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Modulation of Magnetic Field by Steel Rope Defects

Modulace magnetického pole vadami ocelových lan

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The paper is devoted to the modeling of the magnetic field around magnetized steel ropes using the ANSYS software package. The influence of wire cracks on the amplitude distribution of the generated field is specified for two kinds of steel rope assuming surface and inner defects. The first rope is characterized by six rope strands where each strand is completed by 27 wires (two different diameters, 12 thick wires, and 15 thin ones), while the second one has a Z-geometry with a special cross section of wires located on rope surface. The results show a significant influence of surface defects (more than 10 mT) and measurable magnetic flux responses (in the frame of some mT) by cracks in the inner wires with 1 mm gaps. The limits for nondestructive testing of demonstrated ropes are described in detail. Theoretical results support the application of magnetic measurements for nondestructive testing of steel ropes in practice.

***Key words**: Magnetic field; steel ropes; magnetic diagnostics; flaw detection*

Práce je zaměřena na modelování magnetického pole kolem zmagnetovaných ocelových lan pomocí softwarového balíčku ANSYS. Zaměřuje se na modifikaci rozptylových magnetických polí vlivem povrchových, podpovrchových a vnitřních vad ocelových lan, především na roli trhlin jednotlivých drátů v laně a kumulací prasklinových defektů. Vliv drátových prasklin na rozložení amplitudy generovaného pole je studován pro dva typy ocelových lan, kde se předpokládají povrchové a vnitřní vady. První lano je charakterizováno šesti lanovými prameny, kde každý z nich je tvořen 27 dráty (dva různé průměry, 12 tlustých a 15 tenkých dratů), zatímco druhý má Z-geometrii se zvláštním průřezem drátů umístěných na povrchu lana. Výsledky vykazují významný vliv povrchových defektů, kdy při trhlině povrchového drátu s mezerou velikosti 1 mm pozorujeme amplitudovou modulaci magnetické indukce v okolí lana s úrovní výrazně vyšší než 10 mT. Pro podpovrchové defekty shodné geometrie, které nelze diagnostikovat optickými metodami, se amplituda modulačního pole pohybuje na úrovni několika mT pro hodnoty magnetické indukce. Z hlediska budoucího vývoje jsou zajímavé výsledky, které popisují vliv trhlin drátů, které se vyskytují v hlubokých vrstvách ocelového lana. I v tomto případě byl pozorován efekt trhliny na distribuci vnějšího magnetického pole. Tyto výsledky podporují šanci pro aplikaci nedestruktivních diagnostických metod ocelových lan pro komplexní analýzu technického stavu těchto důležitých prvků transportních a nosných systémů. U ocelových lan s uzavřeným povrchem (Z-geometrie) u vnitřních defektů (trhliny drátů) se blížíme k mezním hodnotám snímání poruch, kdy daná konstrukce lana výrazně ovlivňuje modulaci rozptylových magnetických polí interními poruchami. Z popsaných jevů vyplývá, že bude zapotřebí věnovat se také popisu úbytku kovového průřezu (koroze) jednotlivých drátů lana na rozložení výsledného magnetického pole v okolí zmagnetovaného lana.

***Klíčová slova**: Magnetické pole; ocelová lana; magnetická diagnostika; defektoskopie*

Steel wire ropes are complex structures. Most wire ropes operate in demanding conditions and must resist crushing, bending fatigue, and abrasion. Consequences of their failures can often be catastrophic [1]. A steel wire rope consists of wires laid into several strands, which are, in turn, laid around a center core. They belong to the most critical items in the transport industry. Traffic safety is very important, so ropes are routinely controlled by a suitable type of flaw detector. It is well known that magnetic analysis appeared to offer the greatest promise as a nondestructive method for testing wire ropes. This method can naturally be applied only to ferromagnetic materials.

At the VŠB-TU Ostrava, we have developed a flaw detector for the inspection of steel ropes and tubes up to a diameter of 60 mm. Permanent magnets are used as a source of magnetic field. Hall detectors have been used to measure the magnetic field. Permanent magnets as a magnetic source are very stable and do not need electrical power. Hall probes for measuring magnetic fields have the advantage that they enable measuring the rope in a static state (without the motion between the rope and flaw detector). The advantage of this method is the ability to identify individual defects over the total length of the rope, which normally reaches 1000 m (up to 10,000 m). The method is very sensitive to external defects, while internal defects are more difficult to identify.

For this reason, we try to model the responses of individual types of defects for a specific design of steel rope [2]. This method allows us to detect not only the surface breakages (broken wires, imperfections, cracks) but also the internal defects. The physical principle of magnetic testing is based on the generation of a secondary magnetic field, which is created by a magnetized body [3, 4]. Not all flux lines of the magnetized object cross the defect area directly [5]. It means generally that the longitudinal and radial components of the magnetic field are specified. The solution of the field problem of the magnetized bodies is of great importance in several areas of science especially because of the increasing use of permanent magnets and magnetic circuits [6, 7].

1. Modeling

The model of the setup can be formulated using a scalar magnetic potential. Two types of the sub-regions can be distinguished: the source-free medium (air) and the magnetic material (steel rope wires). Both types of the mentioned sub-regions are considered without free currents, and the result is that the tangential components of the magnetic field intensity along their mutual boundaries are continuous. The applied mathematical approach is described in [8] in detail.

The numerical modeling of the experimental array by FEM was carried out using the ANSYS software package. To secure stable results of the computation, the size and the number of the elements in the model was tested. It was found that in order to achieve stable results, models had to contain approximately 2 500 000 elements. Further increasing the number of elements does not substantially improve the stability increase, and moreover, it leads to superfluous growth of computational time.

2. Theoretical Results

The numerical computations of magnetic fields generated by cracks of magnetized steel ropes have been realized on two geometrical constructions of steel ropes. The first one is depicted in Fig. 1, and it is characterized by six rope strands where each of them is completed by 27 wires (two different diameters, 12 thick wires, and 15 thin ones). The second rope has the so-called Z-geometry (Fig. 2), with a special cross section of wires located on the rope surface.

The fundamental question related to magnetic diagnostics (in general) is the limit responsibility for steel rope testing. This question is connected with the secondary magnetic field magnitude generated by defects of the magnetized rope. In the following text we try to describe the magnetic field distribution around magnetized steel ropes with different positions of defects.

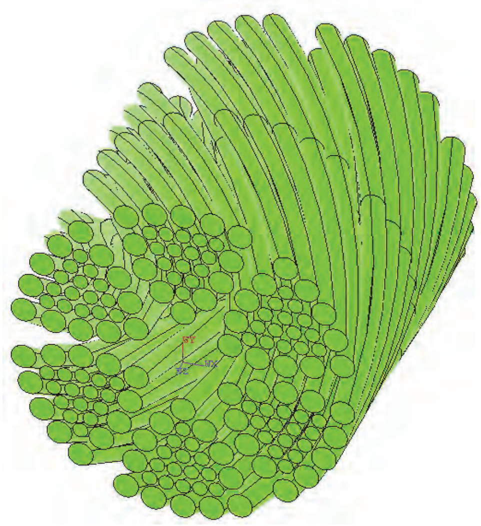

Fig. 1 Cross-section of six strands rope combining thick and thin wires
Obr. 1 Šestipramenné ocelové lano s tenkými a tlustými dráty

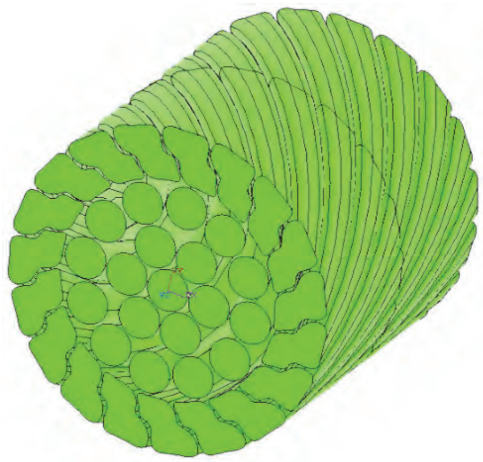

Fig. 2 Z-geometry of steel rope
Obr. 2 Ocelové lano s Z-dráty

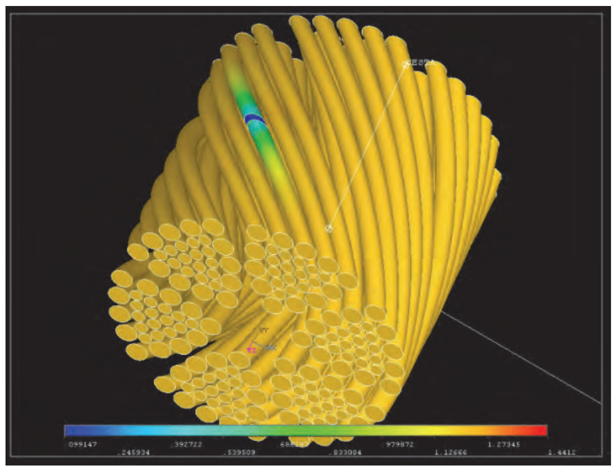

Fig. 3 The rope with a surface defect; the positions of the defect is specified by colored fronts of wire
Obr. 3 Lano s povrchovou vadou; pozice defektu jsou určeny barvami drátu

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The first situation is a wire crack (1 mm gap on the thick wire) on the rope periphery (see Fig. 3). The corresponding 3D distribution of the secondary magnetic field is demonstrated in Fig. 4. The magnetic flux density peak for this case reaches up to 70 mT. For this case, the discussed crack means approximately 1% of the change of the rope cross-section.

For nondestructive testing, the main attention is focused on the possibility to determine inner steel ropes defects, which cannot be disclosed by visual techniques. Figure 5 describes the magnetic field distribution around rope where the underground thin wire is interrupted by a 1 mm gap. The corresponding magnetic flux distribution at the rope rope surface is modulated in the frame of 10 mT (Fig. 6).

For the case when the inner thin wire is broken (1 mm gap, Fig. 7), magnetic field changes in comparison with the perfect rope are approx. 1 mT (Fig. 8).

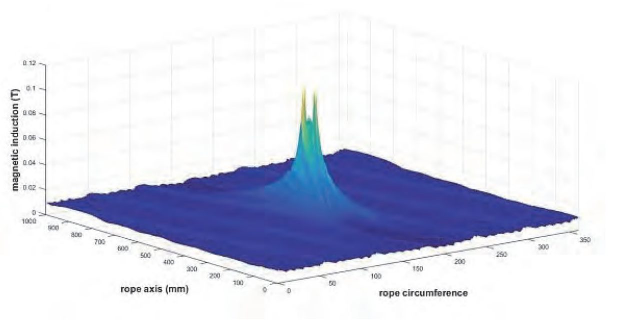

Fig. 4 3D distribution of secondary magnetic field for wire crack (1 mm) on the rope periphery (six strands rope) according to Fig. 3

Obr. 4 3D rozložení sekundárního magnetického pole pro přetržený drát (1 mm) na obvodu lana (šest pramenné lano) podle obr. 3

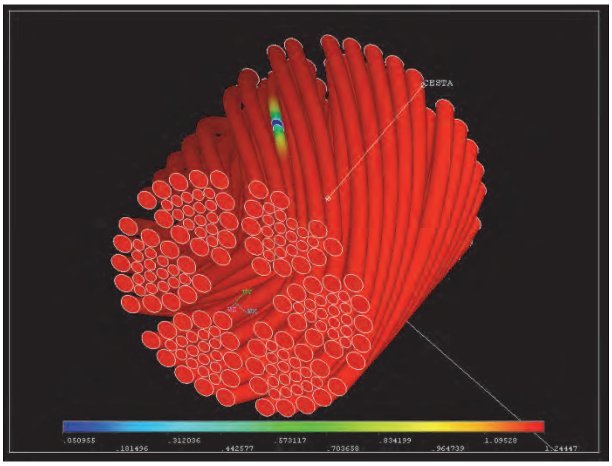

Fig. 5 The underground wire defect (gap of 1 mm on thin underground wire)

Obr. 5 Defekt uvnitř lana (mezera 1 mm na tenkém podzemním vodiči)

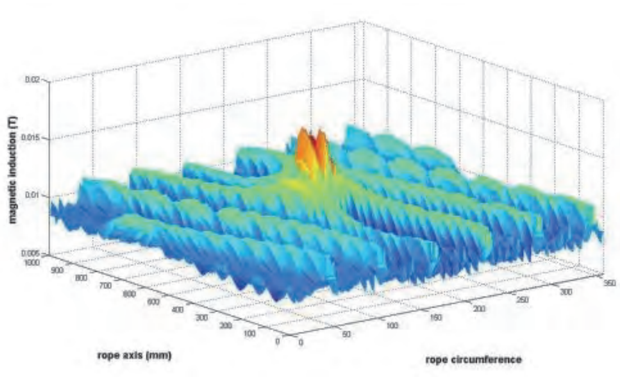

Fig. 6 3D distribution of secondary magnetic field for thin wire crack (1 mm) according to Fig. 5

Obr. 6 3D rozložení sekundárního magnetického pole pro tenké drát (1 mm) podle obr. 5

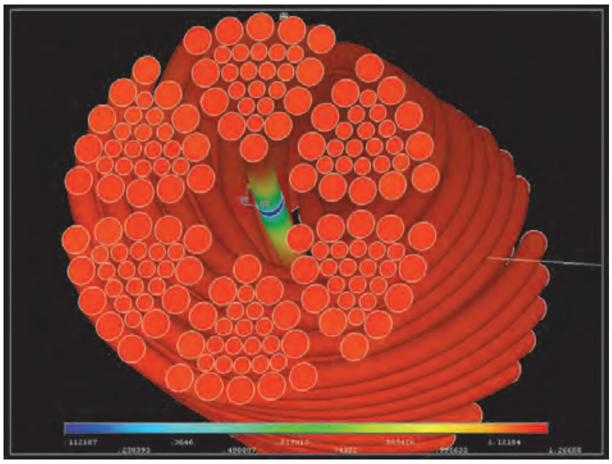

Fig. 7 The geometry of inner wire crack (1 mm gap)

Obr. 7 Geometrie vnitřního defektu (1 mm mezera)

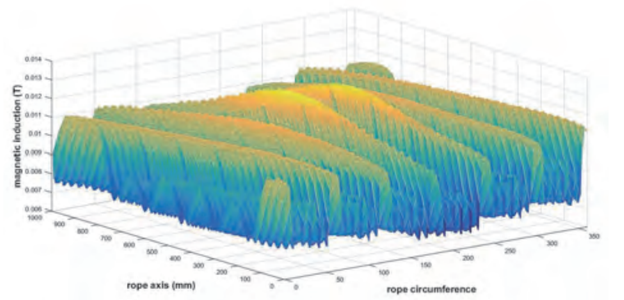

Fig. 8 The distribution of modulated magnetic field by inner wire crack according to Fig. 7

Obr. 8 Rozložení magnetického pole kolem vnitřního defektu drátu podle obr. 7

In order to enable unambiguous decisions related to defects geometry and their positions in the rope the modulation of the magnetic field around magnetized steel rope with cracks,which are repeated (Fig. 9) has been studied. For these cases we can observe importantly different output signal of–flaw detector (magnetic field modulation) in comparison with early discussed situations (Fig. 10).

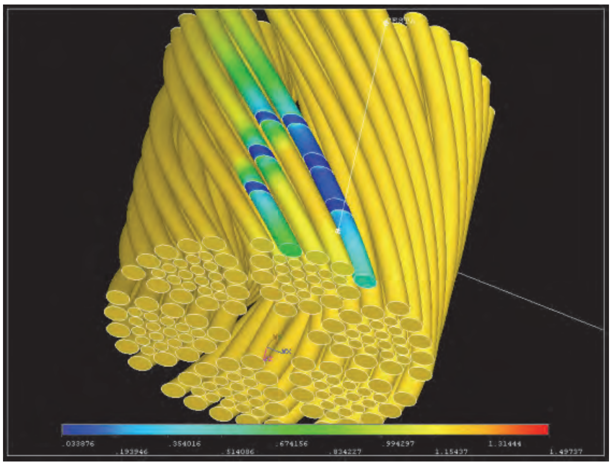

Fig. 9 Steel rope with multiple wire cracks
Obr. 9 Ocelové lano s několika prasklými dráty

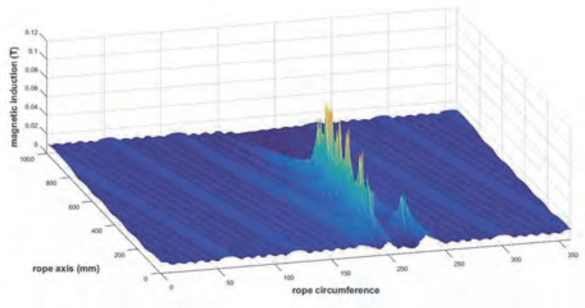

Fig. 10 Magnetic field distribution around steel rope with multiple wire cracks according to Fig. 9
Obr. 10 Rozložení magnetického pole kolem ocelových lan s několika trhlinami podle obr. 9

For the magnetized Z-geometry rope with surface breakage (Fig. 11) the surroundings of the defect are characterized by important magnetic flux changes (Fig. 12). Close to the defect area, we can observe more than 50 mT shifts in the magnetic field amplitude.

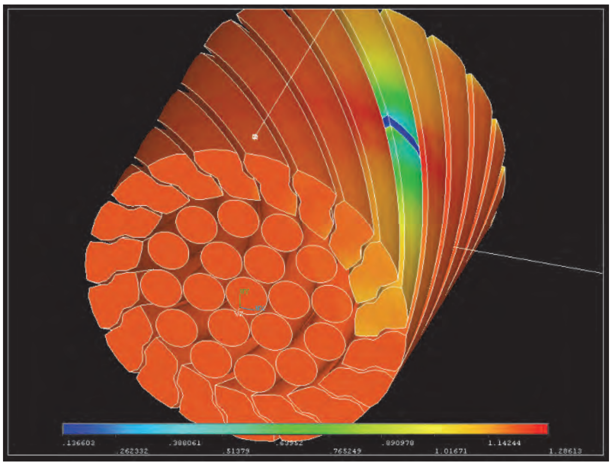

Fig. 11 Z-geometry rope with surface breakage
Obr. 11 Lano Z- geometrie s povrchovými defekty

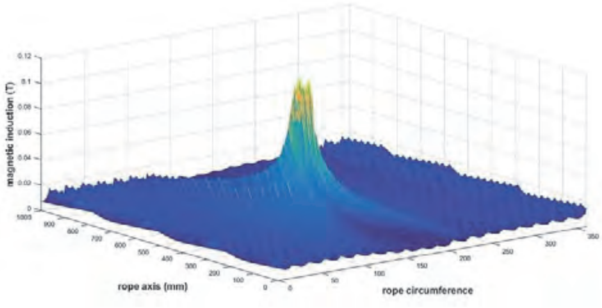

Fig. 12 Magnetic field modulation for Z-geometry rope with surface breakage according to Fig. 11
Obr. 12 Rozložení magnetického pole pro lanko typu Z s defektem povrchu podle obr. 11

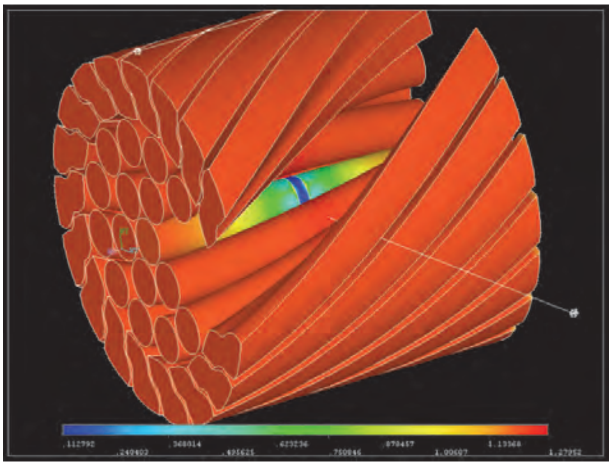

Fig. 13 Steel ropes with a Z-geometry with internal crack
Obr. 13 Ocelové lana se Z-geometrií s vnitřním defektem

It is more attractive for diagnostics to solve the contribution of internal cracks – defects (Fig. 13) to the magnetic field surrounding the tested rope. This question is especially important for ropes with a Z-geometry, because in this case the top wires practically enclose the rope surface. The theoretical results declare the possibility of using nondestructive magnetic diagnostics to inspect Z-ropes with internal defects. For this case, we observed magnetic flux changes of more than 5 mT (Fig. 14).

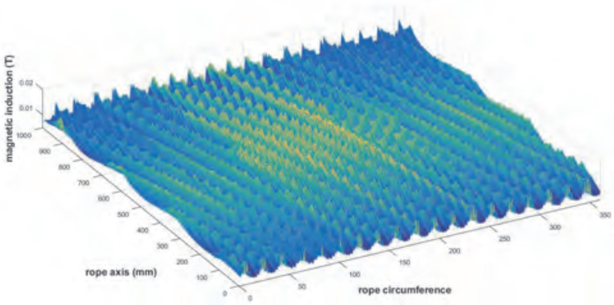

Fig. 14 Modulation of the magnetic field around Z-shape rope by internal crack according to Fig. 13
Obr. 14 Rozložení magnetického pole kolem lana tvaru Z vnitřním defektem podle obr. 13

Conclusions

The numerical modeling of the experimental array by FEM was carried out using the ANSYS software package. It was found that in order to achieve stable results, models had to contain approximately 2 500 000 elements. Further increasing the number of elements does not substantially improve the increase in stability.

The achieved results have confirmed the possibility to apply yoke magnetic flaw detector [1] for diagnostics of surface and internal wire cracks of ropes characterized by six strands geometry and Z-geometry. The magnetic flux density generated by the magnetized rope with different cracks (surface and inner thick and thin wires) exceeds the response limit of flaw detector.

For wire crack (1 mm gap on the thick wire) on the rope periphery, the corresponding 3D distribution of the secondary magnetic field reaches up to 70 mT. For the case where the underground thin wire is interrupted by a 1 mm gap, the corresponding magnetic flux distribution at the rope surface is modulated in the frame of 10 mT.

For the magnetized Z-geometry rope with surface breakage, the surroundings of the defect are characterized by important magnetic flux changes. Close to the defect area, we can observe shifts exceeding 50 mT in the magnetic field amplitude. The theoretical results declare the possibility of using nondestructive magnetic diagnostics to inspect Z-ropes with internal defects. For this case, we observed magnetic flux changes of more than 5 mT.

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Pozinkovací linka č. 3 rekordně

Oceľ VÝCHODU, 24. 9. 2018

V srpnu 2018 bylo na pozinkovací lince č. 3 divizního závodu Zušlechťovny a Obalová větev USSK na Slovensku dosaženo skvělého výkonu, kterým byl překonán poslední rekord ze srpna 2015.

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