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Measurement of the magnetic field of an induction heater for locomotive wheelsets

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Abstract. In this paper, the electrical heating of bandage bracelets on locomotive wheelsets by eddy currents (Foucault currents) is examined. This process is applied when replacing the bandage bracelets due to deformation. The induction of the magnetic field in the vicinity of the induction heater is tested by measurements in order to determine the safe zone for service personnel. The tests were carried out in real conditions in the Plovdiv locomotive depot using contemporary measuring devices. The characteristics are plotted showing the dependences of the magnetic induction on the distance to the induction heater, expressions are also obtained. It can be concluded that an exponential dependence can be used to estimate the induction of the magnetic field around the heater. Measures to limit the harmful influence of magnetic field on the service personnel are suggested.

1 Introduction

The bandage bracelets are the outermost part of the locomotive wheels (plays the role of car tyres). During operation, they deform and wear out, which necessitates their replacement over a certain period of time [1, 2].

There are different ways to replace the bandage bracelets, the most common being:

- Heating the bandage bracelets by burning fuel (coal, coke, propane-butane, methane and others);
- Heating the bandage bracelets by electricity (induction heating);
- Cooling the wheel by nitrogen.

The heating of metal is widely used in various branches of industry such as: metallurgy, mechanical engineering, metalworking, repair activities and many others.

Electrical heating is most often used when replacing the bandage bracelets on the locomotive wheels with new ones. As a result, the bandage bracelet increases in diameter (circumference) and can be easily replaced. Therefore, the induction heaters (devices using electrical heating by eddy currents - Foucault currents) are widely used in locomotive repair facilities of railway carriers. However, studies of the electromagnetic emissions around such devices have not been published. The impact of the electromagnetic field on service personnel has not been studied and safe zone has not been determined. Any protective measures have not been implemented in locomotive repair facilities.

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The article examines an induction heater for repairing locomotive wheelsets – its construction and principle of operation: during heating when replacing a bandage bracelet, a magnetic field is created around the inductor. The induction of this magnetic field in the vicinity of the device is tested by measurements. The safe zone is determined and measures to limit the harmful influence of the magnetic field on the service personnel are proposed.

2 Construction and principle of operation of an induction heater

Using electricity to heat the band bracelets is an efficient, fast, precise and safe method of replacing them.

Changing the bandage bracelets is done by heating it to a temperature of 200÷220℃ [2]. During heating, the wheelset is supported by a crane in the vertical position shown in Figure 1.

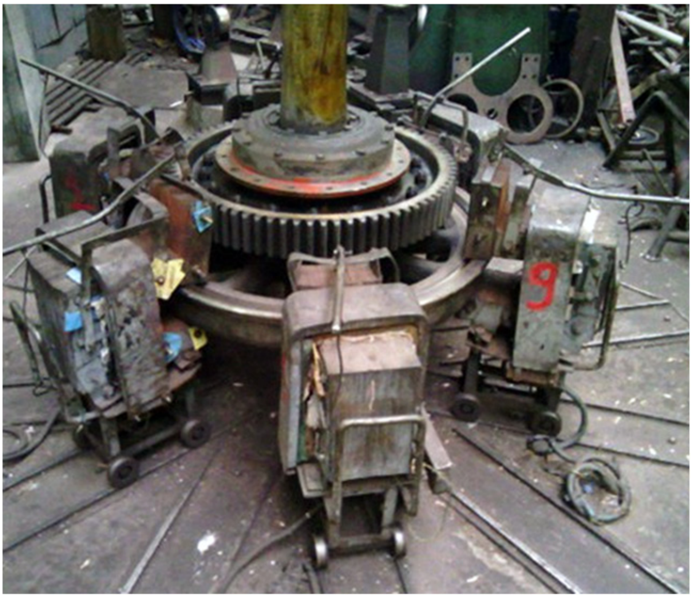

Fig. 1. General view of an induction heater with a wheelset installed for heating the bandage bracelet.

The induction heater consists of six or nine sections (depending on the diameter of the bandage bracelet), connected to a three-phase electrical system, distributed equally in each phase and connected in series in pairs or threes and located opposite each other. They can be connected in star or delta.

A section of two series-connected windings of 30 turns each is shown in Figure 2. They are located along the core of a magnetic conductor composed of lamellae made of electrotechnical steel. In order to provide space for placing the bandage bracelet, the yoke is movable and is lowered from above on the bracelet, the aim being to avoid air gaps (the bandage bracelet becomes part of the magnet wire).

When an alternating voltage is applied to the coil, a current flows through it and creates a magnetic field that passes through the magnetic conductor. In the places where the magnetic conductor is filled with dense ferromagnetic metal (in the case of the bandage bracelet), an electromotive voltage is induced, which creates so-called "eddy currents" (Foucault currents) [3]. Their action throughout the entire volume of the bracelet leads to its heating. The magnetic field, however, dissipates outside the induction heater as well [4-6].

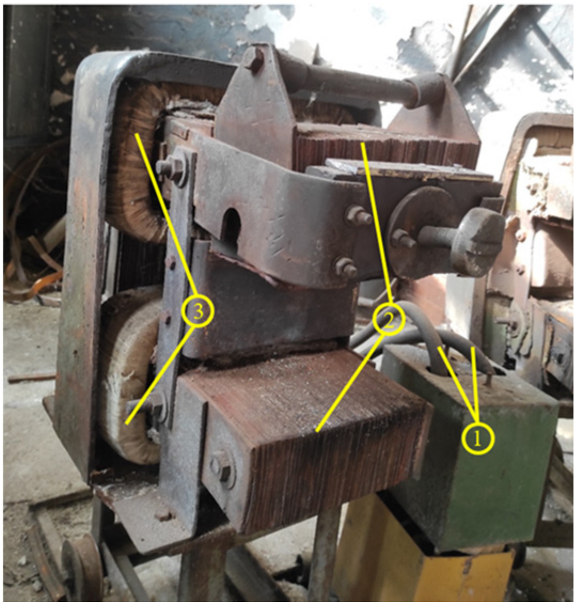

Fig. 2. Induction heater: 1 – power cable; 2 – magnetic conductor; 3 – windings.

A thermovision image of the process - heating the bandage bracelet (with duration 40 ÷ 45 min) is presented in fig. 3. It can be seen that the bandage bracelet heats up evenly (no dark spots are visible around the circumference), which is due to the symmetrical arrangement of the induction heaters.

It is also evident that regardless of the developed high temperature of the bandage bracelet, the induction heaters do not heat up during their operation. The temperature they reached is a consequence of the natural heat exchange between the bandage bracelet and the magnetic conductors and is comparable to the operating temperature of electrical machines.

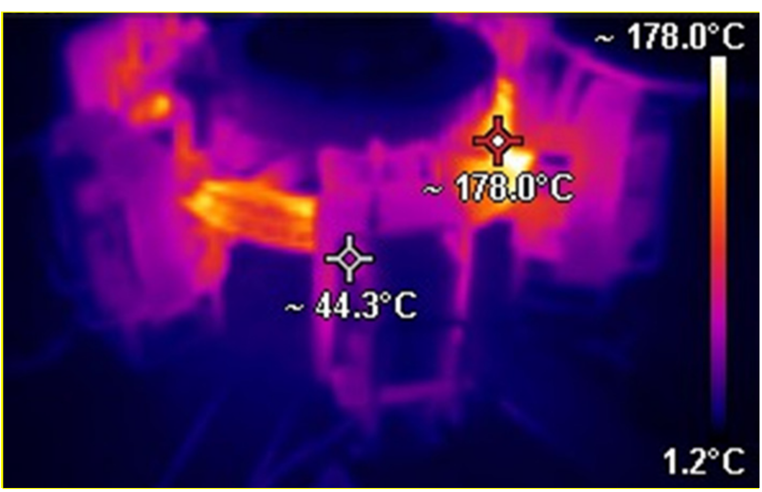

Fig. 3. Thermal image of a bandage bracelet during heating.

3 Devices for measuring magnetic emissions from an induction heater for locomotive wheelsets

Two types of teslameters - digital testers for electromagnetic fields are used for measuring magnetic radiation from the induction heater [7, 8].

The TM-197 model has a measuring range from 0 to 3000 mT at an operating frequency of DC / 40...500 Hz (Figure 4) [7]. It offers built-in features as follows: AUTO HOLD, MIN/MAX, PEAK HOLD (memory of pulse signals), memory for 200 events.

The triaxial device T92 (Gauss/Tesla meter - Figure 5) is a highly precise instrument for measuring static and dynamic electromagnetic fields with a frequency of 30 ... 2000 Hz (extremely low frequency - ELF) [8]. It uses three internal orthogonal sensors (X, Y, Z, sampling 2.5 times per second) to test the magnetic field over a wide range, regardless of the measurement angle. The measurement data is reported in mG and μT, and the measurement principle can be changed at any time with the push of a button (memory with data recording capacity of up to 500 records). T92 offers the ability to retain the reported results (Hold function), as well as functions for automatic shutdown and recording of the maximum and minimum measured values.

Fig. 4. Teslameter TM 197.

Fig. 5. Gauss/Tesla meter T92.

4 Measurement of magnetic field induction in real conditions

The induction B characterizes the magnetic field at any point in space around the device that creates it.

The measurement of the actual values of the magnetic induction of the field around the induction heater was carried out in real conditions in the Plovdiv locomotive depot at two different heights *h* relative to the floor of the room ($h = 1.2\ m$ and $h = 0.8\ m$).

The closest measurement to the inductor was made at a distance *l* of 0.5 m, and the farthest- at a distance of 3 m, at an interval of 0.5 m. From the point of view of safety requirements when making measurements, the test starts from the farthest point to the closest to the inductor.

Measuring devices provide an opportunity to suppress the influence of the environmental field - the device is reset in advance after the probe is moved out of the range of the magnetic field (pressing the "Zero / Rel" button and waiting for the *Zeroing* that complete). Using this feature, only the magnetic field of the test object is measured.

This procedure (the *Zeroing*) has been performed before each measurement in order to increase the accuracy of determining the magnetic induction of the object under study.

The measurement was carried out with 1 section working (three magnetic conductors) and the values were recorded at a current of 220 A. The results of the measurements are presented in Table 1 (at a height from the floor h = 1.2 m) and Table 2 (at a height from the floor h = 0.8 m).

The graphs were plotted and presented in Figure 6 (at a height from the floor h = 1.2 m) and Figure 7 (at a height from the floor h = 0.8 m).

The results of the measurements with the two devices TM-197 and T92 coincided, which can confirm their measurement accuracy.

Table 1. Magnetic induction at h = 1.2 m.

Distance ***l, m***	**Magnetic induction** ***B, µT***
0.5	93.4
1.0	74.8
1.5	34.6
2.0	23.5
2.5	17.4
3.0	10.6

Table 2. Magnetic induction at h = 0.8 m.

Distance ***l, m***	**Magnetic induction** ***B, µT***
0.5	180
1.0	98
1.5	69
2.0	35.4
2.5	22
3.0	13.6

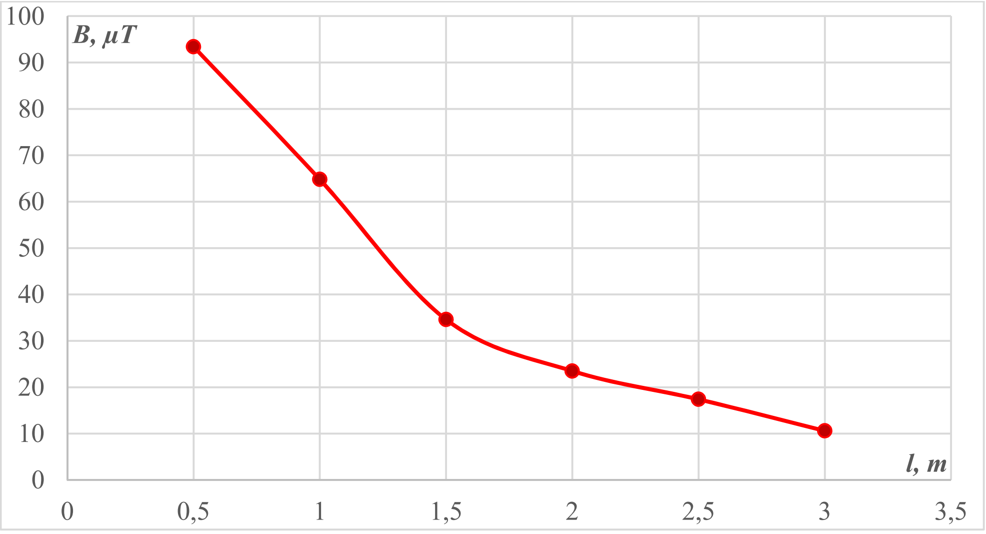

Fig. 6. Magnetic induction of the field of the working environment at h = 1.2 m.

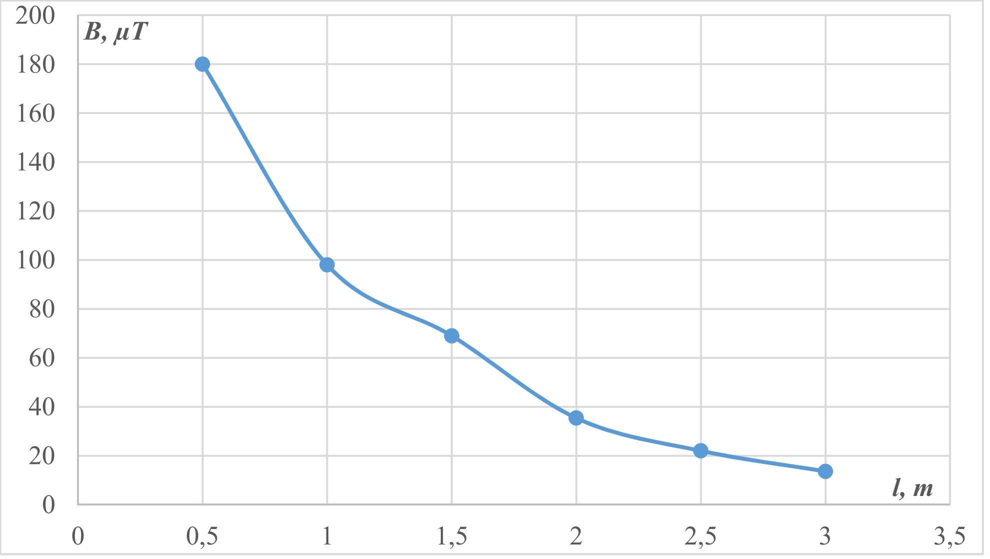

Fig. 7. Magnetic induction of the field of the working environment at h = 0.8 m.

5 Analysis of measurement results

A graphical comparison of the measured values of the magnetic field at two heights is presented in Figure 8. From the graphs it can be seen that with increasing height and moving away from the source of magnetic radiation, the fields weaken.

The trendline for each characteristic was defined and the "R-squared value" R^2 was calculated. These trendlines represent the dependences of the magnetic induction on the distance, and the obtained expressions are as follows:

$$B = 294.81e^{-1.032.l} \quad \text{(at } h = 0.8 \text{ m);} \tag{1}$$

$$B = 142.43e^{-0.869.l} \quad \text{(at } h = 1.2 \text{ m).} \tag{2}$$

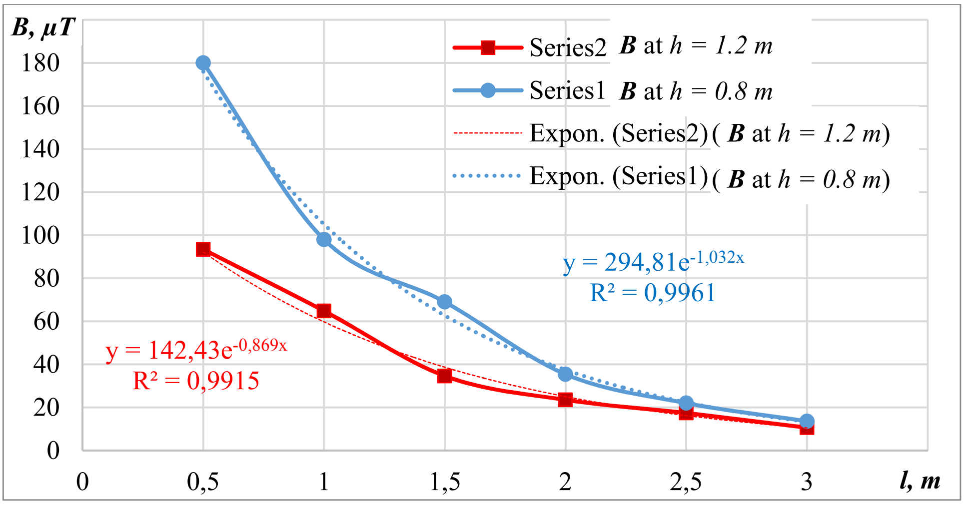

Fig. 8. Comparison of the magnetic induction in height.

The resulting expressions are of the same kind and the value of R^2 is sufficiently high – above 0.99. Therefore, the trendlines are close enough to the characteristics obtained from the measured values and the expressions are of sufficient accuracy. They can be summed up in an exponential dependence:

$$B = C_1 e^{-C.l}, \quad (3)$$

where C and C_1 are coefficients that depend on the height from the floor h (when h increases, C and C_1 decrease).

It can be concluded that the dependence of the magnetic induction on the distance from the induction heater is exponential - when approaching the device, it increases rapidly and its value at distances below 1 m is significant (especially at low heights from the floor). Therefore, some organizational and technical measures must be implemented in order to limit the harmful effects of the magnetic field on the service personnel.

6 Conclusion

In this paper, an experimental study was carried out to determine the induction of the magnetic field around an induction heater, used in the repair activities at the Plovdiv locomotive depot – to replace the bandage bracelets on locomotive wheelsets.

The measurement of magnetic fields is of increasing importance in order to evaluate electromagnetic emissions and their impact on service personnel, as well as for compliance with electromagnetic compatibility standards [9, 10].

The measurements executed under real operating conditions show that the field weakens with distance from the inductor and with increasing height from the floor. It was established that the magnetic emissions are within the limits of the permissible norms according to the European and Bulgarian regulatory framework [11-13] at a distance of at least 1 m from the inductors and are safe for the service personnel. At a distance of less than 1 m, the radiation becomes dangerous for staff, because the emissions are above the norms.

With temporary exposure to magnetic fields at a distance of less than 1 m, service personnel may experience transient symptoms. They can be expressed in dizziness or headache and in sensory perception such as flashes of light or small changes in brain function [14]. When staff report such symptoms, the employer should proceed to review and, if necessary, update the risk assessment. In the presence of such complaints and measurements carried out by licensed laboratories, the employer is obliged to take additional preventive protective measures:

- *organizational measures* - recruitment and training of service personnel: instructions for reducing the time of presence near inductors, use of appropriate work clothing, do not allow workers with active or passive implanted medical devices or those that are placed on the body; as well as pregnant workers, etc.
- *technical measures* - protective fences should be installed to limit the entry of personnel, signs should be placed warning of the presence of strong magnetic fields after passing through the fenced area.

The technical measures provide collective protection and include combating risks at source of the EMF. They are more reliable than organizational measures because they do not rely on people taking action.

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