WHAT CAN BE OBTAINED FROM NDT OF WIRE ROPES?

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Abstract

Large number of ferrous steel wire ropes is in use in different industries, carrying people and freight, supporting bridges and towers, lifting pipes and vessels offshore and onshore, underground and aboveground. The bigger and the longer is the rope, the more expensive it is. Later or sooner ropes deteriorate for different reasons, their further use may be dangerous, and important question arise: whether the rope should be discarded or still may remain in operation. Premature discard and replacement with the new rope involves in unreasonable costs, while operating the rope which already reached discard criteria is dangerous. The sensible answer is discarding in time, i.e. for reason. Reasonable discard is possible based on proper inspection, otherwise technical condition of rope remains unknown. Visual inspection is obvious, but only visual examination is not sufficient due to specific rope design. Nondestructive magnetic inspection of ropes enables to gather comprehensive data for making reasoned decision. Magnetic flux leakage (MFL) equipment with strong magnetization can inspect ropes reliably, and smart software facilitates data interpretation. Reach experience with NDT of ropes spilled over into development of relevant national and international norms and standards.

Ropes and their deterioration

Ropes are widely used for lifting operations – winders, cranes, elevators, cableways, as well as guys for bridges, antennas, chimneys, roofs, etc. Rope integrity effects reliability and safety of installation in which they are in service. Depending on the installation, ropes may have different construction, such as stranded, spiral or full locked, as well as may have rectangular cross-section (flat ropes) and rubber coating. Regardless of the construction, ropes deteriorate during their operation due to similar reasons, e.g. fatigue, corrosion, abrasion, mechanical damage, and overheating. Fatigue in wire rope is normally caused by repetitive bending on sheaves, drums, and causes wire brakes. Broken wires or fractures, allocated on very short distance, are accepted to name as localized flaws (LF). They are one of indicator of rope degradation. When the number of broken wires exceeds affordable limit, the rope must be discarded. Corrosion may occur even in very dry environment, especially on unprotected, non-galvanized wires. Abrasion is very typical for outer wires; however internal wires also may be abraded due to friction, while the rope moves over sheaves. Moreover for some rope constructions deterioration starts internally, and rope which looks good from outside may be dangerous due to high level of deterioration of internal wires. Corrosion and abrasion cause missing some amount of metal from wires. This is called as loss of metallic cross-section area (LMA), and is normally measured as relative amount in percentage to the cross section area of a new rope. According to relevant norms, the rope should be discarded when LMA value reaches limit, established for particular rope construction and application.

Ropes discard policy

The following policies can be considered for discarding wire ropes.

- Discard on timely basis (automatic discard), i.e. after a set period, e.g. 12 months.
- Discard for reason, i.e. when technical condition of rope is bad, and continuing its operation is dangerous.

Using “automatic discard” policy one may be in risk to continue operating rope, which is much deteriorated, and is dangerous. On the other hand discarded rope may have good condition and could be extended in operation. Premature replacement makes unreasonable costs.

Discard for reason means that the rope may be in service until discard criteria not reached. Discard criteria are referred in relevant standards and norms. This approach requires knowledge about rope condition, which can be obtained resulting proper rope inspection.

Wire ropes can be inspected destructively or nondestructively. Destructive inspection can be carried with relatively short section of rope and gives direct reading of rope breaking strength. Results of destructive testing represent rope section which was destroyed, but the question is how to refer these results to the rest length of rope.

How ropes can be inspected nondestructively

Visual testing

Visual testing (VT) enables to reveal outer defects such as corrosion, broken and missing wires if rope surface is accessible for visual examination. VT may be accompanied with haptic testing, use of mirror, magnifying glass, and is carried at low speed. For these reasons VT is tiresome, and requires sufficient time being very subjective. Most wires in the rope may not be visually inspected [1]. Only outer wires are available for examination, but these wires disappear inside the rope on half of their length, and may be covered with heavy grease, that reduces effectiveness of such inspection (Fig. 1). Ropes with protecting coating may not be inspected visually.

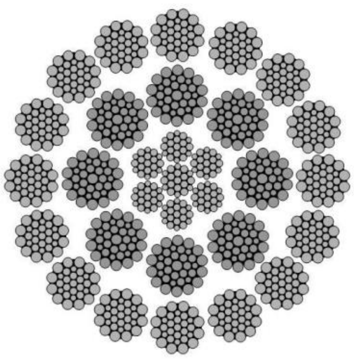

Figure 1. Cross section of multilayer rope (left) and heavy greased crane rope (right).

Note, that low rotation multilayer rope, widely used for lifting operations, start deterioration from inside, however inner broken wires may not be revealed visually. Nevertheless visual inspection in combination with use of magnetic instruments considerably increase reliability of information obtained from tested rope.

MFL rope inspection

Nowadays MFL principle is common for nondestructive testing of wire ropes. MFL instruments can precisely and fast measure LMA to assess level of abrasion and corrosion, and detect outer and inner LFs even under the grease or protecting coating. To obtain high LMA accuracy and LF sensitivity MFL equipment should contain strong magnets to magnetically saturate the rope under test, and inspect the rope at applied magnetic field, i.e. while the rope is magnetically saturated. The operating principle is described at Fig. 2.

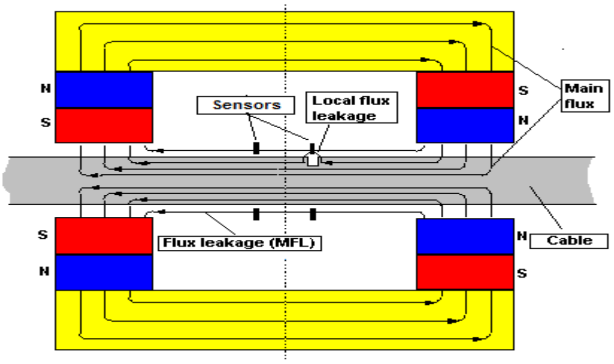

Figure 2. MFL instrument with strong magnetization. Principle of operation.

Magnetic head of the instrument usually comprises magnetizing system with permanent magnets, surrounding the rope under test and producing the magnetic flux along the rope. While rope is passing through the head, the section of rope inside the head is magnetically saturated. Sensors (Hall generators or coils), which are located inside the head close to the rope surface, catch magnetic flux leakage distortion, created by LF or/and LMA. Permanent magnets must be strong enough to magnetically saturate the rope, i.e. to reach working point A at hysteresis curve (Fig. 3). Most of equipment, designed for rope NDT, operate MFL principle, and for this reason inspection of rope with such instruments often called magnetic rope testing (MRT).

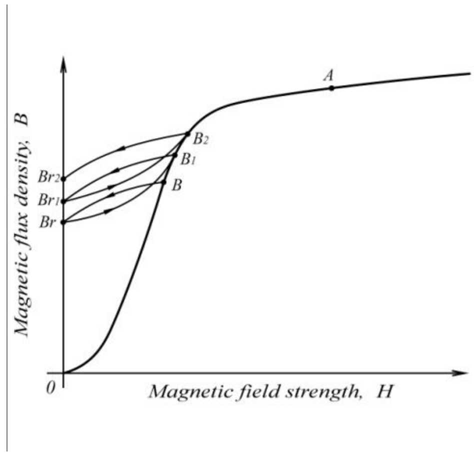

Figure 3. Hysteresis curve. Inspection with applied strong (A) and residual weak magnetization.

The larger is rope diameter the stronger magnets should be used, thus magnetic system becomes heavier and bigger. State-of-the art MFL rope tester INTROS [2] comprises magnetic heads (MH) with strong permanent magnets to inspect ropes of different diameter. Weight and size of magnetic heads are shown in the table 1.

Table 1

Rope Ø, mm/ MH type	*6-24/ MH 6-24*	*20-40/ MH 20-40*	*40-64/ MH40-64*	*60-85/ MH 60-85*	*80-120/ MH 80-120*	*100-150/ MH 100-150*
Weight, kg	*3*	*8*	*15*	*60*	*82*	*112*
Size, mm	*264x188 66*	*330x205x190*	*330x235x190*	*690x526X288*	*895x520x440*	*950x550x490*

Nevertheless there are two important reasons to uphold strong magnetization:

- Magnetic properties of the rope may vary due to operational conditions, mechanical and thermal effect, etc. and variation in magnetic condition may cause reading errors. Strong magnetization makes a magnetic property uniform and so provides higher inspection reliability and increases measuring accuracy;
- Uniform magnetic flux in the rope provides higher sensitivity to both outer and inner broken wires.

Weak magnetization instruments for inspection of rope in residual magnetic field, recently appeared on the market may seem as worthy alternative to MFL instruments mentioned above due to relatively small weight. However weak magnetization may not provide uniform steel magnetic properties and so performance of relevant instruments is worse: they have lower sensitivity, especially to inner defects; readings obtained from consecutive runs vary (B_r, B_{r1}, B_{r2} at Fig. 3) i.e. measuring repeatability is poor. Even use of sensors of higher sensitivity and increase of gain factor may not improve their performance. Besides, the testing results from weak magnetization instrument depend on previous magnetic condition of the rope. For instance, “magnetic spots” on the rope, created by heating, mechanical impact, etc. may be interpreted as defects. This was proved experimentally, by comparative test of weak and strong magnetization instruments available on the market [3].

Survey of standards and guidance for NDT of wire ropes

ASTM E1571 [4] is one of the basic documents, which describes relevant terminology, operating principles, application, equipment, procedures, standards for calibration, etc. This standard was recently accepted in Brazil in Portuguese language by change of the cover. The Guidance for magnetic NDT of steel wire ropes was issued by Russian Federal Department of Industrial Safety in 2000, and accepted in Ukraine in 2003. It contains basic knowledge regarding inspection methods, procedures, reports, qualification, and other helpful information.

Standards for inspection of lifting equipment usually refer to nondestructive inspection of ropes as a considerable mean for increase safety. E.g. safety codes for underground mining industry in many countries describe in details requirements for ropes NDT [5], and provide discard criteria. Depending of rope application – hoisting, balance, conductor, etc. rope discard criteria may vary. Usually standards provide maximum LMA value and LF number at certain length of rope as discard criteria. ISO 4309 [6] refers to rope NDT by electromagnetic method as an aid to visual inspection and recommends initial MRT as soon as possible after installation of rope, considering such inspection as reference point for further examinations of rope.

Carrying and hauling ropes of aerial cableways also play important role in providing safe operation. Relevant norms are accepted in USA, Canada [7, 8], Russia, other countries. European norm EN 12927-8 [9] is dedicated to MRT of aerial ropes and is compulsory for use in all countries in European Union.

Ropes of large diameters are widely used at offshore vessel cranes. These ropes are very expensive and they carry important and expensive equipment, e.g. pipelines, drilling installations, etc. Rope failure may stop operation and cause huge losses. For this reason customers are interested to keep offshore ropes in service as long as possible, but avoiding unreasonable risk. Guidance for MRT of offshore crane ropes [10, 11], accepted by IMCA in 2008 and 2009, explain important questions to assist with rope inspection and rope integrity management.

Practical aspects of MRT

During MRT the rope is passing through testing/magnetic head. Equipment must be ruggedly designed to meet industrial requirements. Holding equipment in hands during inspection as well as high rope speed is hazardous and may injure inspector and damage equipment. Equipment is recommended to reliably fix while rope moves through, and keep speed not exceeding 1,5-2 m/s. In case of inspection of stable ropes (bridge ropes, guy ropes) magnetic head moves along the rope with tugging slings or self-propeller device. Data logger of rope tester INTROS can be fixed on the magnetic head and moved along the rope to record data, thus no long cable is necessary in this case (fig.4).

Figure 4. MRT of bridge rope. Data logger INTROS (circled) is fixed on magnetic head

For better performance it is recommended to magnetize rope prior to inspection run, and make at list two runs for comparison. Lubricant and grease do not affect reading while protruding broken wires may damage the instrument, and it is recommended to cut off protruding wires prior to MRT. Magnetic heads may have wheels or sleeves which align rope in the head, and the latter also protects from protruding wires. Equipment must be equipped with encoder to fix the position of defects. Wire rope tester INTROS measures LMA and reveals LF, and records all data into built-in memory for downloading and further analysis. Test data are arranged in traces format as shown on fig. 5. Following traces are available: LMA, LF, traces from individual sensors, rope speed. On-line registration of traces is also possible (fig. 6) that enables inspector to stop the rope for visual examination in case of suspected defect. Feedback from customers operating INTROS during long time showed that extending rope life based on their NDT, and prompt planning of purchasing new ropes and exchange may provide sufficient benefits [12, 13].

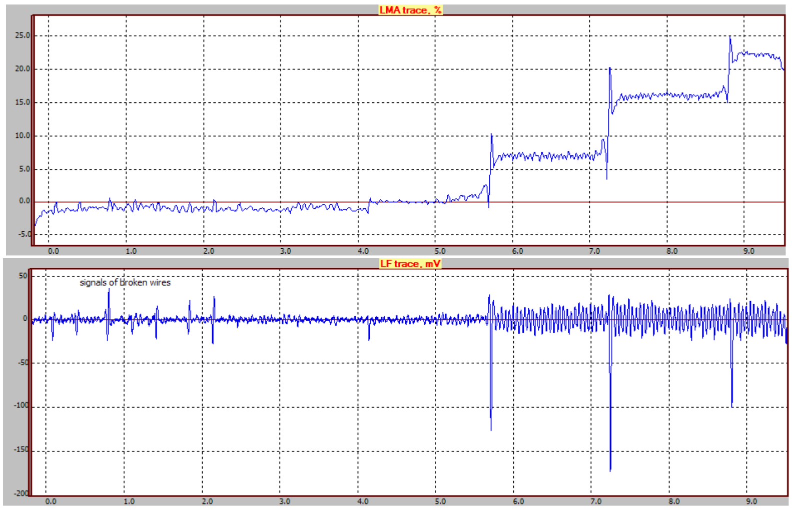

Figure 5. LMA (upper) and LF rope traces obtained from INTROS.

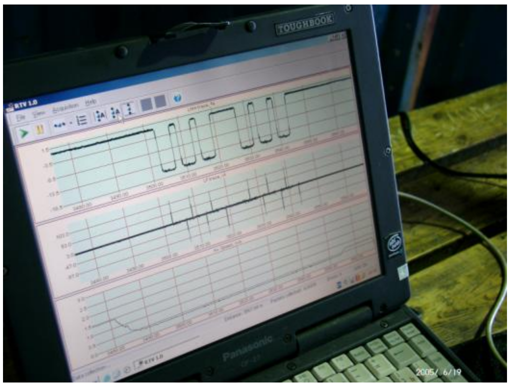

Figure 6. Real time LMA and LF traces shown on laptop screen.

Assessment of rope residual strength

Providing examination of rope, the pursued target is assessment of residual strength of the rope in order to know residual life with consideration of its operational condition. Assessment result enables inspector to appoint the next inspection in reasonable manner. Intron Plus has created a mathematical model of rope deterioration that allows calculating rope safety factor, which, in turn, is used for assessment of rope residual strength [14]. Experiments with ropes carried in rope laboratories in France, Finland, and Ukraine, and following comparison of experimental results with assessed residual strength showed their good agreement. This makes possible to assess rope residual strength based on the LMA and LF traces. As a result distribution of safety factor (SF) along the rope length can be obtained. Fig.8 shows distribution of SF for the bridge stay rope construction 1+7+7/7+14+24+33z+34z+41z, diameter 72 mm containing defects at the distance of 225, 235, 270 (out-of-lock wires) and 315 m (2 outer broken wires). The minimum SF value is noted at the distance 315 m, and it is equal to 2.4. Considering relevant norms minimum permissible SF value is as much as 2, and it can be concluded, that the rope may still remain in service. Assessment of rope residual life time requires accessible data from several consecutive inspections obtained from the same rope.

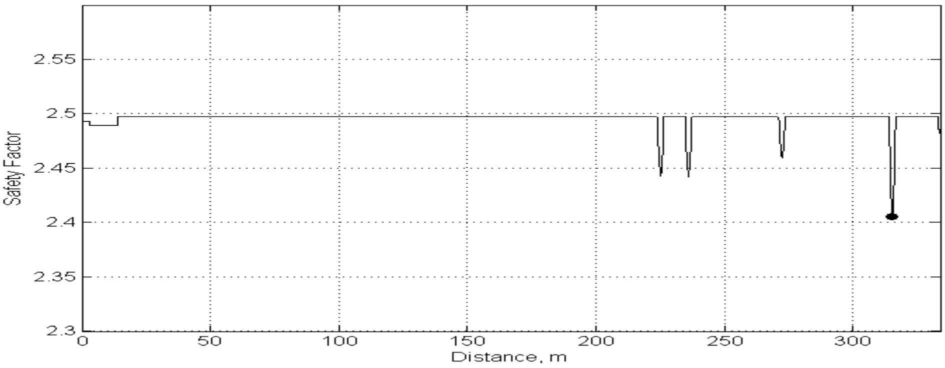

Figure 8. Distribution of rope safety factor of 72 mm bridge rope.

Conclusion

Nondestructive inspection of wire ropes with strong magnetization MFL instruments enables accurate assessment of technical condition of ropes, providing reliable basis for either timely discard of rope or extension its life. In-time discard increase safety of rope installation, while justified extension provides economical benefits.

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