Flaw detector magnetizer with wheels as magnetic poles

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Abstract. The efficiency of a flaw detector magnetizing system using wheels as magnetic poles was studied. To obtain information on the emerging magnetic field distributions, three-dimensional computer simulation and research on an experimental model were carried out. The rail was used as a test object. It is shown that with the same magnetomotive force of the electromagnet, the wheel magnetizing system provides a higher magnetization of the test object compared to the traditionally used U-shaped magnetizing system.

1. Introduction
With magnetic flux leakage non-destructive testing, the efficiency of the magnetizing system is of great importance [1, 2]. Efficiency is understood as the ratio of magnetization level of the test object to the magnetomotive force of the magnetic field sources, taking into account the mass-dimensional characteristics of the magnetizer. The traditionally used U-shaped magnetizing systems [3–6] suggest the existence of an air gap between the fixed test-object and the poles of the moving magnetizing system. The size of the air gap is determined by the presence of possible irregularities in the surface of the test object and can be very significant. Thus with the magnetic inspection of the railway rails, the gap size can reach 20 mm due to the encountered difference in the heights of the rolling surfaces in places of bolted joints. The presence of the air gap influences field distribution in the specimen [5, 6]. A resistance of the magnetic circuit increases, leading to a decrease in the magnitude of the working magnetic flux entering the test object.

We propose to reduce the negative impact of the air gap by engaging in the magnetic circuit a wheel rolling along the surface of the test object (figure 1 (b)). Despite the fact that the area of the contact spot is relatively small, the gap between the lower part of the wheel rim and the object is minimal, which improves the characteristics of the magnetic circuit and leads to an increase in the working magnetic flux. In addition, with this contact method, the fluctuations of the gap that occur during the movement of the U-shaped magnetizing system relative to the test object and generate low-frequency noise in the magnetic sensor signals are eliminated.

To verify the effectiveness of the proposed wheel magnetizing system, a three-dimensional computer simulation of the interaction of magnetizing systems with the test object in the form of a railway rail was carried out (figure 1). The simulations were implemented using Ansys Maxwell finite-element analysis software, which is intended to solve not only magnetostatic problems [7, 8], but also harmonic in time [9, 10] and transient [11, 12] ones. The cross section of the electromagnet core in both cases was 70 cm², and the magnetomotive force of the electromagnet was 8 kAT, the distance between the poles was 60 cm. The distance between the poles of the U-shaped magnetizing system and the rail rolling surface was 10 mm. The thickness and diameter of the wheels of the wheel magnetizing system were 6 and 20 cm, respectively.
2. Simulation results and discussion

The field distribution was studied in the rail head and directly above the rolling surface, where the magnetic sensors are located. Figure 2 shows the results of computations of the magnetic induction distribution in the central longitudinal section of the rail and in the same longitudinal section of the magnetizing system core. According to figure 2, the magnitude of the magnetic flux when using the wheel magnetizing system is higher compared to a U-shaped one. The magnetization of the electromagnet core of the wheel system is close to the saturation state (more than 1.6 T), while the U-shaped level of induction in the core is about 1.3 T. Considering that the cross-sectional area of the magnetic cores is the same in both cases (the height of the central longitudinal section in figure 2(b) is slightly larger, however, this is due to the fact that the cross-sectional profile of the electromagnet core of the wheel magnetizing system is chosen round and the U-shaped square), a larger core magnetization indicates a greater magnetic flux in the circuit due to the lower magnetic resistance of the latter.

An increase in flux in the magnetic circuit is manifested in a growth in the magnetization level of the test object. Figure 3 shows the distribution of the field induction module 1 mm below the rail surface along the longitudinal coordinate X. Given the high uniformity of the field distribution in the rail cross section, similar dependences are also observed at large distances from the rolling surface. The computation results indicate that the magnetization of the test object in the interpolar space when using a wheel magnetizing system is approximately one third higher than the traditional U-shaped magnetizing system (about 1.15 T against 0.85 T). An even greater ratio of magnetization levels is observed near the poles, since a significant concentration of the field is created at the contact points between the wheels and the rail when using the wheel magnetizing system.

Figure 1. (a) the U-shaped magnetizing system, (b) the wheel magnetizing system.

Figure 2. Magnetic induction distributions in the longitudinal cross sections: (a) the U-shaped magnetizing system, (b) the wheel magnetizing system.
Figure 3. Magnetic induction distributions in the rail head for two types of magnetizing systems.

An increase in the magnetization level contributes to the formation of more distinct responses from defects in the test object, since approaching the state of magnetic saturation of the material leads to the appearance of relatively more powerful leakage fluxes in air in the vicinity of the discontinuity. To confirm this, a defect in the form of a transverse crack of the rail head was added to the model in the middle between the poles (figure 4 (a)). In the cross section, the crack was an ellipse 16 mm high. The center of the ellipse was offset from the center to the lateral edge of the rail by 10 mm and was lower than the upper edge by 13 mm. A similar model of the defect was already used in the computations [13], however, there the magnetizing system was replaced in the simulation by homogeneous boundary conditions at the ends of the rail, which is a certain idealization.

Figure 4. Magnetic field distributions near the transverse crack in the rail head: (a) magnetic induction distributions on the surface and in the cross section of the rail head, (b) distributions of the induction longitudinal component in 2 mm above the rolling surface with both types of magnetizing system.
Figure 4 (a) presents the magnetic induction distributions in the cross section and on the surface of the rail near the transverse crack in a case of the wheel magnetizing system.

Figure 4 (b) shows the dependences of the longitudinal component of magnetic induction on the longitudinal coordinate in 2 mm above the upper edge of the rail. It is such a signal that the sensor should generate, moving along the rail and passing directly above the center of the crack. As follows from figure 4 (b), the magnitude of the field in the air above the defect-free rail is higher when using a wheel magnetizing system (~3.3 mT) than when using a U-shaped (~2.7 mT), which is quite natural, given the larger magnetization of the metal in the first case. The peak value of induction, which is reached directly above the crack at the coordinate \( X = 0 \), is 5.3 mT and 3.4 mT, depending on the type of magnetizing system used. Thus, the amplitude of the signal from the same defect when using the wheel magnetizing system is 2.0 mT (about 60% of the background field level), while using the U-shaped one it is only 0.7 mT (about 26% of the background level). There is an advantage of the wheel magnetizing system, both in absolute and relative terms.

3. Experimental verification

To confirm the correctness of the computer model used in the computations, a mock-up of the wheel magnetizing system was made (figure 5 (a)), the dimensions of which coincided with those used in the model. The winding of the electromagnet at a voltage of 12 V created a magnetomotive force of 8 kAT, which also corresponds to the considered model. The value of the vertical induction component of 0.5 mm above the upper edge of the rail was measured with a magnetometer based on a Hall sensor. The measurement results, together with the data obtained by computer simulation, are presented in figure 5 (b). The results of measurements and computer simulations are in good agreement with each other, with the exception of the area of direct contact between the wheel and the rail, in which the upper limit of the magnetometer range was reached.

![image](image.png)

**Figure 5.** (a) an experimental setup, (b) a comparison of induction vertical component measurement data and the computation results.
4. Conclusions and future work
The results of the computer simulation and the experimental data indicate the high efficiency of the considered wheel magnetizing system in comparison with the traditionally used U-shaped one.

The considered model is static, i.e. it does not take into account the effects that occur when the magnetizing system moves relative to the test object. The results obtained are quite relevant up to speeds of the order of 10 km/h. However, at higher speeds of motion, the magnetodynamic effects have a significant effect on the field distribution in the test object [11] and on the efficiency of the magnetizing system. Therefore, to correctly compare the efficiency of magnetizing systems at high speeds, it is necessary to take into account additional factors in the model, for example, the occurrence of eddy currents in the test object, as was done in [11].

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