

## NUMERICAL SIMULATION OF THE HEAT TREATMENT OF THE WELD FOR STEAM GENERATOR

Received – Prispjelo: 2015-11-06  
Accepted – Prihvaćeno: 2016-04-20  
Preliminary Note – Prethodno priopćenje

Heat treatment of the weld of the steam generator is investigated in this paper. Annealing is realized by system of heating elements that are placed on casing of the generator. An experiment using real parameters and a computational fluid dynamics analysis using COMSOL Multiphysics software were performed. Experimental data were compared with results of the analysis. Boundary conditions for numerical prediction had been derived on basis of results obtained from a supplementary calibration experiment. There was good correlation between predicted and measured data. Based on results it can be stated that 67 heating elements with heating output of 60-70 % of maximum range is sufficient number for required heat treatment.

*Keywords:* weld, steam generator, heat treatment, numerical simulation, heating elements

### INTRODUCTION

Technologically proper annealing of welds has major impact at the operational reliability of the exposed device such as a steam generator. Annealing is often carried out by a system of heating elements that are placed on casing of the generator [1]. For placement of the heating elements and the actual simulation of annealing is necessary to experimentally determine the boundary conditions, which requires the calculation of the actual power of the heating element, the heat transfer coefficient from the material and insulation into the surrounding areas and determine the share of electrical power of the heating element, that is in the form of heat energy actually handed to the material. After determining of the boundary conditions, geometrical model of steam generator is processed and layout of the heating elements is designed. Simulation results are then compared with the real experiment.

### EXPERIMENTAL PROCEDURE

Heating blanket with a 6 m length of the resistance wire and 84 V has performance reported 4 kW. The 0,6 m of length required for outlets of the heating elements are not included in the calculations in practice. During the verification measurements were on the cold ends of heating element values 48,4 A and 84,5 V. After deduction of 10 % of the power is converted power of heating blankets 52 kW.

A heating element with the dimensions of 410 x 170 mm was placed on a steel plate with the dimensions of 2 100 x 1 500 x 48 mm and was turned on at full power. The heating element is placed in the middle of the steel plate and the isolation is laid over it, it is a Fibratex mat made of a ceramic fibre with thickness of 40 mm. The Fibratex mat exceeds the heating element of 100 mm on each side. The temperature was recorded in precisely defined points on the steel plate (see Figure 1).

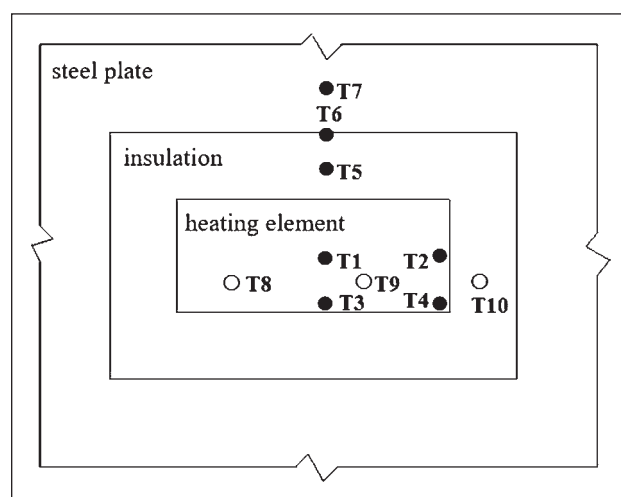


Figure 1 Position of thermocouples during the measurement

The thermocouples number 8, 9 and 10 are located on the bottom of the steel plate, the others are then on the upper side of the plate. Thermocouples 1, 2, 3 and 4 are located under the heating element, 5 and 6 under the insulation and thermocouple 7 is in the open space of the steel plate. The outcomes of the measurement are temperature values processed in Table 1.

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Table 1 Thermocouple temperatures at the end of measurement / °C

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
348	256	303	235	224	182	140	188	297	282

Values were determined:

- heat transfer coefficient  $\alpha_{oc}$  is  $8,5 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ ,
- heat transfer coefficient  $\alpha_{iz}$  is  $0,28 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$
- heat flow  $q_0$  is  $43,5 \text{ kW}\cdot\text{m}^{-2}$ .

The power input required for the heat accumulation of the body  $P_n$  is calculated by multiplying of the specific heat capacity  $c_p$ , material density, the speed of heating  $v_0$  and the volume  $V$ , converted to watts, while the volume  $V$  by the power input  $P_n$  is calculated by multiplying of the difference between circle areas of pipes and heating width  $S_l$  which was calculated according to ČSN 05 0211 [9].

$$P_n = c_p \cdot V \cdot \rho \cdot \frac{v_0}{3600} / W \quad (1)$$

$$V = (\pi \cdot r_2^2 - \pi \cdot r_1^2) \cdot S_l / m^3 \quad (2)$$

$$V = (\pi \cdot 0,95^2 - \pi \cdot 0,81^2) \cdot 0,4 = 0,31 \text{ m}^3$$

$$P_n = 580 \cdot 0,4 \cdot 7650 \cdot 50/3600 = 24\,650 \text{ W}$$

Heat losses by longitudinal conduction into the surrounding material  $P_o$  are calculated by multiplying experimentally detected temperature gradient, thermal conductivity and area  $S$ , which is calculated as distinction of the areas of the smaller (with  $r_1$ ) and the larger pipe ( $r_2$ )

$$P_o = \lambda \cdot 2 \cdot S \cdot \Delta t / W \quad (3)$$

$$S = \pi \cdot r_2^2 - \pi \cdot r_1^2 / m^2 \quad (4)$$

$$S = \pi \cdot 0,95^2 - \pi \cdot 0,81^2 = 0,774 \text{ m}^2$$

$$P_o = 37 \cdot 2 \cdot 0,77 \cdot 1000 = 56\,980 \text{ W}$$

Heat losses in insulation  $P_z$  are calculated by multiplying of the coefficient of the thermal insulation loss  $P'$ , insulation diameter  $d_{iz}$  and its width  $s_{iz}$

$$P_z = 2 \cdot P' \cdot \pi \cdot d_{iz} \cdot s_{iz} / W \quad (5)$$

$$P_z = 2 \cdot 600 \cdot \pi \cdot 1,9 \cdot 1,2 = 8591 \text{ W}$$

The total permanent power input required is 90 221 W and it is calculated by multiplying of the power input required for the heat accumulation of body  $P_n$ , by the heat losses by longitudinal conduction into the surrounding material  $P_o$  and by the heat losses in insulation  $P_z$ .

Subsequently, the 1,3 correction factor was introduced comprising the difference between calculated ( $43,5 \text{ kW}\cdot\text{m}^{-2}$ ) and simulated heat flux ( $52 \text{ kW}\cdot\text{m}^{-2}$ ). Also correction factor of 1,7 was taken into account based on long practical experience and technological knowledge, which is used to achieve a temperature of  $620 \text{ }^\circ\text{C}$ .  $P_{sk}$  – the real permanent power input which is required is 199,4 kW and it comes after taking into account both correction factors.

In the last part of the calculation it is necessary to determine how many heating elements can provide this

power input. Number of heating elements  $n_d$  is calculated as distinction of real permanent power input required  $P_{sk}$  and output of the heating element  $P_d$  that is 66,5 units, which implies that it is necessary to use 67 heating elements. In such case there will not be a problem to heat the weld up to  $620 \text{ }^\circ\text{C}$ , whilst the heating elements should have a maximum output of 65 % of their performance.

## NUMERICAL ANALYSIS

During modelling in the COMSOL Multiphysics program [10], the process went as follows - the choice of an application mode, creation of a geometrical model entering of physical properties of the material, definition of the boundary conditions [11] and setup computational mesh.

When selecting an application mode, the non-steady-state temperature is solved in the body of the steam generator, which means that the problem will be solved in relation to time. The heating is controlled, so it is a task of optimization. For creation of the 3D geometrical model of the steam generator in the COMSOL the method of protrusion and revolving of 2D objects was used. The generator is composed of several parts. This is necessary to distinguish for further calculations. These are the steel casting with thickness of 40 mm, steel base with thickness of 140 mm, tube sheet and the bundle of brass tubes. That relates to the assignment of physical properties of these parts of the model.

Due to the determination of the physical properties of the material, functions of temperature dependences of the three required parameters - density „rho“, thermal conductivity „lamb“ and heat capacity „cp“ were created. Boundary conditions define the interface between the geometry of the model and its surroundings, or the internal borders of the geometric model, while there are distinguished internal and external borders. A condition of the third kind occurs the most in the solved problem; this means the knowledge of heat flux.

$$q = -k\nabla T / W \cdot m^{-2} \quad (6)$$

For a correct entering of the condition, it is necessary to know the values of the heat flux, the heat transfer coefficient, the initial temperature and the ambient temperature. A certain annealing regime must be kept that means the speed of the rising temperature, maintaining of the temperature and speed of the descending of the temperature. Only one part of it is examined here that is the rising of the temperature to a prescribed one, because the aim is to achieve the proper annealing temperature by a controlled way to help the calculation of the number of heating elements and their proper placement.

Various boundary conditions are indicated in the Figure 2. Zone 1 is a series of heating elements which measure 510 x 130 mm, which are laid directly on the

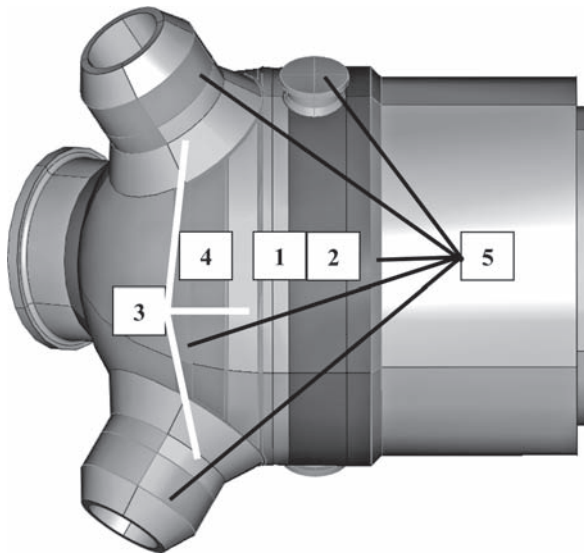


Figure 2 Areas with different boundary conditions

annealed weld. Area 2 is a series of heating elements on the tube plate that have the dimensions of 180 x 405 mm, in fields 3 at the semi rounded bottom of the steam generator are heating elements measuring 510 x 130 mm and on each welded protruded pipe are 4 pieces of heating elements measuring 205 x 365 mm. Zone 4 indicates heating elements measuring 510 x 150 mm. Over all heating elements and also over the area 5 there is Fibratex insulation laid. Other areas in Figure 2 are not insulated steel parts.

Computational mesh describes the geometry of the modelled object. The type and density of the mesh affects the accuracy and the length of calculation and therefore it is important to mesh the object optimally. A very soft mesh was set up in the area of the weld, because in this area it is appropriate to know the precise distribution of temperature field. On other parts of the generator, where it is not necessary to have as accurate results, the mesh was adjusted as thicker by using tetrahedrons and hexahedrons.

## RESULT ANALYSIS

It can be stated that the total number of the heating elements is sufficient with heating output of 60 - 70 % of maximum range. In this case 67 elements were used altogether. Calculation also includes the coefficients for used technologies of heating elements.

The results of the experiment are shown in the following Figures, where temperatures of five control thermocouples are recorded and shown in Figure 3. In Figure 4 are calculated values and in Figure 5 is a scanned graph of real temperatures depending on time that is written by printers placed directly in the sources during the actual annealing.

Result of the experiment corresponds to the created simulation in COMSOL Multiphysics, which includes specific numerical values and dependence. Experiment and simulation show conformity.

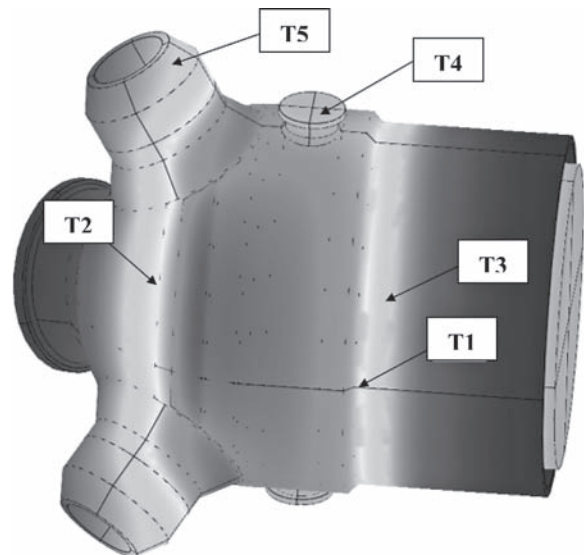


Figure 3 Placement of control thermocouples

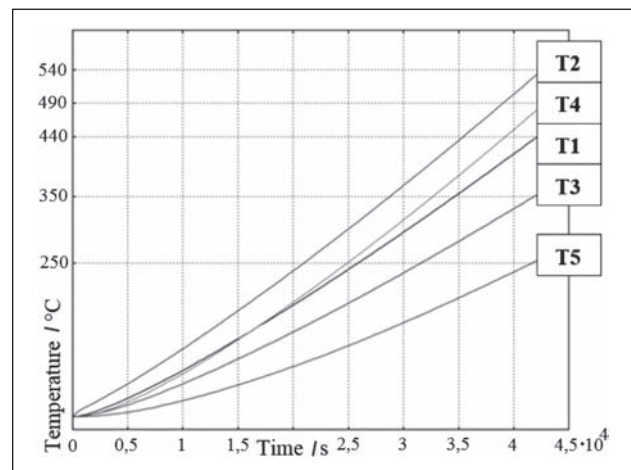


Figure 4 Calculated temperatures of control thermocouples depending on time

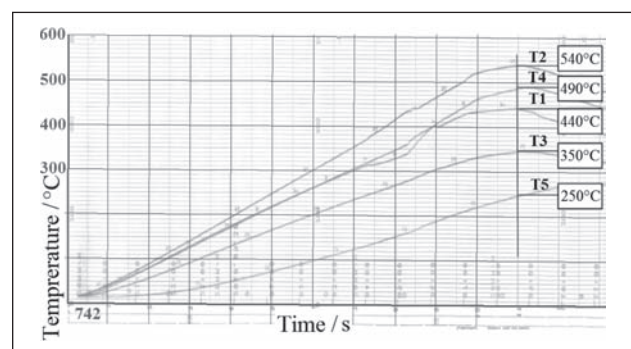


Figure 5 Real temperatures of control thermocouples depending on time

## CONCLUSIONS

The aim of this paper was to design and to validate the model number and location of heating elements for heat treatment of the weld of the steam generator by experimental investigation as well as by numerical approach.

The experiment was based on the real situation of heating element in interaction with the steel material and its weld while obeying technological standards.

Certain important values for the boundary conditions that are required as an input data into the simulation were determined by the experiment. It can be concluded that 67 heating elements with heating output of 60 - 70 % of maximum range is sufficient for required heat treatment. As a main result can be considered the design of an annealing technology with the use of the heating elements. Elements reflect the true real of technology. This was already verified in real conditions.

## Acknowledgements

This paper was created at the Faculty of Metallurgy and Materials Engineering in the Project No. LO1203 "Regional Materials Science and Technology Centre - Feasibility Program" funded by Ministry of Education, Youth and Sports of the Czech Republic and also was elaborated within the project SP2015/86 - Reduction of the energy demands of the material production processes and SP 2015/70 - Specific research in the metallurgical, materials and process engineering.

## REFERENCES

- [1] D. Ivan, Příručka pro tepelné zpracování, HM-Svarservis, s.r.o., 2005, HMS č. 10,14 s.
- [2] M. Yataghene, J. Legrand, A 3D-CFD model thermal analysis within a scraped surface heat, *Computers and Fluids* 71 (2013) 380-399.
- [3] W. I. A. Aly, Numerical study on turbulent heat transfer and pressure drop of nanofluid in coiled tube-in-tube heat exchangers, *Energy Convers. Manage.* 79 (2014) 304–316.
- [4] T. Bajc, M. N. Todorović, J. Svorcan, CFD analyses for passive house with Trombe wall and impact to energy demand *Energy and Buildings* 98 (2015), 39-44.
- [5] J. Ge, D. Zhang, W. Tian, K. Wang, S. Qiu, G. H. Su, Steady and transient solutions of neutronics problems based on finite volume method (FVM) with a CFD code *Progress in Nuclear Energy* 85 (2015), 366-374.
- [6] R. Kocich, M. Bojko, A. Macháčková, Z. Klečková, Numerical analysis of the tubular heat exchanger designed for co-generating units on the basis of microturbines, *International Journal of Heat and Mass Transfer* 55 (2012) 5336-5342.
- [7] A. Macháčková, R. Kocich, M. Bojko, Z. Klečková, Numerical analysis of secondary heat exchanger designed for CHP units with microturbine, *International Journal of Heat and Mass Transfer* 83 (2015) 487–498.
- [8] J. V. Simo Tala, D. Bougeard, S. Russeil, J. L. Harion, Tube pattern effect on thermalhydraulic characteristics in a two-rows finned-tube heat exchanger, *Int. J. Therm. Sci.* 60 (2012) 225–235.
- [9] ČSN 05 0211. Tepelné a mechanické spracovanie zvarových spojov nelegovaných a nízkolegovaných ocelí: všeobecné zásady. Federální úřad pro normalizaci a měření, 1992. 18 s.
- [10] W. Pryor, W. Roger, Multiphysics modeling using COMSOL: a first principles approach. USA, 2009. 852 s.
- [11] J. Kunes, Modelování tepelných procesů. Prague, 1989. 424 s.

**Note:** The paper was translated by Vendula Srničková