Analysis of metallic ropes magnetisation during magneto-inductive testing

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Abstract
The paper presents an analysis of the behavior of the magnetic detector for control of magneto-inductive wire ropes. In particular the scope is to evaluate a correlation between the state of magnetization of the rope and the ability of the instrument to overcome the EN 12927-8 test. The paper presents a study conducted on a set of instruments and cables of different diameters provided by different Italian manufacturers.

Keywords: Metallic ropes, magneto inductive testing

1. Introduction

The magneto-inductive control of a wire rope through the measurement of the leakage flux is used to detect the so called Localized Faults (LF) or Localised Defect (LD) and requires that the rope is properly magnetized [1-2]. The level of magnetization of the rope, expressed as the value of the magnetic induction inside the rope, depends from device to device (detector) and it is a function of the magnetic energy that the device is able to generate. In accordance with the European standard EN 12927-8, the certification of an equipment is a mandatory requirement and must be conducted on a rope with artificial defects generated according standard rule. The achievement of a suitable magnetic flux densities inside the rope it is therefore an essential requirement for the certification of an instrument but also depends on many other factors (e.g. background noise, performance of the magnetic field, the type of sensor, type of system acquisition etc.).

In the present work we want to analyse different types of devices and ropes and in particular the relationship between the level of induction achieved in the rope and the performance of the device in terms of LF signal for the purpose of overcoming the EN 12927-8.

The devices analysed are characterized by different system of magnetization: magnets and current, from different arrangement of the magnetic field source: magnet axial and radial, from different dimension of the rope to be analysed (40, 60 and 80 mm diameter).

The measure of the level of magnetic induction within the rope was detected by a coil wrapped around the rope. The passage of the detector above the coil induces a pulse of electromotive force that acquired and integrated numerically provides the shape of the magnetic induction inside the rope. In the paper will be also analysed the influence of the residual induction of the rope on the detector performances in terms of capability to re-magnetize the rope and on the LD signal. The LD signal obtained for the different instruments will be put in relation to the induction level reached inside the rope to assess how the saturation of the rope can be regarded as a prerequisite for defining the goodness of an instrument.
2. European standard for the verification of compliance: EN 12927-8

The European Standard EN 12927-8 “Safety Requirements For Cableway Installations Designed To Carry Persons - Ropes - Part 8: Magnetic Rope Testing (mrt)” is very important because it defines the requirements and objective criteria for assessing the suitability of the equipment used in the integrity check of the ropes. The equipment must be provided by the detector, the signal display and permanent recording device comply with the requirements of the standard and verified every three years.

Detector features:
- Magnetizing circuit;
- centering system on the rope;
- display of controlled space rope or feeding device for recording with speed proportional to the progress of the rope with a sensitivity of at least 1 m and an accuracy of ± 1%;
- plate characteristics with limits of use (type, diameter, maximum metal section of controllable rope);

and at least one of the following detection devices:
- system for the detection of local defects (LD), based on the measurement of the leakage flux at the localized anomalies (e.g., broken wire);
- system for the detection of loss of the metallic section (AML), based on the measurement of the total magnetic flux, is proportional to the real section;

Characteristics of display system and permanent record of the signal:
- display speed, amplitude and frequency response suitable to represent clearly the signals provided at the time of inspection of test ropes;
- permanent recording ability (storage), enough to store in a single operation, the signals relating to the control of the rope.

2.1 Sample faults and test ropes

The performance of the equipment is tested by evaluating the response of the entire chain in front of an examination of rope containing a conventional defect. The conventional fault to be arranged for the evaluation of efficiency of the channel LD must be realized by the Laboratory that will perform the tests because it does not already exist on sale ropes with fault, and inserted into a piece of rope having the highest metal section controllable by the detector subjected to testing.
It follows that for each detector with certain limit performance a rope dedicated test shall be prepared.

The realization of these testing ropes leads to difficulties:
- research of suitable rope, diameter, metal section and features wires suitable for testing;
- work of realization of the fault, with the use of the measures required to maintain over time the geometric characteristics;
- reconstruction of the rope, without altering the basic features that can introduce anomalous signals disturbing evaluations;
• the appropriate preservation of the rope, for the subsequent checks on the same equipment.

2.2 Characteristics of the conventional fault

As indicated in art. 8.2 of the standard, the defect to be carried on the wire is represented by two adjacent broken, of a width of 3mm, distant from each other by a value equal to the diameter, with a maximum of 50mm.

![Fig. 1 Scheme of the fault and real implementation](image1)

The preservation of the width of the cracks and the distance between them is guaranteed by a brass welding.

![Fig. 2 Radial position of the broken wire in a wired and closed rope](image2)

In Fig. 2 is reported the cross section of a closed and a wire rope where it is possible to observe the radial position of the artificial broken wire.

In the case of a wired rope, the defect is equal to 0.5% of the section of the rope, is placed between a strand and the fiber core, on a rope to a single layer of strands: this corresponds to the greater distance from the outer surface of the rope.

For the closed rope, the defect is inserted into the core wire. In this case the standard does not specify the amount of the percentage missing since the diameter of the central wire is already established by the configuration of the rope.

In Tab. 1 is reported the set of closed test ropes available in LATIF.
<table>
<thead>
<tr>
<th>Ø rated (mm)</th>
<th>Ø real (mm)</th>
<th>Rope section (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26,0</td>
<td>26,3</td>
<td>465</td>
</tr>
<tr>
<td>30,0</td>
<td>29,8</td>
<td>602</td>
</tr>
<tr>
<td>39,0</td>
<td>39,3</td>
<td>1030</td>
</tr>
<tr>
<td>40,0</td>
<td>40,2</td>
<td>1123</td>
</tr>
<tr>
<td>52,0</td>
<td>55,1</td>
<td>1903</td>
</tr>
<tr>
<td>60,0</td>
<td>60,5</td>
<td>2431</td>
</tr>
<tr>
<td>63,0</td>
<td>63,3</td>
<td>2635</td>
</tr>
<tr>
<td>70,0</td>
<td>70,5</td>
<td>3325</td>
</tr>
<tr>
<td>82,0</td>
<td>83,5</td>
<td>4763</td>
</tr>
</tbody>
</table>

2.3 Requirements of the equipment
The equipment must highlight the fault as a signal, characterized by two distinct peaks and vertical amplitude significantly higher than the background noise.
As said the background noise is the set of random signals characteristic of the system (the rope itself, detectors, cables, amplifier).
To define and quantify this characteristic of sensitivity, it must identify two horizontal parallel lines that represent the envelope of the background signals for a stretch equal to 25 times the diameter of the rope, on both sides of the defect.
It is acceptable that the background signal cuts only 5 times these lines.

The signal corresponding to the two faults must:

- have amplitude of at least 2 times the amplitude of the envelope mentioned
- be double and distinct at the two separate breaks in the sample wire

These requirements correspond to the demonstration of enough sensitivity (signal / noise ratio) and resolving power (separation of signal due to defects separated)
The dimensions in Fig. 3 represents:

1 Stretch equal to 40xd related to the end of the rope not necessarily greater than 2m
2 Two wire breaks
3 Distance between breaks ( =d max 50mm)
4 Amplitude of the signal, at least 2x the width of the envelope
5 200mm not to be taken into account (relative to the envelope curve)
6 Envelope of background noise

2.4 Requirements of the equipment

In an annex of the EN 12927-8 standard an additional performance requirements regarding the magnetic saturation capability of the detector is presented. The requirements cite:
“Over an axial extension of 1/2 of its named maximum rope diameter dmax, the magnetizing unit has to be able to create a magnetic flux density B between 1.9 and 2.3 Tesla in a rope (or a metallic test piece for reasons of calibration) of the maximum metallic cross section Amax the unit was designed for. Within this range the thinnest rope which is allowed to be checked with the same unit shall not go below A = Amax /4 in terms of its metallic cross section. Otherwise it has to be proved by measurements, that the magnetic flux density B does not exceed 2.4 Tesla in the thin rope” (see Fig. 4).
This requirement has an important impact for those who are responsible for the certification of MIT devices. In fact, this requirement introduces a number of problems including how to measure the magnetic flux density in the rope and the possibility that the instrument presents a signal conforming to EN 12927-8 but does not meet the range of induction required by the annex.

![Magnetic induction behaviour](image)

Fig. 4 Magnetic induction behaviour in the rope required by the EN 12927-8 standard
3. Magnetic Performances of MIT devices
The magnetic performance of a detector can be determined by measuring the value of B along the axis of the device without and with the rope.

3.1 Magnetic flux density without rope (noload performance)
In the first case by an axial probe gaussmeter it is easy to determine the behaviour of B and such behaviour can depends from the typology of the detector: with axial or radial permanent magnets. In Fig. 5 is reported the B curve for an axial device while in Fig. 6 is reported the B curve for a radial device. It can be observed that the two patterns are very different. In the case of axial magnetization is a greater constancy of induction but the levels reached are typically between 500 and 1000 gauss. In the case of instruments with radial magnetization the trend is highly variable, high peaks are reached in the vicinity of the magnets but these values are lowered close to the center [3]. Decreasing the distance between the magnets the induction value in the center increase (from about 500 G to over 2000 G).

![Fig. 5 Magnetic flux density along the axis of an axial MIT device (expressed in Gauss)](image)

![Fig. 6 Magnetic flux density along the axis of a radial MIT device (expressed in Gauss)](image)
3.2 Magnetic flux density with rope (load performance)

The no-load magnetic performance of the device can be useful for a qualitative estimation of the capability of the device to saturate the rope but for a quantitative evaluation it is necessary to provide a direct measurement.

Such quantity can be obtained by integrating the induced electromotive force (emf) on a coil wrapped around the rope (see Fig. 7). The winding must be made as much as possible in contact with the wire rope and the number of coils must be sufficient to obtain a good signal to noise ratio. In practice, considering the levels of induction that are commonly generated by the MIT devices in the ropes, a winding of 20 turns is sufficient.

In Fig. 8 is reported an example of the behavior of the emf and of the corresponding magnetic flux density.

![Graph](image1)

**Fig. 8.** Example of emf and corresponding magnetic flux density (expressed in T)

The procedure has been tested by a comparison with the magnetic flux density measured by a laboratory gaussmeter. The comparison is of course without the rope (in this case the coil has been wrapped on an aluminum support). As can be seen in fig. 9 the results are in a very good agreement.

![Graph](image2)

**In Fig. 9 Comparison between the magnetic flux density measured by coil and gaussmeter along the axis of the detector.**
4. Experimental results

In this section is analyzed the SNR defined by the EN 12927-8 and compared with the level of magnetic induction reached inside the rope. The test campaign carried out has focused on three Italian manufacturers, named respectively: C1, C2 and C3, which produce magnetic inductive tools for the ropeway sector but not only. All the magnetisers analyzed use permanent magnets, most of the radial type, and some of the axial type. Some tools, in particular those of large size (60-80mm), are of the open type as are used for the control of the track ropes. In fact, the detector must travel on the rope without being raised or opened or removed on the sections of rope placed in contact with the pylons. All detectors have coils as sensors while the recording system is analogic for one manufacturer and digital for the other two manufacturers.

For each instrument was conducted the test EN 12927-8 on the ropes in LATIF ropes and in the same ropes has been carried out the measurement of the magnetic flux density induced by the magnetizer. Tab. 2 shows the results obtained from the testing campaign and is particularly interesting to note that:

1) all the MIT systems are accordance with EN 12927-8;
2) the majority of the devices analyzed brings the rope to a level of magnetic saturation higher than the indication of the standard (between 1.9 and 2.3T);
3) the minimum value of 1.9 is always exceeded

<table>
<thead>
<tr>
<th>Detector</th>
<th>Rope diameter (mm)</th>
<th>Axial/radial magnetisation</th>
<th>Open/closed</th>
<th>SRN</th>
<th>B (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1_1 26.3</td>
<td>Radial</td>
<td>Closed</td>
<td>10</td>
<td>2.94</td>
<td></td>
</tr>
<tr>
<td>C1_2 40.2</td>
<td>Radial</td>
<td>Closed</td>
<td>9.5</td>
<td>2.58</td>
<td></td>
</tr>
<tr>
<td>C1_3 60.5</td>
<td>Radial</td>
<td>Closed</td>
<td>6.4</td>
<td>2.76</td>
<td></td>
</tr>
<tr>
<td>C2_1 26.3</td>
<td>Axial</td>
<td>Closed</td>
<td>4.8</td>
<td>2.35</td>
<td></td>
</tr>
<tr>
<td>C2_2 26.3</td>
<td>Radial</td>
<td>Closed</td>
<td>3.3</td>
<td>2.40</td>
<td></td>
</tr>
<tr>
<td>C2_3 40.2</td>
<td>Radial</td>
<td>Closed</td>
<td>3.8</td>
<td>1.95</td>
<td></td>
</tr>
<tr>
<td>C2_4 40.2</td>
<td>Radial</td>
<td>Closed</td>
<td>4</td>
<td>2.42</td>
<td></td>
</tr>
<tr>
<td>C2_5 60.5</td>
<td>Radial</td>
<td>Closed</td>
<td>3.9</td>
<td>2.59</td>
<td></td>
</tr>
<tr>
<td>C2_6 60.5</td>
<td>Axial</td>
<td>Open</td>
<td>-</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>C2_6 83.5</td>
<td>Axial</td>
<td>Open</td>
<td>2.5</td>
<td>2.41</td>
<td></td>
</tr>
<tr>
<td>C3_1 29.8</td>
<td>Radial</td>
<td>Closed</td>
<td>4.9</td>
<td>2.44</td>
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<tr>
<td>C3_2 55.1</td>
<td>Radial</td>
<td>Closed</td>
<td>3.2</td>
<td>2.15</td>
<td></td>
</tr>
<tr>
<td>C3_3 60.5</td>
<td>Radial</td>
<td>Open</td>
<td>4.6</td>
<td>2.91</td>
<td></td>
</tr>
</tbody>
</table>
4. Conclusions
The present work relates the performance of magneto inductive devices expressed in terms of SNR during the EN 12927-8 with the level of magnetization reached in the rope. The experimental analysis has been conducted on a significant number of MIT devices provided by three different Italian manufacturers. The instruments are characterized by different diameters and are of the closed and the open typology. All the EN 12927-8 tests performed on the considered devices present a SNR higher than 2. Regarding the magnetic flux density, in the majority of the cases, are higher than 2.3 T (maximum limit specified by EN12927-8). As final consideration from the obtained results is that the indication inside the EN12927-8 of a maximum value of magnetic induction may be not convenient. Regarding the minimum value of 1.9 T additional test are under underway.

References