ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1986

Seria: GÓRNICTWO z. 144 Nr kol. 884

1st International Conference - Reliability and Durability of Machines and Machinery Systems in Mining
1986 JUNE 16-18 SZCZYRK, POLAND

Roman MARTYNA
Pedagogical Highshool
Kraków, Poland

THE DETERMINATION OF THE WEAKENING OF MINE WINDING ROPES CAUSED BY THE LONG, SOFT CHANGES OF THEIR CROSS SECTIONAL AREA

Summary. The divect current magnetic method of testing wire ropes widely used in Poland and in the werld, permits detecting and measuring rope defects which disclose themselves as an abrupt change of the rope cross sectional area and especially for detecting broken wires. In cases of accumulation of broken wires, abrasion, advanced corrosion or missing of wires in the rope the determination of the weakening of the rope by means of the induction sensors used with the magnetic method is difficult and sometimes almost impossible. A new original sensors for magnetic defectographs were developed which can measure the above mentioned defects. This paper presents the elements of theory of sensors for long, soft changes of the cross sectional area of rope the methodology for the determination of the weakening of the rope tested by these sensors. The following conclusion can be drawn from the paper: the long changes of the rope cross sections can be measured by the static, magnetic field method, the hall effect - induction sensor and the hybrid sensor can cover the detection and measurement of all essential defects of ropes, the measuring results of the long defects do not depend on the speed and direction of testing.

1. INTRODUCTION

The d.c. magnetic method of testing wire ropes widely used in Poland and in the world, permits detecting and measuring rope defects which disclose themselves as an abrupt change of the rope cross sectional area and especially for detecting broken wires.

In cases of accumulation of broken wires, abrasion, advanced corrosion or missing of wires in the rope the determination of the weakening of the rope by means of the induction sensors used with the magnetic method is difficult and sometimes almost impossible.

A new original sensors for magnetic defectographs were developed which can measure the above mentioned defects.

This paper presents the elements of theory of sensors for long, soft changes of the cross sectional area of rope and the methodology for the determination of the weakening of the rope tested by these sensors.

2. INDUCTION SENSORS

Induction sensors used generally, (fig. 1) measure the defects of an abrupt change of the cross sectional area of rope, because the signal from the sensor (1) is the derivative of the magnetic flux with respect to time t.

$$e = \pm \frac{d\phi_u}{dt} \tag{1}$$

While testing long changes of the cross section the sensor presented in fig. 1 gives signals at the beginning and at the end of that defect but it does not give any information about the change of the cross section of the rope tested.

Similarily the induction convertors of the hybrid sensor (2) presented in fig. 3 do not measure the changes of the cross sectional area of the rope at that type of defects either.

There are also other kinds of induction sensors e.g. the coils without ferromagnetic concentrating rings, but all of them together with those mentioned above are burdened with the following common shortcomings:

- inability of measuring the long, soft defects
- dependence of the signal amplitude on the testing speed
- dependence of the pulse polarization on the testing direction.

The sensors with the flux to voltage convertors have no such deficiencies.

3. SENSORS WITH HALL EFFECT CONVERTORS

The sensors constructed according to (3), diagrammatically presented in fig. 5 can measure the long changes of the rope cross section.

A similar signal can be obtained from the hall effect convertor (3) of the hybrid sensor, fig. 3, as well as from a hall effect induction sensor (4) (fig. 7).

Those sensors besides measuring the long changes of the cross section, can measure local defects what is shown in fig. 8.

The amplitude of the pulses coming from those sensors does not depend on the testing speed (3) and the polarization is also independent from the testing direction, fig. 9.

The other group of sensors measuring the long changes of the cross sectional area the rope using the magnetic method are the sensors which measure the magnetic flux (5) entering the rope.

The sensors mentioned above do not give any information about the local changes of the rope cross section and can be used only for measuring corrosion, missing wires, splices etc. i.e. long changes of the cross sectional area of the rope.

4. PHYSICAL AND MATHEMATICAL PRINCIPLES OF OPERATION OF THE HALL EFFECT SENSORS

A rope section under testing placed inside the magnetic head is magnetized by the static magnetic field produced by the permanent magnets mounted in the head (the electromagnets are used nowadays sporadically). Although there are various magnetic systems of the heads the only aim of all of them is to secure a magnetic flux ϕ_L in the rope giving the induction B_L above the inflexion point of the characteristic $B = f(H)$; where H is the intensity of the magnetic field in the rope tested.

To analyse the processes inside the rope the magnetic circuit of the head can be reduced to that shown in fig. 12.

For the magnetic circuit presented in fig. 12 we can write

$$U_\mu - 2(\phi_L R_{\mu op}) - \phi_L R_{\mu L} = 0 \tag{2}$$

hence

$$\phi_L = \frac{U_\mu}{2R_{\mu op} + R_{\mu L}} \tag{3}$$

where:

U_μ is the magnetic tension of the head,

$R_{\mu op}$ is the reluctance of the air gap between pole shoes and the rope,

$R_{\mu L}$ is the reluctance of the rope.

Substituting the proper expressions for $R_{\mu op}$ and $R_{\mu L}$ we obtain the induction in the rope

$$B_L = \frac{U_\mu}{\frac{F}{\pi \mu_o l} \ln \frac{D}{d} + \frac{b}{\mu_L}} \tag{4}$$

where:

π, μ_o, l are constants,

D - is diameter of pole shoes,

d - diameter of rope,

b - length of rope section inside the head,

μ_L - permeability of rope.

The decisive influence (6) on the value of magnetic induction in the rope has first term in the denominator. Because of this we can determine the relation between the induction in the rope and its diameter if we assume the value both of the magnetic tension in the head and the permeability of the rope. This assumption can be made without committing great error.

From the relation shown in fig. 13 it can be seen, that the induction in the rope, for the diameters (0,4 to 0,75). D is constant. For the diameters smaller than 0,4D an increase of the induction in the rope limits the reduction of the permeability of the rope and thus it hinders the increase of the reluctance of the rope. It is similar for the diameters greater that 0,7D where the increase of induction is limited by the inner reluctance of the head.

The measuring results obtained by means of a properly designed head prove the theoretical analysis. We can say then, that there is a conversion constant of the head and this in turn makes the generalization of the calibration relations possible.

In case of testing ropes with the defects shown in fig. 14 (an abrupt change pf the cross section 1, which turns into the long change of the cross section) the change of the cross section is not accompanied by the change of its diameter.

At the place of an abrupt change of the cross section of the rope there is a disturbance of the magnetic field, whose course and value are described in paper (7) by the following formulae:

$$B_N = \frac{B_L}{4\pi} f_u \frac{R - \rho \cos \xi}{(R^2 - 2R\rho\cos\xi + \rho^2 + x^2)^{1,5}} \tag{5}$$

$$B_t = \frac{B_L}{4\pi} f_u \frac{x}{(R^2 - 2R\rho\cos\xi + \rho^2 + x^2)^{1,5}} \tag{6}$$

where:

B_N, B_t - normal and tangent components of stray field

f_u - cross sectional area of defect

B_L - induction in rope

R - radius of sensor

ρ - distance of defect from rope axis

x - distance of tangent plane to sensor from defect

γ - angle on the tangent plane to the sensor.

The formulae (5) and (6) furnish the description of operation of both the induction and hall effect sensors at measuring the arbitrarily with respect to the rope axis placed defects like an abrupt change of the cross section or a broken wire - will not be here analysed.

The change of induction in the rope from B_{L1} to B_{L2} caused by the change of the rope cross section from F_{L1} to F_{L2} is used for measuring the long change of the cross section of the rope.
The increment of magnetic tension between the concentrating rings of the sensor when the cross section of the rope is changed by f_u, is given by the formula:

$$\Delta U_\mu = - c_1 B_{L1} \frac{f_u}{F_L - f_u} \tag{7}$$

As f_u is very small in comparison to F_L it can be neglected and the formula (7) will take the following form

$$\Delta U_\mu = - \frac{c_1 B_{L1}}{F_L} f_u \tag{8}$$

The hall effect sensor placed in the gap of the magnet keeper converts directly the magnetic flux altered by the drop of the magnetic tension ΔU_μ into electrical voltage.
It is seen from the formula (8) and it also follows from the properties of the hall effect sensor, that the voltage amplitude of the hall effect sensor depends on the change of the cross section and on the constant of conversion k_H.

$$U = k_H \cdot f \tag{9}$$

The relation (9) contains some simplifications, but nevertheless the laboratory verification of that method proves the practical independence of the signal amplitude from the testing speed and also from the off the rope axis positioning of the defect (8).

For the assessment of the long defects of the mine winding ropes one can use the constant of conversion given for each sensor, or can make a comparison with the signal obtained from a test wire.

5. EXAMPLES OF MEASURING LONG CHANGES OF THE CROSS SECTION OF MINE WINDING ROPES

By the examples of measuring the long changes of the cross section of mine ropes presented in figures 15 to 17 one can assess the progress in magnetic defectoscopy of the static field.

6. CONCLUSIONS

1. The long changes of the rope cross sections can be measured by the static, magnetic field method.
2. The hall effect - induction sensor and the hybrid sensor can cover the detection and measurement of all essential defects of ropes.
3. The measuring results of the long defects do not depend on the speed and direction of testing.

REFERENCES

[1] Kawecki Z., Krawczyk E., Ogorzałek J.: Cewka pomiarowa defektografu magnetycznego. Patent PRL 48043."Measuring coil of the magnetic defectograph".

[2] Martyna R., Hansel J., Kwaśniewski J., Świder W.: Czujnik hybrydowy defektografu magnetycznego. Zgłoszenie Patentowe P-242515 "Hybrid sensor for magnetic defectograph" Patent Application.

[3] Stachurski J., Martyna R.: Czujnik defektografu magnetycznego. Patent PRL 114516. "Sensor for magnetic defectograph".

[4] Stachurski J., Martyna R., Kwaśniewski J.: Czujnik defektografu magnetycznego. Zgłoszenie Patentowe P-229608. "Sensor for magnetic defectograph. Patent Application.

[5] Martyna R.: Czujnik długich zmian przekroju liny. Zgłoszenie patentowe P-252268. "Sensor for long changes of rope cross section". Patent application.

[6] Martyna R.: Wyznaczania osłabienia lin metodą magnetyczną z zastosowaniem defektoskopu cyfrowego. Praca doktorska AGH, Kraków 1980. "Determination of the weakening of ropes by magnetic method by means of a digital defectoscope" Doctor thesis UMM Kraków 1980.

[7] Martyna R.: A mathematical model of the Transformation of a Rope Defect into a Magnetic Stray Field. OIPEEC "How Safe is a Rope", Kraków, Katowice 1981.

[8] Martyna R.: Czujnik hybrydowy magnetycznej głowicy pomiarowej. Prace techniczne III Wyd. Naukowe WSP Kraków (w druku). "Hybrid sensor for magnetic head" (in print).

Recenzent: Prof. zw. dr hab. inż. Jerzy ANTONIAK

Wpłynęło do Redakcji: luty 1986 r.

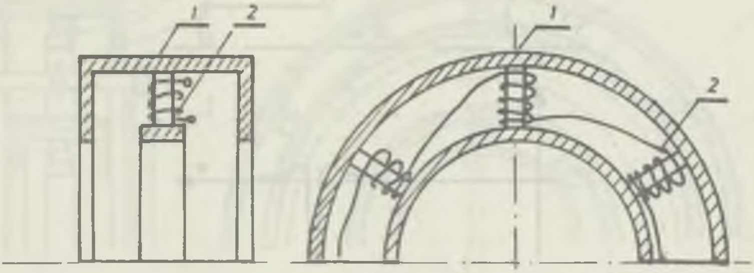

Fig. 1. Induction sensor for magnetic head (1)

Rys. 1. Głowica magnetyczna z czujnikiem indukcyjnym

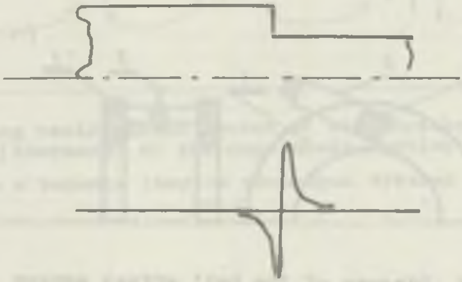

Fig. 2. Induction sensor signals when testing ropes with long changes of their cross sections

Rys. 2. Sygnały czujnika indukcyjnego pochodzące od zmian przekroju badanej liny

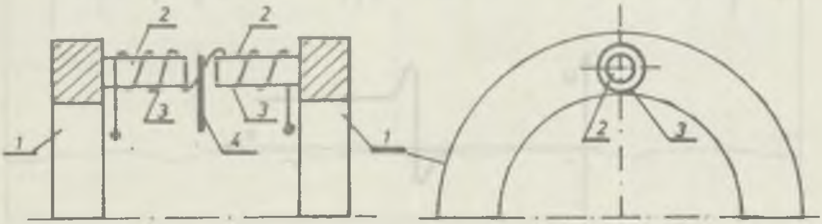

Fig. 3. Hybrid sensor for magnetic head

Rys. 3. Czujnik hybrydowy

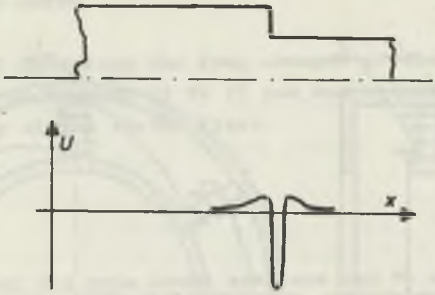

Fig. 4. Induction converter signals of the hybrid sensor when testing ropes with long changes of their cross sections

Rys. 4. Indukcyjne sygnały czujnika hybrydowego pochodzące od zmian przekroju badanej liny

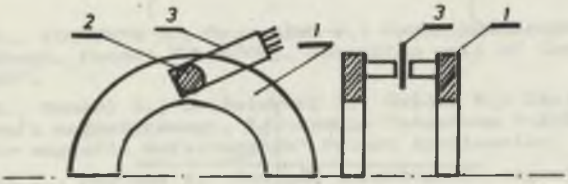

Fig. 5. Diagram of the hall effect sensor

Rys. 5. Wykres czujnika zjawiska Halla

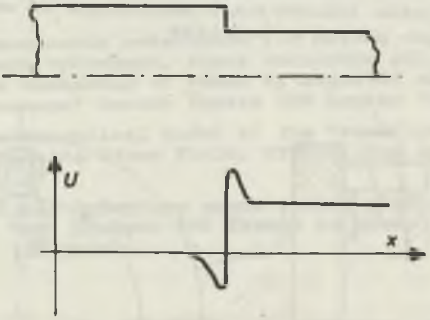

Fig. 6. Hall effect sensor signals when testing ropes with long changes of their cross sections

Rys. 6. Sygnały z czujnika zjawiska Halla pochodzące od zmian przekroju badanej liny

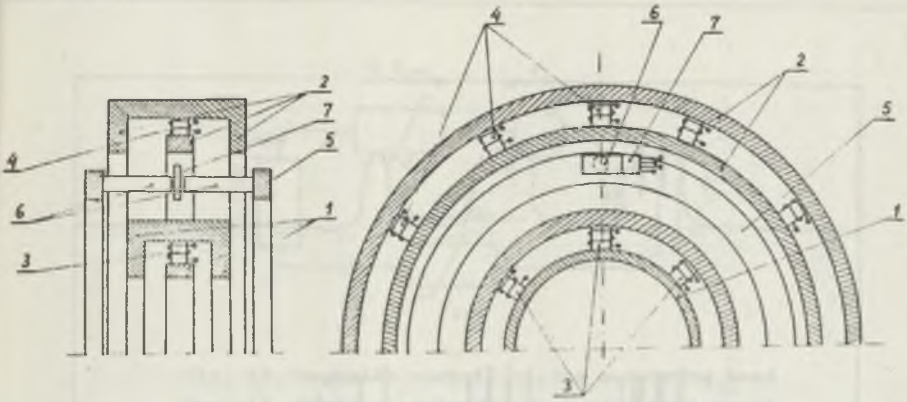

Fig. 7. Hall effect - induction sensor for magnetic head

Rys. 7. Głowica magnetyczna z czujnikiem indukcyjnym zjawiska Halla

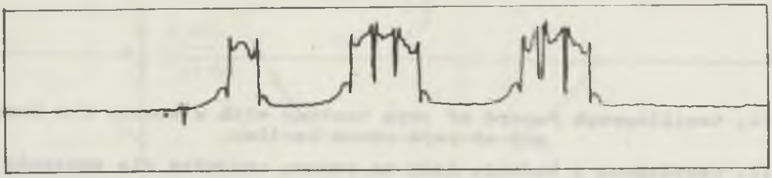

Fig. 8. Rope testing oscillograph record of wire breaks and long changes (increase) of the rope cross section

Rys. 8. Oscylogram z badania liny ze złamanymi drutami i zmianami przekroju

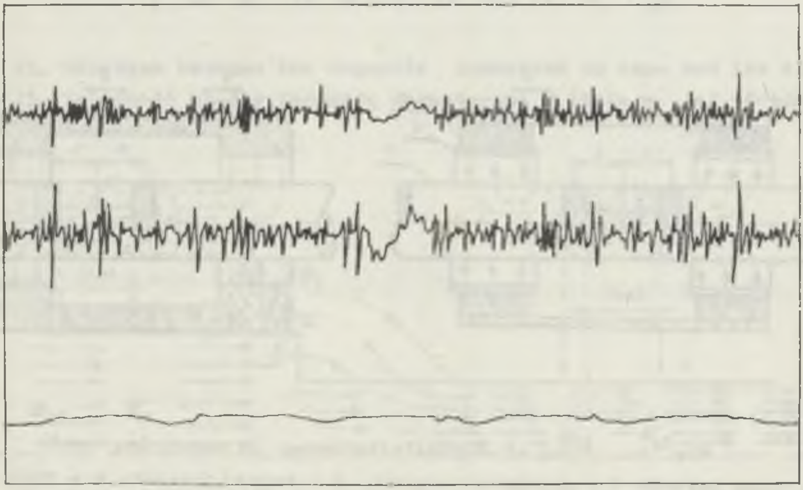

Fig. 9. Rope testing oscillograph record for a rope with wire breaks and changing the testing direction

Rys. 9. Oscylogram z badania liny ze złamanymi drutami i zmiennymi kierunkami badań

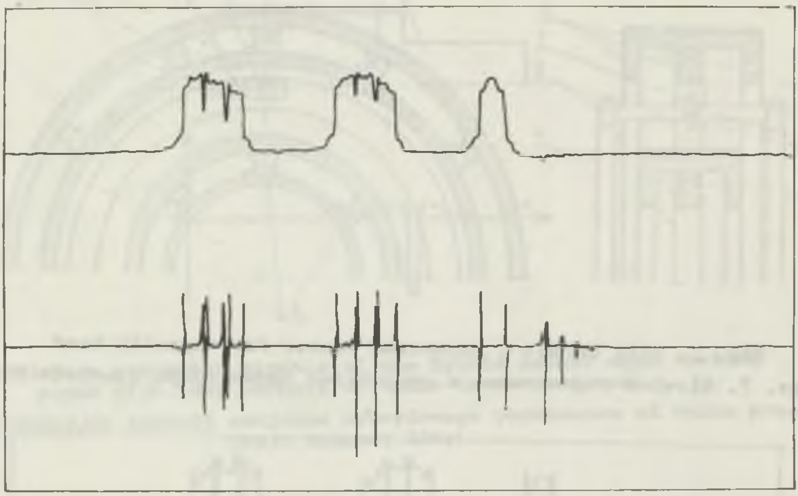

Fig. 10. Oscillograph record of rope testing with a sensor for long changes of rope cross section

Rys. 10. Oscylogram z badania liny za pomocą czujnika dla pomiarów zmian przekroju lin

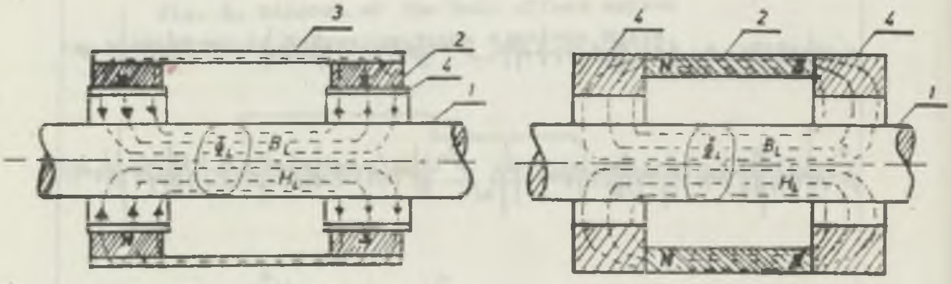

Fig. 11. Ways of magnetizing ropes in measuring heads
1 - rope tested, 2 - permanent magnet, 3 - magnet keeper, 4 - pole shoe

Rys. 11. Sposób magnetyzowania lin w głowicy pomiarowej, gdzie:
1 - badana lina, 2 - magnes stały, 3 - ustalacz magnesów, 4 - ślizgacz

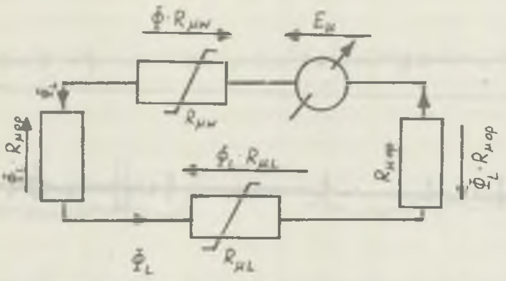

Fig. 12. Magnetic circuit of the measuring head

Rys. 12. Obwód magnetyczny w głowicy pomiarowej

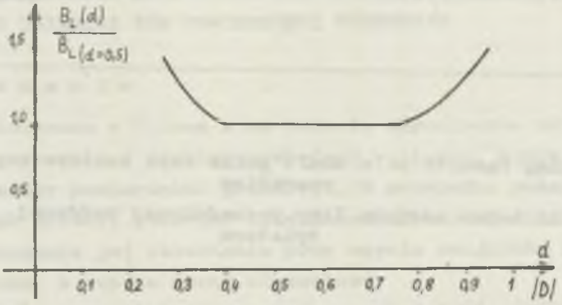

Fig. 13. Relation between the magnetic induction in rope and its diameter

Rys. 13. Zależność między indukcją magnetyczną w linie a jej średnicą

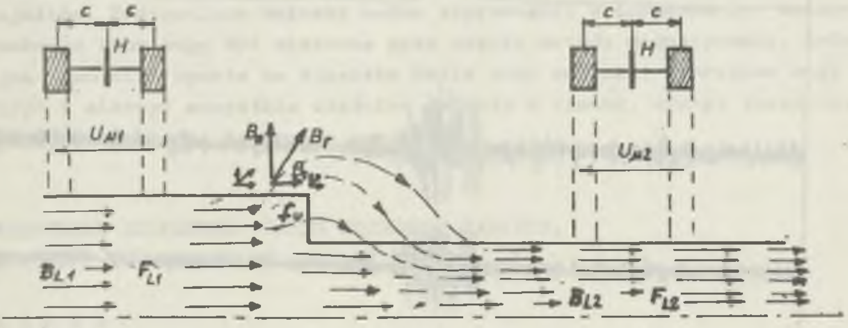

Fig. 14. Testing rope with an abrupt change of its cross section turning into the long one

Rys. 14. Badanie liny z nagłą zmianą przekroju

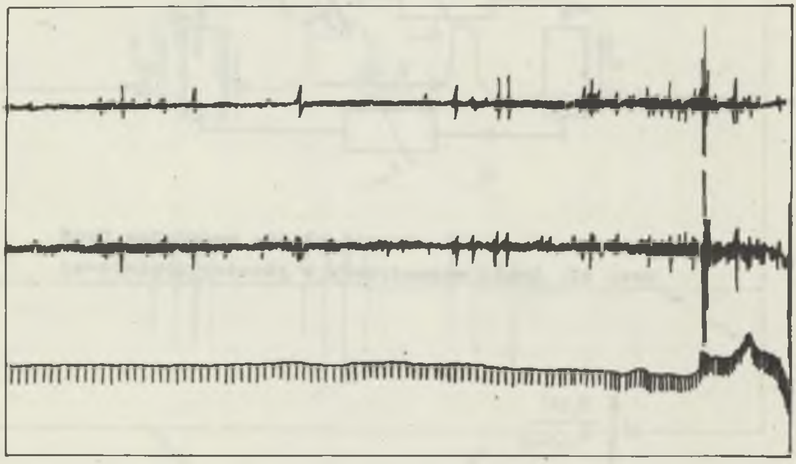

Fig. 15. Testing results of a shaft guide rope section exposed to the fan operation

Rys. 15. Wyniki badań odcinka liny prowadniczej poddanej działaniu wentylatora

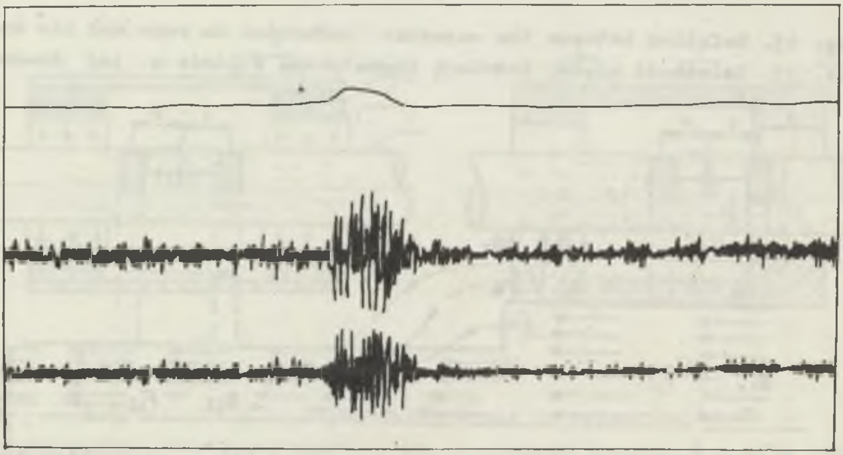

Fig. 16. Testing results of a balance rope loop section

Rys. 16. Wyniki badań odcinka liny wyrównawczej z pętlą

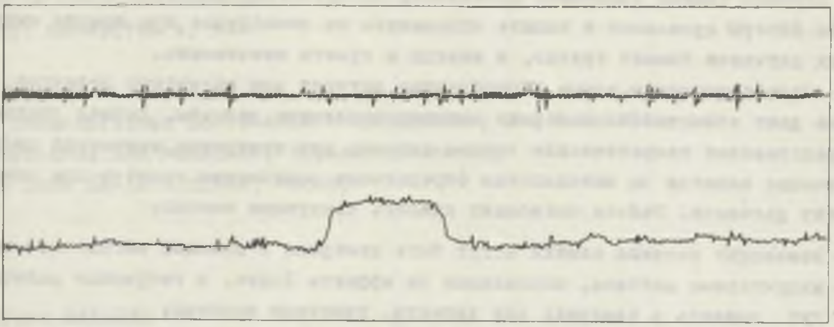

Fig. 17. Testing results of a triangular winding rope with a necking

Rys. 17. Wyniki badań odcinka liny nośnej z przewężeniem

WYZNACZENIE OSŁABIENIA GÓRNICZYCH LIN WYCIĄGOWYCH SPOWODOWANEGO ZMIANAMI ICH POWIERZCHNI PRZEKROJU

Streszczenie

Szeroko stosowane w Polsce i na świecie magnetyczne metody badania lin pozwalają na wykrycie i pomiary uszkodzeń w linach, które ujawniają się jako nagłe zmiany powierzchni przekroju. W przypadku połączonego wystąpienia pękniętych drutów, starcia, zaawansowanej korozji albo ubytku drutów w linie wyznaczenie jej osłabienia przy użyciu czujników indukcyjnych jest utrudnione, a czasem nawet niemożliwe.

Nowe orginalne czujniki dla magnetycznych defektografów zostały skonstruowane, mogą one mierzyć wyżej wspomniane defekty. Artykuł ten prezentuje podstawy teoretyczne czujnika do pomiarów zmian powierzchni przekroju lin i metodologię wyznaczania osłabienia lin przy użyciu tych czujników. Następujące wnioski można wyprowadzić z opracowania: zmiany przekroju liny mogą być mierzone przy użyciu metody magnetycznej, indukcyjne czujniki oparte na zjawisku Halla oraz czujniki hybrydowe mogą wykryć i mierzyć wszystkie właściwe defekty w linach, wyniki testu nie zależą od szybkości i kierunku pomiaru.

ОПРЕДЕЛЕНИЕ ОСЛАБЛЕНИЯ ГОРНЫХ ПОДЪЕМНЫХ КАНАТОВ, ВЫЗВАННОГО ИЗМЕНЕНИЯМИ ИХ ПЛОЩАДИ СЕЧЕНИЯ

Резюме

Широко применяемые в мире и в ПНР магнитные методы исследования канатов позволяют найти и измерить дефекты, которые проявляются в качестве внезапных изменений площади сечения канатов.

В случаях связки лопнувшей проволоки, потертостей, далеко зашедшей коррозии или потери проволоки в канате определить ее ослабление при помощи индуктивных датчиков бывает трудно, а иногда и просто невозможно.

Сконструированы новые своеобразные датчики для магнитных дефектов, которые дают возможность измерять вышеперечисленные дефекты. Данная статья представляет теоретические основы датчика для измерения изменений площади сечения канатов и методологию определения ослабления канатов при помощи этих датчиков. Работа позволяет сделать следующие выводы:

- изменения сечения каната могут быть измерены с помощью магнитного метода;
- индуктивные датчики, основанные на эффекте Холла, и гибридные датчики могут выявить и измерить все дефекты, присущие канатам;
- результаты теста не зависят от скорости и направления измерений.