Electromagnetic wire rope testers offer excellent inspection accuracy and allow economical and safe rope operation

by Herbert R. Weischedel

Electromagnetic (EM) rope inspections are valuable and cost effective for many wire rope operators. However, the use of wire rope test instruments with insufficient *resolution* (or low *inspection accuracy)* frequently leads to premature rope retirement and, therefore, rope under-utilization and waste. Moreover, insufficient resolution can cause dangerous rope operating conditions and, potentially, rope failures.

Usually, the wire rope operator is not aware of the hidden cost associated with premature rope retirement and the associated waste. Unsafe rope conditions also go unrecognized in many cases. Problems associated with dangerous operating conditions usually surface only when a rope fails.

Rope testers with better *inspection accuracy* (or *resolution*) minimize these problems.

What can dual-function (EM) wire rope testers do?

Electromagnetic wire rope inspection instruments have been developed over the past 90 years. Two different and distinct methods have evolved for the detection and measurement of rope defects.

Loss-of-Metallic Cross-Sectional Area (LMA) Inspection, which (quantitatively) measures loss of metallic cross-sectional area caused by external or internal LMA, such as corrosion and wear.

Localized-Flaw (LF) Inspection, which detects a wide variety of external and internal flaws such as broken wires and corrosion.

Modern dual-function EM rope testers allow simultaneous LMA and LF inspections.

What is *resolution*, and why is it important?

The dictionary defines ***resolution*** as "*the fineness of detail that can be distinguished in an image (or a recording)."* Scientific and engineering instruments used in astronomy, radiology, nondestructive testing, etc. are characterized by their *resolution*. Indeed, for these applications, *resolution* is always the premier performance measure. For instance, people use glasses to improve their vision. Another well-known example: To avoid disturbances caused by the earth's atmosphere and to improve resolution, NASA put the Hubble Space Telescope into orbit and repaired it, all at considerable expense to the American taxpayer. Altogether, the concept of resolution is important in all walks of life, especially in science and technology.

In nondestructive testing, the terms *resolution* and *inspection accuracy* are often used synonymously.

For electromagnetic wire rope inspection, what do the terms *quantitative resolution* or a*veraging length* mean?

In the discipline of electromagnetic wire rope inspection, *quantitative resolution* or *averaging length* (sometimes called *scanning length*) is defined as the minimum length of a uniform flaw for which the sensor provides an accurate measurement of a rope's LMA (loss of metallic cross-sectional area).[1]

Because all wire rope testers have a *quantitative resolution* or a*veraging length* that is greater than zero, minimum flaw lengths are always required for an accurate measurement of LMA. The concept of *quantitative resolution* or *averaging length* is important for specifying and comparing the performance of rope testers.

Why does *resolution* matter?

Figure 1 compares the performance of an LMA-Test™ instrument from NDT Technologies, Inc. with that of a competing rope tester.[2] The LMA-Test™ instrument has an *averaging length* of about 2 inches while the *averaging length* of the competitor is about 12 inches (approximately equal to the length of its sensor head). A comparison of the two LMA traces clearly demonstrates the difference.

As illustrated by this figure, the LMA-Test™ instrument shows the LMA caused by broken wires with gap widths longer than 2 inches to its full extent. Broken wires with gap widths of less than 2 inches are also indicated in the LMA trace, although not with their full magnitude.

In contrast, because of its longer averaging length of about 12 inches, the LMA trace of the competing instrument does not show individual broken wires. Only large clusters of broken wires are indicated. A quantitative evaluation of LMA caused by broken wires – or even clusters of broken wires – is clearly impossible.

Note that the LMA and LF (Localized Flaw) signals of the LMA-Test™ instrument indicate broken wires with equal clarity. However, the LMA signal allows an easier and more accurate evaluation of loss of metal. As a rule, for LMA-Test™ instruments, the LF signal is used to locate broken wires, and the LMA signal is used for an accurate quantitative evaluation of damage. Therefore, the LF signal of LMA-Test™ instruments could be considered supplementary.

For competing rope testers, the resolution of the LMA signal is not as good as the resolution of the LF signal. Therefore, quantitative signal interpretation becomes inaccurate, which poses problems.

[1] Herbert R. Weischedel, "The Inspection of Wire Ropes in Service, A Critical Review," Materials Evaluation , 1985, Vol. 43, No. 13, 1592-1605.
[2] The Magnograph™

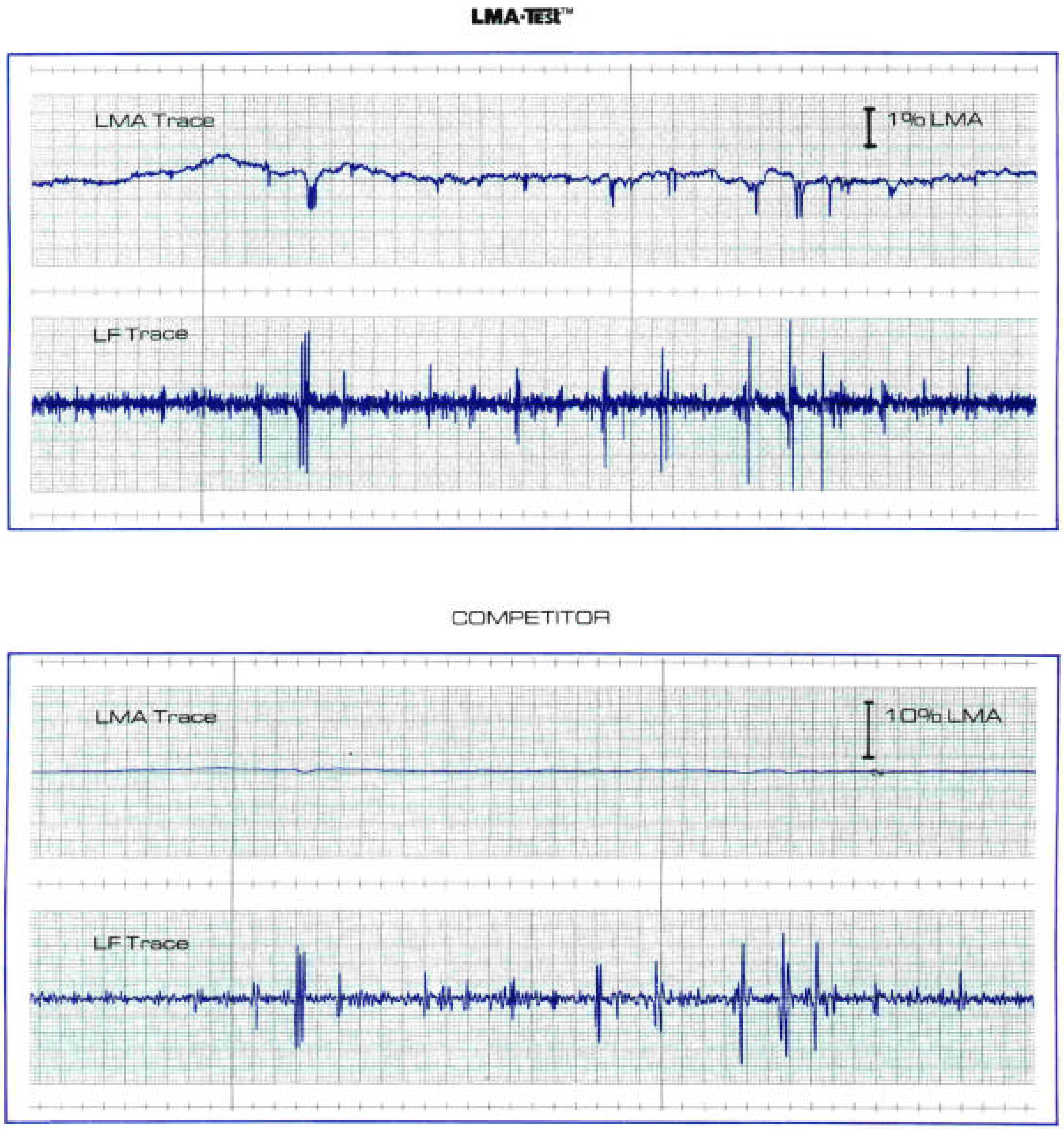

Figure 1: Performance comparison

To visualize the concept of *averaging length*, assume that, instead of measuring metallic cross-sectional area directly, the rope tester continuously measures the metallic volume of consecutive rope sections with lengths that are equal to the *averaging length*. This is illustrated schematically by Figures 2 and 3.

Figure 2a shows a (hypothetical) rope with a uniform 10% LMA extending over a length of 12 inches. An instrument with a 12 inch *averaging length*, should correctly measure this LMA. As illustrated by Figure 2b, a rope tester from the LMA-Test™ series, with an *averaging length* of 2 inches, will also give a true indication of this flaw.

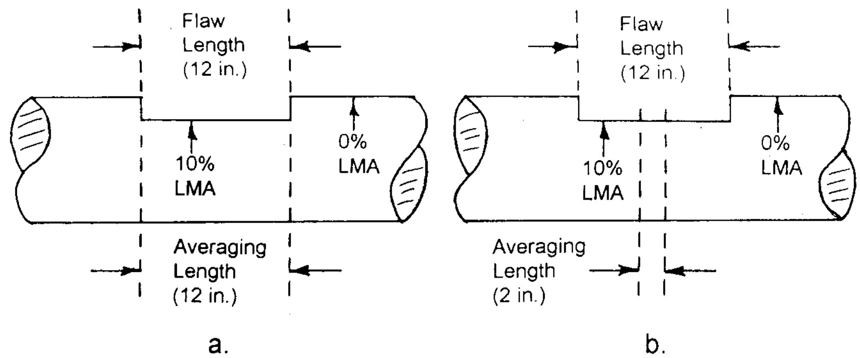

Figure 2: Flaw length and averaging length

The example of Figure 3 shows the importance of a short a*veraging length.* Consider a (hypothetical) rope with a 10% uniform LMA extending over a length of 2 inches. Figure 3b shows that an instrument from the LMA-Test™ series, with an *averaging length* or *quantitative resolution* of 2 inches can determine the exact LMA caused by this flaw. However, an instrument[3] with a an *averaging length* of 12 inches would indicate the same fault as a 1.7% LMA extending over a length of 12 inches – a very inaccurate indication of the true rope condition. This is illustrated in Figure 3a.

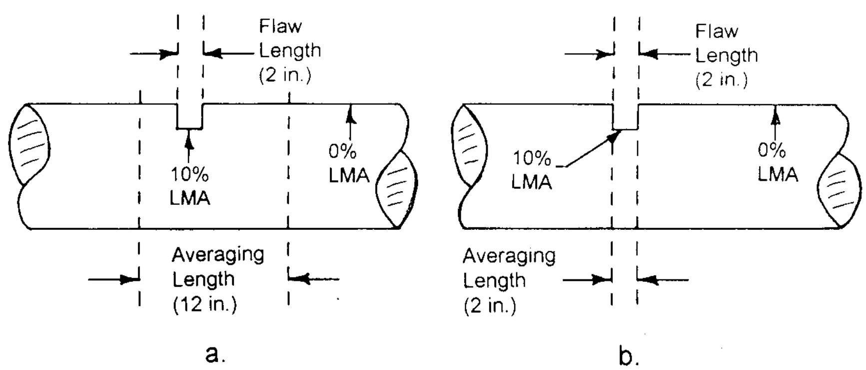

Figure 3: Flaw length and averaging length

An analogy can illustrate the problem: A chain is only as strong as its weakest link. Obviously, the strength of a chain is not determined by the average strength of some of its links. Similarly, the strength of a rope, which has lost metallic cross-section by corrosion and/or wear, is determined by the minimum instantaneous cross-sectional area along the rope's length, and not by some average value of the rope cross-sectional area.

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[3] For example, the Magnograph™ or the Rotescograph™

Typical rope failures caused by LMA illustrate the importance of a short *averaging length*. For example, in many applications, high humidity causes corrosion due to accumulation of water inside the rope. Corrosion causes typical patterns of metal loss: corrosion pitting and corrosion patches. Pitting occurs in the form of very short localized losses on the surface of individual wires, while corrosion patches extend over a number of wires. Corrosion patches have a tendency to form groups with the length of individual patches in the group extending over only a few inches.

These examples show that serious rope deterioration can occur over a very short distance along the length of a rope. Hence, to determine and evaluate a rope's actual metal loss with acceptable accuracy, a short *averaging length* – of no more than a few inches – is important.

Why should wire rope users be concerned about *quantitative resolution*?

The US Code of Federal Regulations (CFR) 30 (Mineral Resources) states – among other conditions - that *a rope must be removed from service …when a loss of more than 10% of rope strength occurs as determined by nondestructive testing*.[1, 4, 5] While the term loss of rope strength is not well defined, it has been implicitly or explicitly – and correctly – interpreted to mean either loss of aggregate strength[6] or, equivalently and in most cases, loss of cross-sectional area (LMA)[7].

In this context, the wire rope inspector must clearly recognize the difference between

- *measured or indicated LMA* (LMA_{meas}), as measured by the electromagnetic rope tester, and
- *estimated LMA* (LMA_{est}), an estimate of the *actual or true LMA* (or simply *LMA*) of a rope.

Depending on the *quantitative resolution* or *averaging length* of a wire rope tester, the inspector has to estimate the *(actual) LMA* from the *measured LMA*. Instruments with low *quantitative resolution* and long *averaging length* do not measure losses of metallic cross-section with sufficient accuracy. A precise evaluation of relatively short defects is not possible with these instruments.

In an attempt to overcome the problems caused by a long *averaging length*, some rope inspection services have developed empirical algorithms for strength estimation. Frequently, these algorithms consist of a simple *correction factor* by which the *measured LMA* reading is multiplied to arrive at a loss-of-strength estimate. A typical value for a correction factor is 1.4.[8]

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[4] D.N.Poffenroth, "Procedures and Results of Electromagnetic Testing of Mine Hoist Ropes using the LMA-Test™ Instruments," OIPEEC Round Table Conference, Zürich, September 1989.

[5] D.N.Poffenroth, "Nondestructive Testing of Mine Hoist Ropes in the United States of America," Open Industry Briefing on Mine Hoist and Elevator Safety, Birmingham, AL, November 1996.

[6] *Aggregate Strength* is defined as the sum of breaking strengths of all individual wires in a rope.

[7] H.R.Weischedel, "Wire Rope Strength Estimates, Retirement Criteria and Electromagnetic Inspection – A Critical Review," Wire Rope News and Sling Technology, December 1993.

[8] For example, Halkin International, Denver CO, in most cases, uses this correction factor for their inspections performed with the Magnograph™.

However, this practice often leads to premature rope retirement – with the associated waste – without completely avoiding dangerous rope conditions.

In some cases, strength-estimation algorithms have been implemented on a computer. However, this is an exercise in futility. The problem is that information is irretrievably lost by LMA averaging. This lost information cannot be recovered by any algorithm – no matter how complicated – or any computer – no matter how powerful. The following simple examples illustrate this situation.

Assume, that a (hypothetical) rope has a uniform LMA of 7.3% extending over a length of 12 inches. An instrument with an *averaging length* of 12 inches will indicate this loss of cross-section to its full extent as a *measured (indicated) LMA* of 7.3%. On other words, if deterioration is extended over a sufficient length of rope, the *measured LMA* is equal to the *actual LMA*, even for an instrument with mediocre *quantitative resolution.* Typically, to arrive at a loss-of-strength estimate, this *measured LMA* value is now multiplied by a *correction factor* of 1.4 to give a *loss-of-strength* estimate of 10.2%, which, according to the CFR, requires rope retirement. This is in spite of the fact that, with an actual 7.3% *loss of strength*, this rope is still in an acceptable condition and does not exceed the CFR retirement criteria of 10% *loss of strength*. In other words, the use of an instrument with insufficient *quantitative resolution* causes premature rope retirement.

It has been observed that, after extended service, ropes frequently – but not always – develop degradation over rope lengths that are longer than the *averaging length* of low-resolution rope testers.[4, 5] In these cases, even low-resolution instruments can indicate directly the correct percentage loss-of-strength. However, because of the low resolution of their instruments, inspectors do not know whether or not their readings are correct. Therefore, to compensate for this uncertainty, they typically apply a correction factor of 1.4. As illustrated by the above (hypothetical) example, the net effect is that, in North America, a great many ropes are retired prematurely after they reach a *loss of strength* of only 7.2%. This causes considerable waste and added expense.

On the other hand, ropes can also develop *loss of strength* areas that extend over lengths that are shorter than the *averaging length* of many rope testers. Then, inspections with low resolution instruments can lead to undetected dangerous operating conditions. The following example illustrates this situation.

Assume that a (hypothetical) rope has a uniform LMA of slightly more than 10% extending over a length of 2 inches. According to the CFR requirements, this rope must be retired. However, an instrument with an averaging length of 12 inches will indicate this loss of cross-section as a *measured (indicated) LMA* of 1.7% extending over a rope length of 12 inches.[9] Now, to arrive at a loss-of-strength estimate, the measured LMA is multiplied by the correction factor of 1.4, which yields a loss-of-strength estimate of 2.4%. This estimate is far off the mark and does not call for rope retirement. Therefore, an instrument with insufficient *quantitative resolution* can grossly underestimate the *loss of strength*. In this case, the use of an instrument with inadequate *quantitative resolution* did not indicate a dangerous rope condition that could, potentially, result in rope failure.

[9] Note, for example, that a uniform LMA of 1.7% extending over a rope length of 12 inches would be indicated by the LMA signal in exactly the same fashion. Therefore, this reading is highly ambiguous.

The above (hypothetical) examples consider rope deterioration of the LMA type with very simple geometries. In reality, the shape of rope deteriorations is much more complex, which makes defect identification considerably more difficult. Therefore, the use of EM rope testers with inadequate resolution becomes even more problematic under actual field conditions.

On the other hand, the U.S. Mine Safety and Health Administration (MSHA)[4, 5] has performed many carefully conducted field and laboratory investigations using LMA-Test™ instrumentation. These experiments have demonstrated that, because of their superior *quantitative resolution*, rope testers from the LMA-Test™ series usually show the true rope condition with sufficient accuracy well within the accuracy limits of the entire EM wire rope inspection method. In other words, for LMA-Test™ instruments, a correction factor of "1" can be used, and the LMA reading can be directly used as the loss-of-strength estimate. For instance, as illustrated by Figures 2b and 3b, LMA-Test™ instruments would show the true rope conditions in both of the above simple example cases.

Summary and conclusion

The use of wire rope test instruments with insufficient *averaging length* or *quantitative resolution* frequently leads to premature rope retirement and/or dangerous rope operating conditions. Rope testers with better resolution can solve most of these problems.

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