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Analysis of resistive and inductive heating of railway turnouts

***Abstract**. Electric heating of railway turnouts is a significant technical and economic problem. For these reasons, research is needed to optimise the heating system of railway turnouts. This paper presents a comparative analysis of energy loss during heating of railway turnouts performed using two different methods. The analysis of the heating of railway was carried out using the ANSYS computer simulation software.*

Streszczenie.** Elektryczne ogrzewanie rozjazdów kolejowych jest istotnym problemem technicznym i ekonomicznym. Z tych względów potrzebne są badania w celu optymalizacji systemu ogrzewania rozjazdów kolejowych. W artykule przedstawiono analizę porównawczą strat energii podczas ogrzewania rozjazdów kolejowych z wykorzystaniem dwóch różnych metod. Analiza ogrzewania rozjazdów przeprowadzono w programie ANSYS.**(Analiza oporowego i indukcyjnego nagrzewania rozjazdów kolejowych)

Keywords: railway turnouts, resistive heating, inductive heating.
Słowa kluczowe: rozjazdy kolejowe, nagrzewanie oporowe, nagrzewanie indukcyjne.

Introduction

Railway turnouts in winter conditions must be heated to maintain operability during snowfall, wind and trains blowing snow on to the rails as well as during freezing rain [1, 2, 3, 4]. The space between the fixed rail and the moveable rail must be free of ice and snow in order to facilitate the change of the turnout position. Railway turnouts are most frequently heated using electric resistance heaters whereas induction heaters are used less often [1, 2]. Due to considerable energy intensity of the heating process, optimisation of the heating system of railway turnouts has become a significant issue. This paper presents the results of comparative analysis of energy loss during electric heating of railway turnouts using a traditional method and using an induction heater. The heating process was analysed by performing computer simulations in the ANSYS programme.

Models of heating of railway turnouts

For the purpose of analysis a long rail with the resistance (Fig. 1) and the induction heater (Fig. 2) was chosen. The differential form of Fourier's law of thermal conduction in a solid body is:

$$q_{tc} = -k\nabla T \,, \tag{1}$$

where: q_{tc} - heat flux density, k - the material's thermal conductivity, T - the temperature.

The convection phenomenon in air is satisfied by Newton law:

$$q_c = h\left(T_s - T_f\right) \tag{2}$$

where: q_c – convective heat flux, h – average convective heat exchange coefficient T_s - temperature of the solid, T_f - temperature of the adjacent liquid.

The radiation phenomenon in air is satisfied by the Stefan-Boltzmann law:

$$q_r = \varepsilon\sigma T^4 \tag{3}$$

where: q_r – radiated heat flux, ε - object's surface emissivity coefficient, σ – the Stefan-Boltzmann constant, T – the radiating object's surface temperature.

It was assumed that in the first case the heater is directly adjacent to the fixed rail whereas in the second case the heater heats a hotplate by electromagnetic induction. The solution with the heater adjacent to the rail is characterised by a considerable energy loss. The fixed rail has a large thermal heat capacity and absorbs a considerable amount of energy. Therefore, this solution requires a relatively large amount of electric energy to heat the area close to the rail. In the case of the second solution the heater is separated from the rail thus decreasing the thermal conductivity between the heater and the rail. This solution is characterised by a smaller energy loss during heating when compared with the solution with a traditional heater. The area above the hotplate is heated as a result of convection and radiation.

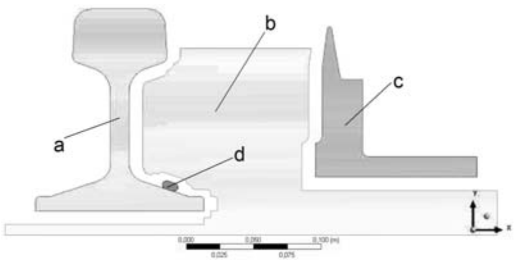

Fig. 1. The model of the railway turnout with the electric resistance heater (a - a fixed rail, b - an 'ice', c - a moveable rail, d - the resistance heater)

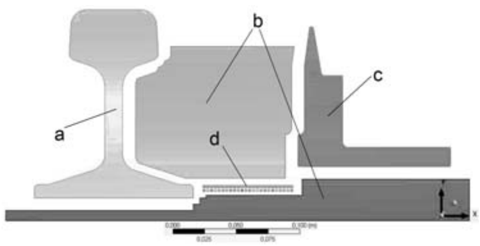

Fig. 2. The model of the railway turnout with the induction heater (a - a fixed rail, b - an 'ice', c - a moveable rail, d - the induction heater)

A dozen or so of types of snow occur in nature. A simplified model of snow was adopted in the analysed railway turnouts models, located in the working space between the fixed rail and the moveable rail. It was assumed that this space was filled with an equivalent solid medium having similar thermal parameters to ice. An assumption was also made that in the heating process neither phase transformation nor melting of the medium modelling the ice occurred. Obviously, this assumption is not physically grounded, however, it allows to perform an approximate analysis of the effectiveness of the railway turnouts heating by applying the described two methods within a relatively short period of time. In the next stage of the tests the authors plan to carry out a numerical analysis of the process of railway turnouts heating taking into consideration phase transformation and ice melting. For the purpose of numerical analysis it was assumed that the electric power of both heaters was 330W per one meter of the rail. The model of the rail with the heaters was placed within the space three times larger in horizontal direction and 10 times larger in vertical direction in relation to the model dimensions. The following boundary conditions were introduced on the space boundary: relative pressure 0 Pa, outside temperature 250K (Figures 3-4). In the model of inductive heating an induction plate of the width of 7 cm and the thickness of 2 cm (Figure 5) was used. Material parameters of the induction plate are presented in Table 1, whereas the parameters of the inductor are presented in Table 2.

Table 1. Induction plate

Material	Cast iron
Relative permeability	100
Bulk conductivity	1.5 MS/m
Mass density	7200 kg/m3
Specific heat	460 J/kg-K
Thermal Conductivity	50 W/m-K

Table 2. Inductor

Material	Copper
Relative permeability	1
Bulk conductivity	58 MS/m
Mass density	8933 kg/m3
Specific heat	381 J/kg-K
Thermal conductivity	387.6 W/m-K
Current	21 A/unit (coil)
Frequency	10 kHz

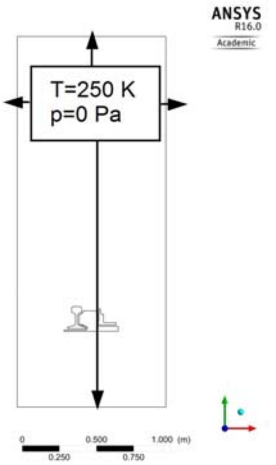

Fig. 3 The model of the railway turnout with the electric resistance heater

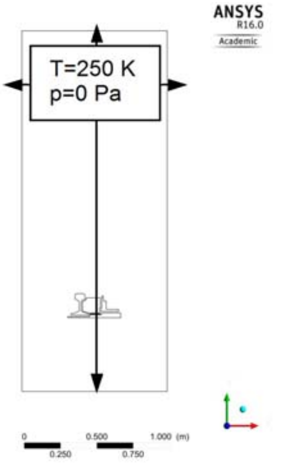

Fig. 4 The model of the railway turnout with the induction heater

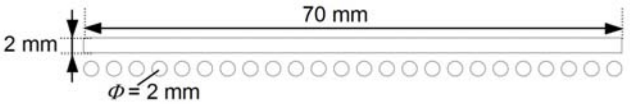

Fig. 5 The induction plate with an inductor.

Results of numerical analysis

For the purpose of numerical analysis it was assumed that the temperature value equalled 250K in the whole area. Figure 6 presents temperature distribution in the model of the rail with the electric resistance heater at the time when the temperature at the boundary between the air and the 'ice' reached the value of 273K. It occurs only after 70 minutes. It can be also observed that the temperature of the whole rail reaches the value of about 273K. The very large heat capacity of the rail results in its absorbing a larger amount of the thermal energy emitted by the heater. A considerable amount of energy is radiated into air by the left and the upper parts of the rail causing a significant energy loss. A part of the 'ice' area adjacent to the rail warms up to the temperature of about 265K at the same time. It can be observed that the heat process of classic heating of the railway turnouts is characterised by a high time constant.

Figure 7 shows the temperature distribution in the model of the railway turnout with the induction heater at the time when the temperature at the boundary between the air and the 'ice' reaches the value of 273K. Due to the small heat capacity of the induction plate, this moment occurs already after 4 minutes. In this instance a part of the thermal energy is transferred by convection and radiation into the 'ice' area much more quickly. Successive figures (Figures 8-11) show temperature distribution for both models for the heating time of 90 min and 110 min (the upper temperature limit was set at 273 K). In the classic heating the process of 'ice' melting begins only after almost two hours. Whereas for the model of the railway turnout with the induction heater the 'ice' melting process begins already after four minutes.

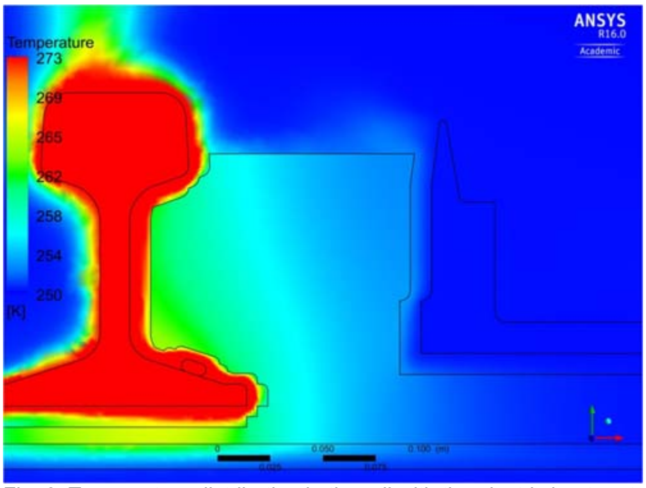

Fig. 6. Temperature distribution in the rail with the electric heater at t = 70 min (the temperature in the boundary of the 'ice' area equals 273K, for the area marked in red $T \geq 273K$)

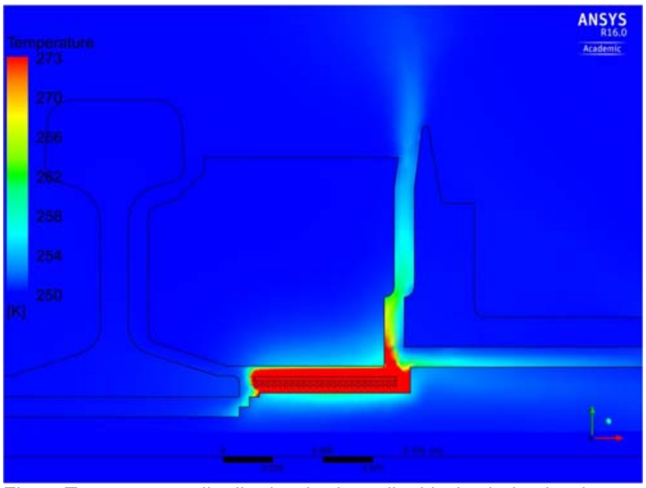

Fig.7. Temperature distribution in the rail with the induction heater at t = 4 min (the temperature in the boundary of the 'ice' area equals 273K, $T \geq 273K$)

Figure 12 and Fig.13 present temperature distribution in the model of the rail with the resistance and induction heater at t = 110 min for the full range of temperatures. It can be observed that for the model with the resistance heater the heater temperature is about 330K, while in the case of the induction heater it reaches the value of almost 450K. Therefore, the rail constitutes a good radiator for the model with the resistance heater and absorbs a considerable amount of the thermal energy.

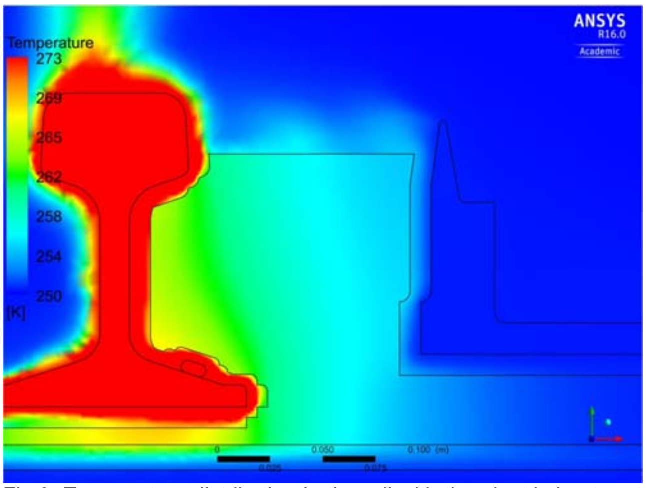

Fig.8. Temperature distribution in the rail with the electric heater at t = 90 min (for the area marked in red $T \geq 273K$)

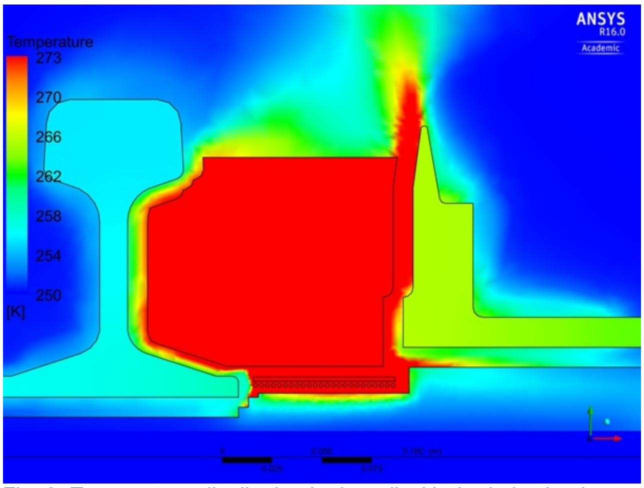

Fig. 9. Temperature distribution in the rail with the induction heater at t = 90 min (for the area marked in red $T \geq 273K$)

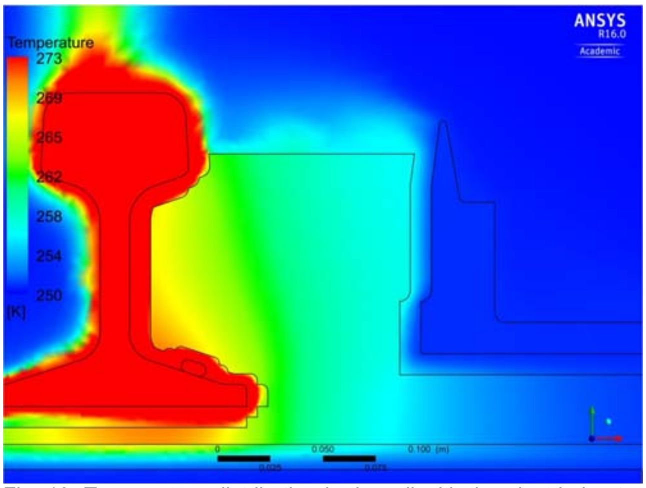

Fig. 10. Temperature distribution in the rail with the electric heater at t = 110 min (for the area marked in red $T \geq 273K$)

Figure 14 presents the increase in the thermal energy of the 'ice' area in the function of time for classic and induction heating of a railway turnout. It can be observed that the increase in the thermal energy in the examined area is considerably higher for induction heating in comparison with the increase in thermal energy in classic heating. The inductive method allows to melt of "ice" in 1/3 area during the 6000 s. If in this area is wild snow then the snow has melted already during the 1000 s while the wet snow during the 5500s. In the case of the classical method of ice melting the process begins after the 4800s.

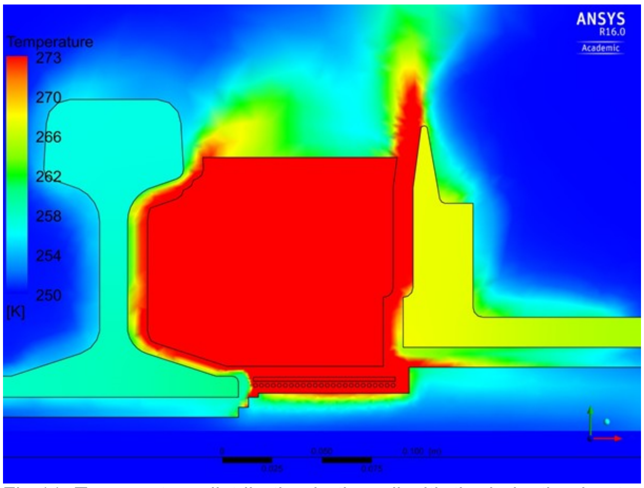

Fig.11. Temperature distribution in the rail with the induction heater at t = 110 min (for the area marked in red $T \geq 273K$)

Figure 16 presents a relative increase in the thermal energy of the rail for both models in relation to the thermal energy emitted by the resistance heater. It is clearly visible that a considerable amount of the thermal energy emitted by the heater is absorbed by the rail. In the first moments of the process the thermal energy emitted by the heater is almost fully transferred to the rail.

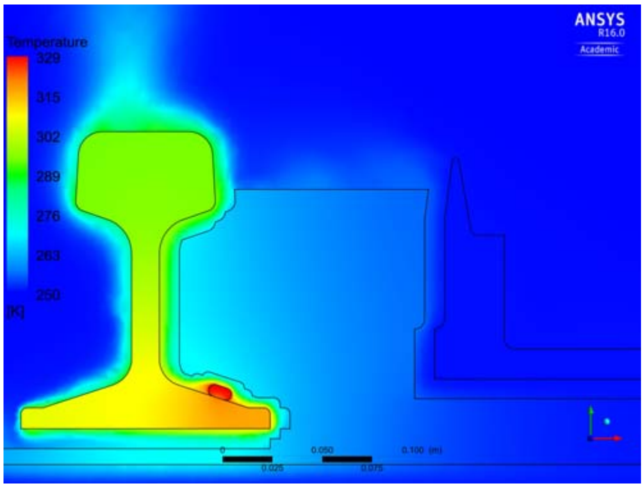

Fig. 12 Temperature distribution in the model of the rail with the resistance heater at t = 110 min for the full range of temperatures.

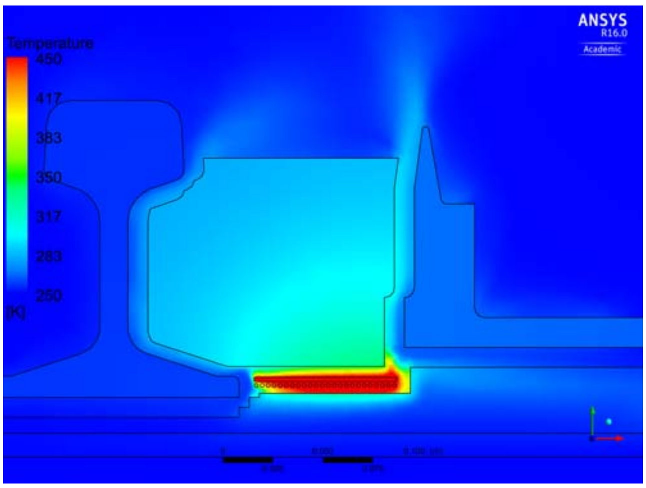

Fig. 13 Temperature distribution in the model of the rail with the induction heater at t = 110 min for the full range of temperatures.

After one hour of heating only 28% of the thermal energy is transferred to the air and the 'ice'. In Fig. 15 a relative increase in the thermal energy of the 'ice' area for classic and induction heating in relation to the thermal energy released by the heaters is shown. In Fig. 15 the time is marked after which the 'ice' surface reaches the melting temperature of 273K. It can be observed that for resistance heating this time is almost 20 times longer than in the latter case. In induction heating the efficiency of heating of the working area after about 30 minutes reaches about 50%. As the time progresses, the efficiency slightly decreases due to larger energy losses resulting from the convection heat radiation into the surrounding air.

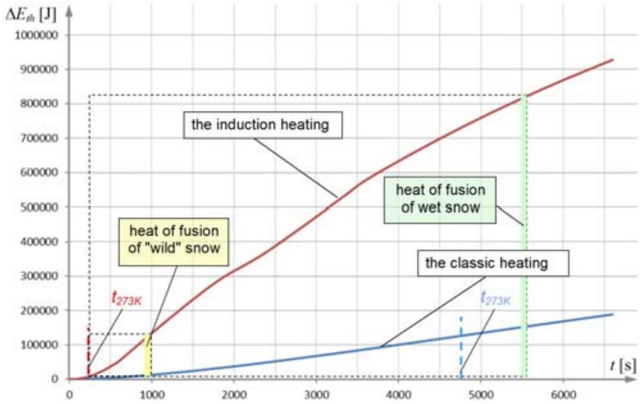

Fig. 14. The increase in the thermal energy of the 'ice', wild and wet snow area for classic and induction heating.

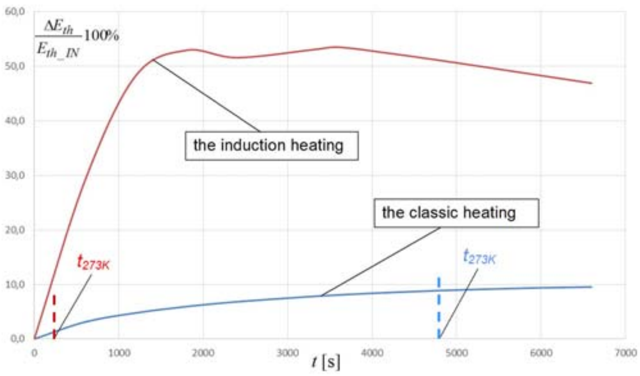

Fig. 15. The relative increase in the thermal energy of the 'ice' area for classic and induction heating in relation with the thermal energy emitted by the heaters.

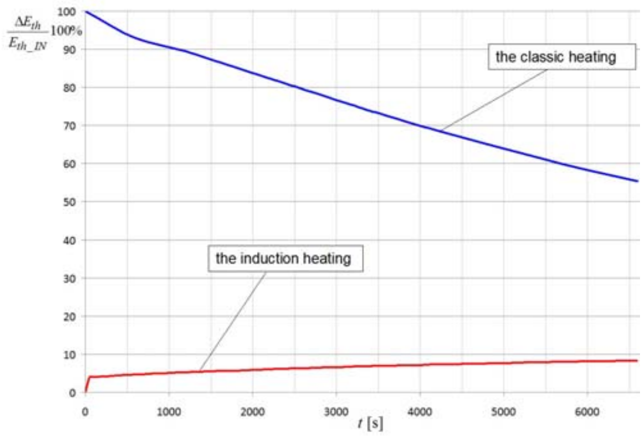

Fig. 16. The relative increase in the rail thermal energy for classic and induction heating in relation to the thermal energy emitted by the heaters.

C0nclusions

The comparative analysis of the energy loss during heating of the two models of a railway turnout, showed a considerable energy intensity of the traditional heating of railway turnouts. Heating the area close to the fixed and the moveable rail requires a relatively large amount of electric energy. Using the induction heater facilitates heating the area close to the rail while incurring a smaller energy loss.

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