MRT detection of fretting fatigue cracks in a cableway locked coil rope

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ABSTRACT

The Magnetic Rope Testing is a non-destructive method in use for the detection of flaws and cracks in steel wire ropes. Given the severe protocol of safety certification for in-service cableway ropes, a proper methodology operating in accordance with new European standard specifications is here presented. A relevant experience about detection of multiple cracks due to fretting fatigue on a peculiar locked coil structure rope is also shown and discussed.

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1. Introduction

Steel wire ropes are used extensively in several applications, as power transmission lines, elevator and mine hoist cables, support cable for aerial tramways, ski chairlifts and suspension cables. Since many events may lead to hazardous situations with high risk impact to persons, there is an obvious need to inspect the integrity of ropes without in any way impairing their function [1]. Specific standards define discard criteria, e.g. the excessive decrease of metallic cross sectional area, the presence of fatigue breaks or corrosion, to be compared before declaring a rope unfit for further service [2].

Aside from visual examination and manual measurement of the external diameter, today automated techniques of diagnosis are available. The Magnetic Rope Testing (MRT) method, also known as Magnetic Flux Leakage (MFL) method, is one of the most diffused automated techniques for many applications [3,4], and has become universally introduced as a reliable diagnostic tool for public transportation systems [5]. The main advantage of MRT is the portability, since the detection of broken wires, wear or corrosion has necessarily to be conducted on the rope in operating conditions: in fact, it would be unthinkable, for economical and logistical reasons, to disassemble periodically a rope to make the inspection [6]. On the other hand, application of MRT can be tricky, since efficacy of tests results from the contribution of experience, skills and care taken by the operator in interpreting the acquired signals [7,8].

In this work, the authors want to summarize their experience in the application of MRT to a peculiar multi-layered locked coil ropes, giving particular emphasis to:

- the portable instrumentation and the technique;
- the interpretation of data;
- the detection of fretting fatigue cracks.

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The experience we want to show here is from a recent investigation on the carrying cable of the “Gran Risa” gondola in La Villa – Italy (one of the FIS World Cup venues). From this work it is shown how the MRT prevents unexpected and hazardous failures, extending the service life of the installation. Indirectly, the method also indicates where the design of mechanical components should be optimized.

2. MRT apparatus and technique

MRT makes use of magnetization to put in evidence anomalies both externally and internally the rope structure. The rope is magnetized locally up to the saturation range of the hysteresis for a variable length of 200–400 mm by permanent magnets mounted on the magnetization heads of the instrument. Any anomaly exceeding a certain size determines a disturbance in the distribution of the lines of the magnetic field flux. The scheme in Fig. 1 depicts the process; lines of abnormal, dispersed flow are “captured” by a detection coil that wraps the rope in the central portion. Following the Lenz law, by the relative movement between the cable and the detector, a voltage spike is induced; this signal is displayed and stored on a recording apparatus/writer under graphic form. The control proceeds over the length of rope concerned; this results in a continuous recording, extended to the whole stretch examined, in which detected defects are highlighted in the form of localized peaks (the so-called “rope signature”).

Usually, peaks emerge also from the irregular and random background noise determined by the basic characteristics of the rope and of the system. The amplitude of the signal is influenced by many factors, as the intensity of the magnetic field, the relative velocity between the rope and the magnetic field, the diameter of the detection coil in relation to the diameter of the rope, the rope structure (stranded, locked, etc.) [9], the type and size of the defect, the distance between the ends of cracked wires, the changes in the magnetic characteristics of the steel (permeability, oxidation, heating), and radial position of the defect [10,11]. However, a wire break is highlighted by two distinct peaks in the signal, with amplitude well above the background noise. The signal that characterizes a defect must have specific amplitude and should be well defined in order to achieve sensitivity (generally the signal-to-noise ratio) and resolution. Therefore a proper tuning of the instrumentation, which is usually conducted on samples in laboratory, is necessary for operating correctly.

MRT equipment must comply with the European standard, which expressly indicates the operative protocol and establishes the safety requirements, test periodicity and instruments calibration under specific operating conditions [2]. Dimensions and weights of equipment can vary, especially depending from the diameter of the rope, from 10–15 kg for wire ropes up to 40 mm in diameter to 30–60 kg for larger ropes up to 70 mm in diameter, which is normal in the cableways designed to carry persons. Today in Italy we have installed cableways ropes of various types between 14 and 76 mm in diameter that are regularly controlled. The difficulty of implementation considerably increases for installations above 80–90 mm in diameter, which may require dedicated or specific solutions; difficulties of installation and handling of the equipment make the use of permanent magnets nearly impossible for cables over 100 mm in diameter. For modern equipment the sensitivity falls within 0.5–1% of the loss of cross sectional area; the sensitivity required by the standard results far below the size of the critical defect causing the cable failure.

In Fig. 2 it is shown the portable apparatus used by the authors for the present investigation. This instrumentation has all the typical characteristics of sensitivity, resolution, maneuverability and low weight of a MRT apparatus, it is easy of install also in difficult environmental situations, and is not influenced by external factors as humidity, low temperatures, vibrations, background electromagnetic fields.
3. Detection of fretting fatigue cracks on the “Gran Risà” installation

The experimental campaign was performed over 2 days on the cableway of the “Gran Risà” slope in La Villa, Südtirol, Italy. The carrying rope of the cableway, which has 5 years of service life, is a 25 type locked coil rope of 56 mm in diameter with a nominal rupture load of about 2500 kN. Details about the rope manufacture are summarized in Table 1. The wires are in galvanized carbon steel (0.8% C, 0.7% Mn, 0.15% Cr) with yield and ultimate strength of 1300 and 1900 N/mm² respectively.

The MRT was performed running the probe at 2 m/s along the rope and recording the signal by a digital instrumentation. A previous visual inspection of the rope did not show any inconvenience, whereas the magnetic flux signal evidenced a large number of alterations in correspondence of the last structure of support. This part of the recorded signal is reported in the diagram of Fig. 3. Over this length of about 15 meters, the dispersed flux diagram shows a strong background noise and several localized, well-defined peaks. The rope has been immediately dismounted from the service and taken to the LA.T.I.F. laboratory in Trento, Italy, for further examination. About 30 breaks in “S” wires of the second layer and patterns of diffused corrosion between the external and the second layer were found. These are clearly visible in Fig. 4 and in Fig. 5.

3.1. Morphology and cause of breaks

Wire breaks have not the typical aspect of failure for prevalent fatigue [12], see the details in Fig. 6. In fact, the investigation evidences:

− breakage of the film of lubricant between the first and second layer of S wires, due to excessive specific pressure;
− patterns of mutual sliding between the wires of external layers due to bending, with consequent formation of steel powder which oxidized generating in turn a strong wearing action (fretting corrosion);
− subsequent formation of micro-cracks and breakage of the wires subjected to external cyclic loading.

Hence, breaks are due to a combined phenomenon of fretting and fatigue. Fretting is well known in cableways, but almost exclusively for the multi-strand ropes [13–16]: in these structures, due to internal high pressures, the lubricant degrades determining a localized direct contact between the wires and generating the mutual abrasion which produces powders and oxidation. Fretting fatigue in locked coil ropes is less investigated, at present. It has been observed, almost qualitatively, that initiation of fretting wear is encouraged by the breakdown of the added lubricant and the magnitude of the contact stresses [17], and that residual radial stresses and environmental conditions play a crucial role in the cable performance [18,19].

Table 1
Characteristics of the locked coil rope under study.

<table>
<thead>
<tr>
<th>Elastic modulus (N/mm²)</th>
<th>Diameter (mm)</th>
<th>Cross section (mm²)</th>
<th>Number of wires</th>
<th>Diameter of internal wires (mm)</th>
<th>Height of external 5 wires (mm)</th>
<th>Layout</th>
<th>Minimum rupture load (kN)</th>
<th>Design load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>160,000 ± 4%</td>
<td>56</td>
<td>2143</td>
<td>169</td>
<td>3.85</td>
<td>6.00</td>
<td>1 + 6 + 12 + 18 + 24 + 36 ± 36 ± 42</td>
<td>2523</td>
<td>1100</td>
</tr>
</tbody>
</table>

Fig. 2. MRT portable device.
Fig. 3. MRT signal evidences multiple breaks and diffused corrosion.

Fig. 4. Cracks in the 2nd layer.

The shape of cracks in broken wires (letters E, H in Fig. 4), and the fracture surface morphology (detail of Fig. 6) indicate the action of corrosion/abrasion in conjunction with mechanical fatigue. Abrasion is due to the loss of lubricant agent, fatigue crack initiation is generated by the action of the products of wear under cyclic loading.

4. Evidences of poor design

Localized fretting between the wire layers is due to the excessive transverse load on the rope. The analysis of video frames showing the damaged portion of rope during the passage of a cabin, revealed us an anomalous behavior of the
hauling rope, as shown in Fig. 7. The images show us an excessive deflection of the hauling cable when the cabin leaves the support. A quantitative estimation of this deflection (about 5 cm), gives us an idea of the localized overload on the carrying cable, which results of the same order of magnitude of the weight of a fully populated cabin. A fatigue life estimation of the rope conducted taking into account this overload confirms a working condition that is critical.

After these considerations, the design of some components of the support has been modified with the aim of transferring the extra-load to other elements of support and not to the carrying cable. The solution seems to be successful.

5. Conclusions

The results of the MRT portable diagnostics on a cableway locked coil rope are analyzed and discussed. The method detected internal cracks showing the typical morphology of intra-layer fretting fatigue. The phenomenon is peculiar of the
Fig. 7. Hauling cable working not properly causes an over pressure on the carrying cable at the exit of the holder (“Gran Risa” cable car, La Villa, Italy).

locked coil structure, and in this case has been due the progressive lubricant deterioration under an overpressure acting in conjunction with the cyclic loading. In conclusion, our MRT inspection delivered important information that has been used for the selection of corrective measures in the design of new components.

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References


