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TOMASZ KRAKOWSKI

The magnetic testing of steel ropes in hard-to-access places

The increasing requirements for safety, reliability and quality mean that the testing of steel ropes has become an inseparable element in their production and operation stages. The basic method used in testing has become the magnetic testing method of steel ropes (MTR). Despite the extensively developed knowledge, equipment, and methods of analysing diagnostic signals, difficult to access places and the ends of steel ropes are not fully covered by diagnostics. Visual inspection, which is one of the basic methods of non-destructive testing in this area of ropes, has many limitations. This area of magnetic defectoscopy is a place where new solutions and structures for testing steel ropes are created. The article presents an example of solutions used for diagnostics in places with difficult access. A new concept of a diagnostic system for magnetic testing of ropes in these sections is described. The results of initial laboratory verification measurements of the new solution are also presented.

Key words: *steel ropes, diagnostics, magnetic testing of steel ropes*

1. INTRODUCTION

The method of magnetic testing of steel ropes is a non-destructive method. It consists in detecting defects and damage to steel ropes, which are previously magnetized with a constant magnetic field. In the case of a defect around the tested ferromagnet, magnetized with a constant magnetic field, a disturbance of the magnetic field force lines appears. The size of the disturbance, also occurring in the space surrounding the object, can be interpreted and analysed as an external magnetic field anomaly. This disturbance is usually related to the size and location of the defect. The basic set of measuring equipment consists of two units: a measuring head unit and a recorder unit or another device processing the diagnostic signal. The result of the measurement is a defectogram with recorded results, which requires further development [1, 2]. Magnetic testing consists in magnetizing the rope along its axis with a constant magnetic field (using a magnetic head), observing and recording phenomena that occur during the magnetization of the rope (sensor), interpreting and calculating the degree of rope wear based on the received signals. The main elements of the magnetic head are the magnetic circuit, which is defined as a closed path of the magnetic induction flux, which is a part of the magnetic field with a higher energy density per unit compared to the surrounding parts, and sensors that are placed in the symmetry plane of the head [2]. The magnetic circuit consists of (Fig. 1): the tested element (steel rope), pole pieces (ensure better penetration of the magnetic flux into the rope), permanent magnets (source of the magnetic field, their magnetic energy determines: detectability of defects, dimensions and weight of the head, magnets made of Ne-Fe-B, Al-Ni-Co, Sm-Co alloys or sinters are used), magnetic jumper (closes the magnetic circuit).

Two types of sensors are currently used in magnetic wire rope defectoscopy. The first is an inductive sensor, which is used to detect discontinuities of a step nature (broken wires, missing wire, excess) whilst the second type is the Hall sensor, which enables the detection of so-called continuous damage, abrasions, corrosion, etc., and quasi-continuous damage such as dense wire cracks along the length of the rope, corrosion pits, and the loosening of strands. The measuring equipment currently employed uses sensors that record the change in the radial component of the value of the magnetic leakage flux above the tested element. The magnetic heads available on the market are excellent for testing long sections of wire ropes. However, their design has one basic limitation, namely the difficulty of testing in places with limited access, such as testing ropes with mounted clamps, at their ends, etc. This limitation results directly from the construction of the testing equipment and the fact that the sensor assembly is placed in the middle of its magnetic circuit. Such a design of the magnetic circuit and the sensor placed in its central part will always result in a certain untested section of the rope (Fig. 2).

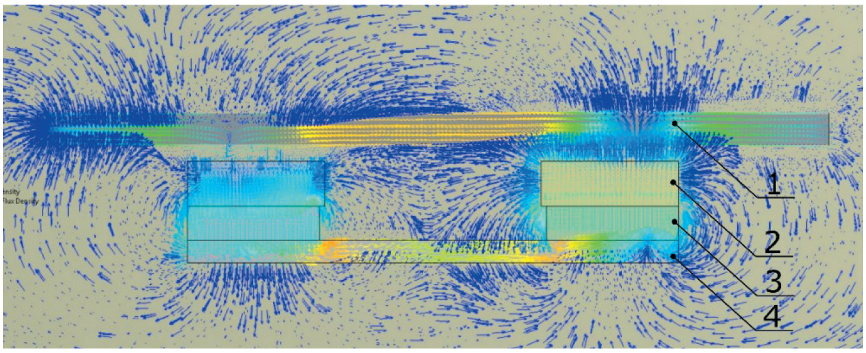

Fig. 1. Magnetic core and magnetic flux density distribution of the head:
1 – tested rope, 2 – pole piece, 3 – permanent magnet, 4 – magnetic jumper

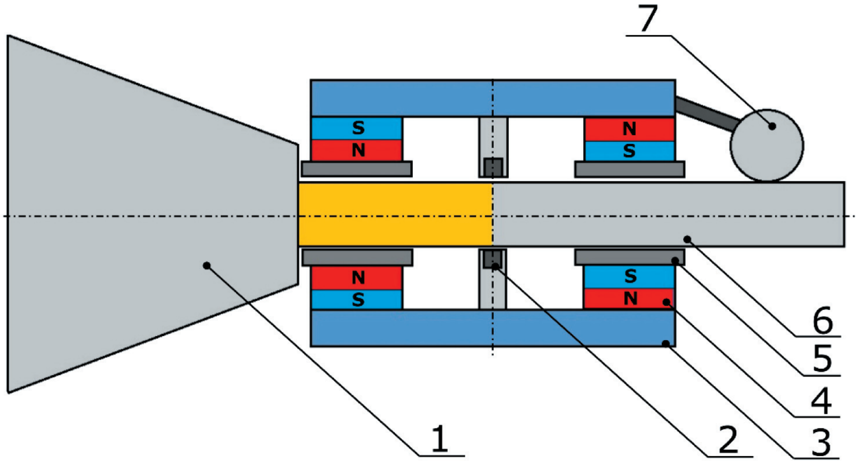

Fig. 2. Schematic diagram magnetic head, the untested area of the rope is marked yellow:
1 – tapered socket, 2 – magnetic sensor, 3 – magnetic jumper, 4 – permanent magnet, 5 – pole piece,
6 – tested rope, 7 – travel sensor

2. MEASUREMENT HEADS FOR LOCAL TESTING OF STEEL ROPES

The creators of the magnetic method, Mieczysław Jeżewski, Ludger Szklarski and Zygmunt Kawecki, were all professors of the AGH University of Krakow. They began their research in 1946 by creating the theoretical foundations of the method and making the first attempts to build measuring equipment. Previously, attempts to detect internal damage to ropes without unravelling them had been conducted in the 1920s in the USA by R. Sanford and in the 1930s by A. Otto and F. Wever, but the measurement results did not match the actual state. The research at AGH began by proving the thesis that damage inside the rope causes changes in the magnetic field. The results of laboratory tests were verified on real objects and, in 1962, the world's first magnetic defectograph for testing ropes, rods and steel pipes was patented. In 1963, the creators patented a new solution for a measuring sensor that allows the determination of the distance of damage from the axis of the tested rope [3]. Over the following years, the magnetic testing method was developed in the scope of its application in testing steel ropes as well as other elements such as conveyor belts with steel cords [4], belts reinforced with steel cords [5], steel-polyurethane load-carrying belts [6], passenger lift guiding systems [7]. The development of the magnetic method in the area of diagnostics of steel ropes in hard-to-reach places has been carried out for many years. The output of this activity has been numerous concepts, some of which were filed as patents or utility models [8–11] and described in publications [12–16]. In most cases, they are based on a solution in which in the area of a stationary magnetic circuit magnetizing the rope longitudinally, the magnetic sensor moves circumferentially or longitudinally in relation to the tested hard-to-reach part of the rope. Selected examples of such solutions are presented below. The first example of such equipment is the magnetic head shown in Figure 3. According to the patent description [8], it consists of pole pieces placed both on the rope and its end, permanent magnets placed directly on the pole pieces, and magnetic jumper closing the magnetic circuit. The invention [9] shown in Figure 3 allows for diagnostics of a selected cross-section of the rope (12) in any of its fragments, including at their ends, for example at the tapered socket. The device consists of a two-part body, which is the place of attachment of the magnetic circuit elements: pole pieces (7), permanent magnets (4), shaped inserts adapted to the diameter of the rope (7) and the tapered socket (13) and the magnetic jumper (6). The magnetic circuit is closed by the tested rope and magnetizes the rope along its length. The sensor (12) moves circumferentially using the drive unit (8). The movement of the measuring sensor system and its drive is also possible between the pole pieces (12), which allows for testing another cross-section of the rope [9].

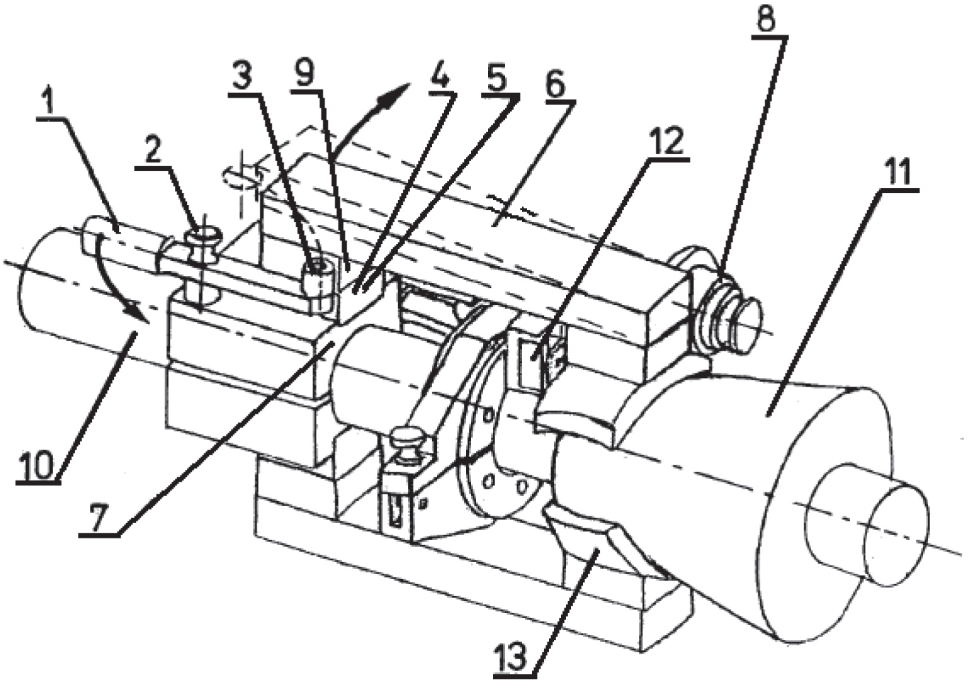

Fig. 3. Device for local testing of steel ropes [9]

Another concept, according to the utility model [10], assumes that the device (Fig. 4) is composed of appropriately polarized magnetizing units placed on the rope (A) and the tapered socket (B). The magnetizing units are composed of permanent magnets (6) and pole pieces (3, 7) whose shape and dimensions are adapted to the elements on which they are mounted. The pole piece is mounted on the rope using an insert (4), while pole piece 7 is made of a deformable material. Unlike the solution [8], the magnetic circuit does not have a jumper and the magnetizing units are mounted on the rope and its end thanks to the force of attraction of the magnets. This circuit is independent of the sensor system and is placed on the rope and its end in a stationary manner. The registration of the magnetic field around the rope, which is magnetized longitudinally, is carried out using the sensor unit. The system is located between the magnets and has the possibility of adjusting the sensor distance both along the rope axis and the distance from the rope. The measurement is carried out by moving the sensor around the rope [10].

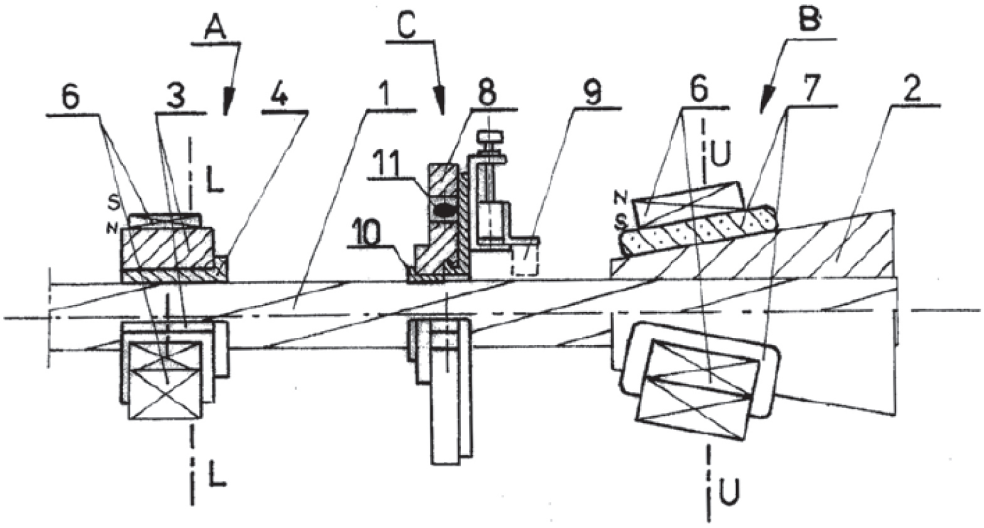

Fig. 4. Set for magnetic testing of steel ropes around the tapered socket [10]

Another solution (Fig. 5) consists of a two-part clamp (1) on which a mechanism is installed that allows the changing of the position of the magnetic circuit along and around the tested rope. As in the previously described solutions, the magnetic circuit magnetizes the tested steel rope longitudinally and consists of at least one magnet (12), a jumper (11) and pole pieces (13, 14), between which a measuring sensor (15) is located. The measurement is performed in a magnetic circuit with constant parameters, with a constant position of the measuring sensor relative to the pole pieces. The measurement signal is recorded as both a function of length and central angle, which allows a spatial image of the damage distribution to be obtained [11].

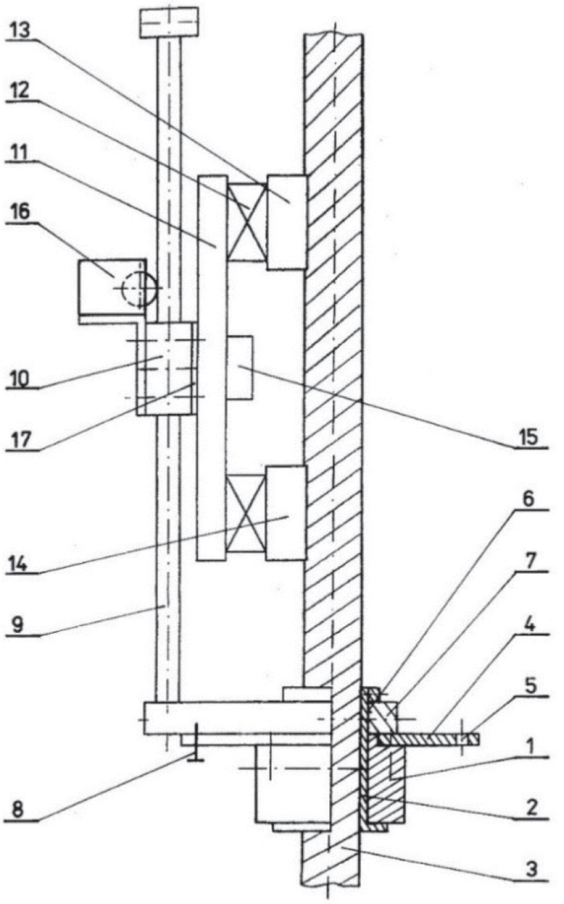

Fig. 5. Machine for testing stationary steel ropes over short lengths [11]

Analysis of the structure of solutions [8–11] and results described in publications [12–17] showed that in laboratory conditions it is possible to use the magnetic method for testing steel ropes in places with difficult access and at their ends. However, the discussed solutions are not free from operational and metrological imperfections. High cohesive forces from permanent magnets are a significant obstacle to the assembly and disassembly of the magnetic circuit. In places with limited access, the assembly and movement of the discussed devices, with large dimensions of the magnetic circuit, may lead to difficulties or even the impossibility of their use. In turn, the use of a system without a jumper, which is characterized by a smaller mass, much simpler structure and method of assembly, requires the use of a larger number of magnets or magnets with higher magnetic energy, which also causes operational problems. The basic metrological problem concerns the asymmetry of the magnetic field distribution in the areas of the rope distant from the source of the magnetic field, in particular in the solution [8, 9]. This is related to the fixed location of the magnetic circuit in relation to which the sensor registering the change in the magnetic leakage field moves. The lack of uniform magnetic field distribution affects the diagnostic properties of the solutions and the measurement accuracy obtained.

This problem has been significantly improved in a system without a magnetic jumper [10], with an increased number of magnets on the circumference of the tested rope. However, this solution is associated with the problem of ensuring a sufficiently high value of magnetic induction enabling the detection of defects in the tendons, thus the value of the useful signal is lower than in the case of traditional heads [12].

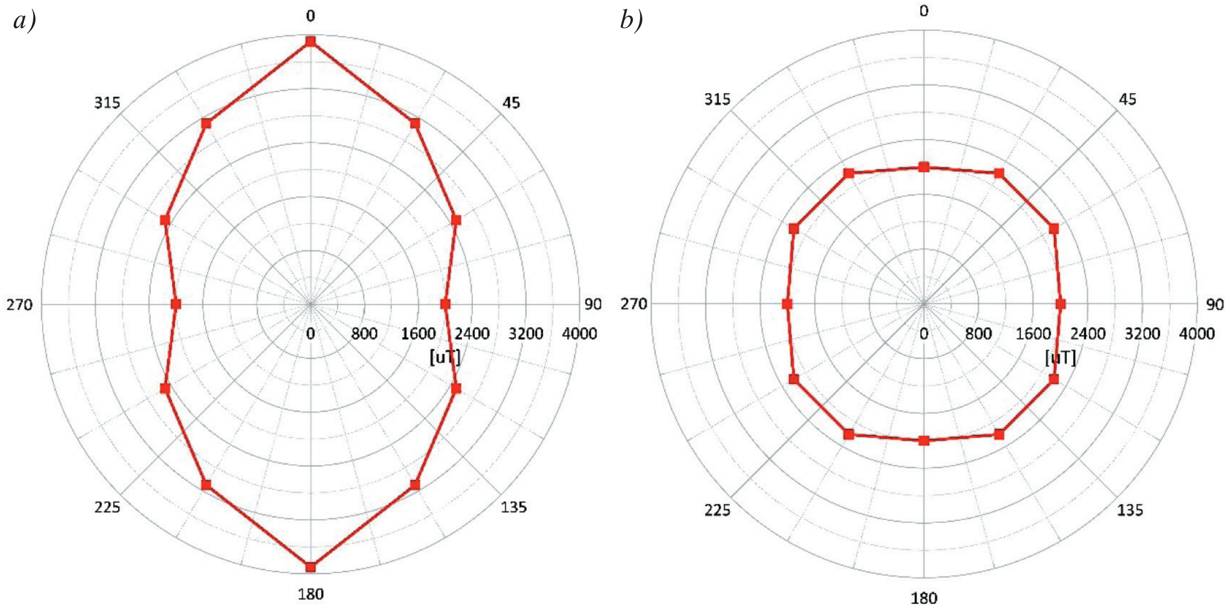

Fig. 6. Distribution of the magnetic field for magnetic heads in the plane normal to the axis of the rope with a diameter of 34 mm at a distance of 20 mm from the frontal plane of tapered socket:
a) a system with a magnetic jumper according to the patent [8];
b) a system without a jumper according to the application [10, 12]

3. DIAGNOSTIC SYSTEM CONCEPT

The analysis of various concepts of systems for magnetic testing of ropes in hard-to-reach places contributed to the establishment of design, functional and metrological assumptions, as a result of which a new concept of a diagnostic system was developed. In contrast to the previously described solutions, it was assumed that the magnetic circuit magnetizing the rope longitudinally or transversely moves with the sensor around the tested rope. This concept is presented in Figure 7. When designing the new solution, the thesis was put forward that the use of such a solution means that in the absence of defects or changes in geometry, the magnetic field in the recording area remains at a similar level because the sensor is located in the same place of the moving magnetic circuit. It moves with the magnetic circuit and not in relation to it. The use of such a solution, in the absence of defects, will allow a symmetrical and uniform distribution of the magnetic field to be obtained. Combining such a design with the analysis of all components of the magnetic distribution of the field will enable the detection of magnetic anomalies resulting from rope damage. Changing the magnetizing system, which is the basic part of the diagnostic equipment, will enable the design assumptions to be met, improve its operational properties, ensure the versatility of the structure and the possibility of using it with different rope diameters and different geometrical limitations of the ends and hard-to-reach places.

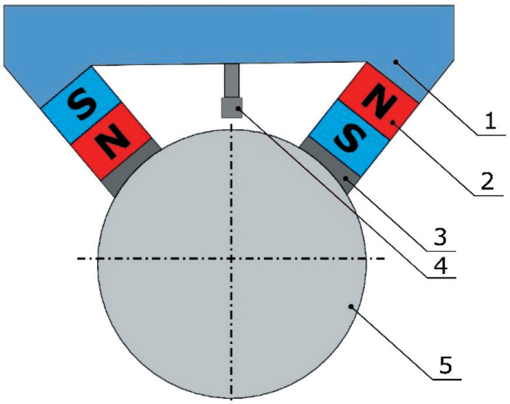

Fig. 7. Schematic diagram of the designed device:
1 – magnetic jumper, 2 – permanent magnet,
3 – pole piece, 4 – magnetic sensor, 5 – tested rope

4. MEASUREMENTS AND THEIR RESULTS

In order to verify the assumptions made, preliminary tests were carried out. Their aim was to confirm the thesis that the proposed measurement system would enable a uniform and symmetrical value of the magnetic field around the tested object to be obtained. In order to minimize the impact of a large number of variables on the obtained results, primarily the geometry of the tested element, and to confirm the thesis regarding the stability of the magnetic field distribution, a maximally simplified model was used in the tests. It was a steel cylinder with a diameter of 35 mm, on the side surface of which a cut was made with a width and depth of approximately 1 mm (Fig. 8).

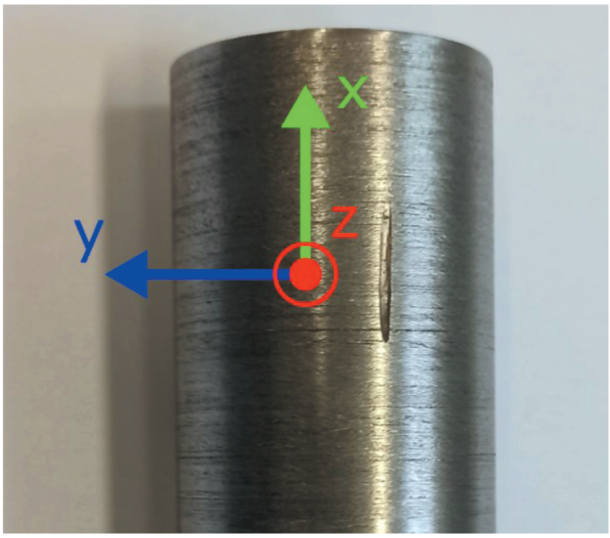

Fig. 8. Modelled damage – cut on the surface

The magnetization system used in the tests was in accordance with the previously described concept (Fig. 7). Ten N42 plate neodymium magnets with dimensions of 25 × 25 × 10 mm were used as the source of the magnetic field, the magnetic circuit consisted of a jumper and pole pieces with a shape adapted to the tested object. The measuring system was built from a part recording the magnetic dispersion field, an 3-axis, digital magnetometer MLX90393 and an Arduino-Mega microcontroller, and a part for recording displacement, which consisted of an Eltra ER30 incremental encoder and an NI USB-6216 measuring card. Signals from both modules were recorded using a program specially developed for this purpose in the LabView environment. The mounting and guiding elements were made of non-magnetic materials, primarily using 3D printing technology.

The measuring sensor, located 1 mm from the surface of the tested element, was mixed circumferentially with the magnetic core. As part of the research, during 4 rotations around the tested surface, 3 components of the magnetic field induction were recorded (Bx, By, Bz – Fig. 8). The recorded results are presented in Figure 9. The visible disturbances of the magnetic field of the three components, appearing cyclically, every 360°, are signals from the cut located on the surface of the tested object.

In order to increase the possibility of identifying the location of damage, the gradient of the recorded signal grad Bx, grad By, grad Bz and the product of these gradients grad Bxyz were determined, the results are presented in Figure 10.

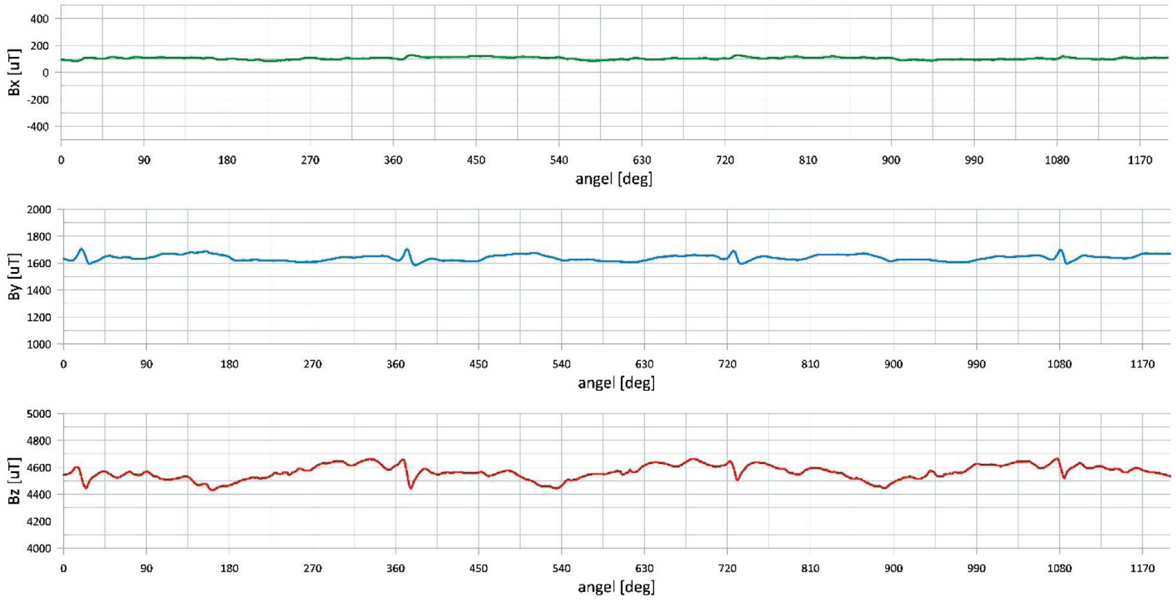

Fig. 9. Recorded values of magnetic field induction, 3 components Bx, By, Bz

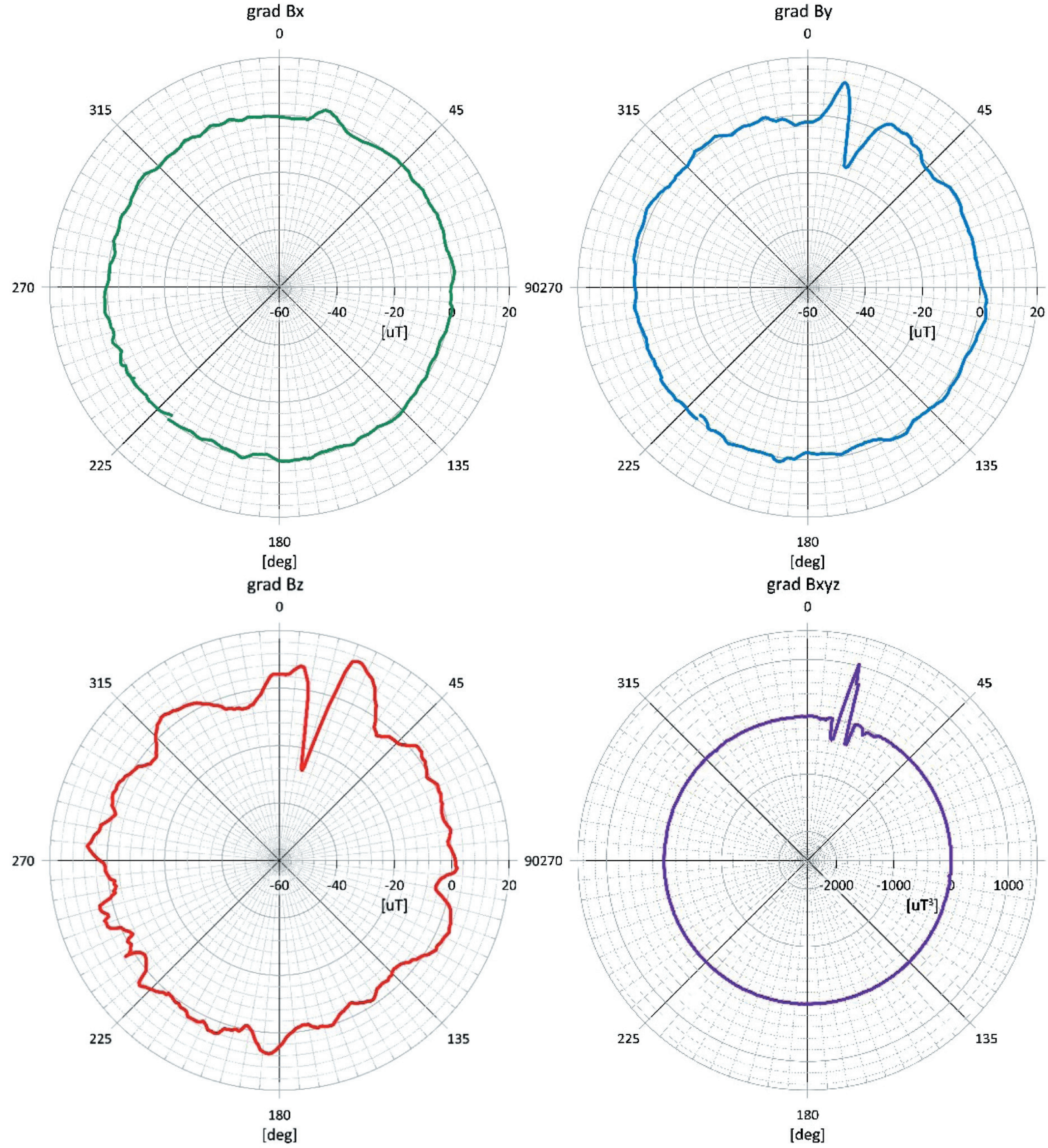

Fig. 10. The gradient of the recorded signal Bx, By, Bz and the product of these gradients, grad Bxyz

5. CONCLUSIONS

The laboratory tests carried out confirmed the thesis. The use of the proposed solution made it possible to obtain a uniform and symmetrical value of the magnetic field around the tested element. A change in the magnetic induction value is visible at the location of the damage. The use of the gradient signal analysis of the recorded magnetic induction values and the product of the gradients of the 3 components allowed for the unambiguous location of the modelled damage. In the laboratory tests carried out, the developed measurement system was characterized by the desired functional properties. Further laboratory tests will be related to metrological aspects, for example optimization of the magnetic circuit by selecting appropriate magnetic sensors and the method of their conduction, the method of signal analysis, and structural and functional aspects resulting from the type of ropes tested. It is also necessary to verify the solutions on a damage model with greater consistency with the real object.

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TOMASZ KRAKOWSKI, Ph.D., Eng.
AGH University of Krakow
al. A. Mickiewicza 30,
30-059 Krakow, Poland,
tomasz.krakowski@agh.edu.pl