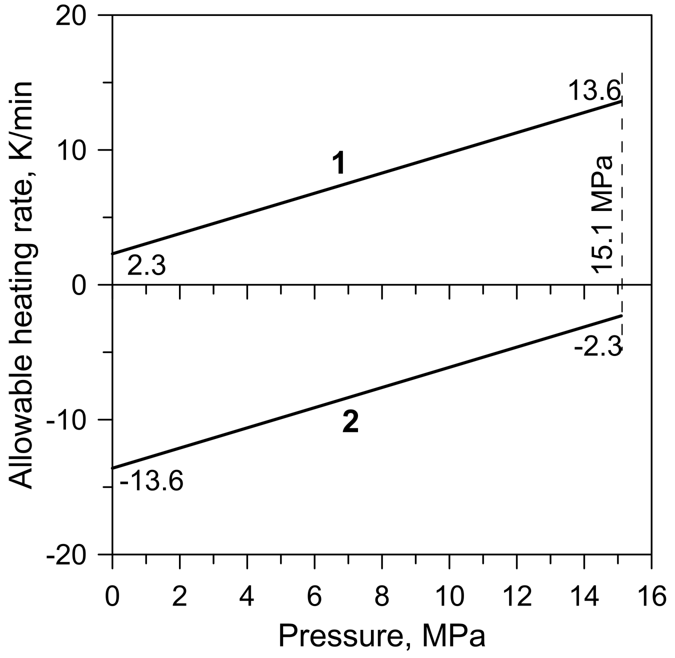

Figure 6: The allowable heating rate in the wall of the boiler drum during start-up (1) and shutdown (2), from cold state

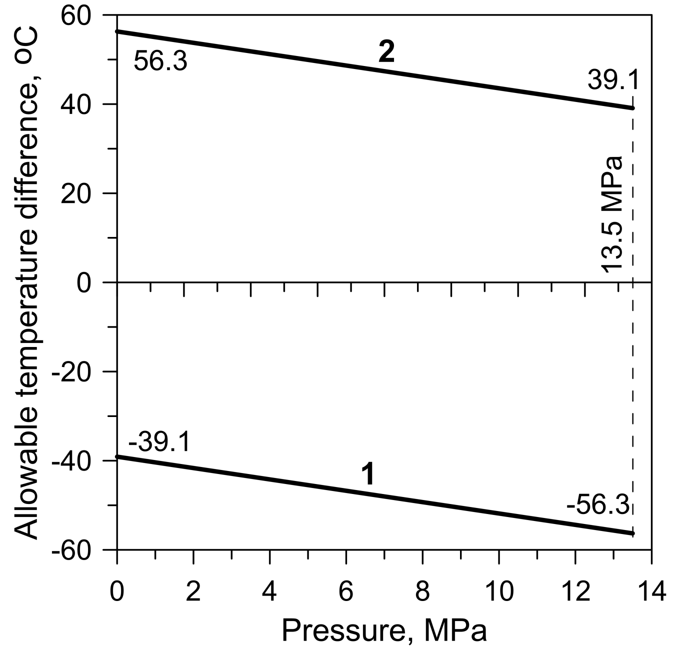

Figure 7: The allowable temperature differences in the wall of the superheater outlet header during start-up (1) and shutdown (2), from cold state

4. Optimum heating and cooling of the selected pressure elements of boiler OP-380

In this section the temperature and pressure waveforms (curves start) for the drum and superheated

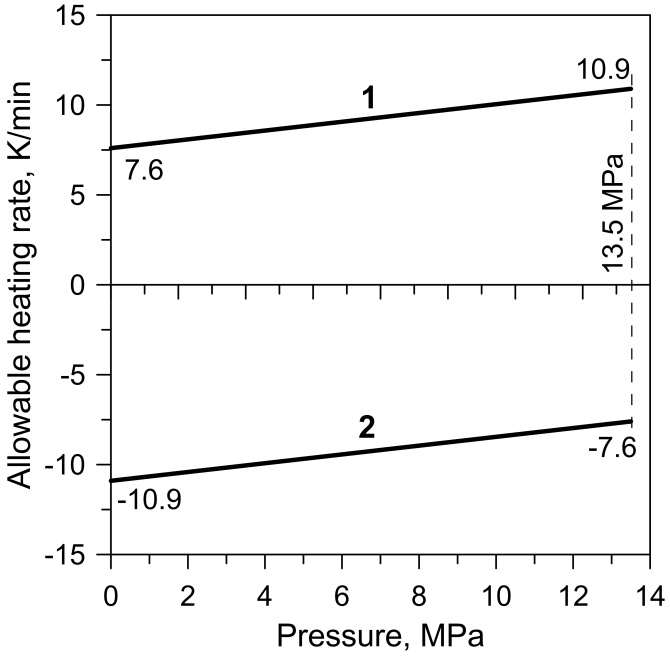

Figure 8: The allowable temperature differences (a) and heating rate (b) in the wall of the superheater outlet header during start-up (1) and shutdown (2), from cold state

steam outlet header, during boiler startup OP-380 were calculated.

Determination of the optimal temperature course required for solving the inverse problem, i.e. the integral equation. This can be avoided by determination of the changes of circumferential thermal stresses at the selected point of the element subjected to fluid temperature changes, a response of the component to a unit step increase in the fluid temperature, so called influence function, has to be determined first (at time tmin function u reaches a minimum value umin.) To determine the minimum value of the circumferential thermal stress (influence function) in the drum OP-380 boiler and superheater header uses program ANSYS v. 13.0.

The rapid initial temperature increase (initial temperature jump) ΔT_0, is set at the beginning of start-up, by dividing the allowable stress values for the minimum value umin influence function. The time dependent temperature profiles were determined from the differential equation:

$$\frac{dT_f}{dt} = f(p) \tag{4}$$

where

$$f(p) = \frac{p_2 v_{T1} - p_1 v_{T2}}{p_2 - p_1} + \frac{v_{T2} - v_{T1}}{p_2 - p_1} p \qquad (5)$$

The pressure p in the drum with water at saturation temperature, is a function of temperature, while in the case of the outlet header, pressure p is a function of time, because the temperature of the superheated steam does not depend on pressure.

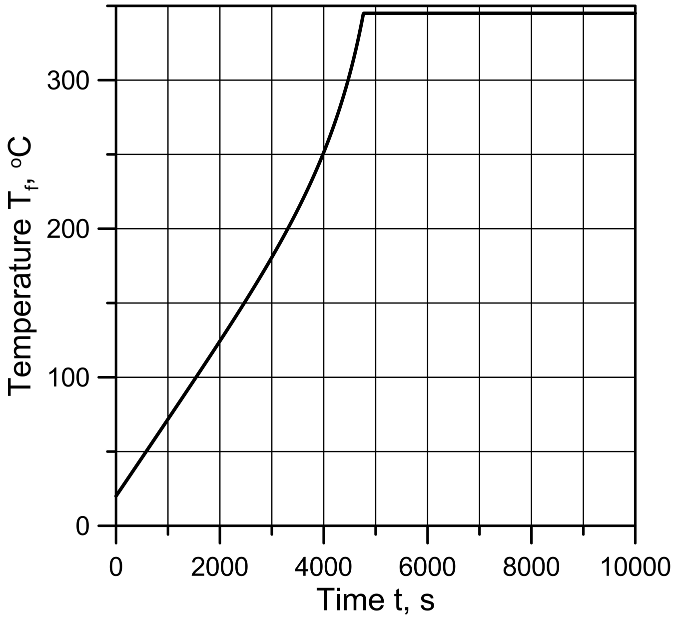

Figure 9: The temperature curve of the working medium in the drum, boiler OP-380 start-up process in accordance with standard EN 12952-3

The time-dependent temperature and pressure courses (temperature and pressure curves) obtained for the drum are shown in Figs (9, 10, 11 and 12). The time-dependent temperature and pressure courses obtained for the superheater header are illustrated in Figs (13, 14, 15 and 16). If the heating (warm-up) of the drum is conducted in accordance with the curves designated according to PN-EN 12952 3 (Figs 9 and 10) the heating of the drum takes about 4,800 seconds. If the step change in water temperature ΔT_0 at the beginning of the warm-up is allowable then the start-up time is shorter and it is equal approximately to 3,500 seconds (Figs 11 and 12).

Heating curves for the outlet chamber are determined for the value of pressure equal to the 90% of the operating pressure in drum. The temperature and pressure curves for heating rates v_{T1} and v_{T2} determined according to PN-EN 12952-3 are shown in Figs 13 and 14.

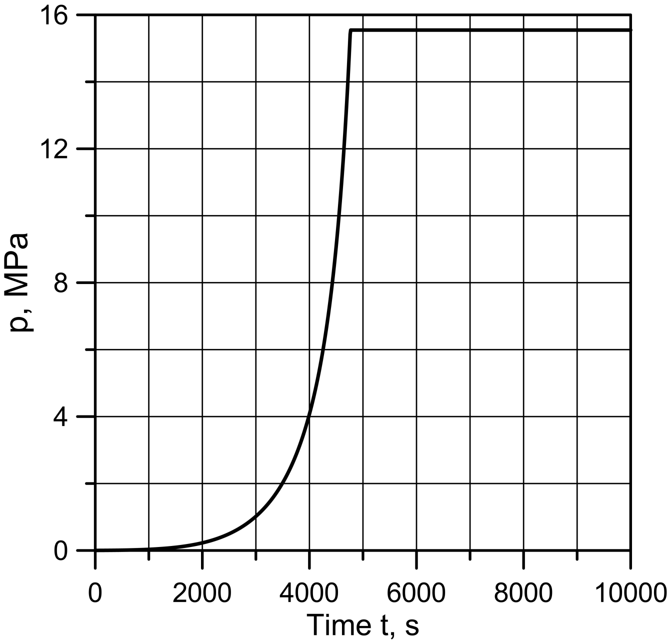

Figure 10: The pressure curves of the working medium in the drum, boiler OP-380 start-up process in accordance with standard EN 12952-3

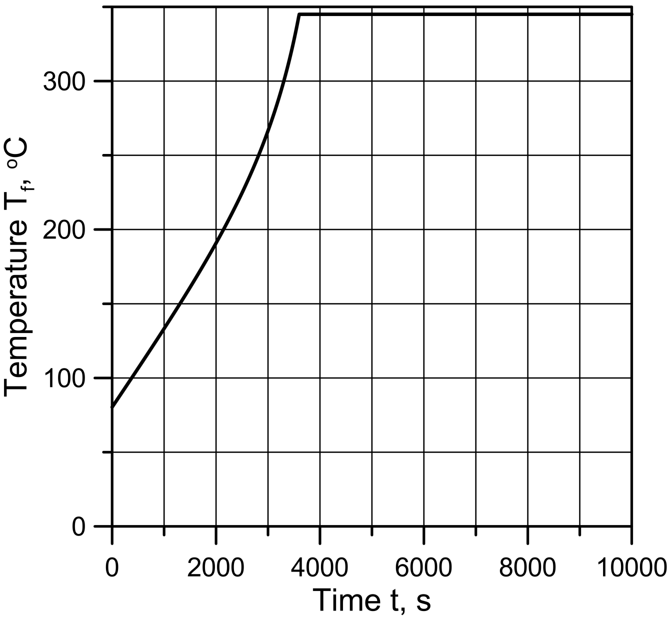

Figure 11: The temperature curve of the working medium in the drum, boiler startup OP-380, taking into account the temperature jump ΔT_0 at the beginning of the startup process

The curves that take into account the initial increase in the steam temperature ΔT_0 are presented in Fig. 15 and 16.

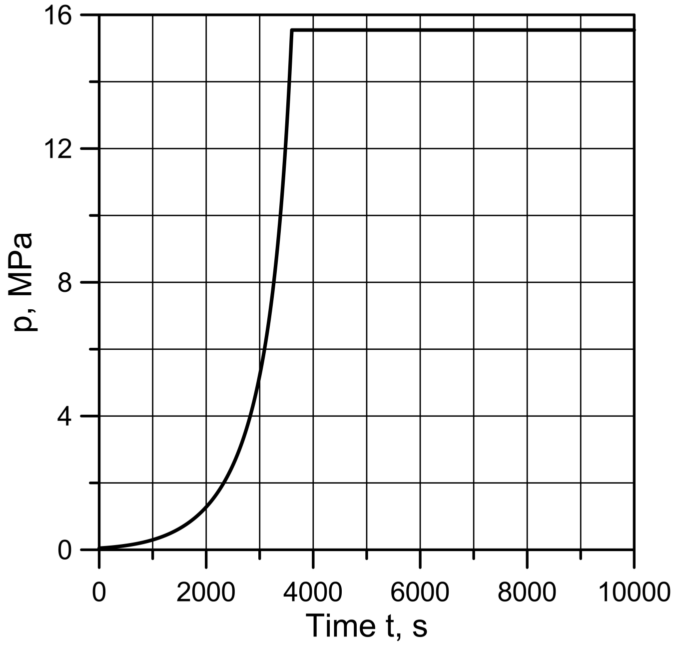

Figure 12: The pressure curve of the working medium in the drum, boiler startup OP-380, taking into account the temperature jump ΔT_0 at the beginning of the startup process

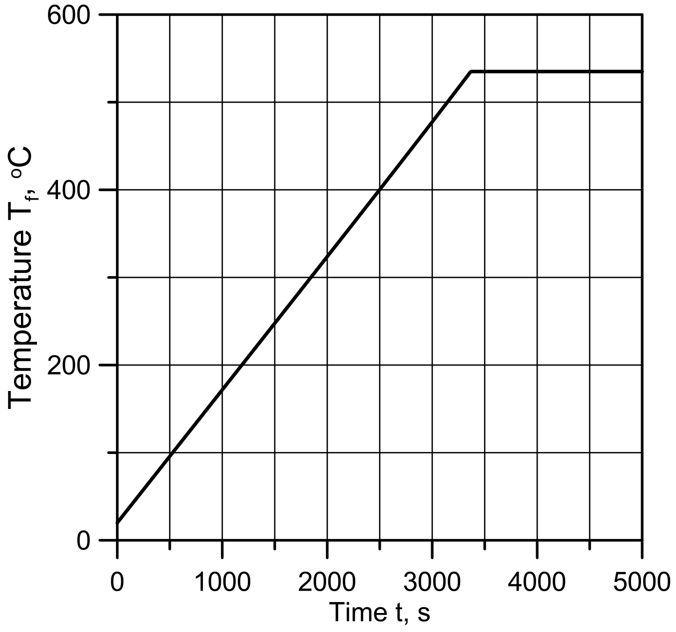

Figure 13: The temperature curve of the working medium in the live steam outlet header, boiler OP-380 start-up process in accordance with standard EN 12952-3

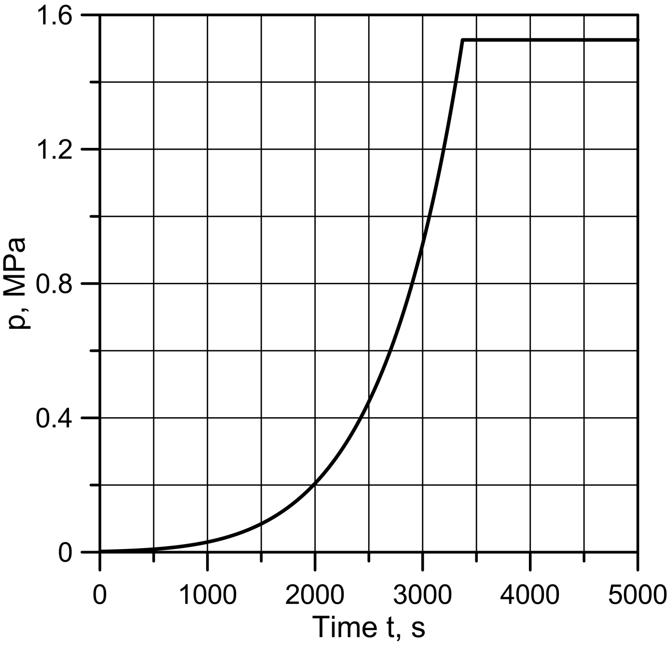

Figure 14: The pressure curve of the working medium in the live steam outlet header, boiler OP-380 start-up process in accordance with standard EN 12952-3

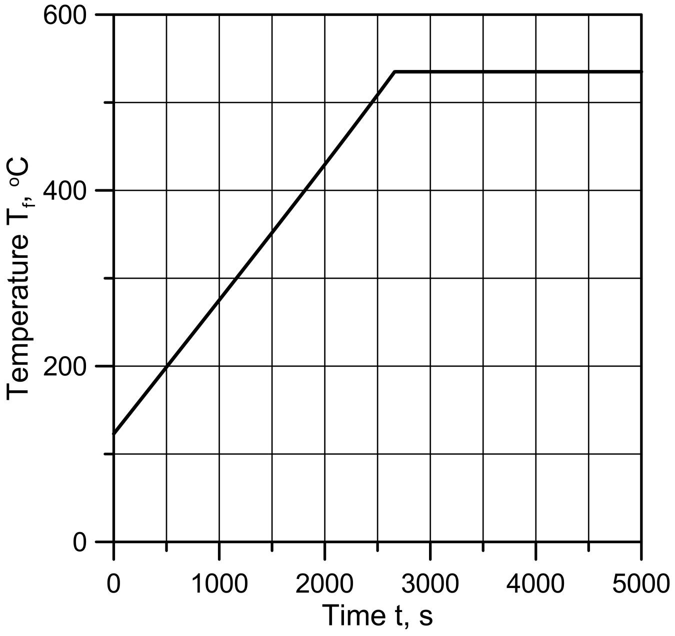

Figure 15: The temperature curve of the working medium in the live steam outlet header, boiler startup OP-380, taking into account the temperature jump ΔT_0 at the beginning of the startup process

Comparing Fig. 9, 10 and 11, 12 with Fig. 13, 14 and 15, 16 we can note that if the rapid initial increase in the temperature ΔT_0 is allowable, then the time of boiler warm-up (start-up) is shorten from 3,400 seconds to 2,650 seconds. The reduction of boiler start-up time is very important due to the reduction of losses and due to the significant reduction in start-up costs.

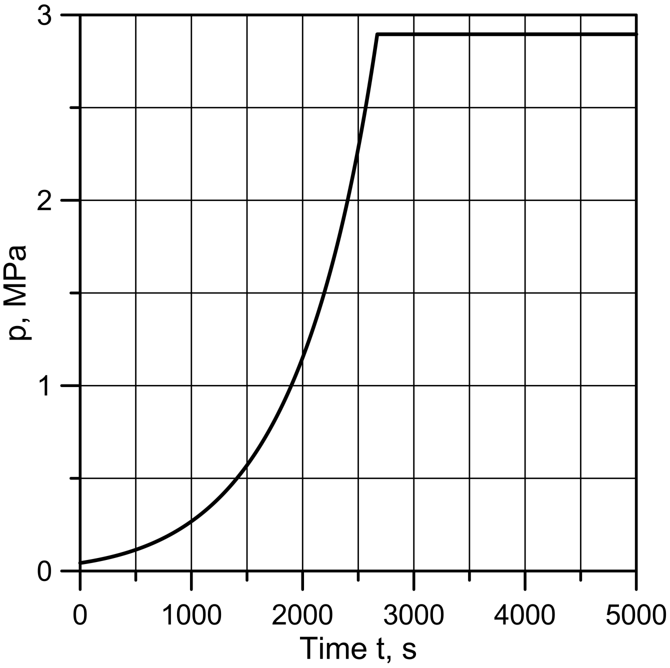

Figure 16: The pressure curve of the working medium in the live steam outlet header, boiler startup OP-380, taking into account the temperature jump ΔT_0 at the beginning of the startup process

5. Conclusions

Stress monitoring will be used from the moment the boiler is started. Thanks to this, time can be saved by optimal heating and accepted metal heating temperature can be kept. Initial boiler startup time is crucial for the purpose of proper startup since that time can be shortened.

Another critical moment of boiler startup is inlet of basic fuel (coal mille) instead of mazout fuel. Meaningful stress differences may also appear during the startup and when analyzed properly, they may allow to regulate the number of mazout fuel burns on and off.

Additional advantage of this system is monitoring of boiler cooling stage in case of boiler shutdown, resulting from leaking. At this stage, the priority is to prepare the boiler for maintenance (by cooling it). Monitoring of this operation can be much safer as far as machinery lifetime is concerned thanks to stress monitoring. It will also allow to prepare boiler for maintenance works in the optimal time.

References

[1] J. Taler, P. Dzierwa, D. Taler, Determining optimum temperature changes during heating of pressure vessels with holes, in: PVP 2013-98025. Proceedings of the ASME 2013 Pressure Vessels & Piping Division Conference PVP2013, Paris, 2013, pp. 14–18.

[2] J. Taler, B. Węglowski, W. Zima, S. Grądziel, M. Zborowski, Analysis of thermal stresses in a boiler drum during start-up., Transactions of the ASME, Journal of Pressure Vessel Technology 121 (1999) 84–93.

[3] T. S. Kim, D. K. Lee, S. T. Ro, Analysis of thermal stress evolution in the steam drum during start-up of a heat recovery steam generator, Applied Thermal Engineering 20 (2000) 977–992.

[4] K. Krüger, R. Franke, M. Rode, Optimization of boiler start-up using a nonlinear boiler model and hard constraints, Energy 29 (2004) 2239–2251.

[5] P. Dzierwa, Encyclopedia of Thermal Stresses, Springer, Berlin, Germany, 2013, Ch. Optimum heating of pressure components of complex shape.

[6] J. Taler, P. Dzierwa, D. Taler, Optimum heating of pressure components of large steam boilers, Forschung im Ingenieurwesen (Engineering Research) 73 (3) (2009) 183–192.

[7] J. Taler, P. Dzierwa, A new method for optimum heating of steam boiler pressure components, International Journal of Energy Research 35 (2011) 897–908.

[8] H. Beuth, TRD 301, Zylinderschalen unter innerem Überdruck. Technische Regeln für Dampfkessel (TRD),143–185, Köln – Berlin, Germany (2001).

[9] Water-tube boilers and auxiliary installations – part 3: Design and calculation for pressure parts (2012).

Table 1: The geometrical parameters and material properties at calculation temperature *t* of analyzed thick-walled components

No.	Parameter	Unit	Boiler drum	Steam outlet header
1	Steel		18CuNMT	10CrMo910
2	Outer diameter	mm	1800	324
3	Wall thickness	mm	100	70
4	Maximum pressure	MPa	15.1	13.5
5	Maximum temperature	°C	345	535
6	Design temperature	°C	263.75	406.25
7	Young's modulus	MPa	2.03E+05	1.75E+05
8	Linear thermal expansion coefficient	1/K	1.26E-05	1.56E-05
9	Poisson's ratio		0.285	0.307
10	Specific heat	kJ/(kg·K)	0.491	0.701
11	Density	kg/m^3	7785	7677