

Application of the Magnetic Method in the Diagnostics of Wire Ropes at Tapered Sockets

Abstract: Presently used magnetic methods for testing wire ropes leave an untested rope section located in the direct vicinity of a tapered socket. However, the aforesaid area may contain damage resulting from existing stresses and wear processes. The article discusses results of a study concerned with diagnostic equipment enabling the assessment of the above-named area in terms of its technical condition as well as presents results of the FEM-based numerical analysis of a magnetisation system and laboratory test results concerning a rope containing simulated damage.

Keywords: wire rope, diagnostics, non-destructive testing, magnetic method

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Introduction

The end of the rope in the tapered socket is a permanent and inseparable joint commonly used in shaft hoists, rope slings of hoppits (Fig. 1), slings of hoisting and balance ropes, ends of guy ropes of TV and radio masts (Fig. 2), bridges, halls, hangars and other objects/buildings. If done properly, rope ends enable the transfer of loads comparable with the tensile strength of the rope [17]. The manner of attachment, usually articulated with a one degree of freedom, can result in the formation of a local point of the contraflexure of wires at the taper outlet (where the rope exits the taper) [3].

Because of variable stresses in the rope, fatigue, vibration, varying rigidity and mechanical properties of joined elements as well as the concentration of stresses, the area where the

rope enters the taper is particularly susceptible to damage. For this reason, it is necessary to apply non-destructive testing methods.



Fig. 1. Lifting sling of a hoppit (left)

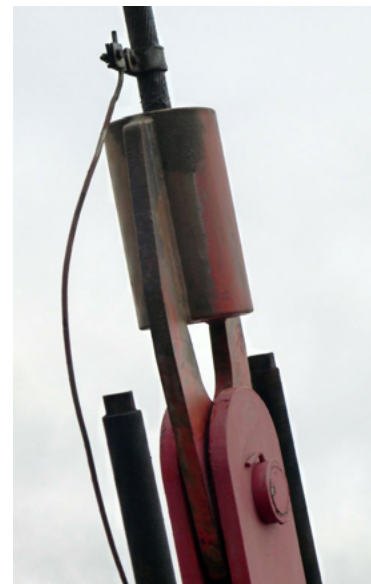


Fig. 2. Ending of the line of the guy of a TV-radio mast (right)

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The primary method presently used for testing wire ropes is the magnetic method (MTR). This method enables the determination of the rope wear degree and the location of damage in the form of abrasion, corrosion or cracked wires across the entire cross-section of the rope. The magnetic method involves the recording of a signal being the function of a change in the radial component of the magnetic field triggered by damage to the rope. The signal is recorded during the movement of the tested rope and that of the probe in the constant magnetic field [4]. One of the primary limitations resulting from the testing methodology and the design of the magnetic circuit and the geometry of measurement probes is the fact that ropes are difficult to test at their end [13]. Research related to the development of diagnostic equipment for testing wire ropes has been conducted at AGH for over 70 years [1]. The year 2000 saw the beginning of research works on diagnostic equipment enabling the testing of rope ends, e.g. at tapers [13]. The works resulted in the development of several diagnostic equipment-related solutions filed as patents [2,11–12] as well as in a number of publications discussing research works along with their results [1,3–7,13,18–19]. During the test, the rope is magnetised using a constant magnetic field generated by permanent magnets, whereas the sensor moves along the rope at the outlet of the tapered socket. A diagnostic signal is a change in the magnetic stray field around the rope.

Simulation tests with the use of numerical methods

The effective development of technical diagnostics methods and measures would not be possible without the use of technologically advanced computer-aided engineering (CAE). Numerical tools using the finite element method (FEM) have long been effectively aiding in strength-related structural works, including, among other things, the development of lifting equipment (e.g. passenger lifts [15–16]) and the

development of magnetic diagnostic equipment such as, e.g. QuickField systems [14] or, currently one of the most advanced, ANSYS [8–10]. Previous experience with the development of magnetic circuits of probes for the testing of ropes and strands was used to carry out an experiment aimed to prove the possibility of performing the effective diagnostics of rope ends in tapers (also constituting the basis of laboratory tests).

The research-related study involved the development of the geometrical (Fig. 3) and material model of the magnetic circuit along with the rope and the taper, the parameters of which corresponded to those of actual elements. The only simplification, resulting from problems connected with the discretisation of the model and limited computing power, was applied by modelling the rope in the form of a rod (cylinder). Using the mathematical-physical tool implemented in the ANSYS system involving the solving of partial differential equations (constitutive equations) based on Maxwellian laws it was possible to determine the distribution of the magnetic field induction in the entire area of the model.

This study discusses the most important area of the model, i.e. the domain of air in the simulated zone in the form of depletion (defect) in the rope. The defect as such was square in cross-section (2 mm x 2 mm) and had a length of 3 mm along the rope (Fig. 3). The aforesaid area was characterised by the formation of strong gradients of the magnetic stray field. The aforesaid gradients resulted from the depletion of the metallic cross-section (Fig. 4). The graphic representation of the distribution and disturbances of the stray field (presented in Figure 4) in the direct vicinity of the defect demonstrated the efficiency of the proposed and developed method enabling the assessment of the technical condition of the above-named structures. The disturbances were read out 1 mm away from the rope, i.e. at the distance enabling the close location of the sensor in cases of actual measurements. The first presentation shows the “ring-shaped”

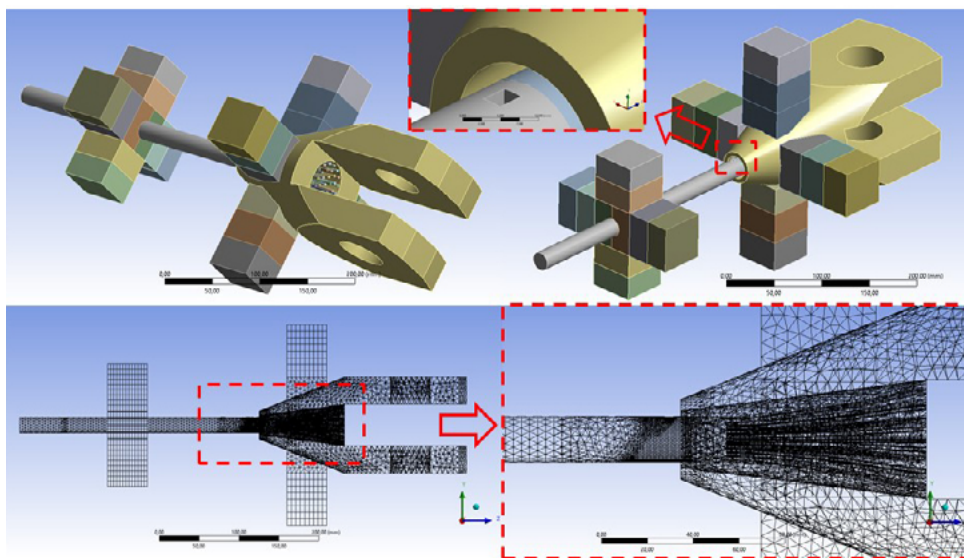


Fig. 3. Geometrical and digitised model of the rope-taper connection along with the magnetising system and the model of the depletion of the metallic cross-section of the rope

distribution of the magnetic field around the rope, which, by analogy, was an equivalent for the signal detected by the sensor moving around the rope at a distance of 1 mm from the rope surface (Fig. 4). The two subsequent presentations contain outline diagrams and the diagrams of the so-called isoline on the cylindrical plane surrounding the rope with an offset of 1 mm (a distance) from the rope (Fig. 4). In each of the above-named cases it is possible to notice clearly

In order to precisely present quantitative data, the “ring-shaped” diagram of the stray field components was expanded and presented in Figure 5. The foregoing was possible because of the collecting of data from 200-point samples from the detection line having the circular trajectory. Because of the applied simplification of the rope in the geometrical model, outside the area of the damage the components of the field were stable and adopted the same values (Fig. 5), which was

not the case with the laboratory measurements involving the strand rope (Fig. 7 and Fig. 8). In the aforesaid case, outside the area of the signal indicating the presence of a defect, also the cross-section of the rope (strand) was simulated. In addition, when analysing the course of the stray field radial component it should be noted that the type of a defect subjected to analysis (i.e. the allowance or the depletion of the metallic cross-section) triggers an increase (Fig. 7 and Fig. 8) or decrease in the measured value (Fig. 5).

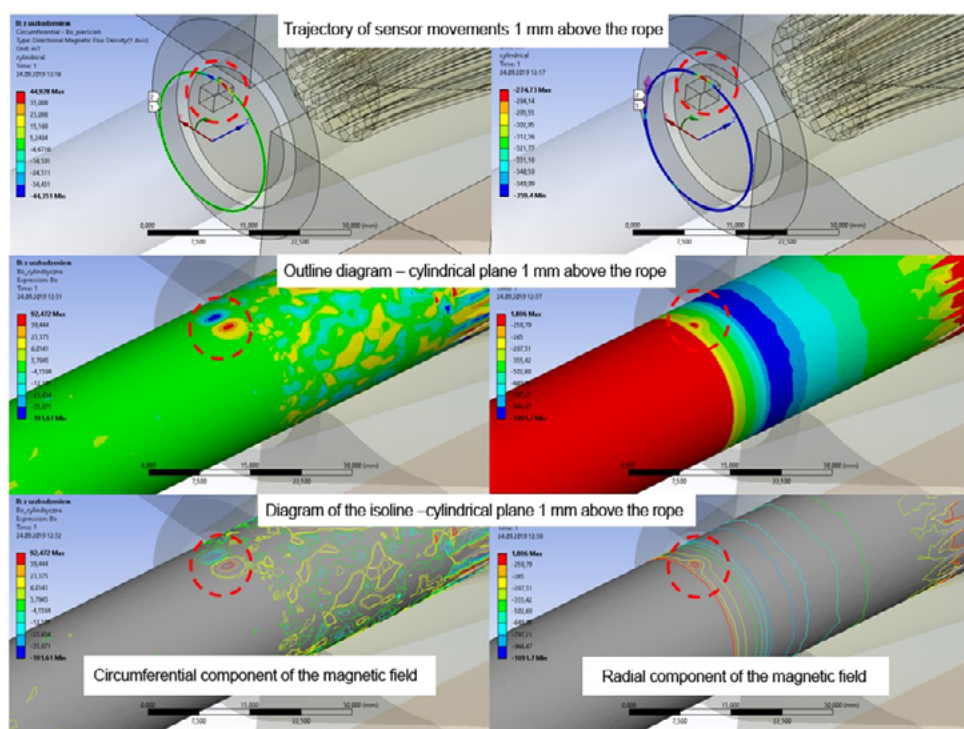


Fig. 4. Disturbances (gradients) in the stray field in the defected area of the rope (graphic results) – circumferential component of the magnetic field (left) and the radial component of the magnetic field (right)

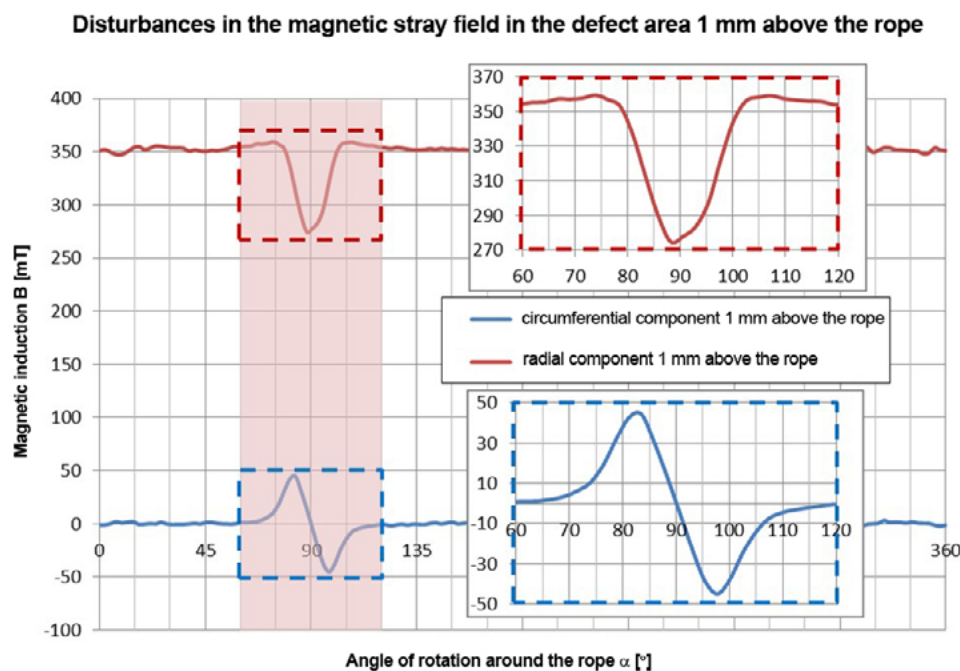


Fig. 5. Disturbances (gradients) in the stray field in the defect area of the rope – numerical results

Laboratory tests with simulated damage

The laboratory tests involved the use of a magnetic circuit composed of magnets placed on the rope and on the tapered socket. The sensor was moved using a laboratory probe for local tests of wire ropes [2] (Fig. 6) modified so that it could be possible to maintain a constant distance between the measurement sensor and the rope along the entire measurement path. The measurement system was composed of an SS49 Honeywell Hall generator and a 3700.1332.0100 Fritz Kubler encoder. Signals were recorded using an NI USB6216 DAQ device and a software programme developed in the LabView environment.

The laboratory tests involving the use of the magnetic method required the simulation of damage in the form of an allowance in the external visible layer of the rope. A wire having a length of approximately 10 mm and a diameter of 1.6 mm and 2.0 mm was placed in the space between strands, approximately 80° from the measurement starting point, in such a manner that it was not located outside the outline of the rope. The diameter of

wires imitating the damage was similar to the diameter of the wires on the external layers of the rope subjected to the test (2.2 mm).

The measurement sensor recording voltage corresponding to the radial component of the magnetic stray field was moved around $\frac{1}{2}$ of the test rope circumference, approximately 5 mm away from the taper butting face. The obtained results are presented in Figures 7 and 8. The movement of the sensor around the test rope was

accompanied by a change in the recorded signal resulting from the rope structure. It was also possible to notice a change in the value of the stray field radial component in the area containing the simulated damage. The absolute value of the difference between the signal recorded in relation to the undamaged rope and the rope containing the simulated damage is presented in Figures 9 and 10. In the area of the damage it was possible to notice a change in the signal, indicating the existence of the damage.

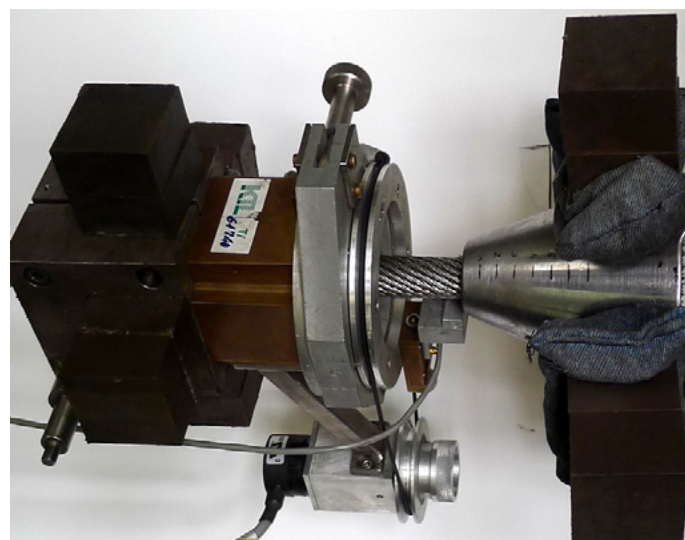


Fig. 6. Laboratory probe for the local testing of wire ropes

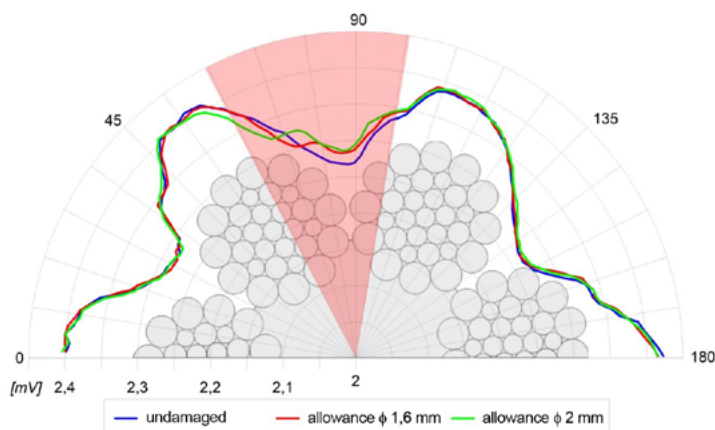


Fig. 7. Voltage signal being the function of the change in the radial component of the stray field around the rope where the rope exited the tapered socket

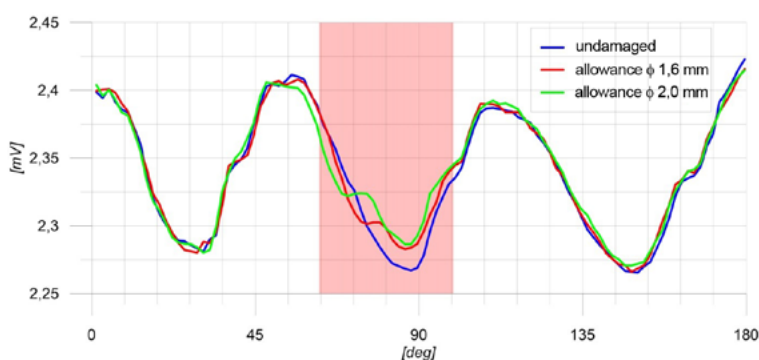


Fig. 8. Voltage signal being the function of the change in the radial component of the stray field around the rope where the rope exited the tapered socket

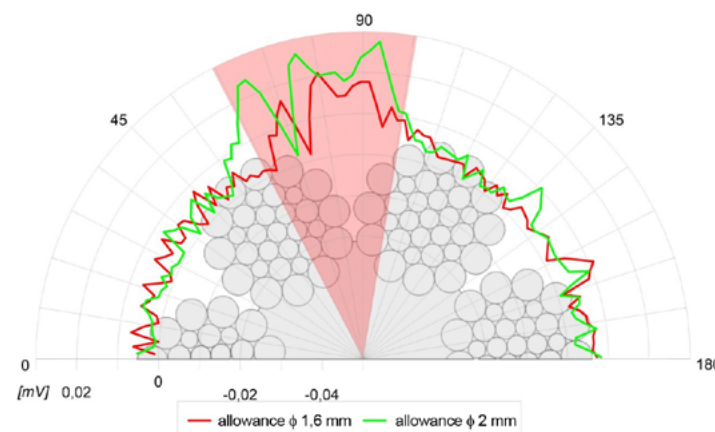


Fig. 9. Difference between the signal related to the undamaged rope and that related to the rope containing simulated damage

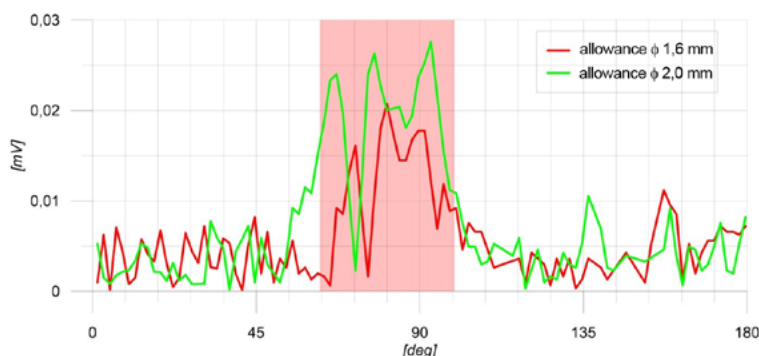


Fig. 10. Difference between the signal related to the undamaged rope and that related to the rope containing simulated damage

Summary and concluding remarks

The above-presented numerical analysis results and the results of the laboratory tests of the rope with simulated damage demonstrated the possibility of the effective application of the magnetic method in the diagnostics of wire ropes at tapered sockets. The measurement system used in the tests made it possible to locate simulated damage. Further research works require the optimisation of the metrological and functional parameters of the developed method and applied equipment. It is necessary to design and make a new system enabling the stable movement of the sensor at a constant distance from a rope subjected to a test. It is also necessary to optimise the magnetisation system. In addition, the verification of the method requires the development of damage simulated in various configuration of the location and size of the defect.

References

- [1] Hansel J.: Polska metodyka badań magnetycznych lin stalowych. Problemy Eksploatacji. Wydawnictwo Naukowe Instytutu Technologii Eksploatacji – Państwowego Instytutu Badawczego, Radom, 2012.
- [2] Hansel J., Kwaśniewski J., Lankosz L.: Urządzenie do miejscowego badania lin stalowych, nr prawa wyłącznego 201156 z mocą dnia 28.12.2001 r.
- [3] Kowalski J., Kwaśniewski J., Lankosz L., Machula T., Molski Sz., Tytko A.: Zastosowanie stałego pola magnetycznego w aparaturze do badania lin stalowych i w innych przyrządach pomiarowych. Zeszyty Naukowo Techniczne Katedry Transportu Linowego AGH, 2006, nr 36.
- [4] Kwaśniewski J.: Badania magnetyczne lin stalowych. Wydawnictwo

- AGH, Kraków, 2010.
- [5] Kwaśniewski J., Ruta H.: Evolution of equipment for testing of wire ropes in the tapered end sections. *The International Journal of Transport & Logistics*, 2010, no. 7, pp. 8–16.
- [6] Kwaśniewski J., Krakowski T., Ruta H., Molski Sz., Pypno M., Ratuszny K.: Qualitative assessment of the working condition of ropes in rope attachments. *Applied Mechanics and Materials*, 2014, vol. 683, pp. 45–49.
<https://www.scientific.net/AMM.683.45>
- [7] Kwaśniewski J., Ruta H.: Wykorzystanie analiz numerycznych przy projektowaniu urządzenia do badania lin stalowych w miejscach ich zamocowań. *Biuletyn Wojskowej Akademii Technicznej*, 2010, vol. 59, no. 4, pp. 147–157.
- [8] Kwaśniewski J., Ruta H.: The design of magnetic circuits taking into account measuring application. *Przegląd Elektrotechniczny*, 2011, no. 9a, pp. 60–64.
- [9] Kwaśniewski J., Molski Sz., Ruta H., Krakowski T.: Analiza właściwości metrologicznych urządzeń diagnostycznych w aspekcie bezpieczeństwa eksploatacji taśm przenośnikowych z linkami stalowymi. [W:] Klich A., Kozieł A.: *Transport szynowy monografia: praca zbiorowa*. Instytut Techniki Górniczej KOMAG, Gliwice, 2015.
- [10] Kwaśniewski J., Ruta H.: Multicriterial optimisation of diagnostic equipment using CAE software. *Czasopismo Techniczne. Mechanika*, 2010, vol. 107, s. 2-M, pp. 157–165.
- [11] Kwaśniewski J., Lankosz L., Molski Sz., Franczyk J.: *Urządzenie do miejscowego badania lin stalowych*, nr prawa wyłącznego 209211 z mocą dnia 10.01.2005 r.
- [12] Kwaśniewski J., Ruta H.: Zestaw do magnetycznego badania lin stalowych w strefie uchwytu stożkowego, nr prawa wyłącznego 065600 z mocą dnia 01.06.2009 r.
- [13] Lankosz L.: Badanie lin w miejscach ich zakończeń przy stożkach. *Zeszyty Naukowo Techniczne Katedry Transportu Linowego AGH*, 2006, no. 36.
- [14] Lankosz L.: Magnetyczna metoda badania lin w miejscach ich zakończeń przy stożkach. *Zeszyty Naukowo Techniczne Katedry Transportu Linowego AGH*, 2007, no. 41, pp. 59–65.
- [15] Lonkwic P.: Construction Optimisation of the Lift Carrying Frame Suspension by Using a Numerical Fatigue Analysis. *Advances In Science And Technology-Research Journal*, 2019, vol. 13, no. 1, pp. 29–36.
<http://www.astrj.com/Construction-optimisation-of-the-lift-carrying-frame-suspension-by-using-r-na-numerical,100630,0,2.html>
- [16] Lonkwic P.: Optimisation of the Lift Carrying Frame Construction by Using Finite Element Method. *Advances In Science And Technology-Research Journal*, 2018, vol. 12, no. 4, pp. 207–215.
<http://www.astrj.com/Optimisation-of-the-lift-carrying-frame-construction-by-using-Finite-Element-Method,100499,0,2.html>
- [17] Tytko A.: *Eksploatacja lin stalowych*. Wydawnictwo Śląsk, Katowice, Warszawa, 2003.
- [18] Tytko A., Kwaśniewski J., Lankosz L., Koszyk M.: Potentials of magnetic testing of hoisting ropes at the fixing points. *Zeszyty Naukowo-Techniczne Katedry Transportu Linowego AGH*, 2003, no. 31, pp. 88–102.
- [19] Tytko A., Koszyk M.: Non-destructive testing of guy rope ends. *Zeszyty Naukowo-Techniczne Katedry Transportu Linowego AGH*, 2002, no. 29, pp. 59–65.