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Magnetic Testing of Wire Ropes, Theory vs Practice

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Abstract **This paper is presenting an advance NDT (non-destructive testing) method by using MRT (magnetic rope testing) in estimation of the wire rope status regarding safety & risk-free process operations. Throughout many years of development both theoretical & practical solutions have resulted that nowadays some modern NDT configurations offer advanced instruments & procedures enabling end users to rely on results of NDT inspection. Apart of the said regulations & specific standards were developed in order to facilitate practical attempts & decision making i.e. does the particular rope is within acceptable range of capacity or to be rejected. This paper presents R&D and long years practical experience of the advance LRM NDT-NDE technology well known worldwide.**

Keywords— Wire rope, NDT, MRT, LMA, LF

I. Introduction

Wire ropes are the weakest component of rope equipment. During operation, as a result of material fatigue, corrosion and mechanical damage to the rope wires, and other accidental events, wear and tear progresses. The service life of ropes is shorter than that of a rope device. A fundamental problem for NDT testing to ensure the safety of transporting people or materials is determining when to replace a damaged rope with a new one. The safety factor adopted for the rope protects against catastrophic events and minor errors in assessing the condition of ropes. Only non-destructive magnetic testing MRT (Magnetic Rope Testing) combined with visual testing (VT) by an experienced expert gives a chance to correctly assess the state of degradation of the rope. Due to the increasing diameters of ropes used in lifting equipment, and the use of modern multilayer compacted rope designs, the importance of MRT magnetic testing of in-service ropes is increasing, as most wire damage is concentrated in the inner invisible layers of the rope. Visual testing does not provide a chance to see inside the rope, in addition, the coverage of the rope with lubricant, sometimes inaccessibility to the rope, fatigue or momentary inattention of the examiner can lead to overlooking significant rope damage.

Rather often it happens that a rope is in good condition, well-lubricated but may have a short section as in (Fig.1) difficult to access for visual examination and re-lubrication meaning its condition becomes critical.

II. Brief History of MRT Development

Since the 1940s, two magnetic methods of wire rope testing have been mostly developed:

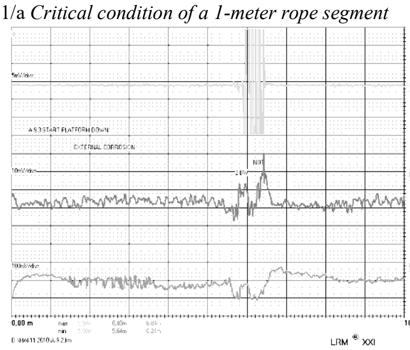
a) The alternating field method in the USSR, Canada, France,
- measurement of the loss of metallic cross section of the rope due to corrosion and abrasion directly in percent;
- relatively lightweight construction;
- the main disadvantage of this method is the inability to detect broken individual wires.

b) The direct field method in Germany, Poland, England.

In the early days of the development of the permanent field magnetic rope testing method, electromagnets powered by a battery bank high capacity were used. Such apparatus was heavy and cumbersome to use, but allowed detection of broken wires and other local defects.

(a)

Fig.1/a *Critical condition of a 1-meter rope segment*



(b)

Fig.1/b *MRT trace of the 1 m rope critical segment*

Professors of AGH Krakow, were creators of the Polish method of testing magnetic wires with a permanent field. It was the first in the world to use permanent magnets in measuring heads, making the measuring heads lightweight and convenient to use. The development of LMA (Loss of Metallic Area) sensors by R.Martyna [1-7] and their implementation in magnetic measuring heads with permanent magnets embedded in one measuring head offered the advantages of both methods (LF & LMA) and practically eliminated the use of alternating field in wire rope testing.

The LRM-NDE laboratory has been developing the theoretical basis, apparatus and technology for MRT wire rope testing for more than fifty years. LRM-NDE's apparatus and technology are used all over the world especially for testing ropes of ski lifts, lifting equipment, mining hoisting, rope bridges, and especially in the marine industry (offshore).

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III. THEORETICAL BASIS OF MRT BY MFL

The MFL (Magnetic Flux Leakage) method of magnetic rope research has been developed for more than fifty years. The creators of the Polish MFL method Professors of AGH M.Jeżewski, L. Szklarski and later Z. Kawecki and J. Stachurski developed the basics of the MFL method described theoretically a special case - a broken wire located in the rope axis. They adopted a "POLAR" physical model for magnetic field scattering over LF (Local Flaw) type faults [8].

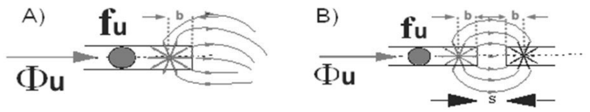

Fig.2, *polar models a) end of wire, b) broken wire*

This "polar" physical model assumes that the ϕr flux emitted from the "pole" misses the wire defect. The adopted "polar" physical model of the magnetic field of scattering does not violate the principle of sourcelessness of the magnetic field, since the magnetic flux scattered from the pole ϕr is equal to the flux entering the damaged wire ϕ_U. The adopted "polar" physical model served to describe well and effectively the distribution of the magnetic field scattered over LF-type faults, i.e., it meets the condition of "model suitability" as verified by verifying the calculation results with physical measurements.

LRM-NDE lab has been developing throughout years the theoretical basis, apparatus and technology of MFL including a mathematical model for an arbitrarily located relative to the rope axis damage [2].

It was assumed that:

1. the currently analyzed defect always lies on the OX axis at the center of the coordinate system.
2. the rope is standing and the measuring head is moving, (when examining ropes, movement is relative).
3. The axis of the rope lies in the xy plane and is displaced parallel to the axis about OX by r (r - eccentricity of the position of the fault).

The adopted assumption that the coordinate system lies in the currently analyzed damage rather than, as adopted by the creators of the Polish MFL method of rope testing on the rope axis allowed effectively solve the problem of calculating the value of the scattered magnetic field entering the sensor LF at any point, for an arbitrarily located with respect to the axis of the fault line.

Assuming, according to assumption 1, that the magnetic pole is located at the center of the coordinate system at any point P distant from the pole by p, the induction vector Br will have the value Br calculated from relation (1).

$$Br = (\phi r)/(4\pi *p2) = (Bl*fu)/(4\pi * p2) \qquad (1)$$

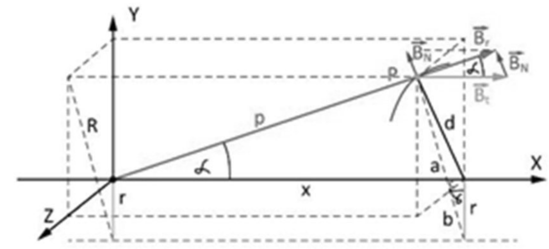

Fig. 3, Induction of scattering flux ϕr at any point P on a sensor p away from the pole

The values of the normal ϕ1NS and tangential ϕ1TS components of the flux ϕr scattered over a single "pole" (end of the wire) entering the sensor at point P were determined by relations (2) and (3).

$$\Phi_{1NS} = \frac{B_l}{2\pi} * f_u * \int_0^{\pi} \frac{\sqrt{(R - r*\cos\gamma)^2 + (r*\sin\gamma)^2}}{\sqrt{(R - r*\cos\gamma)^2 + (r*\sin\gamma)^2 + x^2}^3} \, d\gamma \qquad (2)$$

$$\Phi_{1TS} = \frac{B_l}{2\pi} * f_u * \int_0^{\pi} \frac{x}{\sqrt{(R - r*\cos\gamma)^2 + (r*\sin\gamma)^2 + x^2}^3} \, d\gamma \qquad (3)$$

These relations were also used to describe the scattered magnetic field over the broken wire. The current state of development of the mathematical model for the MFL method makes it possible to analyze the influence of damage and sensor parameters on the result of measurements, and to optimize the parameters of the sensors.

IV. WIRE ROPE TEST RESULTS vs FAILTS & SENSORS

The MRT is mostly indirect inspection method. So, the results of the testing depend on the parameters of the faults and sensors, and on the knowledge & experience of the inspector. The Fig. 4 below shows practical process of MRT including visual inspection of the recorded faults.

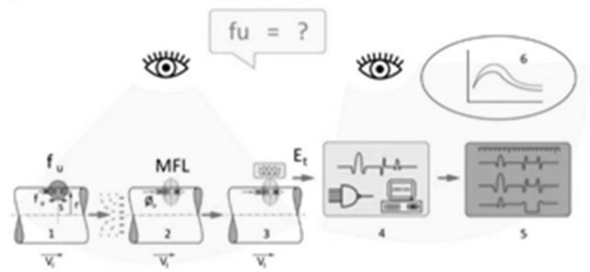

Fig.4, Indirect processing of rope damage values fu

The **fu** damaged rope is magnetized by a constant magnetic field in the measuring head. Sensors convert the scattered MFL magnetic field into **Et** electrical signals. Most of the world's manufacturers of equipment for magnetic testing of wire ropes are satisfied with recording and measuring the amplitude of **Et**. Rope inspectors then obtain an accurate result of inaccurate measurement, since the amplitude of the **Et** pulse depends not only on the cross-sectional area of the damage **fu**, but also on the length of the gap **S** between the ends of the broken wire, but also on the eccentricity **r** of the position of the damage with respect to the rope axis and the density of the damage. Correct interpretation of MRT test results requires experience and knowledge of the influence of factors interfering with the measurement. Examples of sensor pulse waveforms and their dependence on damage parameters are given below (Fig.5).

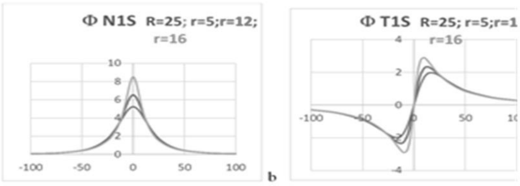

Fig. 5, Signal waveforms as per equations (2) & (3)

The waveforms shown in Fig.6 thru 8. show the results of testing the same damage to the rope: three broken wires only located at different distances.

Relations (2) and (3) allow analysis of the effect of other fault and sensor parameters on the final diagnostic pulse waveform.

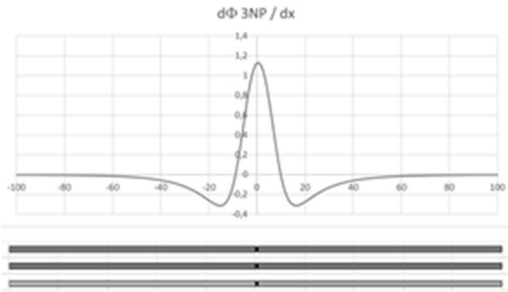

Fig.6, Three broken wires not offset from each other

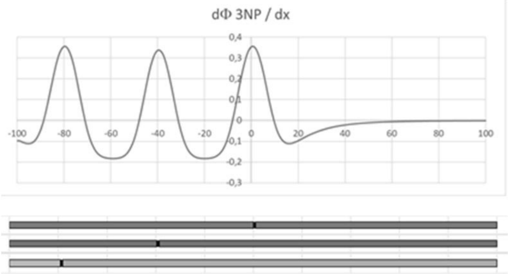

Fig. 7, Three broken wires offset by 40 & 80mm

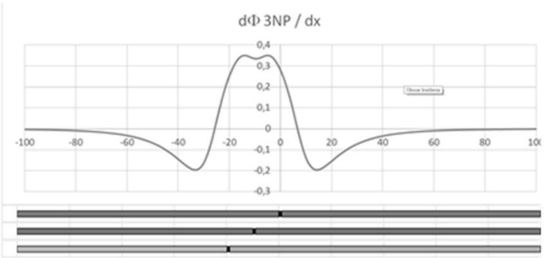

Fig 8, Three broken wires offset by 10 & 20 mm

V. LRM-NDE MRT MAIN FEATURES & PRACTICE

The main property of MRT method is to facilitate inspectors in performing their job with full performance. Applied method, hardware & software should provide reliable NDT by MRT. That means all sensors such as LF (local faults) & LMA (loss of metallic area) & other features of the configuration should provide the said. In the Fig. 9 a typical tracing of signals is shown for an illustration.

The Fig.10 present an in-situ MRT tracing of the rope splice of a ski-lift.

The Figures 11 thru 14 present some practical in-situ MRT inspection of various ropes worldwide.

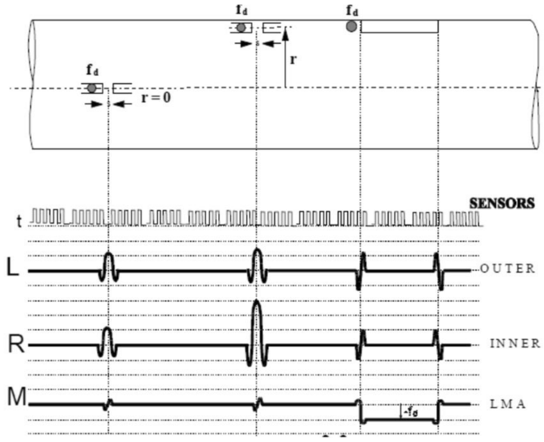

Fig. 9, Sensors typical tracing

Fig.10, In-situ MRT tracing of a rope long splice

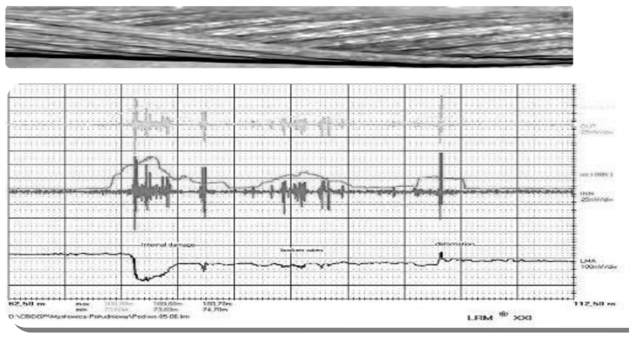

Fig. 11, Rope MRT testing results with heavy corrosion

Fig. 12, In-situ MRT configuration, ski-lift

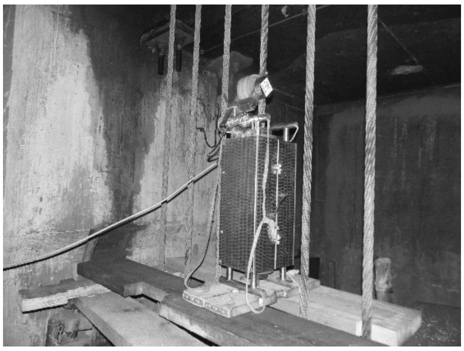

Fig. 13, In-situ MRT of multi-rope mine hoist

Fig. 14, Typical in-situ MRT inspection

One of the most powerful MRT component of the LRM-NDE technology is an advanced software for processing MRT on-line & off-line. Also, the software offers many options such as distant mode & time mode, comparing two traces of the same rope (previous & current MRT), fast review of the entire rope length (sometimes several km) etc.

VI. SUMMARY & CONCLUSION

The rope inspection by implementing NDE-MRT is related to safety issues. That means the responsibility of inspector(s) is rather high. One of the main LRM-NDE lab concerns, among other key issues, is training of potential inspectors. Numerous national regulations have been introduced just to impose limits of criteria for a rope status either to allow use or to be rejected. Several international standards provide guide-lines such as EN 12927, segments 1 thru 8 & others. The previously said indicates that permanent R&D in this particular field of NDT is required what is the primary concern of LRM-NDE laboratory.

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