

The use of magnetic marks in steel wire ropes

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Abstract. Various methods of marking wire ropes are not devoid of certain disadvantages. In this paper, the authors consider the theoretical possibility of using integrated magnetic marks. The use of mathematical modelling (GMSH + GetDP) assessed the degree of shielding magnetic field of a mark by rope wire. Through the simulation, the authors have determined that the using of a cylindrical mark with the magnetization direction along the rope has qualitative advantages over other forms of marks, or the transverse magnetization direction in terms of its detection by the external detecting device. This type of mark can be easily embedded in the polymeric core of the rope.

1. Introduction

With the development of the cable transport, a need for marking the different portions of the rope arises. For example, it becomes necessary to analyse rope slacking, registering its speed or measuring the distance, which the section of rope or the structure, rigidly connected with it (cabin, column), passed.

Currently, there are several ways of marking mining ropes and armored cables. Thus, the marking of the mining rope or cable can be accomplished by coating ferromagnetic powders on the outer surface of the armor or strands with their subsequent magnetization. The resulting marks have a low life due to mechanical abrasion of the mark caused by friction and reversal magnetization by external magnetic fields. Another method of marking is through the magnetized portions of the armor mining rope [1]. Magnetic marks are pretty quickly demagnetized, because the armor of mining cables is made of soft magnetic steel. Furthermore, the application of such marks to a rope or armor of the moving rope or cable, for example during the manufacture of the product, leads to the longitudinal deformation of the mark. Longitudinal deformation of the mark is caused by a displacement of the rope towards the magnetizing device for the time needed to magnetize the rope part.

There is also a well-known method for making magnetic marks consisting in creating capsules with a ferromagnetic fluid, enclosed into a flexible magnetic material of the core rope [2]. In this case, the material fills the space (gap) between the strands and the length of the capsule which is equal to a strand pitch. As the identifier marks RFID tags [3] are applied, their use may be complicated by interference in reading data from the mark caused during the work of the cableway devices or other devices.

In paper [4], it was proposed to implement magnetic marks based on the permanent magnets in the core of the rope, which will greatly increase their service life in comparison with the external marks (ferromagnetic powders or the obtained magnetization portion of the rope or armor). The major problem is that in most of cases, mild unalloyed steel is used for rope manufacturing, which largely shields the magnetic field. In order to investigate and to study the possibility of using magnetic marks that are integrated into the core of the rope, the numerical simulation of the electromagnetic field distribution in the part of the rope with a permanent magnet fitted in the core, is performed. This design can be implemented on the ropes with a polymeric core that can be replaced by rubber ferrite.

2. The model and simulation

For the analysis, the authors used the method of finite elements with the implementation of it in the software package 'GMSH + GetDP' [5, 6]. The computational domain is the portion of the rope with six strands (the geometric parameters correspond to those listed in The State Standard 3062-80) [7] which are homogeneous areas (Figure 1). The length of the portion of the rope is set to be 70 mm. The magnetic properties of the rope model correspond to the magnetic properties of steel AISI 1010 (St 10). The model rope [8] takes into account the lateral gap between the strands, the presence of which corresponds to the state of a rope not worn out [9].

The magnetic mark is installed into the core, made of a nonmagnetic material having a minimum gap size of 0.5 mm from the inner wires of the rope. The rope core used in a model simulates airspace. The magnetic mark is represented by characteristics corresponding to hard-magnetic material ANI-8 (the value of the residual induction – 0.53 T, coercive force – 790 kA/m).

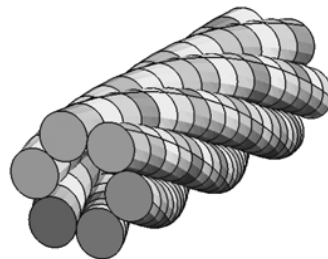


Figure 1. The 3D model of the rope.

When the magnetization takes place along axes Y and Z, the magnetic mark is performed in the form of a rectangular parallelepiped (dimensions ranging from 8x8x4 to 8x3x2 mm (Figures 2a, 2b)). For magnetizing along the X axis, the cylindrical mark was used (mark length is 4 mm, the diameter varied from 2 to 6 mm (Figure 2c)). When conducting the research, the rope diameter and the diameter of the strands ranged within 12-30 mm and 4-10 mm, respectively.

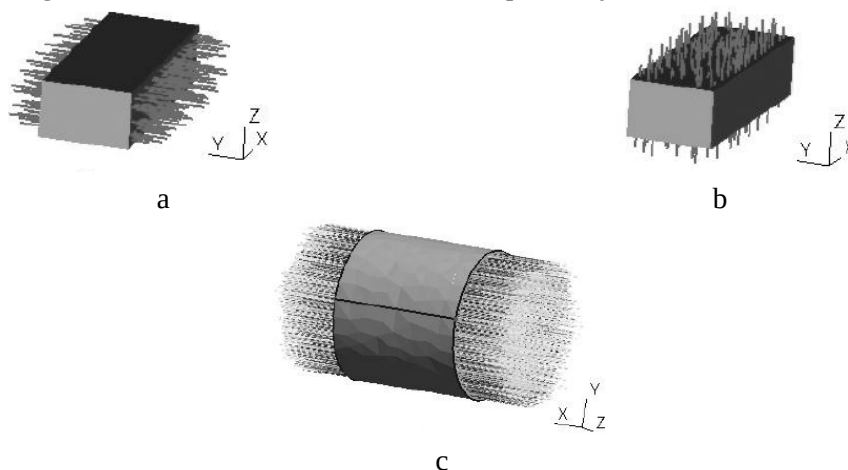


Figure 2. The magnetic mark is magnetized: a – along axis Y; b – along axis Z; c – along axis X.

The picture of the magnetic field was obtained using the finite element method. The computational domain (a three-dimensional model of the rope with the magnetic mark and the magnetic concentrator) is divided into a finite element mesh with built-in GMSH package [10]. The simulation has found that the strands of the rope largely shield the magnetic field generated by the magnetic mark: the magnetic field induction on the surface of the rope along the line of magnetic mark arrangement is evenly distributed (Figure 3).

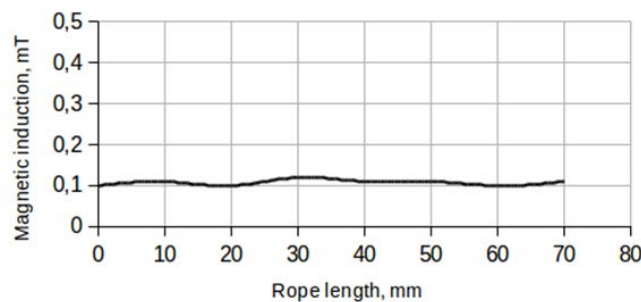


Figure 3. Distribution of the magnetic field in the rope without a magnetic concentrator.

For pronounced inhomogeneity of the magnetic field, a horseshoe-shaped ferromagnetic concentrator (Figure 4), partially covering the cable, is placed at the location of the magnetic mark. The gap between the ferromagnetic concentrator and the rope is 1 mm, the thickness of the concentrator is constant along its length and is equal to 3 mm. The radius of the curvature varies depending on the diameter of the rope to ensure the air gap between the rope and the concentrator is equal to 1 mm. The width of the magnetic concentrator located directly above the magnetic mark equal to the length of the permanent magnet. The magnetic properties of the material of the magnetic concentrator correspond to structural steel AISI 1008 (St 08). In case of using a cylindrical mark, the magnetic concentrator has a U-shape and is located on the lateral surface of the rope, the length of the concentrator is 12 mm (Figure 5).

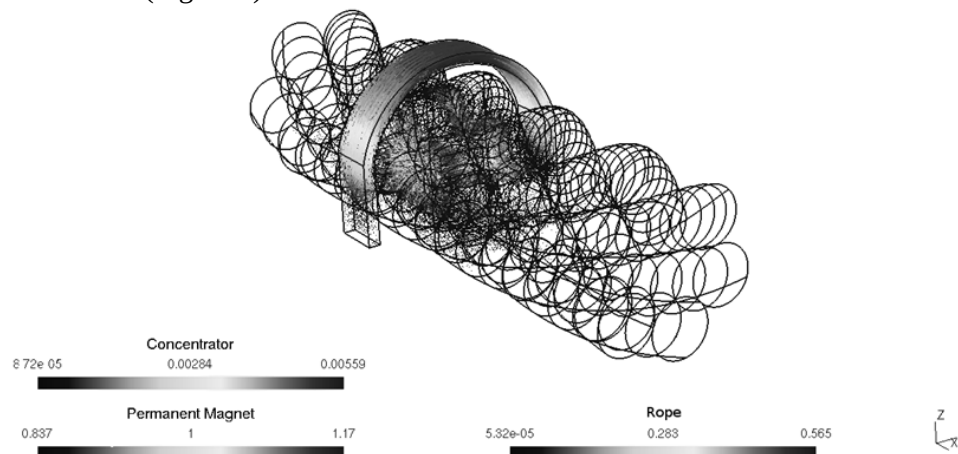


Figure 4. Distribution of the magnetic field with the magnetization of the magnetic mark directed along the Y-axis.

With the magnetization of the magnetic mark is directed along axes Y and Z (across the rope), the magnetic induction in the gap of the concentrator depends on the angle of rotation of the mark (rope with a mark) around axis X. Modulus values of the magnetic induction will be maximal if the vector of magnetic induction of the magnetic mark is directed from one pole to the other pole of the magnetic concentrator, i.e. along axis Y.

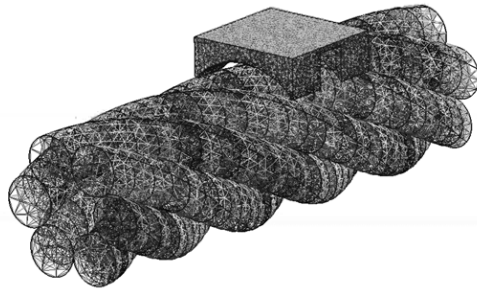


Figure 5. The 3D model of the rope with the mark and the concentrator is divided into finite elements.

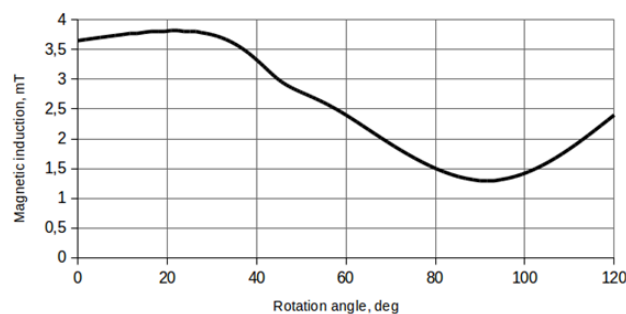


Figure 6. Dependence of the magnetic induction on the rotation angle of the rope relative to the stationary concentrator for the magnetization mark transversely the rope.

With increasing the angle of rotation of the mark, the value of the magnetic induction in the gap of the concentrator is lowered and reaches a minimum when the mark rotational angle is 90° , which corresponds to its magnetization along axis Z. The magnitude of the magnetic induction is 20-25% of the initial value (the rotation angle is 0°). The dependence of the modulus magnetic induction on the rotation angle is shown in Figure 6.

Thus, the authors concluded that magnetization of the mark along axes Y and Z (transversely the rope) has a drawback. It is a variation of the value of magnetic induction in the gap of the magnetic concentrator depending on the angle of rotation of the mark. The magnetic induction in the gap of the concentrator during magnetizing the magnetic mark along the X-axis does not change during the rotation of the rope, since the direction of the magnetic induction vector in this case is not changed.

3. The resolution

To determine the resolution when reading the signal, the dependence of the magnetic induction in the concentrator gap on the value displacement of the magnetic mark relative the concentrator along the rope axis has been studied. The geometrical dimensions of the model were not different from those mentioned above. Zero displacement corresponds to the location of the concentrator above the magnetic mark. The magnetic induction in this case reaches its maximum. The simulation was carried out for both rectangular and cylindrical marks. The value of the air gap between the concentrator and the rope was 0.5 and 2 mm.

When using a cylindrical mark, a sharp decrease of the magnetic induction in the gap of the concentrator with increasing displacement occurs. The 5-time reduction of the magnetic induction is achieved with the displacement of the magnetic mark by 16 mm (four lengths of the mark) in case of a cylindrical mark, and by 28 mm (seven lengths of the mark) in case of a rectangular mark (Figure 7).

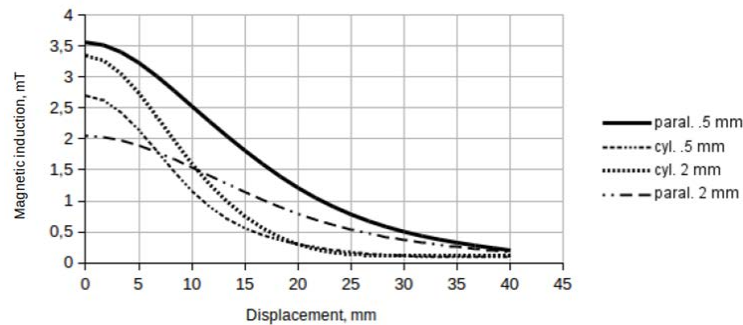


Figure 7. The dependence of the magnetic induction in the gap of the concentrator on the displacement of the cylindrical and parallelepipedic magnetic marks with the corresponding magnetization direction and the shape of the concentrator.

The authors concluded that the more reliable detection of the magnetic mark, possibly by determining the place of changing the sign of the normal (in the direction of the radius of the rope) component of the magnetic induction vector. The sign of the normal component of the magnetic induction vector abruptly reversed itself above the magnetic mark (hereinafter the mark is cylindrical). Increasing the length of the mark leads to a significant increase in the difference between the maximum (positive) and minimum (negative) value of the normal component of the magnetic induction vector, which has a positive effect on the quality of the potential detection of the magnetic mark. The negative effect is a somewhat decrease in the rate of the change in the value of the normal component, for example, during passage of the recording device above the mark (Figure 8).

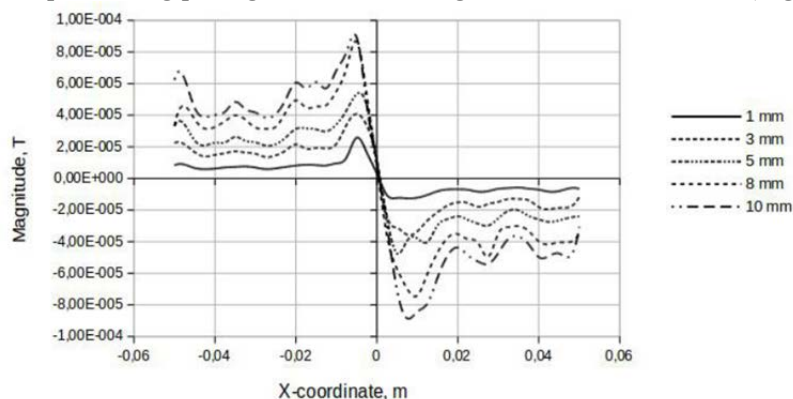


Figure 8. Changing the value of the normal component along the length of the rope for different values of the length of the magnetic marks.

The resolution will be determined by changing the sign of the normal component of the number of times corresponding to the number of marks. To estimate the resolution in determining the mark by the aforementioned method, the numerical simulation of the rope part with the length of 200 mm was performed with two cylindrical magnetic marks with the length of 5 mm. The distance between the adjacent ends of the marks was varied from 1 to 40 mm. Simulation results are presented in Figure 9. The value of the normal component corresponds to the values of the magnetic induction along a line parallel to the axis of the rope at a distance of 1 mm from the outer surface. The small distance between magnetic marks prevents from identifying the two marks. Thus, a double change in the sign of the normal component of the vector of magnetic induction recorded only at distances between the magnetic marks about 15 mm and more, which exceeds the diameter of the rope (11.5 mm).

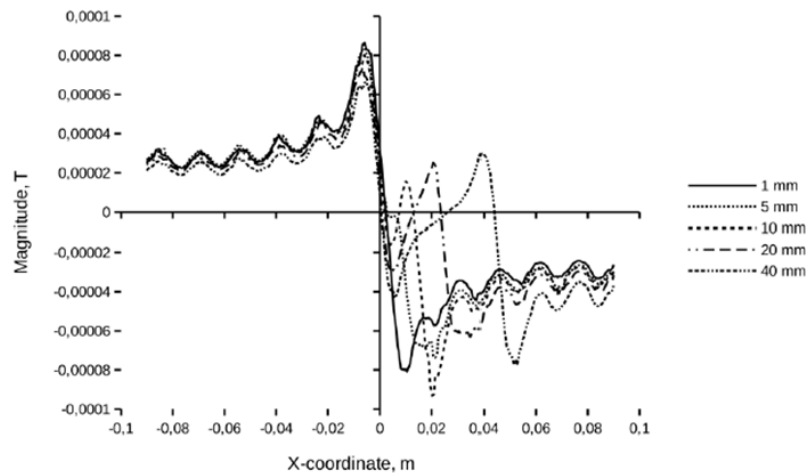


Figure 9. Changing the value of the normal component along the length of the rope for different values of the distance between the magnetic marks.

At shorter distances, the identification of two marks by the aforementioned method is not possible.

4. Conclusion

Analysis of research results leads to the following conclusions.

- The results confirm the possibility of mathematical modelling and the efficient use of permanent magnets in marking the rope with six strands.
- It was determined that for display a maximum variation of the magnetic field in a zone of the mark in the reading device, it is advisable to install a concentrator composed of the ferromagnetic material.
- Analysis of the magnetic field, generated by the permanent magnet, which form a magnetic mark, confirms the effectiveness of the registration normal component of the magnetic field induction vector.
- Using the permanent magnet with the magnetization direction along of the rope reduces the influence of the angle of rotation about the axis relative to the concentrator on the value of the induction in the concentrator measuring gap.
- Increasing the length of the permanent magnet performed as a magnetic mark increases the magnitude of the amplitudes of the normal component of the magnetic field induction vector on the relevant section of the rope that allows improving the quality of the reading signal of the magnetic mark.
- The distance between the individual adjacent marks should be more than the rope diameter for reliable identification.

Acknowledgments

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