Possibility of Application of a Low Frequency Inductive Heating to Selected Ferromagnetic Objects

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Abstract: Possibility of application of the low frequency inductive heating for heating ferromagnetic has been considered and discussed. On the basis of simulations and investigated results the heater structure for railway rails was developed.

Keywords:
Inductive heating, Low frequency, Ferromagnetic

1. Introduction

We have found that a low frequency inductive heating can be successfully applied for specified problems e.g. heating of explosive liquids and/or ferromagnetic materials [1, 2]. One of the examples is the use of this method for heating the railway rails under the track laying [1]. So far the rails are heated by means of gaseous heaters using propane-butane mixture which results in dangerous overheating of the surface generating as a result the extensive stress of the rail material. It has to be noted that the track laying of a rigid railway rail must be carried out under specified thermal conditions (so called neutral temperature which in Poland is to be in the range from 291K to 303K) to avoid dangerous tensile and compressive stresses in the rails during heavy weather conditions. To overcome this problem one can apply the inductive heating as a choice where the heat (due to eddy-current losses) is generated inside the selective volume of the rail. By the use of the low frequency supply it is possible to avoid the skin effect and to control the heat transfer inside the rail body.

In the paper the possibility of application of the inductive heating to heat up the ferromagnetic railway rails is discussed. The investigations were carried out for the low time-varying magnetic fields up to 900Hz. On the basis of the results the conclusions regarding the efficiency of such the method in practice are formulated.

2. Inductive heating of the railway rails

Lack of any butt joints, total electrical isolation of the heating inductor from the rail and the simple delivery of the energy to the rail volume are the key factors. High heating efficiency implies a heavy density of a magnetic flux invading the required rail volume. Since the heating of the whole rail volume is impossible to realize, therefore the flux can be concentrated inside the rail head, accessible part of its web or in the head and web simultaneously as illustrated in Fig.1.

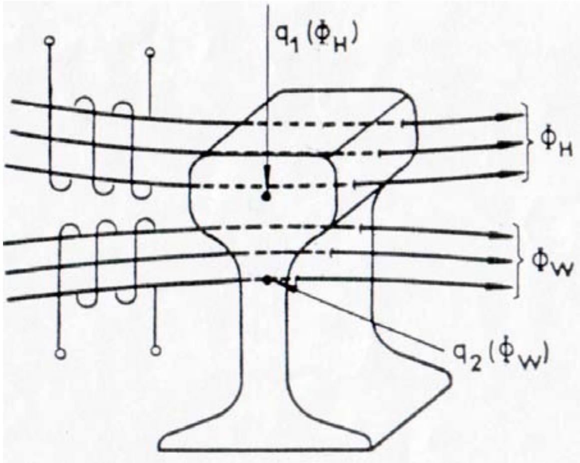

Fig.1. Principle of inductive heating of the railway rail

ϕ_H, ϕ_W - magnetic flux penetrated head and accessible part of the rail web respectively,

$q_1(\phi_H), q_2(\phi_W)$ - heat sources related to eddy currents in head and web.

To ensure the required efficiency of the heating one has to approach different problems like: optimization of the electromagnetic heating inductor to produce the maximum

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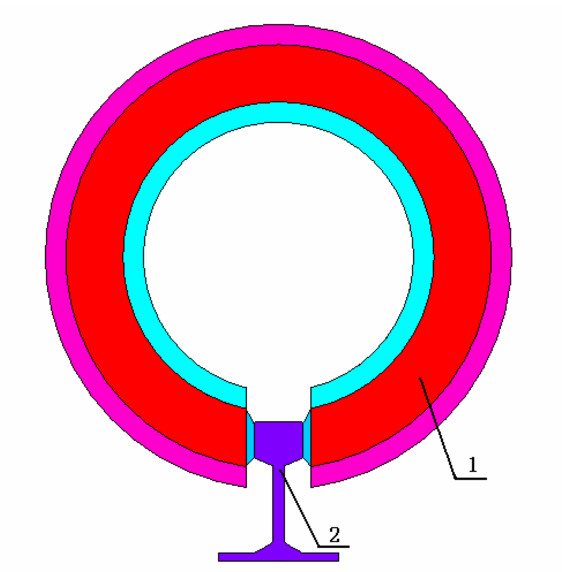
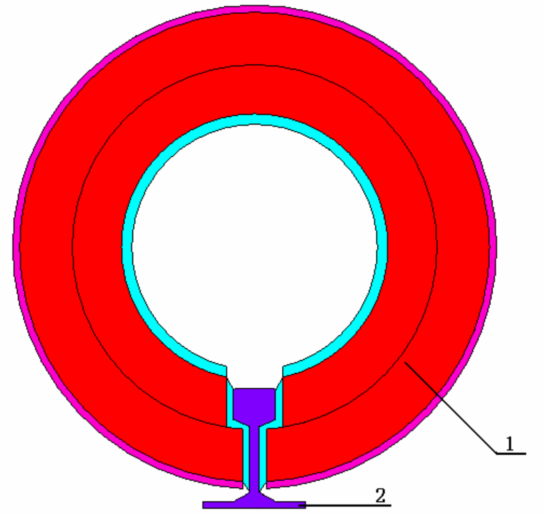
heat power, non-uniform heat distribution related to both location of the heater and effect of the eddy current losses, elongation of the rail with temperature for non-uniform heating. We have designed and developed the inductive heater which produces the heat proportional to the MMF value what takes place independently on the inductor locations. To investigate and to explain the heat transfer both measurements and calculations were performed.

3. Analysis of the heating efficiency



(a) heater located only at head of rail



(b) heater located at head & web of rail

Fig.2. The model for analysis of the inductive heating by use ANSYS software (1 - inductive heater, 2 – rail)

In order to study the thermal effects, we assumed that the workpieces (rails) do not interact thermally. The thermal problem is thus described by the Fourier's equation as follows

$$-\nabla \bullet \lambda \nabla T + c\rho \frac{\partial T}{\partial t} = p \qquad (1)$$

where T - temperature; t - time; c – thermal capacity; ρ - mass density; λ - thermal conductivity; p - volume power density. This equation must be solved with the following boundary conditions at the surface of the rail:

$$-\lambda \frac{\partial T}{\partial n} = \alpha_c (T_s - T_a) + C_s (T_s^4 - T_a^4) \qquad (2)$$

The subscripts (s,a) denote surface and ambient temperatures, α_c and C_s are convection and radiation coefficients and n is the outward normal to the surface respectively.

The analysis was performed for heating the head and the web or the head and web simultaneously for the ferromagnetic field ranging from 50Hz up to 900Hz (as illustrate in Fig.2).

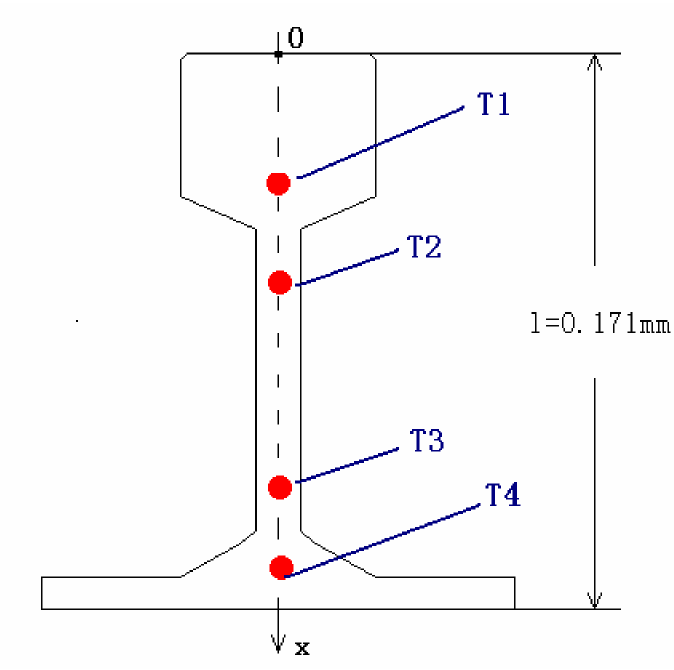
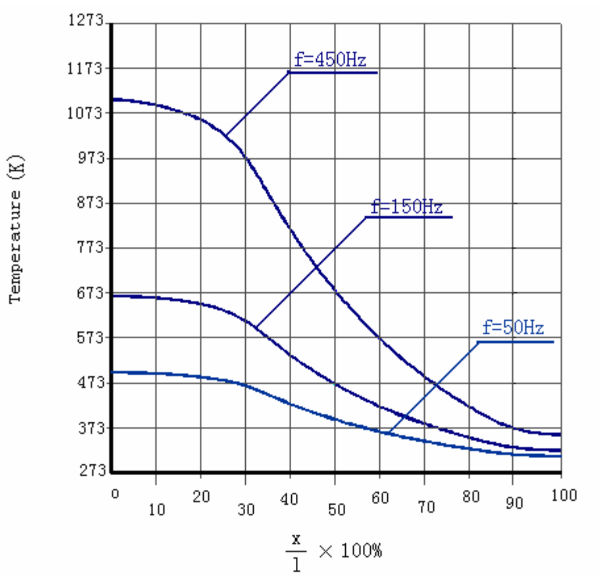
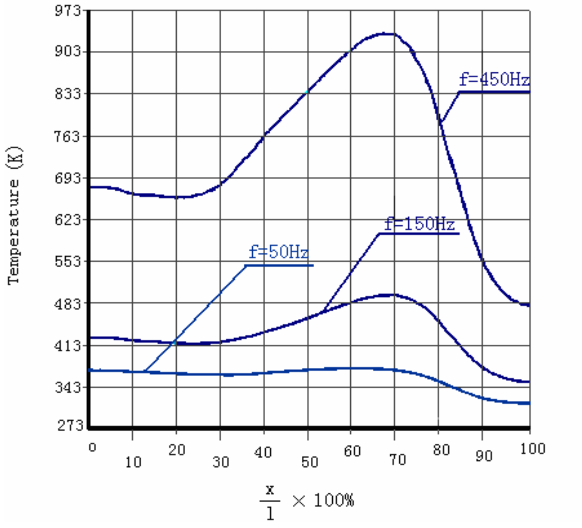


Fig. 3. The temperature test points of the rail

The influence of the heavy ambient conditions was tested under simulation of rain and wind as well. Temperature for selected points at cross section along axis of symmetry was controlled during the heating and cooling process (see Fig.3).



(a) heater located only at head of rail

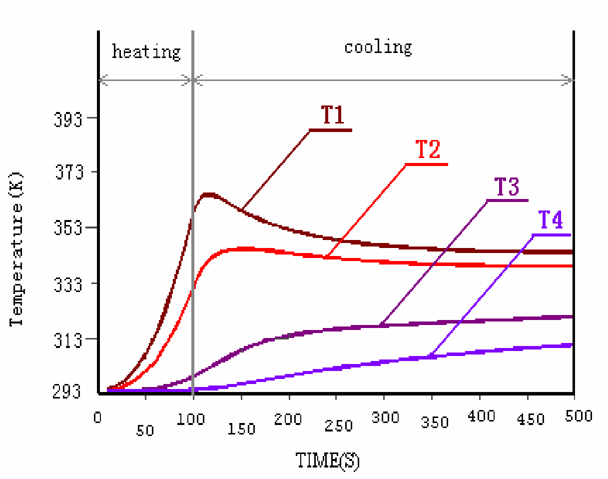


(b) heater located at head & web of rail

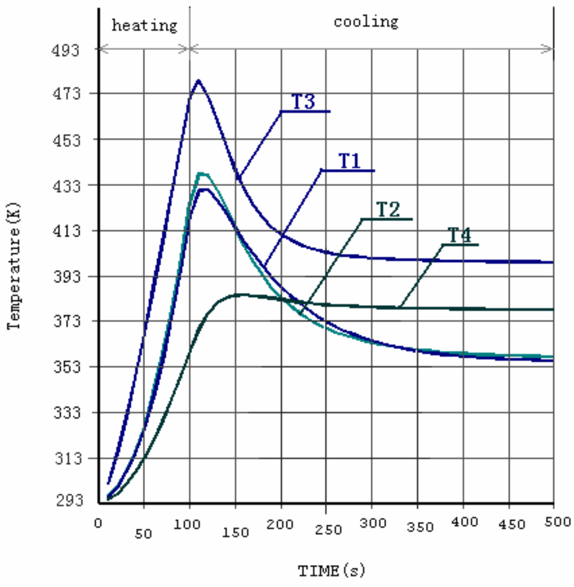
Fig.4. The temperature distribution in the rail cross section along the x-axis of symmetry after 400s of heating with different frequency of the supply source(ambient temperature 294K, convection coefficient equal to 10)

For the same magnetic force generated by the heater (MMF about 2000A) when the heater is located only at the head the temperature distribution (after 400s of heating) within the rail body (along the cross section) for different frequency (up to 450Hz) can be compared from Fig.4a. As it can be seen from this figure the highest temperature is obtained just at the rail surface while decreasing tremendously towards to the rail foot. Its value (at the surface) is multiplied almost by factor 2 with respect to the increased frequency. However, for the heating both the head and the web simultaneously the temperature variation is totally different indicating the highest temperature at the place close to the foot volume (see Fig.4b).

With respect to the heating efficiency of the whole rail volume the cooling process is great of importance as well. The temperature field distribution under heating of the head (150Hz) for 100s and following cooling is shown in Fig.5a.The temperature stabilization after about 300s is noticed and its lowest value inside the foot volume (T4) is closed to the required neutral temperature.



(a) heater located only at head of rail



(b) heater located at head & web of rail

Fig.5. The temperature variation at the selected points of the rail cross-section (points T1-T4) for the inductor located only on the rail head during heating (100s) and following cooling process(f=150Hz, ambient temperature 294K, convection

coefficient equal to 10)

In order to optimize the heater, one has to consider the influence of increased frequency and to compare the heating efficiency for different heater location (only head and/or head and web simultaneously). It was found that the same maximum temperature, however, at the different rail points can be obtained when compromise the heater location with the supply frequency what can be compared from Fig. 6 and 7. For the heater located only on the head but for the increased frequency of the supply (up to 750Hz) the maximum temperature (after 100s of heating) is generated just at the head surface (x=0, see Fig. 3). On the contrary it is reached at the area close to the foot (point T3) when the heat is produced both in the head and web, however, at decreased frequency to about 150Hz. In this way one can select the most efficient way of the heating procedure as is illustrated in Fig. 7.

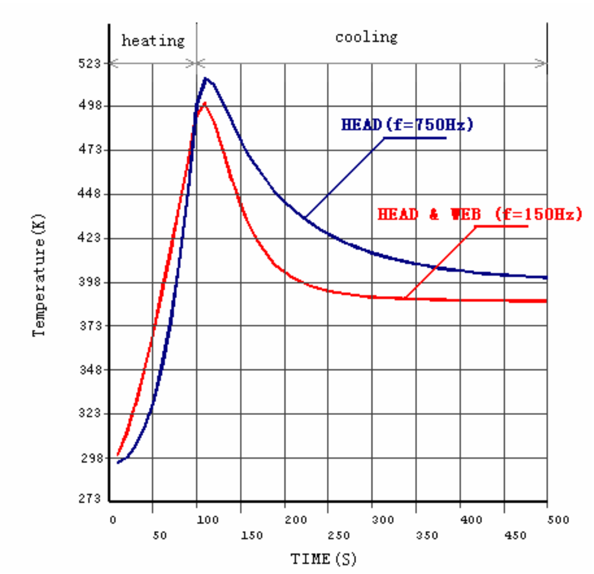


Fig.6. Comparison of heating and cooling efficiency for different frequency and different heater location (heating for 100s, ambient temperature 294K, convection coefficient equal to 10)

However, with point of view of a resultant heating and cooling process of the whole rail volume the optimizing procedure including the space heat distribution must be performed. It was done on the basis of both the simulations and measurements on the physical model. The results of calculations are found to be in a satisfactory agreement with measurements.

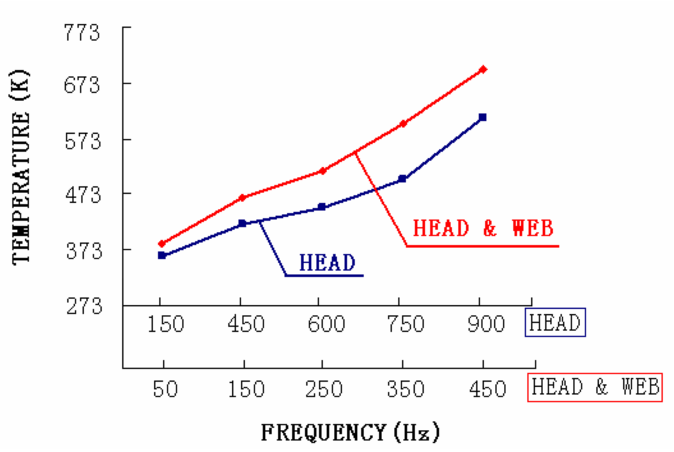


Fig.7. Variation of maximum temperature (at point as in Fig.6) under heating for 100s with supply frequency and the heater location

4. Investigated results

The inductive heating method using low time-varying magnetic field has been successfully applied in especially designed inductive heater of the railway rails. (Fig. 8) It is characterized by high heating efficiency and practical independence on the weather conditions. Moreover, it is easy and safe for handling. The measured heating power and its relation to the field magnetic density B_m of the heating inductor for 50Hz is illustrated in Fig.9.

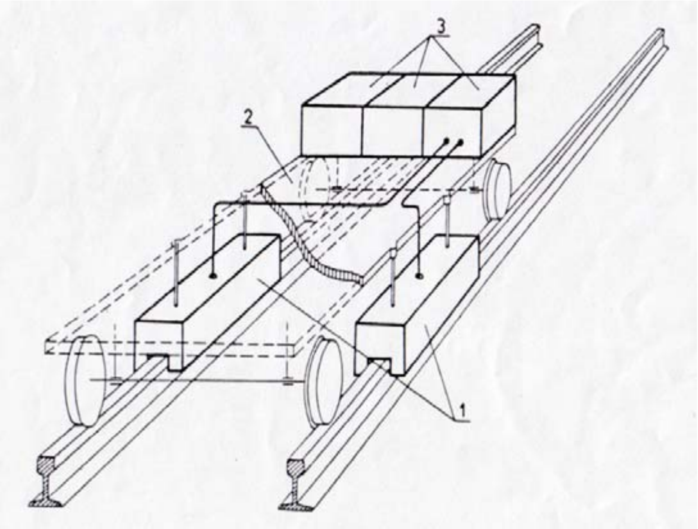


Fig.8. Schematic of the inductive heater of railway rails:
1 - heating inductors, 2 - supporting structure,
3 - source and frequency convertor.

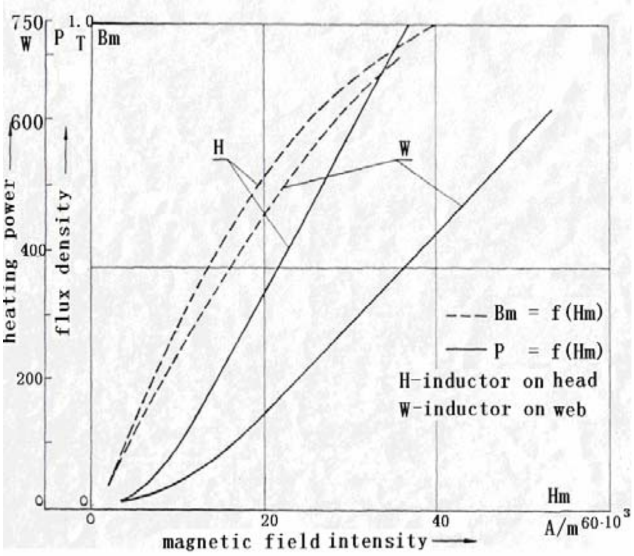


Fig.9. Heating power (eddy current losses) P relations in magnetic field intensity H_m of the heating inductor (for 50Hz)

5. Conclusions

The inductive heating by means of the low time-varying magnetic field has been successfully applied for the newly developed inductive heater of the railway rails. It is characterized by the high efficiency (speed about 300m/h, power generated of 200kW at 150Hz) and weather conditions independence.

References

[1] Miedzinski, B., Okraszewski, Z., Szymanski, A., Kristiansen. M.: “Low frequency inductive heating of a rigid track during track laying”, Proc. 30th IAS Annual Meeting, Orlando, Florida, USA, October 8-12, 1995, pp. 1903-1909.

[2] Miedzinski, B., Szkolka, S., Szymanski, A., Wasylkowski, .M.: “Low frequency heater of liquids”, Gazeta Cukrownicza, No.4, pp. 67-69 (in polish).

[3] Stoll. R. L: “The analysis of eddy currents”, Clarendon Press, Oxford, 1974.

[4] Roman A.: “The influence of the skin effect on eddy current losses in the plane for single and multidomain wall models”, IEEE Transactions on Magnetics, Vol. Mag-20, No.6, Nov. 1984, pp. 2019-2116.