Research Article

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Residual magnetic field as a source of information about steel wire rope technical condition

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Abstract: Research has been undertaken to analyze the possibilities of using the residual magnetic field, as a result of local changes in the electromagnetic properties of the rope material, for identification of steel wire rope technical condition. Under the influence of cyclically changing workloads, due to the effects of magnetomechanics, changes in electromagnetic properties occur both in the wires and in the entire rope. The article presents the use of magnetic sensors to determine the relationship between the number of steel wire rope bends and its magnetic field induction value. This knowledge, referred to as ropes working on real objects, allows us to determine the state of stress prevailing in them as well as their technical condition.

Keywords: non-destructive testing, residual magnetic field, steel wire rope

1 Introduction

Steel wire ropes have many different applications and are used in almost every area of industry. As a result of continuous use, they inevitably have been degraded. Most often, this degradation is caused by four phenomena: fatigue, friction fatigue, wear or corrosion. These phenomena may occur on their own, but almost always occur in all combinations and with different intensities. The basic forms of fatigue of steel wire ropes are tension-tension fatigue, free-bending fatigue, torsion fatigue and bending over sheaves fatigue [1,2].

Sudden rupture of the rope can threaten the life and health of people and cause costly downtime. Accidents resulting from damage to wire ropes are a serious problem and a challenge for designers and constructors – especially when it comes to the safety of human life. The basis for increasing safety and improving the efficiency of rope use is a good knowledge of the degradation process. Many authors conduct numerous studies searching for a correlation between the magnetic signal of the tested object and its degree of intensity. The magnetomechanical effect and the physical mechanism of this spontaneous magnetic phenomenon are discussed in many experiments, including tensile fatigue tests, static tension tests or bending fatigue tests, tensile fatigue tests, and bending fatigue tests. In ref. [3], researchers provide a novel method for quantitatively inspecting stress concentration, microcracks and micro-defects with the metal magnetic memory testing method. The authors of the ref. [4] also look for a correlation between a Residual Magnetic Field (RMF) and the degree of stress concentration in magnetic materials subjected to tensile stresses. The authors mentioned previously conduct their research on uniform ferromagnetic elements, focusing on tensile stresses. The fatigue processes mentioned earlier have the greatest impact on the development of degradation. The aim of the research is to analyze the possibilities of assessing the technical condition of steel wire ropes based on RMF. The article presents preliminary studies on the impact of the number of wire rope bending cycles on the potential diagnostic signal – values of RMF components.

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2 Background and theory

The technique relies on the self-magnetization of ferromagnetic engineering structures by ambient fields such as the earth's field. The passive stress measurement technique takes advantage of this phenomenon to obtain information about the stress history of the sample by studying the magnetism that has built up in the sample over time, under the influence of the earth's magnetic field. The technique has the potential to identify several different areas of concern, including the following:

– cyclic loading of the material; as the stress induced magnetization of a structure consists of both reversible and irreversible components, each stress cycle changes the level of magnetization, leading to an increase in magnetism in areas experiencing cyclic loading,
– geometric discontinuities; defects in the material will cause the magnetic fields to leak out of the material into the air,
– stress concentration zones; areas of maximum magnetic resistance reflecting residual stress concentrations in the material, formed during the fabrication of ferromagnetic products due to heat treatment or mechanical treatment [5,6].

The link between the magnetic properties of a sample and applied stress is illustrated by the phenomena of magnetostriction; the changing of a material's physical dimensions in response to applied magnetization. The reverse effect is the magnetomechanical effect [7], where stress applied to a material changes the magnetism and magnetic properties of the sample. An equation describing the change in magnetism (M) with applied stress (σ) was developed by Jiles [8]:

$$\frac{dM}{d\sigma} = \frac{1}{\varepsilon^2}\sigma(1-c)(M_{an}-M_{irr}) + \frac{dM_{an}}{d\sigma}, \qquad (1)$$

where c and ε are constants. equation (1) describes the dependence on the material magnetization on not only stress but also the anhysteretic magnetization – M_{an} (the ideal or lossless magnetization curve of a material) and M_{irr} the irreversible component of magnetization. Another important equation in stress/magnetic coupling is the stress energy (E_σ) induced by external stress (σ), which is given by:

$$E_\sigma = -\frac{3}{2}\lambda_S \sigma \cos^2\theta. \qquad (2)$$

The equation highlights the dependence of E_σ on θ, the angle between applied stress and magnetization and λ_S, the saturation magnetostriction, determined by the maximum elongation due to magnetostriction experienced by the material when exposed to an external magnetic field.

3 Experimental details

The objects on which the test was carried out were steel wire rope samples, 400 mm length, different diameters and constructions (Table 1). Only rope no. 1 underwent the process of demagnetization to eliminate the stress history of the tested object, rope no. 2 was in the delivery state, and ropes no. 3 and 4 were in a state of exploitation.

Each of the ropes was subjected to the bending cycles using the equipment presented in Figure 1.

Each bending cycle began in the vertical position of the rope (Figure 1) and included two 90-degree inflections in opposite directions. Then, after each single bending cycle, the straightened rope was removed and measured using the SpinMeter-3D sensor (Figure 2). The measuring range of the sensor is ±1,000 μT, providing a sensitivity of 0.1 μT ≈ 0.08 A/m. The procedure of the test is shown in Figure 3.

Table 1: Details of the ropes

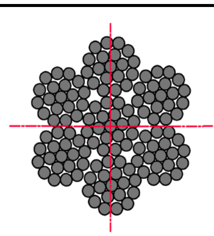
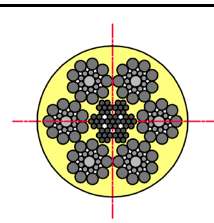
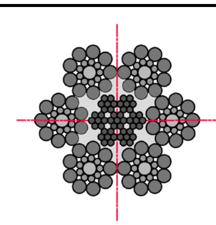
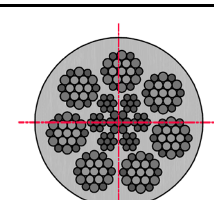
No. of the rope	1	2	3	4
Cross section				
Diameter	ø6.0 mm	Ø5.1 mm	ø6.0 mm	ø6.5 mm
Construction	6 × 19M + IWRC	6 × 19S + IWRC (7 × 7) coated	6 × 19S + IWRC (7 × 7)	7 × 19W + IWRC (7 × 7) coated

Figure 1: Equipment for bending steel wire rope.

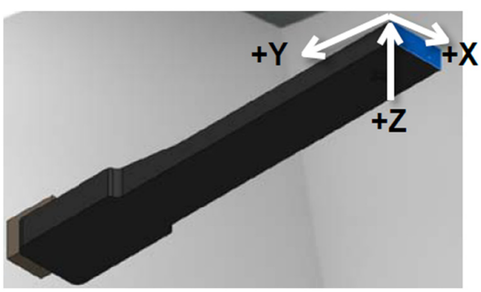


Figure 2: SpinMeter-3D sensor [9].

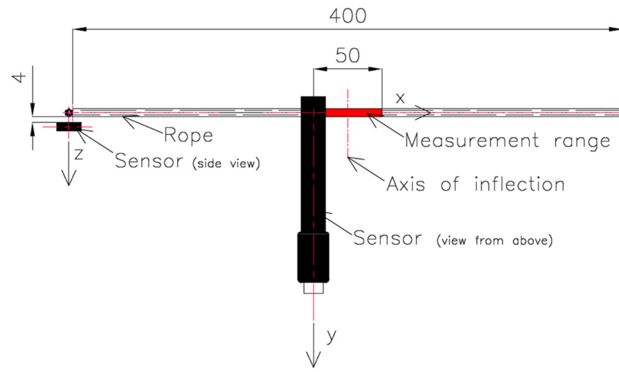


Figure 3: Procedure of the test with the SpinMeter-3D sensor.

The results of the measurements are the values of the three RMF components:

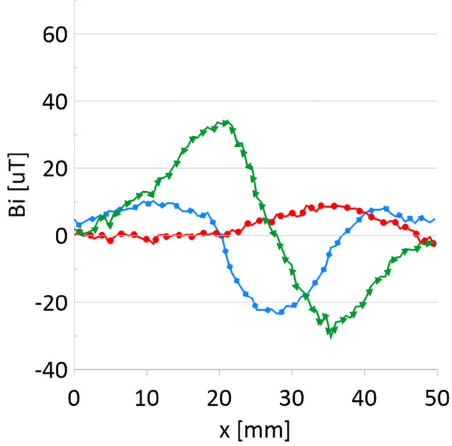
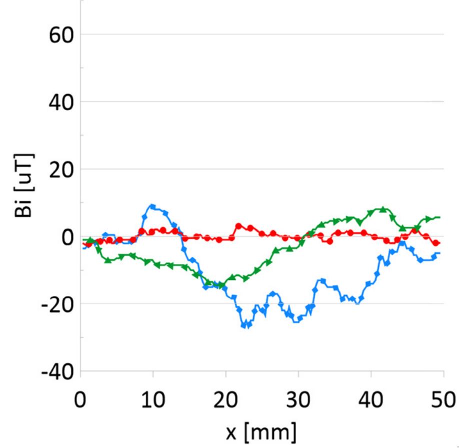
- B_x is the tangential component parallel to the rope axis,
- B_y is the tangent component perpendicular to the axis of the rope,
- B_z is the normal component to the rope axis.

The components are shown in Figure 2.

4 Measurement results and their analysis

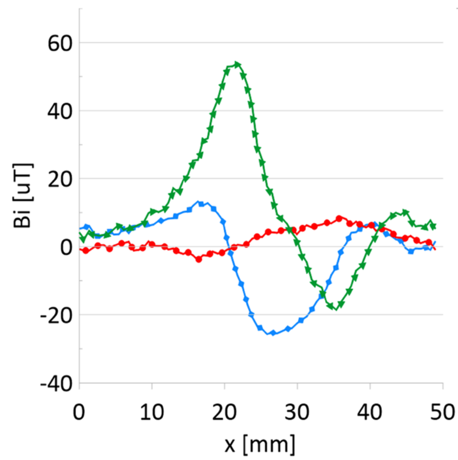
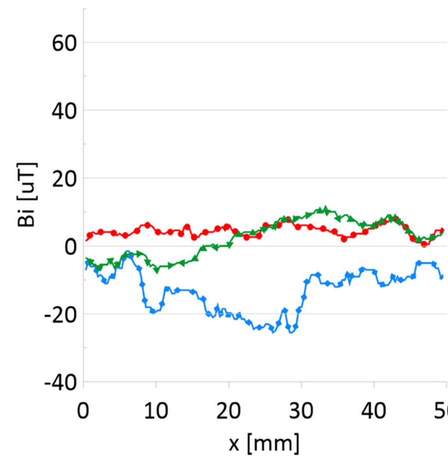
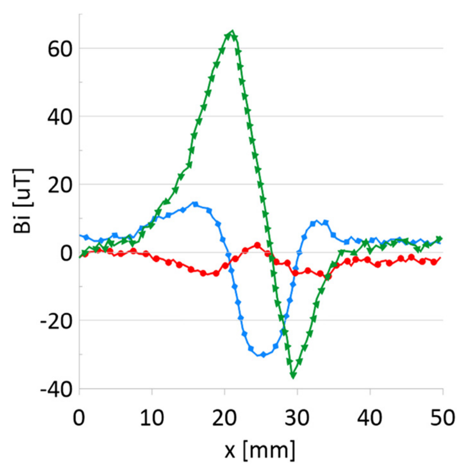
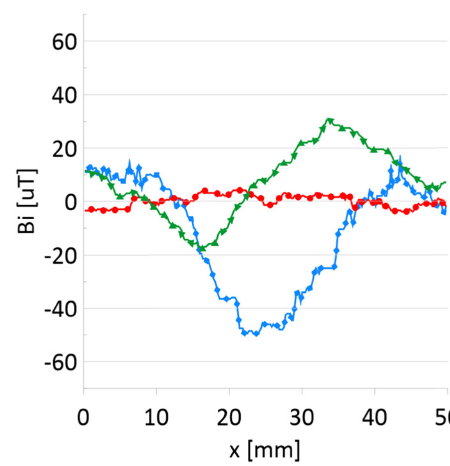
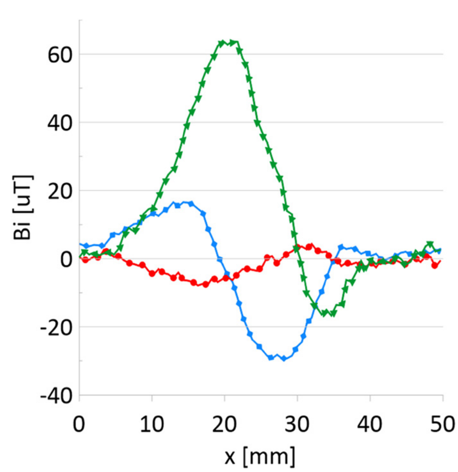
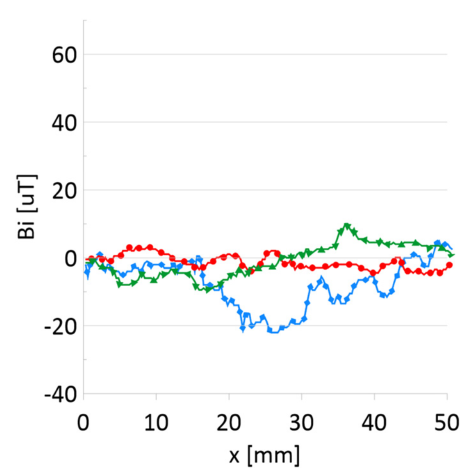
The impact of the number of bending cycles on the values of RMF components is shown in Tables 2 and 3. It can be

Table 2: Results - ropes no. 1 and 2

No. of the rope	**1**	**2**
Additional information 2 Bends	Demagnetised 	Delivery state 

(*Continued*)

Table 2: *Continued*

No. of the rope	1	2
4 Bends		
6 Bends		
7 Bends		

(*Continued*)

Table 2: *Continued*

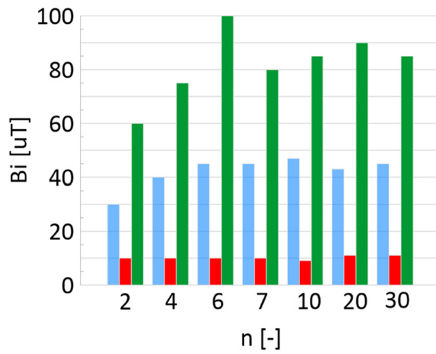
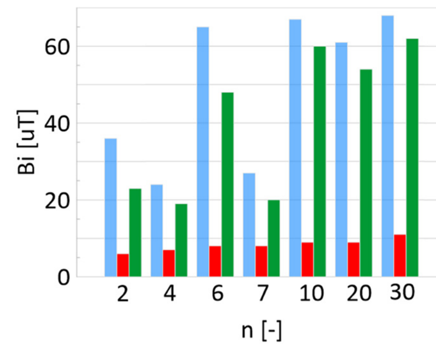
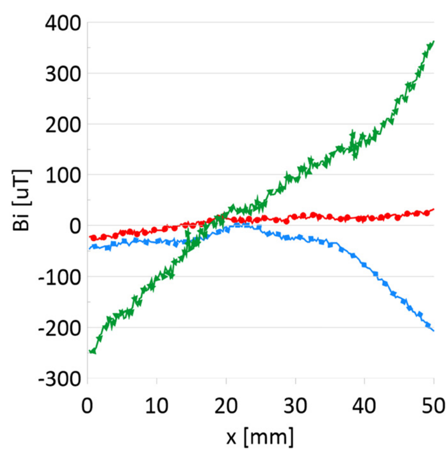
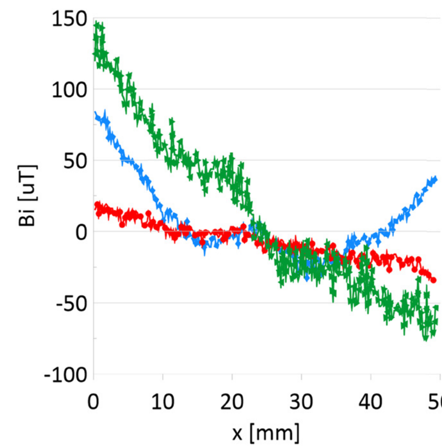
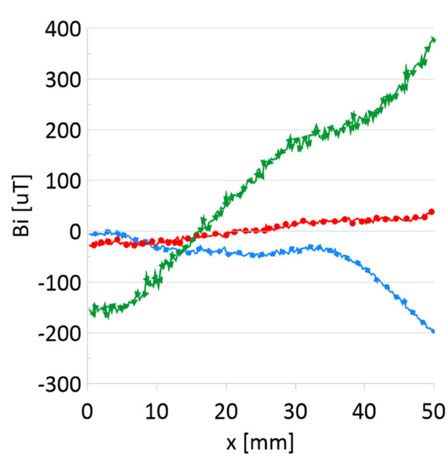
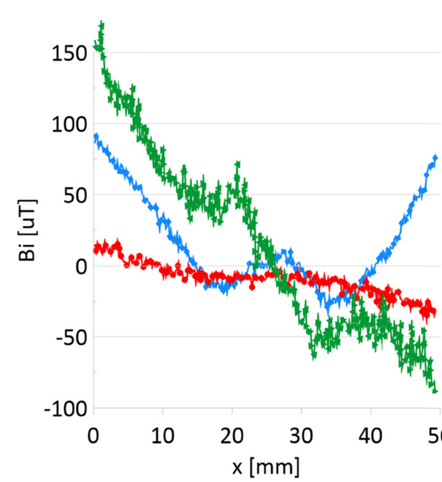
No. of the rope	**1**	**2**
Global results		
Legend		

Table 3: Results - ropes no. 3 and 4

No. of the rope **Additional information**	**3** **State of exploitation**	**4** **State of exploitation**
2 Bends		
4 Bends		

(*Continued*)

Table 3: *Continued*

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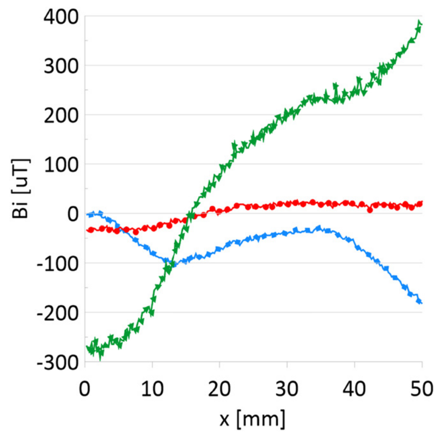
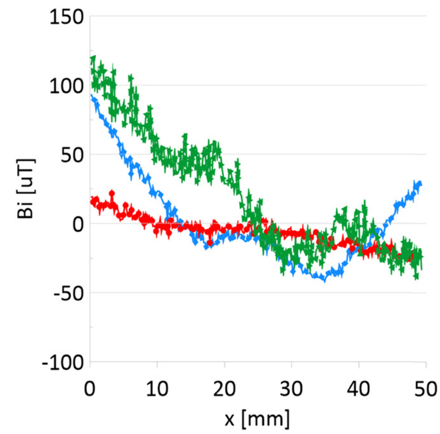
Additional information</th><th>3
State of exploitation</th><th>4
State of exploitation</th></tr>
<tr><td>6 Bends</td><td>
</td><td>
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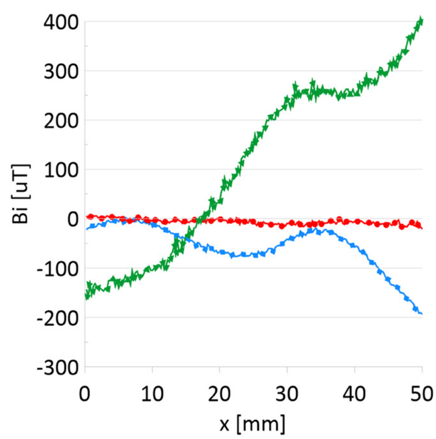
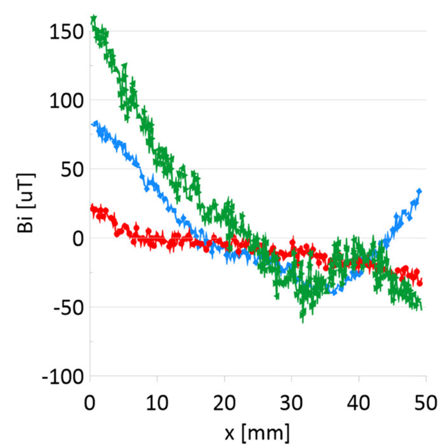
<tr><td>7 Bends</td><td>
</td><td>
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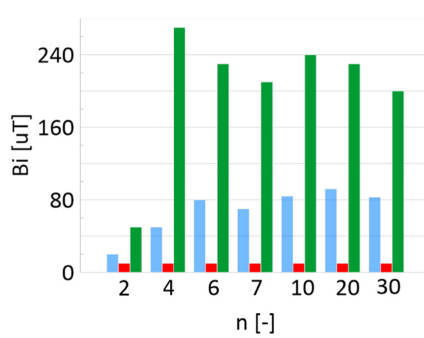
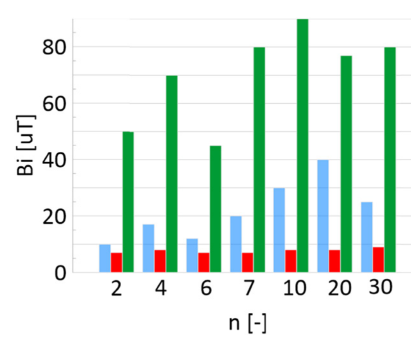
<tr><td>Global results</td><td>
</td><td>
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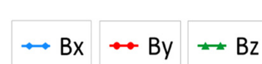
<tr><td>Legend</td><td colspan="2">
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</table>

seen that the component that best correlates with the number of cycles is the B_x component, i.e. the wires parallel to the axis and B_z presents a normal component to the rope axis. The largest changes in component values occur for the first bending cycles and decrease with each subsequent cycle. After a certain number of cycles, the changes are virtually unnoticeable. These results are consistent with the results presented in ref. [10].

Bending causes two areas: extended and compressed, separated by a neutral axis. Due to the nature of the sample (change of bending direction), in both areas of the rope alternating compression and tensile stresses occur. In the studied case, plastic deformations occur in the bending zone, and thus, the appearance of residual stresses that determine changes in electromagnetic properties.

The changes are due to the impact of magneto-mechanical coupling. In a material with positive magnetostriction, tensile stresses cause a rise in magnetic permeability in the direction parallel to the direction of the applied load, as well as reversible and irreversible changes in magnetization. The measurement result is affected by both these quantities – a rise in magnetic permeability involves a decrease in the RMF, whereas changes in magnetization either strengthen or weaken the field intensity depending on the initial state. Causing compressive active stresses decreases the magnetic permeability value in the applied load direction. This results in a rise in the RMF intensity.

5 Summary

An analysis of the possibility of using RMF components as a diagnostic signal in assessing the technical condition of steel wire ropes was investigated. A study was carried out on the effect of the number of bending cycles on changes in RMF component values measured on the rope surface. It was found that the largest changes occur for the tangential component parallel to the rope axis. These changes are intense for the first few bending cycles, while subsequent cycles do not cause significant changes. The obtained results show that based on the RMF component values, it is not possible to identify the number of bending cycles. However, based on the analysis of RMF component distributions over the length of the rope, it is possible to identify the area subjected to bending – the more stressed area. This article focuses only on the first few bends of the rope; further research will focus on the fatigue analysis of the tested ropes. The authors will try to answer how the signal changes in the case of multiplied successive inflexions – whether the value of the magnetic induction on the rope remains at the same level or whether it drops. The researchers will also investigate the influence of various rope structures and their diameters on the values of RMF component values.

Conflict of interest: The authors state no conflict of interest.

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