NDT TECHNOLOGIES, Inc.
Wire Rope Nondestructive Evaluation
Know Your Ropes. Know What. Know Where. Know Why.

What is Wire Rope Roughness (WRR)?

Why is it Important?

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ABSTRACT

Modern wire ropes have a tendency to deteriorate internally, which makes visual inspections ineffective.

Furthermore, although more dependable than visual inspections, the reliability and effectiveness of present wire rope nondestructive evaluation (NDE) methods and practices leave a lot to be desired.

For example, the custom of using Loss-of-Metallic Cross-Sectional Area (LMA) alone as a rope retirement criterion can be dangerous and is suspect.

In addition, the so-called Localized Flaw (LF) signal, commonly used for evaluating the number of broken wires and clusters of broken wires, is unreliable and frequently deceptive. Therefore, its use for making rope retirement decisions is risky.

The present report outlines the Wire Rope Roughness (WRR) analysis method that can remedy this situation.

WIRE ROPE DETERIORATION MODES

Aside from mechanical damage caused by mishandling and adverse operating conditions, all wire ropes in service deteriorate – and eventually fail – by two principal degradation modes.

1. **Loss of Metallic Cross-Sectional Area (LMA)** caused, for example, by corrosion and wear.
2. **Wire Rope Roughness (WRR)** caused by external and internal broken wires, single and in clusters, inter-strand nicking and corrosion pitting.

   WRR is defined as the aggregate surface roughness of all wires in a rope. WRR is typically caused by and indicates corrosion pitting, inter-strand nicking, broken wires and clusters of broken wires.

WIRE ROPE DETERIORATION MODES OF THE WRR-TYPE, EXAMPLES

The following examples describe some typical rope deterioration modes of the WRR-type.

Corrosion Pitting

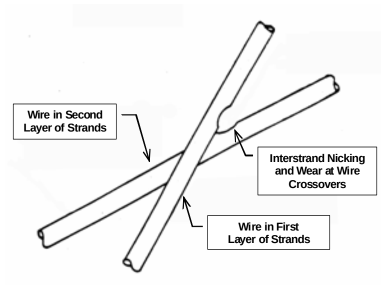
Corrosion is a serious hazard to a wire rope.

Corrosion pitting causes stress concentrations. This kind of corrosion is extremely insidious, as it causes little loss of material with rather small effects on the rope surface, while it damages the deep structures of the metal. The pits on the wire surfaces are often covered by corrosion products.

Corrosion pitting inhibits the free movement of wires and strands, which produces additional stresses in wires. The increased wire stresses combined with the above mentioned stress concentrations can drastically accelerate the development of fatigue breaks.

Corrosion assisted wear can also cause wires to corrode uniformly over their entire surface which may cause a loss of their cross-sectional area (LMA).

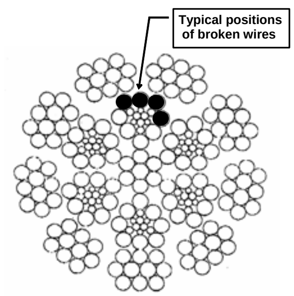
a. Multi-Strand Rope Construction



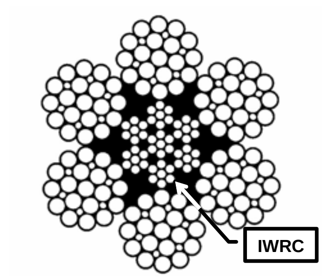
b. Inter-Strand Nicking

c. Inter-Strand Nicking

d. Broken Wires in Second Layer of Strands

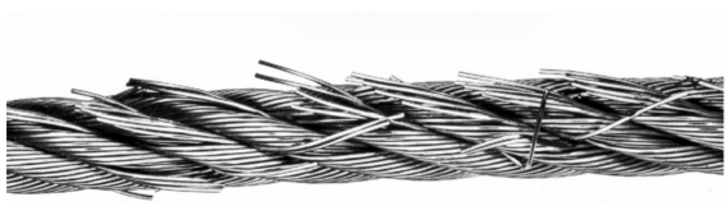


e. Typical Positions of Broken Wires in Multi-Strand Ropes



f. IWRC Rope Construction

g. Internal Broken Wires in the Outer Strands of a Multi-Strand Rope



h. Valley Breaks in an IWRC Rope

Figure 1: Inter-Strand Nicking and Internal Broken Wires

The severity of corrosion often varies along the length of a rope. Frequently, corrosion is localized but, nevertheless, dangerous. The extent of corrosion is often difficult to gauge and – as shown by experience – is usually underestimated.

Internal Broken Wires (Single and in Clusters), Inter-Strand and Inter-Wire Wear and Nicking

Many ropes are of the torque-balanced multi-strand type, comprising two or more layers of strands. Figure 1a shows a cutaway section of such a rope. Torque balance is achieved in multi-strand ropes by laying outer and inner strands in opposite directions.

This type of rope construction limits axial rotation of a freely suspended rope under load. In addition, multi-strand ropes offer flexibility and a wear resistant surface profile.

However, the wires and strands in different layers of these ropes touch locally and at an angle. Therefore, when multi-strand ropes bend over sheaves or on a drum, they are subject to the combined effect of radial loading, relative motion between wires and bending stresses.

Therefore, multi-strand ropes are prone to develop inter-strand nicking (Figures 1b and 1c) and internal broken wires (Figure 1d). This breakup occurs primarily on the interface between the outer and second layer of strands, usually with no externally visible signs as indicated by Figure 1e.

The wires in the second layer of strands typically show nicking and breaks caused by a combination of fluctuating axial wire stresses, inter-wire motions and fluctuating radial loads. The broken wires usually show squared-off and z-shaped ends that are typical for fatigue breaks.

As the wires in the second layer of strands break, the outer strands lose their radial support. This allows the wires of the outer strands to bear against each other tangentially and against the wires of the second layer of strands. The resulting inter-strand nicking restricts the movement of the strands within the rope. Without this freedom of movement, secondary internal fatigue breaks (*"valley breaks"*) in the wires of the outer strands will develop.

Internal wire breaks of the outer strands often will display typical fatigue break patterns with wire ends twice as long or three times as long as those occurring at the crown of the outer wire. Long free wire ends indicate that the breaks did not occur on the rope's surface (see Figure 1g).

As a rule, valley breaks hide severe inter-strand nicking and countless internal wire failures mostly in the second layer of strands. Because valley breaks are usually a sign of severe rope deterioration, ropes with even a single valley break should be retired.

Since deterioration of non-rotating ropes is not easily detected, failure of these ropes is often unexpected.

Similar nicking and fatigue patterns occur also in IWRC (Independent Wire Rope Core) ropes. Figure 1f shows a typical cross-sectional diagram of such a rope. For IWRC ropes, the outer wires of the outer strands have a larger diameter than the outer core strand wires. To minimize inter-strand nicking between the outer strands and the IWRC, these ropes are designed such that the wires of the outer strands and the IWRC are approximately parallel. (This is usually achieved by choosing a *lang lay* construction for the IWRC and an *ordinary lay* construction for the outer strands.)

Typically, the wires of the outer strands are well supported by their neighbors while the outer wires of the IWRC are relatively unsupported.

The result of these geometrical features is that, under fluctuating tensile loads, the outer IWRC wires are continuously forced into the valleys between the outer strand wires and then released. This mechanism results in secondary bending stresses leading to large numbers of core wires with fatigue breaks. These breaks can be very close together and can form groups of breaks. Eventually, the IWRC can break, or it can even completely disintegrate into short pieces of wire about half a lay length long. This condition is commonly called *complete wire rope core failure*.

As the IWRC fails, the outer strands lose their radial support. This allows the wires of the outer strands to bear against each other tangentially. The resulting inter-strand nicking restricts the movement of the strands within the rope. Without this freedom of movement, secondary fatigue breaks in the wires of the outer strands will develop at the strand tangent points. Because these fatigue breaks develop in the valleys between the outer strands, they are also called *valley breaks* (Figure 1h).

Another example. Spiral strand (Figure 2) is made up of concentric layers of wires, some of which are spun in opposing directions to give the strand a measure of torque balance. Therefore, the individual wires in different layers touch locally and at an angle, and the helical geometry within the layers creates radial inter-layer contact forces. When used in mooring applications, spiral strand is subject to fluctuating loads and, especially, bending. Then, depending on the level of axial tension and radius of curvature, spiral strand is subject to interlayer slippage, which causes axial motion between wires in different layers combined with tension and torque stresses. Therefore, it is to be expected that, as a result of these geometrical features, wires in different layers will develop inter-wire nicking and fretting and, eventually, secondary fatigue breaks.

As an aside, spiral strand is frequently protected by plastic sheathing, which prevents corrosion and corrosion pitting. However, plastic sheathing makes visual inspections ineffective..

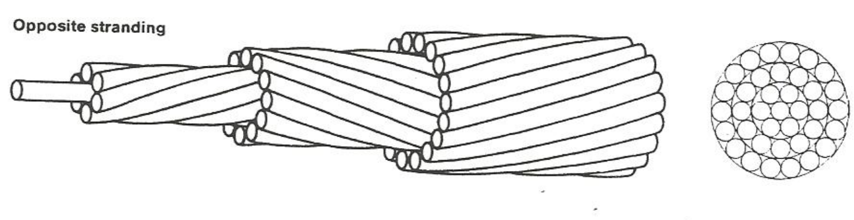


Figure 2: Spiral strand construction

WIRE ROPE NONDESTRUCTIVE EVALUATION METHODS

Three different and distinct wire rope nondestructive evaluation (NDE) methods are now available for the detection and measurement of the above described rope defects.

1. *Loss of Metallic Cross-Sectional Area (LMA) Inspection*, which (quantitatively) measures loss of metallic cross-sectional area caused by external or internal corrosion (due to environmental conditions or poor lubrication) and wear (due to rubbing along floors, nicking, high pressures, and/or poor lubrication).
2. *Wire Rope Roughness (WRR) Analysis*, which (quantitatively) measures external and internal corrosion pitting, inter-strand nicking, broken wires and clusters of broken wires. Broken wires are usually caused by fatigue and inter-strand nicking.
3. *Localized-Flaw (LF) Inspection*, which frequently – but not always – can (qualitatively) detect a wide variety of external and internal discontinuities such as broken wires and corrosion pitting.

The LMA signal is best suited for the detection and measurement of cross-sectional area loss (LMA) caused, for example, by corrosion and wear.

Usually, rope discard criteria specify that a rope must be retired when its percentage LMA exceeds a certain limit. However, if used as the sole retirement criterion, this practice is questionable because the LMA signal does not allow the determination of the number of – especially internal – broken wires in a rope.

To quote one wire rope expert:

> *"We warn strongly against Loss of Metallic Cross-Sectional Area (LMA) measured by a magnetic rope test instrument to be used as discard criterion alone. In practice, we have had ropes fail under their own weight with LMAs of 3 to 5%. It is indeed a very dangerous practice to discard ropes based on LMA alone. A small loss in metallic area of a rope can lead to major reductions in the remaining strength of a rope. Again, from practical experience in the field of NDT and destructive tests of numerous discarded rope samples one must be very, very circumspect in using LMA as discard criterion."*

The WRR signal trace is used for the quantitative characterization (measurement) of external and internal broken wires (single and in clusters) and corrosion pitting. While it allows the reliable estimation of the number of broken wires in clusters, WRR does not allow the measurement of LMA that is caused by corrosion and wear.

The LF signal is primarily useful for the detection of single broken wires. However, the detection of single broken wires in isolation is irrelevant because they are not only rare but also do not affect the strength of a wire rope.

On the other hand, a typical LF chart recorder signal of a single broken wire has a positive and a negative going section. Therefore, positive and negative LF signal components, caused by closely spaced broken wires in a cluster, have a tendency to and will overlap and cancel. This makes the LF signal unsuitable and deceptive for estimating the number of broken wires in clusters.

For example, the amplitude of the LF signal can even decrease as the number of broken wires in clusters increases. This paradoxical behavior makes it impossible to determine – or even estimate – the number of broken wires in a cluster. This has led in the past and leads to erroneous LF signal interpretations with associated serious and potentially dangerous errors in evaluating the actual rope condition. Therefore, the LF signal can be misleading for estimating the number of broken wires in clusters, and it cannot – and should not – be used for making rope retirement decisions.[1]

While all commercially available instruments offer an LF signal, the most advanced triple-function EM rope testers allow simultaneous LMA inspections combined with WRR analysis.

LMA inspections and an associated WRR analysis complement each other.

- LMA inspections allow the measurement of a rope's LMA caused by corrosion and wear.
- WWR analysis allows the reliable estimation of the number of broken wires per unit of rope length and the severity of corrosion pitting.

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[1] This has been convincingly demonstrated in a report titled Martin Dohm: "An evaluation of international and local magnetic rope testing instrument defect detection capabilities and resolution, particularly in respect of low rotation, multilayer rope constructions", pp. 36-59.

To be useful, inspections should be quantitative. This is true because retirement criteria must be – and usually are – based on quantitative data such as *number of broken wires per unit of rope length*, *percentage loss of metallic cross-sectional area, etc.* Therefore, LMA as well as WRR can be used in connection with retirement criteria. For example, typical retirement conditions could be:

- A rope must be retired when the LMA percentage loss exceeds 10%.
- Similarly, while exact retirement values are not yet completely established, a rope could be retired when the WRR exceeds 1% of the rope's metallic cross-sectional area.

A complete wire rope non-destructive evaluation consists of several components. This means, a thorough inspection should, if at all possible, consider all aspects of a rope's condition, including:

a. The findings of a visual inspection,

b. The results of an EM rope inspection, including
  (i) an LMA inspection and
  (ii) a WRR analysis.
  (iii) While quite unreliable, an LF inspection is frequently used as a substitute for a WRR analysis for instruments without a WRR capability.

c. The rope construction,

d. The rope's operating conditions and related damage mechanisms, and

e. The history of the rope under test and that of its predecessors.

In other words,

- the inspector should use all inspection methods available to him, and
- he should know in advance what type of rope deterioration he can expect to find.

SUMMARY

LMA inspections and WRR analyses complement each other, and combined LMA/WRR inspections offer a complete and comprehensive nondestructive evaluation of wire ropes.

In contrast to present LMA/LF inspections, the LMA/WRR evaluation method can be used for making rational – i.e., safe and economical – retirement decisions.

Tables 1a and 1b illustrate the quantitative and qualitative characterization capabilities of magnetic and visual wire rope non-destructive evaluation methods.

TABLE 1a. <u>Corrosion</u> Detection and Quantitative Characterization Capabilities of Electromagnetic Rope Testers Manufactured by NDT Technologies, Inc. and of Visual Inspections

Inspection Method	Corrosion/Wear Detection and Characterization Capabilities	Uniform Corrosion and Wear		Corrosion Pitting	
		External	Internal	External	Internal
LMA Inspection	Quantitative	feasible	feasible	not feasible	not feasible
	Qualitative	feasible	feasible	limited feasibility	limited feasibility
WRR Analysis	Quantitative	not feasible	not feasible	feasible	feasible
	Qualitative	not feasible	not feasible	feasible	feasible
LF Inspection	Quantitative	not feasible	not feasible	not feasible	not feasible
	Qualitative	not feasible	not feasible	limited feasibility	limited feasibility
Visual Inspection	Quantitative	not feasible	not feasible	not feasible	not feasible
	Qualitative	feasible	not feasible	feasible	not feasible
Diameter Measurement	Quantitative	feasible	feasible	not feasible	not feasible
	Qualitative	feasible	feasible	not feasible	not feasible

Legend: feasible (green) not feasible (red) limited feasibility (yellow)

TABLE 1b. Broken Wire and Interstrand Nicking Detection and Quantitative Characterization Capabilities of Electromagnetic Rope Testers Manufactured by NDT Technologies, Inc. and of Visual Inspections

		Single Broken Wires, Gap Width: Wide (>50 mm)		Single Broken Wires, Gap Width: Tight (< 50 mm)		Broken Wire Clusters, Various Gap Widths		
Inspection Method	**Broken Wire Detection and Characterization Capabilities**	External	Internal	External	Internal	External	Internal	Total Core Failure
LMA Inspection	Quantitative	limited feasibility	limited feasibility	limited feasibility	limited feasibility	not feasible	not feasible	feasible
	Qualitative	feasible	feasible	feasible	feasible	limited feasibility	limited feasibility	feasible
WRR Analysis	Quantitative	feasible	feasible	limited feasibility	limited feasibility	feasible	feasible	feasible
	Qualitative	feasible	feasible	feasible	feasible	feasible	feasible	feasible
LF Inspection	Quantitative	not feasible	not feasible	not feasible	not feasible	not feasible	not feasible	not feasible
	Qualitative	limited feasibility	limited feasibility	limited feasibility	limited feasibility	limited feasibility	limited feasibility	limited feasibility
Visual Inspection	Quantitative	feasible	not feasible	feasible	not feasible	feasible	not feasible	not feasible
	Qualitative	feasible	not feasible	feasible	not feasible	not feasible	not feasible	not feasible
Diameter Measurement	Quantitative	not feasible	not feasible	not feasible	not feasible	limited feasibility	not feasible	not feasible
	Qualitative	not feasible	not feasible	not feasible	not feasible	limited feasibility	limited feasibility	feasible

Legend: feasible (green) not feasible (red) limited feasibility (yellow)