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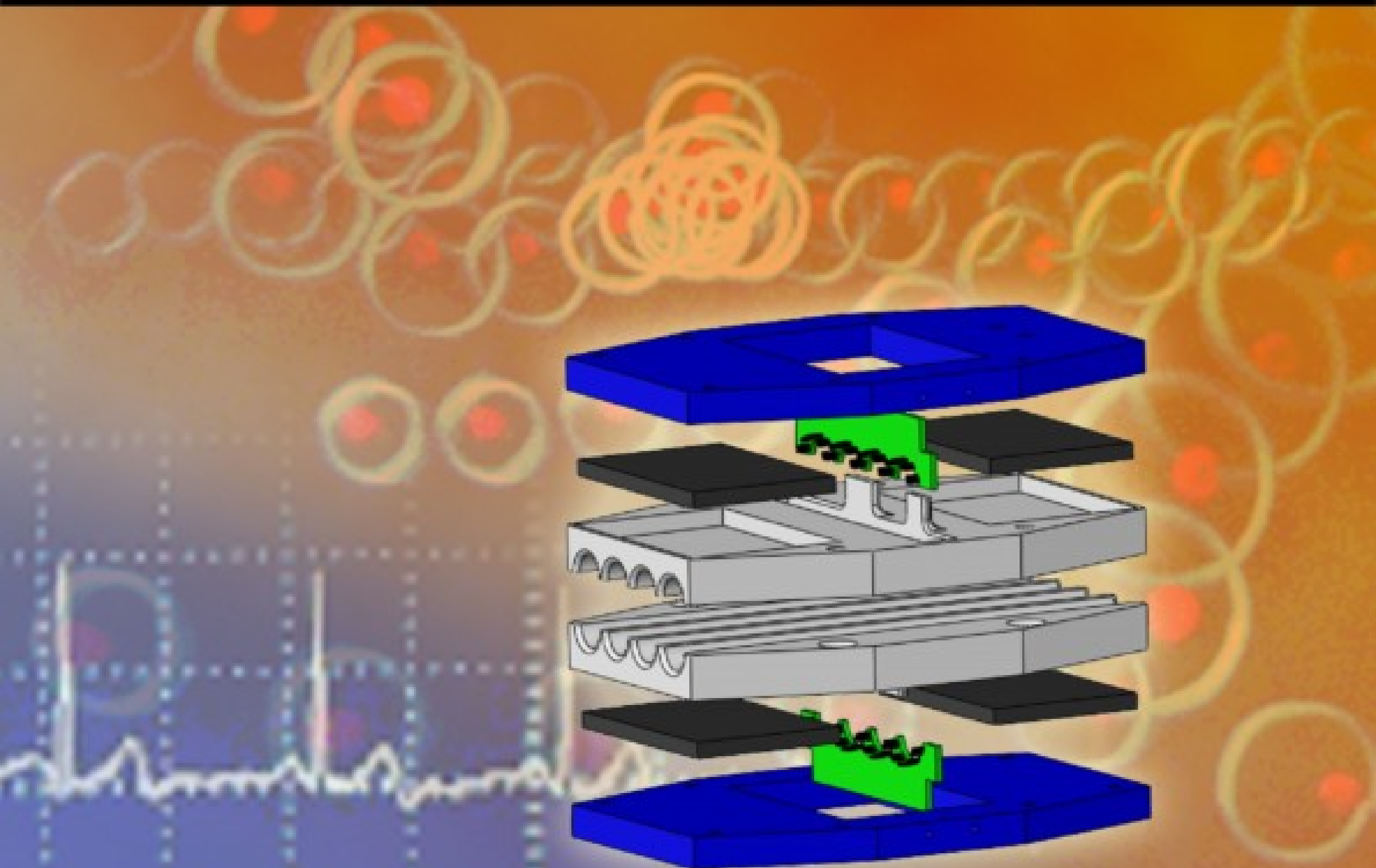

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Magneto-inductive Sensors for Metallic Ropes in Lift Application

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Abstract: In this paper an innovative system for the contemporary, selective and reliable control of integrity of multiple rope plants is presented. The system is based on magneto-inductive technology and is composed by a magnetic detector connected to an acquisition system. The core of the detector is constituted by an array of Hall sensors properly placed inside the instrument.

After a brief introduction to the Non Destructive Techniques applied to the control of metallic ropes, the first part paper deals with the design and behavior of the detector and the acquisition system. In the second part of the paper a performance analysis for different rope size and experimental results on an elevator plants is presented and discussed. *Copyright © 2010 IFSA.*

Keywords: Non destructive testing, Metallic ropes, Hall sensors.

1. Introduction

Generally NDT, also called nondestructive evaluation (NDE) or nondestructive inspection (NDI), is testing that does not destroy the test object and it is crucial for constructing and maintaining many types of components and structures. The problem complexity lies both on the phenomena interaction which governs the flaw generation and on the identification process which requires a feasible and reliable detection principle. Several NDT techniques are used in different fields of application and the most employed are: radiographic, ultrasonic, acoustic emission, thermography, magnetic and electrical. The main field of application regards the flaw detection in materials as the corrosion in wire ropes or pipelines, the weld defects or fatigue cracks in steel bar concrete materials [1]. In particular regarding ferromagnetic ropes [2-3] two techniques based on the Magnetic Inspection (MI) are proposed: the Magnetic flux leakage (MFL) and the Magnetic Reluctance Variation (MRV) techniques. In the two techniques a magnetic flux produced by permanent magnets or currents is pushed inside the ferromagnetic parts to be tested. The presence of the flaw is detected by the measurement of a leakage flux in the MFL method and by the measurements of a variation of the magnetic flux in the MRV technique. The first approach allows only the identification of the flaw presence while the second one allows also a quantitative evaluation of the flaw volume. For these reason the first technique is called LF (Localized Faults) while the second one is called LMA (Loss Magnetic Area). The LF is usually efficient in the detection of broken wires even if the to part of the broken wire are very closed (narrow gap). The LMA is more reliable for the detection of flaws due to fatigue or corrosion because they can produce a generalized reduction of the wire cross section area.

The measurement of the magnetic field is usually provided by two main sensor technologies: coils and hall sensors. The coils are principally used when only the LF test is required while hall sensors are used when both LF and LMA are required. Many aspects influence a good flaw identification: detector topology, sensor technologies, magnetic saturation level of the body under test, position and dimension of the flaw, etc.

In the most countries of the world the NDT (LMA or LF) of ropes is compulsory only for cableways [4] but the demand in other fields of application it is increasing. It is worth to notice that NDT has been recently introduced for crane ropes [5], which are characterized by relative small diameters. Many plant managers of such plant are starting to requires today the NDT and the number of control requests are increasing dramatically. For such application the heavy and costly device adopted for cableway are non suitable. So the develop and market of lighter and cheaper devices is started for such field of application.

Another of the most promising sector of application for the NDT of ropes is represented by the elevators. The need is manly due to two factors. The first one regards the need of testing and maintainers staff to carry out and objective control. The second is linked to the technique tendency of going towards solutions characterized by ropes having an always inferior diameter (in order to reduce the hoisting dimensions) therefore in growing number. The second feature makes the visual inspection more complex and expensive in terms of time, as well as, less reliable. The regulatory bodies are therefore considering the introduction of magneto inductive control in the field of vertical lifting of people. In such way the control of these ropes is more objective than the actual one provided by visual inspection or by using a “wooden tablet” pushed against the ropes. It is worth noting that the tendency of the lift manufactures to go versus higher number of ropes increasingly thin (in order to reduce the pulley dimensions) will correspond to a necessary automatic and objective control which cannot be provided by visual inspection. Similarly, the use of ropes or straps metal covered with plastic makes the view examination impossible to perform.

The control technologies for the rope lift control can be adapted from the ones already developed for ropes of big cableways but they require some critical changes. Besides the technical aspects regarding the device resizing there are some substantial changes of operating aspects and market. First operating aspect deals with the capability of correctly executing a magneto inductive test. Usually these tests are carried out by specialized technicians and the existing market device don’t focus on user interface.

Usually there are devices that provide test results in print-out format that is of difficult consultation. A testing device for lift rope verification used by standard maintenance personal must be easy to use, simple to handle (e.g. it must have a display for a the real time visualization of rope state) and must be of clear comprehension. Moreover existing technologies are characterized by low scale production the technological/productive aspect are always neglected. Due to the low number of devices produced, at the moment the rope testing device for cableways may cost several tens of thousands of euro: lift maintenance cannot effort the expenses of such a device, which should be reduced to a few thousand euro. As for as this technologies are concerned, it is worth noting that the major part of actual devices is based on coil technology: the need to reduce device size calls for the use of other technologies, such as those based on Hall effect probes.

The paper is divided in two main parts. In the first one is presented the system and the device designed and realized by the author for the magneto-inductive test of a multiple rope system. In particular the magnetic design of the device represent and important step in order to get good detector performances: high signal to noise ratio, low height, low influence of the rope oscillation, etc. Due to the particular structure of the device the magnetic analysis are carried out by using a 3D numerical software [6]. Such code is a general purpose electromagnetic simulator based on the Finite Integration Technique (FIT) of the Maxwell's equations.

In the second part are presented the performance obtained in laboratory for different rope sizes and in an experimental campaign on a several number of real plant. The lifts analyzed are characterized by different parameters: rope size, number of ropes, age of the ropes, and so on.

2. Magneto Inductive Principle

In order to better understand how the MI of ropes works it is better to start from the description of a metallic rope. In Fig. 1 is reported an example of a strand rope which is constituted by a set of elementary metallic wires (usually made of ferromagnetic materials) grouped to form a set of strands which are them selves joined to constitute the rope.

Fig. 1. Scheme of a strand rope.

Sometimes ropes can show several kinds of defects. Before the rope use wire interruptions or wire crosses can occur; while during the rope use: rope wear, wire corrosion, core degradation or rope abrasion are possible cause of faults.

The NDT detector is based on a magnetic circuit closed to the ferromagnetic rope under test. The magnetic flux is produced with strong PMs (usually NdFeB) and is conducted to the ferromagnetic rope through a proper magnetic circuit made of high permeability massive iron. When the rope presents a discontinuity (as a broken wire), two magnetic effects occur: a variation of the main magnetic flux due to the reluctance variation and a magnetic flaw near the discontinuity (as sketched in Fig. 2). The exploitation of the two magnetic effects allows to obtain the two separate signal associated to:

a) Localized Fault LF;

b) Loss Metallic Volume LMV.

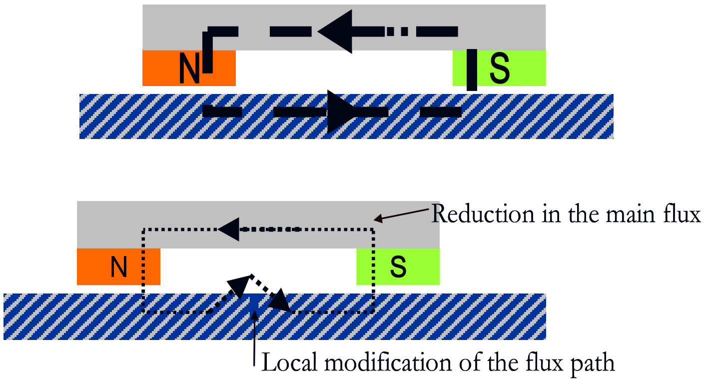

Fig. 2. Rope under MI test: qualitative flux path with and without faults.

The magnetic sensors can be adopted for the revelation of two signals can be manly of two types: coils or hall sensors. The first kind of sensor behavior is based on Faraday law and so give a signal proportional to the flux variation, on the contrary, hall sensors allow the measurement of the absolute value of the magnetic flux density (B).

Most of the commercial detector are based on coils. This is mainly due to technological-historical reasons. In fact the LF signal has been the signal required for the control rope since 50 years ago and, in the same time, coils are very sensitive to local flux variation produced by local flaws.

Hall effect are relative recent and a system based on such technology is more complicated on the electronic and signal conditioning point of view. On the other hand an hall sensor provides a local measurement of B and by using array of them, new concept sensor topologies can be developed. Regarding the magnetic circuit that imposes the B inside the rope, the main requirement is to reach the higher saturation level inside it. A sensitive analysis for the optimization among rope saturation, detector weight and cost has been done in previous paper [7, 8].

The extension of the magneto-inductive technology control to the lifts, imposes some additional requirements due to the contemporary testing of all the plant ropes. The number of ropes and their size may depend from the size of the lift and the number of sheaves. From two up to six there are the great numbers of lift typologies. It is clear that a magneto-inductive detectors for the lift must have a number of technical and functional requirements that will enable the maintainer or the controller to a simple, quick and efficient review of all the ropes at once.

3. Multiple Rope System

3.1. Multiple Rope System

The main NDT characteristics cited above (sensitivity, SNR, weight, etc.) can be related to some magnetic performances. The first one is the need to reach high saturation level inside the rope. This request is manly related to the improvement to the LF signal when the fault is internal to the rope. In this case the flaw of the magnetic flux lines is partially shielded by the rope itself and it is difficult to be detected: increasing the saturation level the LF signal sensitivity improves. According this specification the detector has to designed in order to reach high magnetic flux density inside the rope. Due to the impossibility to measure the magnetic flux in the rope the experimental evaluation of the detector performances are evaluated by measuring the magnetic flux density without the rope (no-load conditions). As an example for the case of the 4 rope detector, in Fig. 3 are reported the magnetic flux densities in the centre of the different holes (or channels) without the ropes. The magnetic induction is about 0.5 kG in the centre of the detector which is a satisfactory value.

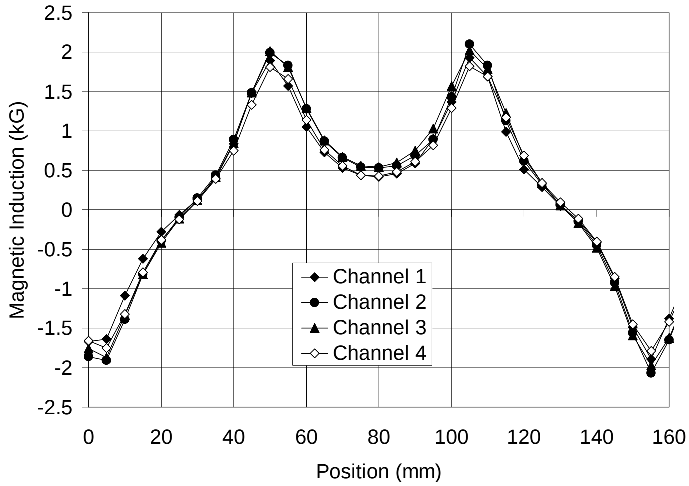

Fig. 3. Magnetic induction measured in the different channel of the detector.

A second important goal is the reduction of leakage of the main flux. This objective is important for two reasons: to maximize the exploitation of the permanent magnet and to reduce the magnetic "noise" in the region where the magnetic sensors are placed.

For the performance requirements cited above, the numerical model for the design of the detector magnetic circuit has to consider two important aspects as:
1) the geometry is three dimensional;
2) the rope and the ferromagnetic detector jokes are strongly saturated.

In the present paper the magnetic simulations are performed by using the FIT technique [6]; the Maxwell equations and the constitutive relations are transformed in a discrete domain, by placing the electrical quantities on a grid G and the magnetic quantities on a dual grid G'. In Fig. 4 is reported a scheme of the virtual detector designed through the help of the 3D numerical solution, and its field solution for a defined working condition. All the other technical details are reported in [9]. In Fig. 5 is reported the detector manufactured and distributed by the academic spin off AMC Instruments (www.aemmeci.com).

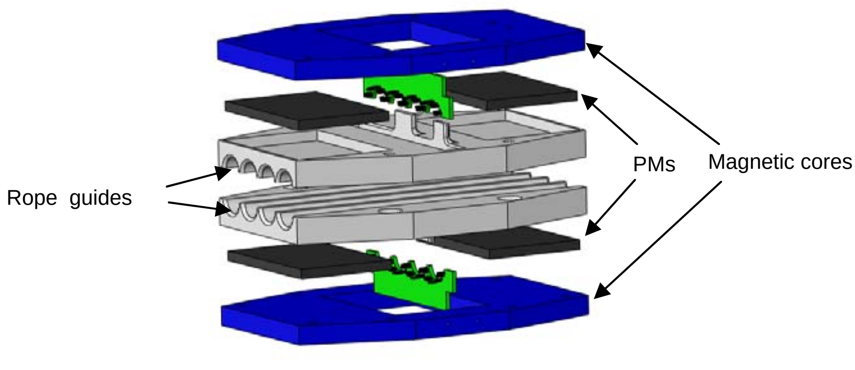

Fig. 4. Magnetic layout of the device.

Fig. 5. Detector for the M-I control of metallic ropes for lift application.

Finally, it should be noted that the limitation to the LF control (LMA sensors are not present) is sufficient for ropes adopted in lifts, since the ropes are typically installed in a place protected from weather (it is worth noting to remember that LMA is particularly effective in relief of defects as corrosion). It is not excluded in the future to provide a configuration also having a control type LMA. If now people involved in maintenance are ready to accept a technology as LF, is necessary to proceed by degrees in innovation, considering that until now the rope control was based on a visual inspection characterized by a high degree of empiricism.

3.2. Sensor Array

The electronic developed for the sensor head is made by two electronic boards: the sensor array board and the conditioning board. Boards change with instrumentation depending on number and diameter of plant's ropes. The sensor array board is made by a number variable from 4 to 6 crowns of hall sensors. The crowns are the transducer elements that get the information about the rope state in the magnetic domain and put it on the electric domain.

The conditioning board connects the output signal of each crown to the input stage of the acquisition system. The conditioning board is made by three blocks. A first sum block, that output the total sum of the signals of each crowns, a second low-pass filter stage and a final gain stage and each crown has a dedicated conditioning circuitry. Fig. 6 shows the 3D representation of the sensor and conditioning board for a 4 channel detector.

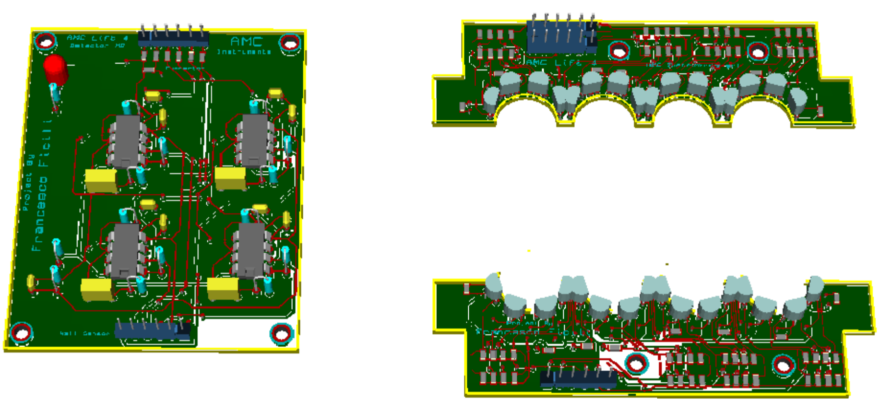

Fig. 6. Sensor ad conditioning board for 4 channel detector.

3.3. Acquisition System

Connected to the magnetic field sensors there is the acquisition system. The purposes of this element is to supply the electronics of the sensor head, to acquire and store the signals that indicates the rope status and, after the acquisition, to post process the information acquired, in order to provide to the operator a complete diagnostic tool.

The system has been designed in order to be portable and fully integrated. The project choice was to make a PC based system, with an external acquisition board, all integrated inside a single hard suitcase (Fig. 7).

Fig. 7. Acquisition system.

The components used is a NI USB-6008 (Fig. 8), 8 channel USB acquisition board linked to and a commercial Windows based laptop. The use of a laptop with an external acquisition board simplify the design of the acquisition system and give more flexibility to the system.

Fig. 8. NI USB 6008 acquisition board.

3.4. Software Features

The acquisition and post-processing software was developed using LabView 8.6. The use of LabView and G-language makes the software easy to test and upgradable. The software interface (visible in Fig. 9) is made by an acquisition software and a post-processing tool.

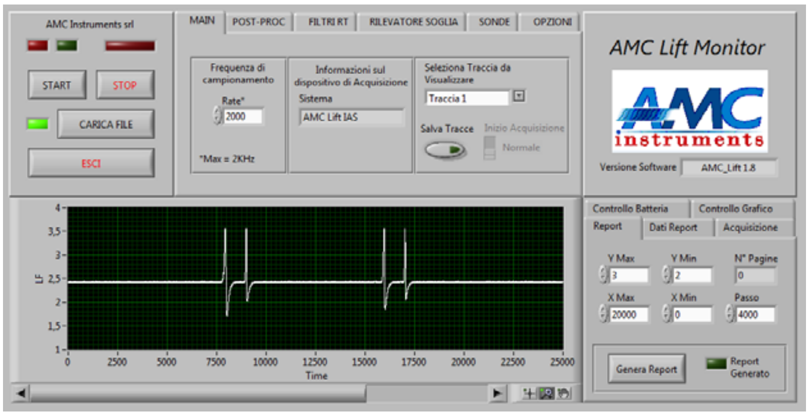

Fig. 9. Acquisition and post processing software (LabView 8.6).

The acquisition software can acquire up to 6 channels simultaneously, and offer a real-time visualization of a single selectable channel. During the acquisition process some basic diagnostic feature are available (crown status, battery status, real time filtering, etc.). The post-processing tool offers the possibility of load a saved trace, filter, zoom and put marker, in order to separate the signal from the background noise. Another useful tool is the report generation toolkit that allows the generation of a multipage report with trace (separated in strip) and plant information.

4. Laboratory Test

In a first experimental stage were carried out laboratory tests at the Politecnico di Torino, in order to define some important parameters in NDT as tolerance band (width of the background noise) and consequently the signal to noise ratio (SNR). In all NDT based on magneto-inductive technique the signal is obviously affected by a noise linked to the rope trefoil and his swing and the presence of a defect is highlighted by a peak which exceeds a tolerance band. This approach is used in the performance evaluation of NDT device for cableway ropes.

For example, in the follow (from Fig. 10 to Fig. 12) are reported some tests on ropes of different diameter: from 9, 10 and 11 mm, composed of 114 wires, of which only one wire has been broken and the ends are 5 mm close. The experimental results show that the range of tolerance varies between 70 mV (9 mm cable) to approximately 100 mV (11 mm rope). When the signal exceeds the range of tolerance, eg 50% above, is certain that a broken wire occurs in the rope.

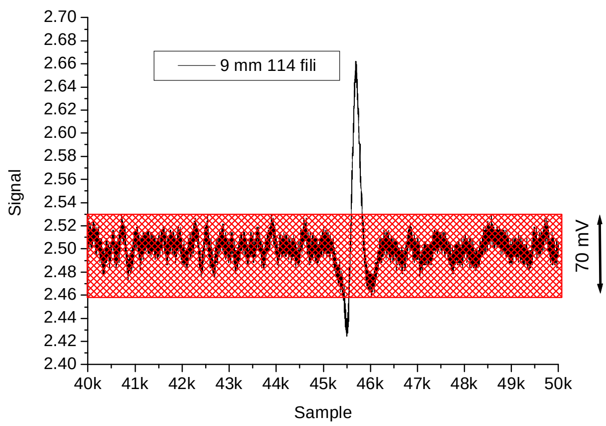

Fig. 10. LF signal for a rope diameter of 11 mm.

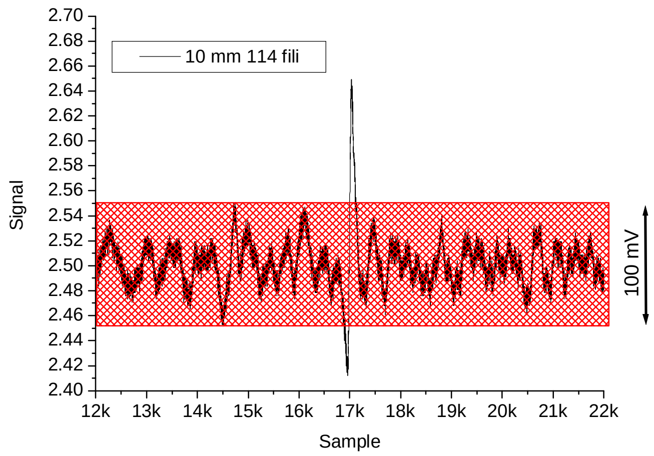

Fig. 11. LF signal for a rope diameter of 10 mm.

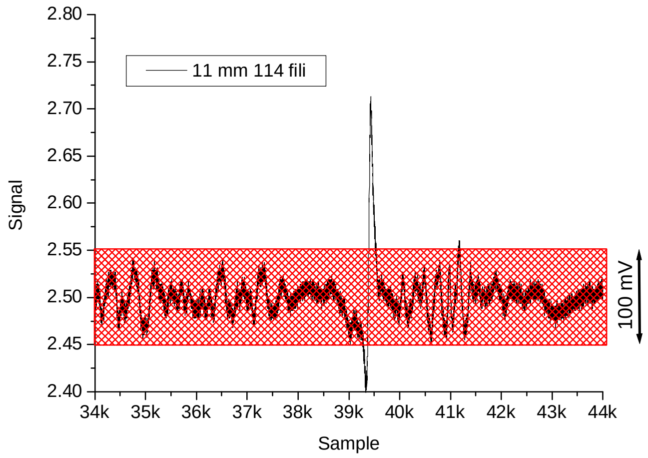

Fig. 12. LF signal for a rope diameter of 11 mm.

5. Test on Working Lifts

A significant number of tests on field have been provided in collaboration with ICEPI Notified Body by the Ministry of Industry. About 15 plants were chosen to ensure that the sample was as representative as possible. Although one do not want to give to these tests a statistical significance, it should be noted that the installations are characterized by different:

- Year of installation;
- Number of ropes;
- Number of floors;
- Type of rope.

Overall, were considered about 40 ropes and tests have shown very particular situations, as:

- no defects in recent plants, and sometimes for some ropes in old plants (over 20 years): this means that the replacement of the ropes should be related to their real condition and not to their age;
- in some elevator (even recent) a single rope with a relative high number of defects occurs: there is often one of the ropes that works more than the others and so it is more worn and the ability to detect it would provide indication for possible corrections;
- some ropes with a number of defects, greater than 5, that were not detected by the traditional "wooden tables" test;

- one broken wire in most of the analyzed ropes (even recent): probably a check of the rope at the end of the production process which provide a "status track" of the rope would improve the quality of the product and would give the maintainer or the verifier an important indication on the goodness of the rope.

As an example in the follow are reported the result obtained in an electric lift with 2 ropes of 10 mm (1977). This is an example of a relatively old facility with a rope without faults and a rope with many defects. It should be observed here that the instrument works with fewer ropes than detector channels and so some channels of the instrument are not reported because they are empty (see Fig. 13).
Details about all the other analyzed plant are reported in [10].

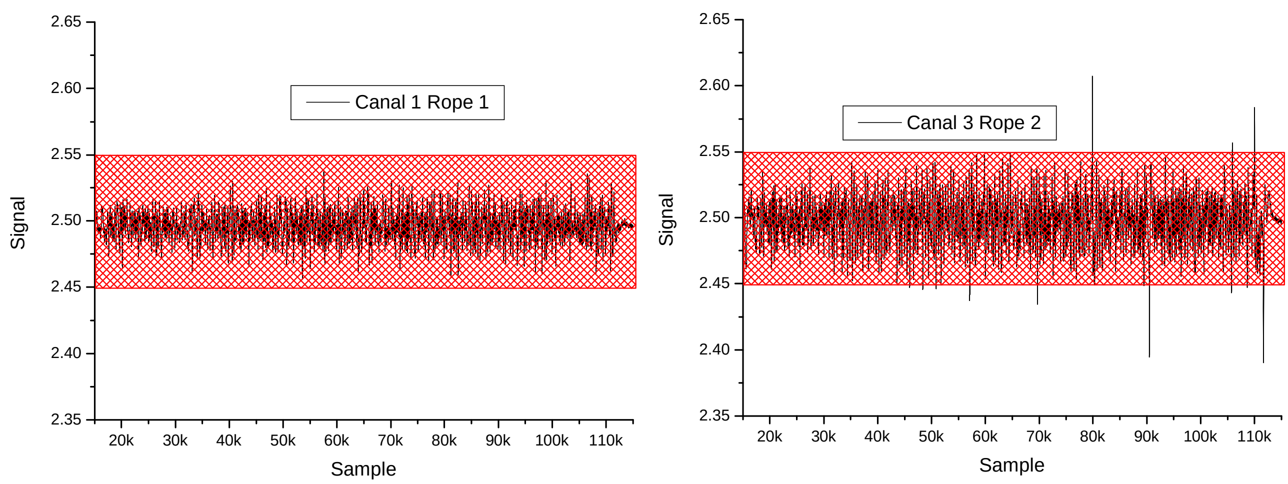

Fig. 13. LF signal for a 2 ropes of 10 mm (1977).

6. Conclusions

The present paper deals with the possibility to employ the magneto-inductive (M-I) technique for the non-destructive control of metallic ropes adopted in elevators.

A tool able to provide such kind of control is presented and a test campaign has been performed. In all the test on field, the M-I control was always preceded by a visual examination in order to check the status of rope wear, the evaluation of possible rope slipping on the pulley and, by the "wooden tablet", to highlight external broken wires.

In particular the traditional technique based on "wooden tablet", in all the cases, did not allow to express a clear opinion on whether or not to replace the ropes and did not reveal situations close to the limit. Conversely, the control of the magnetic detector emphasized plausible events for "old age" (eg case 7 [10], rope, 1975, with several broken wires) as well as events caused by wrong stretched of the ropes (eg case 8 [10], ropes of 2008, one with a broken wire).

Last but not least, with the use of an objective methodology will tend to zero situations of conflicting assessments between the different actors: the building owner, the manager, the maintainer and the verifier.

References

[1]. N. P. de Alcantara Jr. and M. E. L. Gasparini in: Steel Bars Identification in Reinforced Concrete Structures by Using ANN And Magnetic Fields, *Prog. in Electromagnetics Research Symposium*, Hangzhou, China, 2005, pp. 428-430.

[2]. H. R. Weischedel, The Inspection of Wire Ropes in Service: a Critical Review, *Materials Evaluation*, Vol. 43, No. 13, 1985, pp. 1592-1605.

[3]. Crotti A., Dalla Chiara B., Imbimbo N., Proposal for Enhancement of Magneto-inductive Steel Wire Rope Testing on Cableways and its Applications for Elevators, Elevator Technology 12, *Proceedings of Elevcon, 12th Inter. Conf. on Vertical Transportation Technologies*, Milano, Italy, 24-27 June 2002, pp. 54-63.

[4]. CEN -EN 12927-8:2004 Safety requirements for cableway installations designed to carry persons — Ropes — Part 8: Magnetic rope testing (MRT).

[5]. ISO 4309:2006: Cranes - Wire ropes - Care, maintenance, installation, examination and discard.

[6]. CST EM Studio, CST Computer Simulation Technology, http://www.cst-world.com

[7]. A. Canova, B. Vusini, Magnetic Analysis of Non Destructive Testing Detectors for Ferromagnetic Ropes, *COMPEL*, Vol. 27, No 4, 2008, pp. 867-878.

[8]. V. Cacciatore, A. Canova, A. Vallan and B. Vusini, Experience and technologies in NDT of ropes, *Key Engineering Materials*, Vol. 347, 2007, pp. 627-632.

[9]. A. Canova, F. Ficili, G. Gruosso, B. Vusini, Device for the monitoring of multicable system, Patent WO2009IB50656 20090218.

[10]. A. Canova, P. Boschiazzo, F. Ficili, P. Frighi, B. Vusini, Magneto-inductive testing of steel ropes in elevators, *Elevatori*, *The European Elevator Magazine*, 2, 2009, pp. 66-75.

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
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- Nanosensors;
- Microsystems;
- Applications.

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