Active thermal insulation for induction heating of specific metal parts

Bohuš Ulrych, Václav Kotlan, Ivo Doležel,

*Faculty of Electrical Engineering, University of West Bohemia, Univerzitní 26, 306 14 Plzeň
E-mail: {ulrych, vkotlan, idolezel}@kte.zcu.cz

Abstract: **The concept of active thermal insulation is explained and its application for induction heating of specific metal parts is analyzed. Its features ale illustrated by a typical example whose results are discussed**

Keywords: **Active thermal insulation, induction heating, temperature field, numerical analysis.**

I. INTRODUCTION

In numerous technical applications (power devices, chemical reactors, metallurgy, heat treatment processes) an important role is played by thermal insulation of various structural parts. This is mostly realized using classical passive thermal insulations (PTIs) represented by materials with very low thermal conductivity λ (we can mention, for example, polystyrene, some plastics, felt, glass wool, grinded basalt, asbestos, etc.). These materials minimize the undesired loss-making thermal flux $\boldsymbol{q}_{\mathrm{loss}} = -\lambda \,\mathrm{grad}\, T$ flowing from the insulated body to its environment.

But beside the above PTIs there exist also active thermal insulations (ATIs). These are realized by generation of another thermal flux $\boldsymbol{q}_{\mathrm{act}}$ going against the loss-making flux $\boldsymbol{q}_{\mathrm{loss}}$. This flux $\boldsymbol{q}_{\mathrm{act}}$ is mostly generated by direct ohmic heating of appropriate current-carrying resistance elements. If such a system is proposed properly, the surface of the insulated body is characterized by isothermic or even adiabatic state.

Until recently, the ATI was used only in several specific applications such as space technology, where it served for keeping isothermic regime of some measuring devices. But it can also successfully be applied in common technical practice where it is able to improve the efficiency of various processes.

The paper shows a possibility of using the ATI principle for induction heating of active wheels of gas turbines before their pressing on a shaft.

II. FORMULATION OF THE PROBLEM

The principal arrangement of the inductively heated wheel is depicted in Fig. 1. During the process of heating the wheel is insulated by ATI in order to reduce the thermal losses and improve its efficiency. More detailed information about induction heating of such wheels can be found in [1] and [2].

The heated wheel **1** fixed on cylinder **4** is inserted to the inductor **3** consisting of two parts. The inductor is made from a massive copper conductor cooled with water. Time variable magnetic field produced by the inductor generates in the wheel eddy currents and Joule heat. The wheel is (with respect to its environment) insulated either with PTI **2.2** formed by, for example, a layer of asbestos filaments, or with ATI formed by an asbestos foil with embedded resistance heating elements, for example, a resistance conductor. The aim of the paper is to compare the parameters of the heating process when using PTI and ATI.

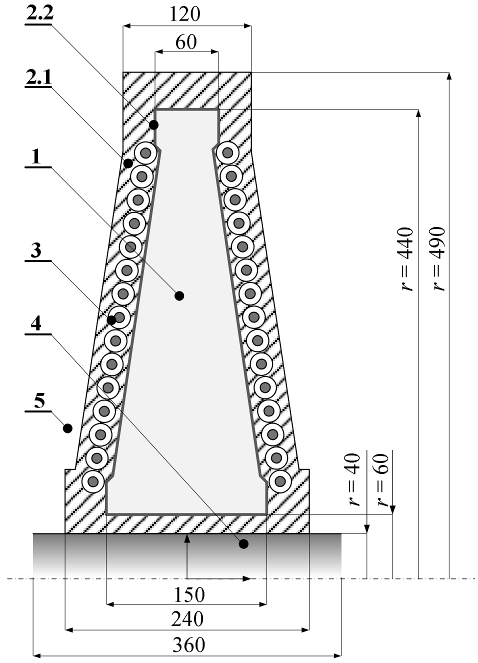

Fig. 1. The system with heated wheel (dimensions in mm)
1–heated wheel, **2.1**–passive thermal insulation, **2.2**–active thermal insulation, **3–**inductor (Cu pipe, cooled with H_2O), **4**–fixing cylinder, **5**–ambient air

III. MATHEMATICAL MODEL

The general equation describing the distribution of temperature field T in the heated wheel reads [3]

$$\mathrm{div}\,(\lambda \,\mathrm{grad}\, T) = \rho c \frac{\partial T}{\partial t} - q_{\mathrm{J}}\,, \qquad (1)$$

where λ denotes the thermal conductivity, ρc is the specific thermal capacity of the heated material, and q_{J} stands for the volumetric heat sources (in our case given by the volumetric Joule losses).

For example, in the layer **2.1** (PTI) equation (1) in the cylindrical coordinates may be written as follows

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} = \frac{\rho c}{\lambda}\frac{\partial T}{\partial t}\,. \qquad (2)$$

If the layer is formed by asbestos filaments, its external surface is characterized by the boundary condition

$$-\lambda \frac{\partial T}{\partial n} = \alpha_{\mathrm{c}} \left(T - T_{\mathrm{ext}} \right), \qquad (3)$$

where α_c it the coefficient of convective heat transfer and T_{ext} denotes the ambient temperature. The influence of radiation can be neglected.

In case of ATI (**2.2**), the boundary condition on the surface of the heated body (where the ATI foil is placed) may be characterized by the relation

$$\frac{\partial T}{\partial n} = 0. \quad (4)$$

IV. Numerical Solution and Discussion of Results

The numerical solution of (1) for the investigated wheel was carried out by a FEM-based code QuickField 5.0 [4]. For computations we considered the average heat losses $q_J = 3.616\times10^6$ W/m^3, which was taken over from [1] (this value corresponds to external current density $J_{\text{ext}} = 5\times10^3$ A/m^2 with frequency $f = 50$ Hz). The physical parameters of materials and their temperature dependencies are also presented in [1].

Selected qualitative results are shown in Figs. 2 and 3.

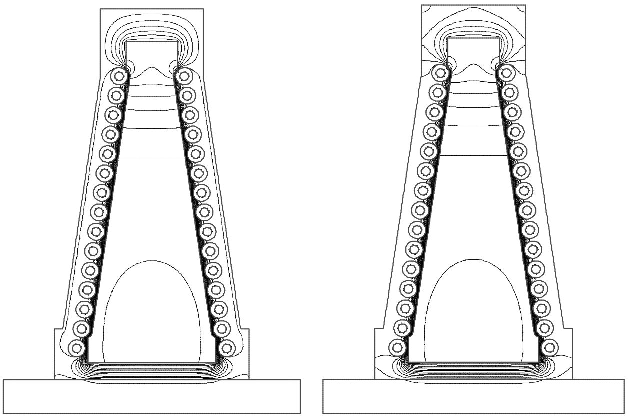

Fig. 2. Left – Temperature field in the wheel after 15 minutes of heating with classical insulation ($I_{\text{ext}} = 5\times10^3$ A, $f = 50$ Hz, $q_J = 3.616\times10^6$ W/m^3, $T_{\text{avrg}} = 609$ °C, $T_{\max} = T(r_1) = 696$ °C, $\Delta T = 50$ °C), Right - Temperature field in the wheel after 15 minutes of heating with ATI, the heating system being placed on the external surface of the shell ($I_{\text{ext}} = 5\times10^3$ A, $f = 50$ Hz, $q_J = 3.616\times10^6$ W/m^3, $T_{\text{avrg}} = 609$ °C, $T_{\max} = T(r_1) = 696$ °C, $\Delta T = 50$ °C)

Figure 2, left part shows the temperature field of the wheel after 15 minutes of heating provided that the insulation is of the PTI type. The right part of this figure shows an analogous field with ATI placed on the external surface of the insulation shell. The fields are practically the same, because the wheel is cooled by water flowing in the hollow conductor of the field coil. Now the condition $\partial T/\partial n = 0$ holds only behind these hollow conductors and practically does not influence the temperature of the wheel. On the other hand, Fig. 3 shows the distribution of temperature field for the same parameters, but now ATI is placed on the surface of the wheel. We can see that the average temperature of the wheel is now substantially higher (by about 87 °C).

Some quantitative results are shown in Fig. 4. It is obvious that ATI provides temperatures by about 15 % higher than PTI, with the same value of q_J. But for more precise computations it would be necessary to use the hard-coupled formulation and also the energy lost in the system of resistance elements forming ATI.

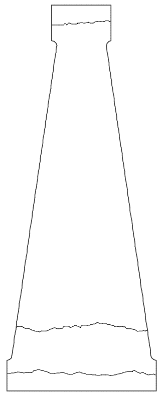

Fig. 3. Temperature field in the wheel after 15 minutes of heating with ATI, the heating system being placed on the internal surface of the shell ($I_{\text{ext}} = 5\times10^3$ A, $f = 50$ Hz, $q_J = 3.616\times10^6$ W/m^3, $T_{\text{avrg}} = T_{\max} = T(r_1) = 696$ °C, $\Delta T = 0.01$ °C)

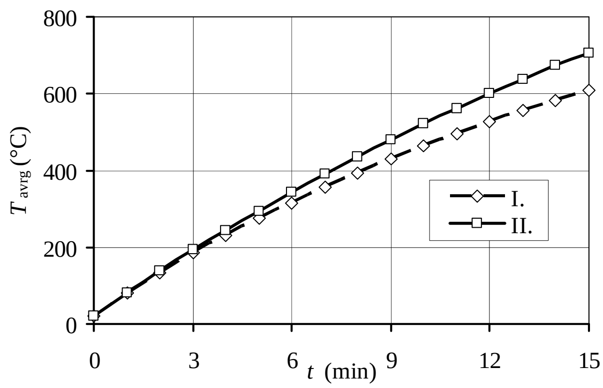

Fig. 4. Evolution of average temperature T_{avrg} of the wheel in time ($I_{\text{ext}} = 5\times10^3$ A, $f = 50$ Hz, $q_J = 3.616\times10^6$ W/m^3): I–PTI, II–ATI

V. Conclusion

The results show that application of ATI may increase the efficiency of the regime of induction heating of solid bodies. On the other hand, however, more attention should be paid to physical realization of ATI, i.e., to arrangement of resistance elements in the asbestos foil or fabric and to determination of current I_{ATI} necessary for elimination of thermal flux $\boldsymbol{q}_{\text{loss}}$.

VI. Acknowledgements

This work was supported by the European Regional Development Fund and Ministry of Education, Youth and Sports of the Czech Republic (project No. CZ.1.05/2.1.00/03.0094: Regional Innovation Centre for Electrical Engineering – RICE) and by projects P102/11/0498 and 102/09/1305 (Grant Agency of the Czech Republic).

VII. References

[1] I. Doležel, V. Kotlan, B. Ulrych: Modeling of Shrink Fit of Action Wheel in Gas Turbine. Proc XIICLEE 2011, Ponta Delgada, Portugal, July 2011.

[2] I. Doležel, V. Kotlan, B. Ulrych: Hard-Coupled Modeling of Induction Shrink Fit of Gas-Turbine Active Wheel. Proc. ISTET 2011, Klagenfurt, Austria, July 2011.

[3] J. P. Holman: Heat Transfer. McGrawHill, New York, USA, 2002.

[4] www.quickfield.com.