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Magneto-inductive examinations on ropes: new frontiers

Dott. Ing. Giuseppe CALCAGNO, Politecnico di Torino, Dip. DIATI – Trasporti
Prof. Ing. Bruno DALLA CHIARA, Politecnico di Torino, Dip. DIATI – Trasporti

The evolution of non-destructive testing on ropes: from magneto-inductive and visual examination to expert systems support; the role of AI

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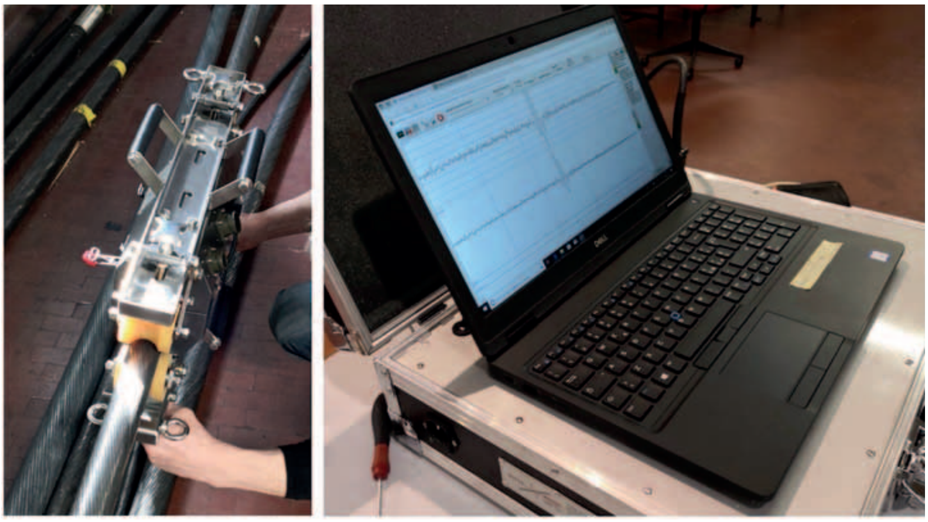

As is well known, the safety of ropeway installations depends directly on the condition of the steel ropes. In ropeway and lifting installations, the rope is not simply a mechanical component but the main structural element that supports and transfers loads, guarantees movement throughout the installation and fully determines its reliability. From this statement arises the crucial importance and delicate nature of the periodic inspection of the rope condition, including wear, oxidation and corrosion, as well as, where possible and effective, the end attachments.

For at least sixty years, the principal and undisputed technical reference has been and remains the magneto-inductive method [1]; however, new technologies have for some time been shifting the frontier toward integrated systems, in which the magnetic signal, inspection assisted by automated computer vision tools, expert systems and even the proposed use of artificial intelligence (AI) contribute to building a faster, documentable and repeatable diagnostic framework, deserving reflection on the role of the human expert and automatic systems. These systems may imitate experience, but without assuming responsibility or taking initiatives; nevertheless, they can provide additional support to those examining the rope.

First of all, it must be firmly stated that the issue is therefore not the replacement of the engineer or expert technician, but rather the enhancement of their analytical capability: new technologies can reduce examination times, increase traceability of results and focus the operator's attention on the most significant anomalies. However, they are not in themselves "intelligent": they are simply very fast at processing data and correlating even extremely large numbers of variables, where required.

The magneto-inductive method (Figure 1) is based, as is known, on the ferromagnetic properties of steel: the rope is magnetically saturated over its entire length by means of an instrument equipped with powerful magnets, today at 2,000 Gauss, perhaps excessive, whereas in the past 500 Gauss was used. Any discontinuities, broken wires, corrosion, significant oxidation or reductions in section alter the induced magnetic field; these variations are detected by dedicated sensors generating visible and analyzable signals.

It should be remembered that this method, by its intrinsic nature, cannot be fully considered among quantitative methodologies, although reliable, but must still be regarded as qualitative; it remains the task of the experienced operator to decide, based on informed interpretation of the trace, whether to proceed with visual inspection, possible rope opening (Figure 2), or further analyses using instruments capable of investigating the detected issue in a more

1. **A detector for magneto-inductive testing on a locked-coil rope, in laboratory conditions, with related digital recorder**
2. **Example of opening of two different haul ropes**

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precise and quantitative way.

The interpretation of traces remains and must remain a specialist activity: the signal is never merely a number, but requires knowledge of the rope, its type, its operating and maintenance history, service conditions and applicable acceptance thresholds according to standards. This reaffirms the central role of the qualified technician, whose importance is not diminished but increased by technology.

Alongside magneto-inductive testing, visual inspection also remains essential because it allows identification of surface defects, evident corrosion, strand deformations, crushing, abrasions, abnormal lubrication or external contamination. However, the limitation of traditional visual inspection is equally evident: it depends on the operator's experience, environmental conditions, lighting, observation speed, available time and human fatigue. It is precisely here that a new frontier emerges: through *computer vision*, we can envisage transforming visual inspection into more objective data that can be recorded and analyzed with tools.

A moving rope can already today be recorded using high-resolution cameras at extremely high frame rates, while controlled lighting systems can highlight surface defects and inclusions. The frames can then be analyzed by algorithms capable of detecting surface damage such as geometric or chromatic variations and external broken wires. The objective is not simply to produce photographs, but to build a "visual map" of the rope. Each image can be linked to a metric progression and to the corresponding magneto-inductive signal. The true innovation does not consist in replacing the magneto-inductive trace with the image, but in connecting the two worlds.

This step is decisive: diagnostics are no longer based on a single information channel, but on integrated interpretation carried out with full awareness.

The review of such a mass of data is implicitly even more demanding and difficult for a human operator than visual inspection itself; in this context, *Machine Learning* models can be trained to recognize recurring patterns: broken wires, corrosion, localized wear, variations in strand lay, crushing, chromatic anomalies, accumulations of foreign material or surface alterations.

Expert systems, which in their evolution today fall under the definition of AI applied to computer vision, can perform four main functions [2]:

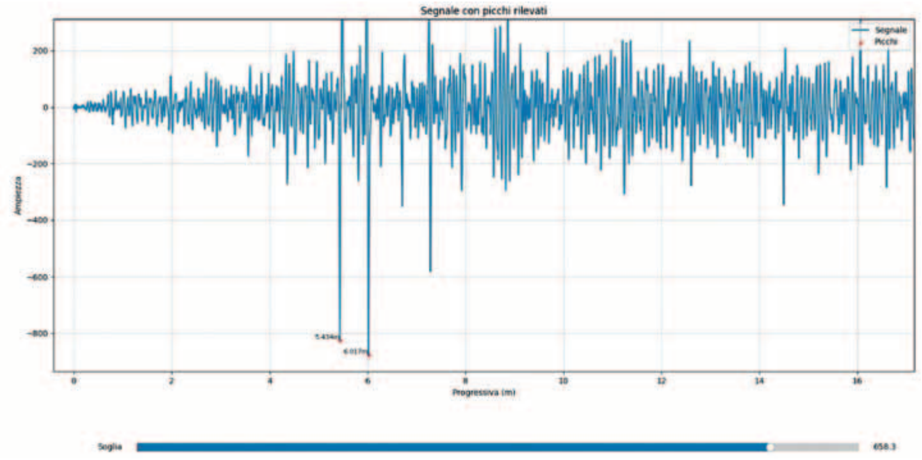
a. Detection: identifying the point where a possible anomaly appears.
b. Classification: distinguishing between corrosion, breakage, deformation or intrusion.
c. Attention level: assigning a priority level to the detected defect.
d. Integrated report: list of anomalies with associated images, metric positions, comparison with previous inspections and indication of areas requiring human verification.

In this way, the report will no longer be merely a sequence of signals but a multilayer diagnostic document, where the technician can observe the peak in the trace, verify the image of the rope at the same point and decide whether the anomaly is consistent with a breakage, corrosion, disturbance or known structural feature. This integration may prove particularly interesting in cases where the magnetic signal alone is ambiguous. A local variation may derive from a broken wire, a surface discontinuity, a contact effect, a construction variation or an operational disturbance. The associated image can indeed help reduce uncertainty [3].

One of the most concrete and immediately applicable frontiers for LF and possibly LMA magneto-inductive examinations [4] concerns numerical trace analysis through dedicated software tools. Signals produced by an MRT (*Magnetic Rope Test*) system can be considered as measurable, filterable, comparable and classifiable data series and, in this context, computational environments such as Python, together with libraries such as NumPy, SciPy, Pandas and Matplotlib, allow transformation of the magneto-inductive trace into a richer analytical object. The signal can be imported, normalized, filtered, segmented by progression and compared with reference thresholds. The ultimate objective is to move from purely visual interpretation to controlled numerical interpretation [5].

A particularly important aspect is the correct use of test wires as calibration references. In test traces, wires of known diameter applied in a defined area generate peaks with measurable amplitude clearly distinguishable from background noise. These peaks can constitute a practical threshold for comparing and evaluating the significance of subsequent anomalies. The algorithm can automatically calculate the amplitude of the peaks generated by the test wires, and subsequent anomalies are therefore highlighted only when their amplitude equals or exceeds the threshold derived from the test wires. This approach is particularly useful because it makes evaluation more consistent between different examinations and reduces the risk of subjective interpretations, increasing repeatability and comparability of trace history. The result can be represented in tabular or graphical form, highlighting the rope areas presenting concentrations of noteworthy events. In this way, the technician can have an ordered list of the most critical sections, with metric position, amplitude and ratio with respect to the reference threshold.

Regarding the above, it is useful to emphasize that one undeniable advantage of numerical tools is the possibility of easily comparing traces acquired at different times, since the examination must be considered in all respects a decision-making element for predictive maintenance. It is not enough merely to know whether an anomaly exists, but also to understand whether it is growing and at what rate, in order to implement appropriate countermeasures. A single anomaly may not be critical if stable, but can become so if it grows rapidly: the value of the inte-



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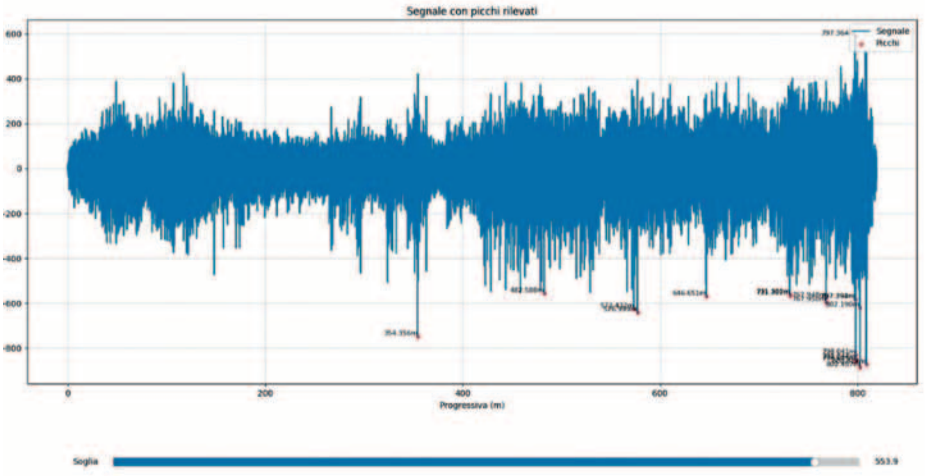
grated system lies precisely in its ability to more easily follow rope evolution throughout its lifecycle.

Despite these advances, the use of expert systems and today's so-called AI applied to steel ropes still presents significant implementation limits. The first limitation concerns datasets, because training a reliable model requires images and signals of real defects classified by experts, acquired under different conditions and representative of many rope types. A model trained on few cases risks correctly recognizing only anomalies already encountered and failing on less frequent defects. The second limitation concerns causality: in the inspection field it is not sufficient for an algorithm to indicate an anomaly; it is also necessary to understand why it was identified, with what confidence and on what basis. The third limitation is technical validation: before being used as a decision-support tool in a safety context, an AI system must be tested, compared with established methods and subjected to repeatable verification procedures. For these reasons, the approach – where AI is used – must remain hybrid: AI does not autonomously determine rope condition nor define objectives independently, but supports the technician in more rapidly identifying critical areas.

3. Example of Python analysis of test wires and detection of the related peaks (Politecnico di Torino)

4. Example of Python analysis of an in-service rope with amplitude peaks highlighted in the area surrounding the test wires

The frontier of magneto-inductive rope examinations is not represented by a single technology, but by the convergence of several tools: "classic" MRT for initial qualitative analysis, visual inspection for surface or internal verification through rope opening, *computer vision* to make visual inspection – at least externally – more complete, objective and documentable, machine learning to classify signals and images, and historical databases to compare defect evolution over time.



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Magneto-inductive examination remains today the primary tool for non-destructive testing of steel ropes, and its strength lies in the ability to detect internal defects and section losses not visible externally. However, the new frontier concerns integration between trace, image, AI where applicable, together with human expertise. The most credible future is an augmented inspection model, in which the technician has access to more powerful tools, richer reports and better-organized data, where the role of AI can accelerate anomaly detection, reduce inspection subjectivity and build archives comparable over time.

The final decision, however, must remain entrusted to qualified personnel capable of interpreting the data in light of experience, regulations and the actual operating conditions of the installation, assisted where necessary by direct observation (abnormal vibrations, noises, frequent stoppages more or less explainable).

The frontier, therefore, is not a rope inspected by a machine instead of a human being, but a rope observed through multiple senses amplified and objectified by technology, with the specialized technician remaining at the center of the decision-making process.

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