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

Inspector Training

Introduction

Wire ropes are **safety critical**, **single points of failure** and **mission critical**.

Wire ropes are complex machines with a great many moving parts. They require attention, skilled operators, careful maintenance, inspection and lubrication.

And yet, in spite of their critical importance, wire ropes are frequently treated as and considered low-tech, uninteresting commodities. Failures are viewed and accepted as "inevitable."

Considering this, we are acutely aware of the fact that an MRT can be only as good as the inspector.

Therefore, we consider operator training an essential element to ensure that our equipment is used correctly. This is true especially in the beginning, when our equipment is first introduced.

We offer training at our facilities at no extra charge with the purchase of our equipment. Training on customer premises is available.

In support of our training efforts we have produced and are producing a series of tutorial videos that can be used as step-by-step guidance for the entire MRT process.

It is our opinion that any inspector familiar with visual wire rope inspections can reasonably acquire the additional skills necessary for MRT examinations with NDT Technologies equipment.

Human Factors

"Human factors" which influence the reliability of MRT are in some instances the weakest link in the MRT quality chain. The MRT quality infrastructure is least developed in this regard.

Attention is required to human motivation to achieve quality inspections. In fact the motivation and commitment to quality of MRT personnel and management is of prime importance in the quest for quality in MRT operations. It is most unlikely that quality can be achieved by certification, standards and validation alone unless the individuals executing MRT are properly trained and motivated.

In many organizations the MRT staff are salaried, work regular hours and are included with other staff in personnel training schemes, staff development schemes, quality circles etc., i.e. they are fully integrated, have the means of achieving a satisfying and worthwhile career and can call upon technical and managerial support.

In contrast, in other cases MRT has often been carried out by staff or by personnel with little or no training and/or insufficient technical background. This is not conducive to high quality.

Management of MRT

Among purchasers and suppliers of MRT services there is often an over-reliance on the use of standards and personnel certification as a guarantee of quality in MRT More emphasis should be placed on the use of all relevant elements of the MRT quality infrastructure, especially

- qualifications and training of inspectors
- use of a supervisory MRT Engineer to:
    - assess task required (inspection geometry, defect targets, proposed procedure) and time available
    - decide if certification and training of inspectors are adequate
    - decide if Job Specific training is required
    - decide if development of specific procedures are necessary, including use of special equipment

Contractual arrangements should be clear in the definition of who takes responsibilities. Users should think in terms of employing a service company capable of accepting technical responsibilities and providing back-up rather than employing operators as individuals.

Either the purchaser of the service retains the key responsibility and simply ‘hires a pair of hands’ or the purchaser buys a service and specifies clearly his requirements. The supplier of the service may then have to qualify his offer if the demands are more onerous than he can guarantee.

The time allowed for preparation and then for execution of an inspection is crucial. Sufficient time must be allowed for both and the contractual arrangements must allow the inspection company to recover its costs.

Training Videos and Trial Software

As a first step to inspector training, we would like to offer tutorial videos and a trial version of our NDT_CARE™ 3.0 (**C**omputer **Ai**ded **R**ope **E**valuation) program.

The link below will direct you to the program (*.ZIP) as well as training videos (*.MP4) and two sample data files (*.ASC and *.txt).

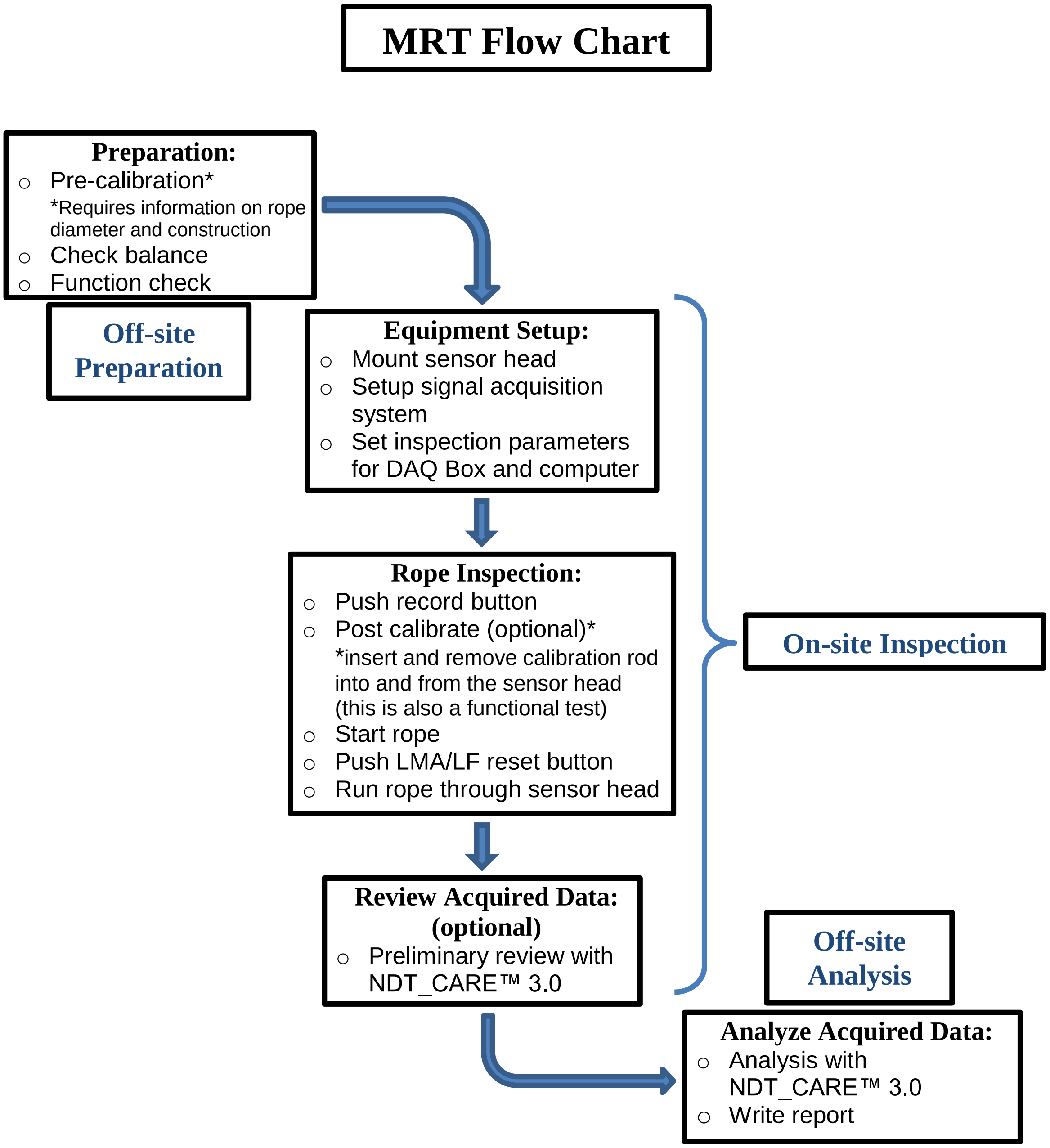
Please download the ZIP file and unzip. Then run the executable file which will walk you through the installation. The first video provides installation instructions if needed. Please select "create a desktop icon" during installation to avoid the need to run as administrator.

https://www.dropbox.com/sh/el75lx5dt0fo2ag/AACfIKkS2foVwbmQQ3RS1f3Ha?dl=0

The software trial period will end on June 30, 2019.

MRT Inspection Process

The following MRT Flow Chart illustrates the MRT inspection process.



As illustrated by the MRT Flow Chart, the inspection process is performed in 3 steps.

Preparation is usually performed off-site at the home base.
It consists primarily of Pre-Calibration, which requires advance knowledge of diameters and construction of the *Rope(s) under Test (RUT)*. LMA pre-calibration and LF balancing are performed by inserting and removing a calibration rod into and from the sensor head. LF balancing can be manual or automatic at the push of a button. LMA calibration is intuitive by setting two markers on the computer screen and then pushing the 'Calibrate' button. The pre-calibration process is illustrated by this video:
https://www.dropbox.com/s/jfb4fkajxumg12b/Calibration%20and%20Equalization%20-%20Take2.wmv?dl=0
Set-up including calibration parameters for various RUTs are stored in individual configuration files for use during on-site inspections. Pre-calibration represents, at the same time, a functional check and an LMA/LF balance check.

On-Site Inspection consists of

- **a.** Equipment setup
  - i. Mount sensor head on rope
  - ii. Set up signal acquisition system: Load appropriate configuration file to set inspection parameters for computer and DAQ box
- **b.** Rope inspection
  - Push record button
  - Post calibrate (optional)*
    *insert and remove calibration rod into and from the sensor head (this is also a functional test)
  - Start rope
  - Push LMA/LF reset button
  - Run rope through sensor head
  - Preliminary review of acquired data (optional)

Analyze inspection results
Our recently developed *NDT_CARE™ 3.0 (Computer Aided Rope Evaluation) Software* allows the accurate and reliable analysis of inspection results. Our Wire Rope Roughness (WRR) analysis method together with our 'Echo Cancelation' algorithm allows highly accurate and reliable quantitative identification and discrimination of external and internal clusters of broken wires, interstrand nicking, and corrosion including corrosion pitting. Our use of Histograms greatly facilitates identification and pinpointing and highlighting the location of rope sections with various pre-specified degrees of deterioration. Histograms indicate at one glance the condition of the entire RUT on one or two diagrams.

The software is purposely designed to be intuitive and guides the user step by step through the analysis process. To illustrate please watch these videos:
https://youtu.be/H3Cf37xEYoE and
https://www.dropbox.com/s/l18vl7smrdc2ip3/14%20NDT%20CARE%203_0%20Stationary%20Calibration%20and%20Speed%20Signal.mp4?dl=0

Note that the example inspection discussed in the video is well documented in several papers that you can download as follows:
Wire Rope Roughness (WRR), a new indicator for the quantitative characterization of wire rope deterioration and **here**.

The basic NDT_CARE™ 3.0 software comes with several add-ins. One of these – very sophisticated – extensions, NDT_CARE™ 3.0 "3D" allows simultaneous plotting of results from consecutive MRTs in one 3-dimensional chart to illustrate the progression of rope deterioration over time.

Another add-in, **NDT_CARE™ (Computer Aided Rope Evaluation) 3.0 "VISTA"**
https://www.dropbox.com/s/xmeunabpn8g58fb/16_NDT_CARE_VISTA.mp4?dl=0 allows the comprehensive documentation of potentially very complex wire rope evaluation procedures involving, for example, combined MRT and visual inspections, including frequent rope stops and reversals.

NDT_CARE VISTA gives a complete record of an entire, possible very complex, rope examination, including

1. LMA, LF and WRR signals
2. Inspection time, distance along rope, total length of rope inspected, rope speed, and start-stop operation.

For example, this software can be used for monitoring the rope condition, distance and speed, and time during complex rope maneuvers like

1. A&R operations of pipelay vessels,
2. Deep sea lifts.
3. Combined visual and MRT inspections when the rope is stopped during an MRT inspection and moved back forth for a visual examination, etc.

Shown in the video are

1. An experimental inspection performed on a test rope at NDT Technologies' facilities. Here, the ends of the rope are welded together to form an infinite loop. The rope is exactly 5 m long. The weld shows clearly on the LMA/LF traces, and it can be used as a 5 m distance marker.
2. Spooling of a Φ 78 mm A&R winch rope that is 3.2 km long and lasted about 10 hours with numerous lengthy stops for repositioning of the pipelay vessel and the supply barge.

Calibration

At this point, it is necessary to emphasize the importance of instrument calibration. In order to assess the wire rope condition properly and to obtain meaningful inspection results, **the LMA signal must be calibrated.** Please read the instructions on **Pre-Calibration and Post-Calibration** below.

Instrument calibration is absolutely necessary because all rational retirement criteria that are based on destructive and/or nondestructive testing must be quantitative (for example: number of broken wires per unit of rope length, percentage loss of rope diameter or loss of rope strength, etc.). The following table illustrates this.

Rope Evaluation Method	Retirement Criteria
Break Tests	Use retirement criteria based on the percentage loss of breaking strength (LBS)
Visual inspection	Use retirement criteria based on number of surface broken wires, rope diameter changes, change of lay length, etc.
Magnetic NDE **Loss of Metallic Cross-sectional Area (LMA) Signal**	Use retirement criteria based on wire rope loss of metallic cross-sectional area (LMA). The LMA signal can be used for the (quantitative) measurement of LMA caused by wear and corrosion.
Magnetic NDE **Wire Rope Roughness (WRR) Signal**	Use retirement criteria based on wire rope roughness (WRR). The WRR signal can be used for the quantitative characterization of the effects of interstrand nicking, number of external and internal broken wires in clusters, corrosion pitting, etc.).
Magnetic NDE **Localized Flaw (LF) Signal**	Retirement criteria based on the LF signal are not feasible and not available. The LF signal might be somewhat useful for the (qualitative) detection of surface or near surface broken wires, and corrosion pitting.

Reference: **Wire Rope Nondestructive Evaluation (NDE) Procedures, Retirement Criteria and Lifetime Prediction Methods for the Safe and Economical Use of Wire Ropes**

In-Situ LMA CALIBRATION

An ***in-situ*** calibration procedure like the approach described in the following is the most accurate and direct method. For an additional discussion of calibration procedures, see the papers of the Appendix.

Calibrating the instrument allows a reading of a rope's loss of metallic cross-sectional area as a percentage of the rope's total metallic cross-sectional area.

Calibration Procedure: *Calibration Wire* Method

The simplest and most direct method of calibrating the LMA output is by comparing the rope cross-sectional area "**A**" to the known cross-sectional area "**a**" of a piece of reference wire (or bundle of reference wires). This procedure is described in the following.

Procure a piece of reference wire (or bundle of reference wires), about 400 mm long or longer. Any wires made from ferromagnetic steel (e.g., florist wires, etc.) are suitable for this purpose.

Cross-Sectional Area of Reference Wire

It is necessary to know the wire metallic cross-sectional area **a** in order to determine the percentage change of a rope's cross-sectional area.

Determine the wire cross-sectional area:

The wire cross-sectional area is
Area $a = (\pi/4) \bullet d^2$ or $a = 0.785 \bullet d^2$,
where **d** is the diameter of the reference wire.
This means, the metallic cross-sectional area of a wire with diameter d = 1 mm is
$a = 0.785 \bullet 1^2 = 0.785\ \text{mm}^2$.

For diameters other than 1 mm, multiply the area of a 1 mm diameter wire by the square of the wire diameter.

Example:

Find the cross-sectional area of a 1.5 mm diameter wire.

Answer:

Wire diameter squared: $d^2 = (1.5)^2 = 1.5 \bullet 1.5 = 2.25$
Multiply diameter squared by $(\pi/4) = 0.785$
Area $a = 1.5^2 \bullet 0.785 = 1.766\ \text{mm}^2$

Example:

Find the cross-sectional area of a 0.079 inch diameter wire.

Answer:

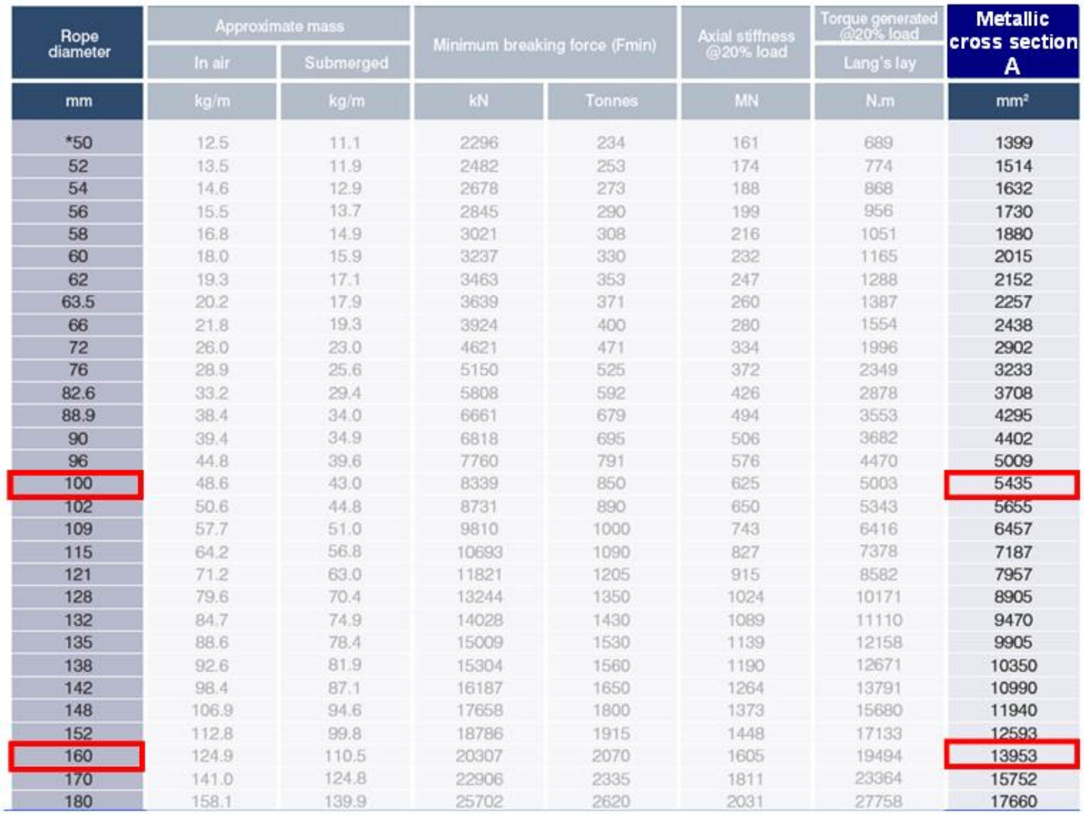
Wire diameter squared: $d^2 = (0.079)^2 = 0.006241$
Wire cross-sectional area: $a = 0.006241 \bullet 0.785 = 0.00490\ \text{inch}^2$.

Wire Rope Cross-Sectional Area

Determine the metallic cross-section A of a wire rope.

The rope manufacturer can usually provide this information.

For example, the following table shows the metallic cross sectional area provided by the manufacturer of Bridon HydraPlus Low-Rotation Multistrand Ropes.



Rope diameter	Approximate mass		Minimum breaking force (Fmin)		Axial stiffness @20% load	Torque generated @20% load	Metallic cross section A
	In air	Submerged				Lang's lay	
mm	kg/m	kg/m	kN	Tonnes	MN	N.m	mm²
*50	12.5	11.1	2296	234	161	689	1399
52	13.5	11.9	2482	253	174	774	1514
54	14.6	12.9	2678	273	188	868	1632
56	15.5	13.7	2845	290	199	956	1730
58	16.8	14.9	3021	308	216	1051	1880
60	18.0	15.9	3237	330	232	1165	2015
62	19.3	17.1	3463	353	247	1288	2152
63.5	20.2	17.9	3639	371	260	1387	2257
66	21.8	19.3	3924	400	280	1554	2438
72	26.0	23.0	4621	471	334	1996	2902
76	28.9	25.6	5150	525	372	2349	3233
82.6	33.2	29.4	5808	592	426	2878	3708
88.9	38.4	34.0	6661	679	494	3553	4295
90	39.4	34.9	6818	695	506	3682	4402
96	44.8	39.6	7760	791	576	4470	5009
100	48.6	43.0	8339	850	625	5003	5435
102	50.6	44.8	8731	890	650	5343	5655
109	57.7	51.0	9810	1000	743	6416	6457
115	64.2	56.8	10693	1090	827	7378	7187
121	71.2	63.0	11821	1205	915	8582	7957
128	79.6	70.4	13244	1350	1024	10171	8905
132	84.7	74.9	14028	1430	1089	11110	9470
135	88.6	78.4	15009	1530	1139	12158	9905
138	92.6	81.9	15304	1560	1190	12671	10350
142	98.4	87.1	16187	1650	1264	13791	10990
148	106.9	94.6	17658	1800	1373	15680	11940
152	112.8	99.8	18786	1915	1448	17133	12593
160	124.9	110.5	20307	2070	1605	19494	13953
170	141.0	124.8	22906	2335	1811	23364	15752
180	158.1	139.9	25702	2620	2031	27758	17660

Note that the rope cross sectional area A increases approximately as the square of the rope diameter D.

<u>Example:</u>

From the above table, a rope with diameter D_1 =100 mm has a cross sectional area A_1 = 5435 mm^2. Therefore, a rope with diameter D_2 = 160 mm has a cross sectional area

$\mathbf{A_2 \approx A_1 \bullet (D_2/D_1)^2}$. Or

$\mathbf{A_2 \approx 5435 \bullet (160/100)^2 = 13913\ mm^2}$.

This is close to 13953 mm^2, which is the value given in the table.

Example:

Specifically, with reference to the metallic cross-section of a rope with diameter **D_1 = 100 mm**, a rope with a "standard diameter" **D_s = "1"** (for example, 1 inch, 1 cm, or 1 mm, etc.) has a "standard metallic cross sectional area"

$$A_s = A_1 \bullet (D_s/D_1)^2 = 5435 \bullet (1/100)^2 = 0.5435$$

The "standard metallic cross sectional area" **A_s** is approximately constant for ropes of the same construction. **This means that A_s is independent of rope diameter for all ropes of identical constructions.**

For example, Bridon HydraPlus Low-Rotation Multistrand Ropes have a standard metallic cross sectional area **$A_s = 0.5435$**.

Other ropes with different constructions have their own **A_s** values that can be determined as described above.

If **A_s** for a certain rope construction is known, cross sectional area values **A** of ropes with any diameter can be determined without resorting to a table.

Example:

Without using the table, find the area A of a 1 inch diameter Bridon HydraPlus Low-Rotation Multistrand rope.

Answer:

$$A = A_s \bullet (1\ \text{inch})^2 = 0.5435 \bullet (1\ \text{inch})^2 = 0.5435\ \text{inch}^2$$

Example:

Find the area A of a 3 inch diameter Bridon HydraPlus Low-Rotation Multistrand rope.

Answer:

$$A = .5435 \bullet (3\ \text{inch})^2 = 0.5435 \bullet 9\ \text{inch}^2 = 4.89\ \text{inch}^2$$

Example:

Find the area A of a 76 mm diameter Bridon HydraPlus Low-Rotation Multistrand rope.

Answer:

$$A = 0.5435 \bullet (76\ \text{mm})^2 = 0.5435 \bullet 5776\ \text{mm}^2 = 3139\ \text{mm}^2$$

The above concepts are further illustrated by the following table that can be used to determine the cross-section of ropes of various constructions.

(C.f., "Wire Rope Users Manual," Wire Rope Technical Board http://www.wireropetechnicalboard.org/main_prod.html).

STANDARD METALLIC AREAS A_s OF ROPES WITH VARIOUS CONSTRUCTIONS*

Construction	Fiber Core	IWRC or WSC
5 x 7	.390	.457
6 x 6	.320	.386
6 x 7	.384	.451
6 x 12	.232	
6 x 19 12/7	.376	.442
6 x 19 S	.404	.470
6 x 19 W	.416	.482
6 x 21 FW	.412	.478
6 x 21 S	.411	.477
6 x 24 15/9	.329	
6 x 25 FW	.417	.483
6 x 26 WS	.409	.476
6 x 29 FW	.420	.486
6 x 31 12/19	.385	.452
6 x 31 WS	.414	.481
6 x 33 FW	.423	.490
6 x 36 WS	.419	.485
6 x 37 18/19 W	.393	.459
6 x 37 FW	.427	.493
6 x 41 SFW	.425	.491

*** Values given are based on 3% oversize because this is a common design "target." But, this figure often varies and is not to be considered a standard. Wire sizes in specific constructions also vary, thus the given values are approximate. They are, however, within the range of accuracy of the entire method that is, in itself, approximate.**

It is necessary to know the metallic rope cross-sectional area in order to determine the percentage change of a rope's cross-sectional area.

For diameters other than "1", multiply the area given in this table by the square of the nominal rope diameter.

Example:

Find the area of a 1/2" diameter
6 x 36 WS IWRC rope.

Answer:

Value from the table: .485
Diameter squared: $(1/2)^2$=1/4 or .5 x .5 =.25
Multiply table value by diameter squared:
Area: .25 x .485 = .121 inch^2

Example:

Find the area of a 1-1/4" diameter
6 x 25 FW FC rope.

Answer:

$(1.25)^2$ x .417 = 1.563 x .417=.652 inch^2

Example:

Find the area of a 28 mm diameter
6 x 37 FW IWRC Rope.

Answer:

28^2 x .493 = 386 mm^2

Percentage Change of Cross-Sectional Area Caused by Reference Wires

Compute the percentage change of the cross-sectional area caused by the reference wire(s). Typically, this percentage change could be about 1% to 5%.

The percentage change of cross sectional area, %CSA, caused by one or several calibration wire(s) is

%CSA = n•(a/A)•100%,

where **a** is the cross sectional area of one calibration wire. **n** is the number of calibration wires**,** and **A** is the cross sectional area of the wire rope under inspection.

Example:

A calibration wire with diameter **d = 1.3 mm** has a cross sectional area of

$a = (\pi/4)\cdot d^2 = (\pi/4)\cdot(1.3\ mm)^2 = 0.785\cdot1.69\ mm^2 = 1.33\ mm^2$.

From the Table, a Bridon HydraPlus Low-Rotation Multistrand rope with diameter **D = 76 mm** has a metallic cross section area **$A = 3233\ mm^2$**.
Therefore, the cross section change for one calibration wire is

%CSA = (a/A)•100% = (1.33/3233)•100% = 0.04%.

For calibrations during actual field inspections of deteriorated ropes, %CSA values around 4-5% are desirable. Therefore, we choose a bundle of **n = 100 wires** for calibration with a total

%CSA = n•(a/A)•100% =100•0.04% = 4%.

Example:

A calibration rod with diameter **d = 7 mm** has a cross sectional area of

$a = (\pi/4)\cdot d^2 = 0.785\cdot1.69\ mm^2 = 38.5\ mm^2$.

From the Table, a Bridon HydraPlus Low-Rotation Multistrand rope with diameter **D = 109 mm** has a metallic cross section area **$A = 6457\ mm^2$**.

Therefore, the cross section change for one calibration rod is

%CSA = (a/A)•100% = (38.5/6457)•100% = 0.6%.

On-Line Calibration[1]

1. Attach the reference wire(s) to the rope under inspection with self-adhesive tape. Make sure that the rope section with the attached calibration wire will run through the sensor head for each test. This way, the attached calibration wire will appear on chart recordings and in acquired computer data files.
2. **Note:** For on-line calibration, the cross-sectional area of the reference wire(s) should be at least 4-5% of the rope cross-sectional area. This is necessary to make the reference wire(s) clearly recognizable even for deteriorated ropes that might have significant LMA variations along their length.

3. Besides serving as a rope cross-section reference, the test wire also establishes a reference location along the length of the rope. This helps to locate the position of anomalies along the rope from corresponding indications on the chart recording.
4. Run rope test.
5. Using the chart recorder, the percentage loss of metallic cross-section along the rope under test can be determined by comparing the amplitudes caused by the test wire(s) to the rope anomaly indications on the chart recordings.
6. The **NDT_CARE™** (Computer-Aided Rope Evaluation) program allows easy and convenient rope evaluation (including on-line calibration) with uncommon accuracy. Please watch the "**Calibration Video**."

Off-Line Calibration

1. For this calibration procedure, mount the sensor head on the stationary rope under test.
2. With the rope stationary, start the data acquisition including, optionally, the chart recorder.
3. Insert and remove the test wire (or test rod), parallel to the rope under inspection, into and from the sensor head.
4. Immediately after off-line calibration, start the rope and proceed with the inspection.
5. **Note:** The Off-Line Calibration and the Pre-Calibration Procedures are very similar. However, for Off-Line Calibration, the **NDT_CARE™** (Computer-Aided Rope Evaluation) program is used instead of the **RopeView**™ data acquisition program. For details, please watch the "**Calibration Video**."

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[1] Instrument calibration should be performed and dimensions of calibration wires should be chosen by considering the following.

- The **length of the calibration wire** should be at least equal to the averaging length, and preferably several times the averaging length.
- Before using the **post-calibration** procedure of the NDT_CARE software, the LMA signal should be enhanced with the **"echo cancellation"** or **"signal enhancement"** algorithm.

The percentage value of **metallic cross-sectional area** of the calibration wire for on-line calibration should be sufficient to make it clearly stand out above "inherent rope discontinuities" that typically occur in used ropes.

Capabilities and limitations of visual and magnetic wire rope inspection methods

1. A complete wire rope inspection consists of several components. This means, a thorough inspection must consider all aspects of a rope's condition, including:
   a. the findings of a visual inspection,
   b. the results of an EM rope inspection,
   c. the rope construction,
   d. the rope's operating conditions and related damage mechanisms,
   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.

2. 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 length*, *percentage loss of metallic cross-sectional area, etc.*

   While often used for the evaluation of test instrumentation, the detection of single broken wires is usually meaningless and not important for making rope retirement decisions.

3. The LMA signal is best suited for the detection and measurement of cross-sectional area loss caused, for example, by corrosion and wear.
4. The Wire Rope Roughness (WRR) signal is used to measure and/or estimate the number of 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.
5. The LF signal is primarily useful for the detection of single broken wires. Note however, that – in contrast to the LMA signal – a typical LF chart recorder signal of a broken wire has a positive and a negative going section. Therefore, positive and negative signal components, caused by closely spaced broken wires in a cluster, have a tendency to overlap and cancel. This idiosyncrasy makes it impossible to determine – or even estimate – the number of broken wires in a cluster, which leads to erroneous LF signal interpretations with associated serious and dangerous errors in evaluating the actual rope condition. Therefore, the LF signal is not useful for estimating the number of broken wires in clusters. The LF signal is mostly used to confirm the indications of the LMA signal.

6. Visual Inspection can detect external deterioration such as external broken wires and external signs of corrosion and wear. Inherently, visual inspection cannot detect internal rope degradation.

   An advantage of visual inspections is the fact that they do not require any special instrumentation. On the other hand, visual inspection can be cumbersome, expensive and unreliable because rope surfaces are frequently covered with grease and must be cleaned before a visual inspection.

7. Diameter Measurements are mostly useful for the detection of severe internal damage such as total core failure and major internal corrosion.

8. Instrumentation from NDT Technologies allow the estimation of the *number of internal broken wires per unit of rope length*, an important capability for the inspection of torque-balanced and IWRC ropes. For these types of rope, internal clusters of broken wires and – ultimately – core failures are the single largest concern for rope inspectors.

   In this context, it should be mentioned that the detailed detection and quantitative characterization of internal broken wires in ropes with many breaks and clusters of breaks pose problems. Difficulties are caused by the fact that, for electromagnetic wire rope inspections, the indication of a broken wire is influenced by a number of parameters like

   a. broken wire cross-sectional area,
   b. broken wire gap width, and
   c. the position of the broken wire within the cross-section of the rope.
   d. For clusters of broken wires, an additional problem is caused by the fact that the relative position of broken wires with respect to each other along the length of the rope is not known. For example, the gaps of broken wires could be aligned or staggered.
   e. Finally and most importantly, broken wires with zero or tight gap widths are not detectable by electromagnetic inspections because they do not produce a sufficient magnetic leakage flux.

   Considering the above, only an estimate of the number of broken wires is possible. Conventionally, the LF trace is used for the detection of broken wires. However, as discussed previously, the LF signal is not quantitative and cannot be used for estimating the number of broken wires.

   On the other hand, for many broken wires and clusters of broken wires, the LMA trace usually shows rapid relatively small variations of cross-section. These variations are significant and can be used to estimate the number of broken wires per unit of rope length. Note, that the *averaging length* or *quantitative resolution* of the instrumentation used must be sufficient to allow this quantitative defect characterization.
   Round Robin tests have demonstrated that only MRT rope inspection instruments from NDT Technologies have sufficient resolution to allow the quantitative evaluation of internal fatigue damage of multi strand and IWRC ropes. All other instruments have failed at this task, some of them miserably. For a further discussion of this topic please refer to the paper titled **Wire Rope Roughness (WRR), a new indicator for the quantitative characterization of wire rope deterioration**.

9. The detection and evaluation of internal broken wires, including broken wire clusters, becomes routine after the correlation between internal fatigue damage and the corresponding results of EM wire rope inspections has been established.

10. The capabilities and limitations of different inspection methods for various types of rope deterioration are classified in Tables 1 and 2.

11. To summarize, nondestructive MRT inspections, if performed by a competent inspector, can greatly increase wire rope safety.

12. Visual inspections, including diameter measurements, can detect some types of wire rope deterioration. However, these inspections are by no means simple and inexpensive, and they require an experienced inspector. An advantage of visual inspections is the fact that no expensive instrumentation is required.

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

		Uniform Corrosion and Wear		Corrosion Pitting	
Inspection Method	**Corrosion/Wear Detection and Characterization Capabilities**	External	Internal	External	Internal
LMA Inspection	Quantitative	🟩	🟩	🟥	🟥
	Qualitative	🟩	🟩	🟨	🟨
WRR Analysis	Quantitative	🟥	🟥	🟩	🟩
	Qualitative	🟥	🟥	🟩	🟩
LF Inspection	Quantitative	🟥	🟥	🟥	🟥
	Qualitative	🟥	🟥	🟨	🟨
Visual Inspection	Quantitative	🟥	🟥	🟥	🟥
	Qualitative	🟩	🟥	🟩	🟥
Diameter Measurement	Quantitative	🟩	🟩	🟥	🟥
	Qualitative	🟩	🟩	🟥	🟥

Legend: 🟩 feasible 🟥 not feasible 🟨 limited feasibility

TABLE 2. 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				Broken Wire Clusters Various Gap Widths		
		Gap Width Wide (>50 mm)		Tight (< 50 mm)				
Inspection Method	**Broken Wire Detection and Characterization Capabilities**	External	Internal	External	Internal	External	Internal	Total Core Failure
LMA Inspection	Quantitative	🟩	🟩	🟨	🟨	🟥	🟥	🟩
	Qualitative	🟩	🟩	🟩	🟩	🟨	🟨	🟩
WRR Analysis	Quantitative	🟩	🟩	🟨	🟨	🟩	🟩	🟩
	Qualitative	🟩	🟩	🟩	🟩	🟩	🟩	🟩
LF Inspection	Quantitative	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Qualitative	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Visual Inspection	Quantitative	🟩	🟥	🟩	🟥	🟩	🟥	🟥
	Qualitative	🟩	🟥	🟩	🟥	🟩	🟥	🟥
Diameter Measurement	Quantitative	🟥	🟥	🟥	🟥	🟨	🟥	🟥
	Qualitative	🟥	🟥	🟥	🟥	🟨	🟨	🟩

Legend: 🟩 feasible 🟥 not feasible 🟨 limited feasibility