The reason of occurrence of a longitudinal residual induction of steel spindle after circular magnetization

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Abstract. A special attention is paid to the possibility of appearance of a longitudinal residual magnetic flux leakage (MFL) field in the tested ferromagnetic spindle after its circular magnetization. The reasons of appearance of this field and experimental verification of the interpretation are given. When the occurrence of such field is unacceptable, the spindle has to be demagnetized.

1. Introduction
Recently, some vehicles were recognized by the customer as of limited use due to the incorrect working of their navigation equipment. The reason for this was the presence of magnetic field, which is comparable with natural geomagnetic one, at the location of the navigator. This field results from the longitudinal remanent magnetization of the vehicle’s spindle obtained in the process of the magnetic particle inspection. The spindles were magnetized by passing a significant electric current pulse along them; their demagnetization, which is necessary according to the technological process, was, however, not carried out. The reason for the rejection of the operation of demagnetization was simple. When the current is passed through the spindle, the latter is magnetized circularly. The lines of residual induction are concentric circles concentrated in the body; they can go beyond the spindle only if there are surface defects. Since the products with such defects must be rejected, the defect-free product should not have residual magnetic field. This means that their demagnetization, which is rather laborious (the weight of a spindle is about 30-40 kg), seemed redundant and unnecessary.

Nevertheless, when the procedure of demagnetization of the spindles was returned to the technological process, the vehicles began to satisfy all the customer requirements.

In this work, the author will try to find the reasons for the appearance of an external residual magnetic field (MFL) in the case of circular magnetization.

2. Model
Figure 1 shows the elements of device of circular magnetization in a cut.
Figure 1. Components of a contour of circular magnetization in a cut.  
1 - tested object, 2 - return conductor,  
\( R \) - distance between the centres of symmetry of the tested object and return wire.

The current 1 flowing through the tested object creates circular magnetizing field inside it. The current flowing through a return conductor creates a field \( H \) directed nearly vertically (in this case) along the diameter of a product. The strength of the field is given by

\[
H = \frac{I}{2\pi R}
\]  

(1)

The field increases with decreasing distance \( R \) between the centers of symmetry. Let us consider what determines the value of \( R \) in reality.

The elements of magnetizing system are schematically shown in figure 2. The smaller the total length of the conductors in the circuit, the greater the amplitude of the magnetizing impulse current if other quantities are kept unchanged. The length of the tested product, \( L \), is given; the length of the return conductor cannot be less than the length of the tested object. Only the length of the lead wires, which in sum is equal to 2\( R \), is to be minimized.

Figure 2. Sketch of a system circular magnetization in plan:  
1 - tested object, 2 - return conductor, 3 - make wires, 4 - source of magnetizing current.

Let a tested object be a spindle of typical \( L = 2 \) m and \( R = 0.2 \) m. When the amplitude of a current is 1000 A, then, according to (1), the amplitude of the field created by the return conductor is 800 A/m. Along diameter of a cylinder, magnetic susceptibility is close to 2, therefore this field causes magnetization of about 1.5 kA/m in the product. This can be the reason for noticeable residual magnetization along the diameter and hence the appearance of MFL.

Since \( L \gg R \), the permeability along the cylinder is much greater than permeability in the transverse direction. It follows that even a slight deviation of the return conductor from being parallel to the cylinder axis can result in appearance of essential magnetization along the longitudinal axis of the tested object. Some part of the longitudinal magnetization will of course remain after the magnetizing current is switched off.
The angle between the cylinder and the return conductor can be rather large, see figure 3. In this case, the components of a magnetic field along the diameter of the product caused by the return conductor is significantly different near the left and near the right ends of the product, which inevitably causes a magnetizing field along the length and hence a longitudinal residual magnetization.

![Figure 3](image.png)

**Figure 3.** The plan of a potential type of a system of circular magnetization.
1 - tested object, 2 - return conductor, 3 - lead wires, 4 - source of magnetizing current.

If a product is not subjected to demagnetizing operation, then this residual magnetization can interfere with the navigation equipment of a vehicle.

### 3. Experiment
To verify the correctness of our consideration, the following experiment was performed. A circular cylinder with a length of 340 mm and a diameter of 10 mm was made of hardened steel St5. The cylinder was subjected to circular magnetization. According to figure 1, a reverse conductor was located at a distance of 25 mm from the cylinder axis. The MFL field that appeared after circular magnetization was measured by a fluxgate type magnetometer [1] whose sensor was located directly above the center of the investigated cylinder at a distance of 100 mm. Both the vertical and horizontal (along the axis of the cylinder) components of the resulting residual field were measured.

The impulse of the magnetizing current was provided by the discharge of an electrolytic capacitor with a capacity of 1000 μF, charged to a voltage of 50 V [2]. The amplitude of current (60 A) was measured by the voltage drop across a resistor of 0.1 Ohm connected in series into the magnetizing circuit. A simple calculation by formula (1) shows that the testing cylinder was affected by a field of a return conductor of 380 A/m along its diameter. It was found that the induction along the length of the cylinder was 3 μT and that in the radial direction was about 0.3 μT.

We see that the assumption about the cause of the appearance of the residual magnetization in the vicinity of a ferromagnetic cylinder after circular magnetization has found its experimental confirmation. Calculating the numerical dependences was not included into our task.

### 4. Conclusions
On a contrary to a popular belief, the circular magnetization of the extended cylindrical ferromagnetic product can influence the appearance of noticeable residual MFL in the vicinity of the product under the certain circumstances. The possibility of occurrence of such field should be taken into account and in critical cases demagnetization of a product should be carried out after the NDT.

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References
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