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The Inspection of Offshore Wire Ropes: The State-of-the-Art

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ABSTRACT

This paper discusses problems associated with the inspection and discard of wire ropes used offshore. Rope degradation mechanisms are reviewed. Special attention is given to conditions that can lead to internal damage. Electromagnetic (EM) nondestructive inspection methods and their emerging role for offshore applications are discussed and illustrated by examples, which include crane ropes, mooring ropes and diving bell hoist ropes.

INTRODUCTION

Because the reliable and safe use of wire ropes is crucial to offshore operations, concern with their integrity is a constant preoccupation of safety authorities and users. In spite of these concerns, a reluctance to apply appropriate wire rope inspection methods and discard criteria compromises the safety of many offshore operations.

More dependable inspection methods, combined with a better understanding of degradation mechanisms and discard criteria, can notably increase wire rope safety.

Because many offshore ropes deteriorate internally, their inspection solely by visual methods is unsafe. For these ropes, reliable inspection procedures are particularly important. In other cases, visual inspection is possible but may not be practical. For example, mooring ropes are often covered with mud and marine growth. This makes their visual inspection difficult, or impossible.^{1,2} Following the API recommendation³ of washing the rope with a high pressure water jet, is both time consuming and can remove valuable lubricant/blocking compound.

On the other hand, electromagnetic (EM) inspections at regular intervals can significantly increase the safety of offshore ropes. EM inspections are particularly effective when they are combined with visual examinations as part of a comprehensive inspection program.

References and illustrations at end of paper.

Electromagnetic and visual wire rope inspections complement each other. Both are essential for safe rope operation, and both methods should therefore be used for maximum safety.

Because EM nondestructive examinations provide an important additional element of wire rope inspection, the thrust of evolving regulations is clearly toward combined periodic EM and visual inspections.

Furthermore, wire rope inspection and retirement standards are becoming simpler and more lucid. Future guidelines will be easier for inspectors to interpret and for rope operators to fulfill.

A thorough inspection must consider all aspects of a rope's condition, including:

- (1) the findings of a visual inspection,
- (2) the results of an EM rope inspection,
- (3) the rope's operating conditions and related damage mechanisms,
- (4) the history of the rope under test and that of its predecessors.^{4,5}

Users as well as regulatory authorities recognize that careful inspections can significantly increase the safety of wire ropes.

Moreover, dependable inspection procedures, using combined visual and EM methods, can detect rope deterioration at its earliest stages. Therefore, wire rope users can employ them as an effective preventive maintenance tool. To illustrate, here are some practical examples.⁵

- (1) The early detection of corrosion allows immediate corrective action through improved lubrication.
- (2) Accelerating wear and interstrand nicking can indicate a need to reline sheaves to stop further degradation.
- (3) Careful inspections can monitor the development of local damage at the

crossover points of the rope on a winch drum. This way, the operator can determine the optimum time for repositioning the rope on the drum.

A program of periodic inspections is especially effective. To establish baseline data for subsequent inspections, such a program should commence with an initial inspection of the installed rope after a certain break-in period. Subsequent inspections should then be performed at scheduled intervals. In particular, periodic EM inspections allow the documentation of a rope's deterioration over its entire service life.

Offshore applications of wire rope include crane ropes, diving bell lift ropes and mooring ropes.

Offshore crane ropes and diving bell hoist ropes typically have diameters of 25 - 35 mm. These ropes are of the torque-balanced multistrand type comprising two or more layers of strands. Figure 1 shows a cutaway section of such a rope. Torque balance is achieved in multistrand ropes by laying outer and inner strands in opposite directions.

This type of rope construction limits axial rotation of the freely suspended rope under load. However, while multistrand ropes offer flexibility and a wear resistant surface profile, they have a tendency to deteriorate internally.

Mooring ropes for offshore structures are usually of a six-stranded (6x36 or 6x49 Warrington Seale) construction with independent wire rope core (IWRC). Typical diameters are in the range from 70 mm to 127 mm. They are long and expensive. The development of floating production platforms (FPPs) has led to the use of other rope types including large diameter spiral strand and multistrand.

WIRE ROPE DEGRADATION

Several types of damage influence the operating safety of wire ropes. Deterioration can be categorized as follows:

Loss of Metallic Cross-Sectional Area (LMA), a deterioration mode that includes distributed defects such as corrosion (rust) and wear.

Localized Faults (LF), a class of defects that includes broken wires, and corrosion pitting.

In addition, the category of **Structural Faults (SF)** can be defined, which includes various distortions of the rope structure such as loose wires, deformation, mechanical damage, and martensitic embrittlement.

Various types of rope damage, including their associated deterioration mechanisms will be discussed in the following.^{4,2,7,8}

Broken Wires

In running ropes, broken wires develop primarily in sections that move over sheaves, pulleys and winch drums. Typically, they are caused by bending-over-sheave fatigue cycling.

Usually, breaks develop in segments of the rope surface that come into direct contact with the sheave. Here, various contact phenomena compound the fluctuating bending stresses. Breaks in these areas are external and usually visible. However, internal breaks also can develop depending on the loading and, especially, the rope construction.

When multistrand 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. This causes fretting wear or fatigue and interwire nicking across the interface between layers.

Therefore, multistrand ropes are prone to develop internal broken wires. This breakup occurs primarily on the interface between the outer and second layer of strands, usually with no externally visible signs. Figure 2 illustrates the typical internal breakup on the second layer of a die-formed (compacted) multistrand rope after fatigue. It shows interstrand nicking and broken wires caused by a combination of fluctuating axial wire stresses, inter-wire motions and fluctuating radial loads. Note that the broken wires show squared-off and z-shaped ends that are typical for fatigue breaks.

Mooring ropes of the IWRC type are subject to similar fatigue mechanisms. A combined bending-tension fatigue mode is usually focused on the fairlead pulley region.⁹ External and internal fatigue breaks often develop in this area.

Independent of bending, continuing operation under fluctuating tensile loads can cause fatigue breaks of wires in the IWRC and, eventually, failure of the core. Then the reduced core support allows the wires of the main outer strands to bear against each other circumferentially. The resulting interstrand nicking initiates fatigue wire breaks in the valleys between strands at the contact points of the main strands (so-called valley breaks).

Corrosion (Rust)

Corrosion is a serious hazard to a wire rope. Corrosion pitting causes stress concentrations. Moreover, similar to interstrand nicking, corrosion pitting inhibits the free movement of wires and strands. This produces additional stresses in wires. Corrosion, combined with stress concentrations and increased interwire frictional shear stresses, can drastically accelerate the development of fatigue breaks.

Wires can also corrode uniformly over their entire surface. This may reduce their cross-sectional area and cause loose

unstressed wires. Rust can cause shallow pitting on the working surfaces of a rope where the steady rubbing action of the sheave prevents deep cavities. This mechanism accelerates wear. Furthermore, deep corrosion pitting on the internal surfaces of wires can severely shorten service life. The severity of corrosion often varies along the length of a rope. Frequently, corrosion is localized and, therefore, especially dangerous.

Offshore ropes are either immersed in the sea or continually wetted by salt water spray. In addition, heavy use in a marine environment can displace and degrade the rope lubricant. The combined effects of fatigue, corrosion and lubricant degradation can cause rapid internal deterioration where there is no effective form of protection.

Agitation and higher oxygen levels near the water surface will cause more rapid corrosion of mooring ropes in the splash zone.

Wear

Wear results in loss of cross-sectional area of the wires. The problems related to external and internal wear require special attention. External wear usually occurs on the working surface of a rope. Severe external wear can indicate that internal wires are similarly worn. Sometimes, severe wear can cause outer wires -- or clusters of outside wires -- to break abruptly. Rubbing between wires of a strand can cause internal wear.

Loose Wires

External and internal corrosion and wear reduce the strength of wires. Then, instead of breaking outright, wires may stretch locally and become loose. This type of damage can be treacherous. External loose wires do not carry load. Therefore, other -- internal -- wires must bear a disproportionate share of the load and may

break without externally visible signs. Moreover, loose wires allow moisture to penetrate and cause internal corrosion. Loose and corroded external wires, which can sometimes be manually moved, indicate acute danger. Continued use of a rope with loose wires is hazardous.

Deformation and Mechanical Damage

Corkscrew-type deformations can be caused by sheave grooves that are too tight, through manufacturing errors or as a result of severe wear. Corkscrew deformations can cause rope damage by increased exposure to wear. Furthermore, they increase the pressure between adjacent strands, which will eventually cause broken wires.

Kinks are permanent distortions caused by loops that are drawn too tightly. Loops, often precursors of kinks, are formed when a section of a rope under high torsion is allowed to become slack. Usually, ropes with kinks must be removed from service.

A common deterioration mode is peening, also called plastic wear, produced by localized impact or very high bearing pressure. This can occur by the slap of the rope at crossover points as the rope slips from layer to layer while winding on multilayer drums at high speeds. Peening sometimes gives the appearance of heavy wear although there is little loss of cross section. Plastic wear can cause a fin on the edge of a worn wire that provides a ready site for the initiation of fatigue cracks.

Mechanical damage can have many causes such as a solid object hitting the rope, improper handling during rope installation, overloading or shock-loading. Usually, mechanical damage is clearly visible and easy to detect. However, some forms of mechanical damage, such as wire plucking, can be more difficult to locate. (Wire plucking is mechanically equivalent to guitar string plucking.) Lateral scraping of the rope at cross-over points on a winch drum frequently causes this damage mechanism.

It can lead to localized damage in the form of one or several broken wires at set intervals along the rope.

Martensitic Embrittlement

Martensite is a brittle phase of steel formed, for example, when the steel is heated above a critical temperature and then rapidly quenched. It occurs in wire rope as a result of frictional surface heating and the mass cooling effect of the cold metal beneath. Martensitic embrittlement can develop at rope crossover points while winding on multilayer drums. Here the rope can be heated by contact with the adjacent turn, then rapidly quenched by the surrounding metal. Martensite cracks very easily, and such cracks can propagate from the surface through the entire wire.

Under certain conditions, localized martensite can be formed on mooring ropes. In trying to recover an anchor, it is common practice to use a chaser that slides down the rope from the fairlead. The chaser easily becomes caught on the rope. The resulting slip-stick motion provides the surface friction conditions for the formation of local martensite. The detection of this form of damage is not easy. However, where the rope examiner is aware of the use of a chaser, he will be alert and pay special attention.

Combined Failure Modes

In practice, combined failure modes predominate. These include corrosion fatigue and corrosion-assisted wear.

Typically, one type of rope degradation can initiate and ferment interactive deterioration mechanisms.

For instance, in spin-resistant multistrand ropes, different layers of strands are arranged in opposite directions. Here, nicking of wires occurs at the cross contact points between the wires and strands in

adjacent layers. Without effective corrosion protection, the rate of fretting wear is notably enhanced by a corrosive medium. The combined effects of nicking, corrosion and friction prevent the wires from moving freely within the rope. This causes increased local stresses where the rope runs over a sheave or onto a drum. Therefore, wire fatigue rapidly develops. As the various deterioration mechanisms progress, they will eventually cause broken or loose wires or clusters of broken wires. Often, these combined deterioration modes occur at the interface between the surface and the second layer of strands, usually with no externally visible signs.

Figure 3 illustrates the severity of such combined damages. This figure shows a multistrand die-formed crane rope that was used offshore in the North Sea and failed in service. At a short distance from the failure, the exterior showed little damage. However, the combined action of interwire fretting, fatigue and corrosion has destroyed the inner layers.

WIRE ROPE INSPECTION AND RETIREMENT

Two different philosophies are used to decide on rope retirement:

- (1) A **Statutory Life Policy** that mandates rope retirement at certain prescribed intervals. (This means, the **Statutory Life Policy** places a maximum on the time a rope can be in service), or
- (2) **Retirement for Cause** based on retirement conditions that are evaluated periodically by nondestructive inspections. (This means, the **Retirement-for-Cause** approach requires that the rope must be retired when the deterioration exceeds a certain limit.)

Because a **Statutory-Life Policy** is inherently wasteful, regulators have tended

to adopt the Retirement-for-Cause approach wherever appropriate.

Wire rope deteriorates gradually throughout its entire service life. To keep abreast of deterioration, wire ropes must be periodically inspected. Because moderate degradation is normally present, the mere detection of rope deterioration does not usually justify rope retirement.

There are two major nondestructive inspection methods for the detection and assessment of rope degradation: Visual inspections and electromagnetic (EM) inspections.

VISUAL INSPECTION

Among the basic visual inspection procedures are (1) the "rag-and-visual" method and (2) rope diameter measurements.

The rag-and-visual method is a simple yet useful method for detecting a wide variety of external rope deteriorations. Using this approach, the inspector lightly grasps the rope -- which moves at inspection speed -- with a rag or cotton waste. External broken wires will often porcupine and, as the rope moves, snag the rag or cotton waste. The rope is then stopped at that point, and the inspector assesses the rope condition by a visual examination.

Frequently, broken wires do not porcupine. Then, a different test procedure must be used. The rope is moved two or three feet at a time and visually examined at each stop. This method is tedious and, because the rope is often covered with grease, many external and internal defects elude detection.

Another visual inspection tool is measurement of the rope diameter. Rope diameter measurements compare the original diameter -- when new and subjected to a known load -- with the current reading under like circumstances. A change in rope diameter indicates external and/or internal rope damage. Inevitably, many sorts of

damage do not cause a change of rope diameter.

Several visible signs can indicate distributed losses of metallic cross-sectional area, due to corrosion, abrasion and wear. For example, corrosion products, flattening of outer wires and loss or, sometimes, increase of rope diameter frequently reveal external and internal corrosion. However, the extent of corrosion is often difficult to gauge and its significance is even more difficult to assess.

The detection of loose wires is hard. Loose surface wires can sometimes be identified by tapping the rope with a light hammer causing them to vibrate. Because rust and dirt often clog up loose wires, they can usually be detected only after careful cleaning.

Visual inspections are inherently not well suited for the detection of internal rope deterioration. Therefore, they have limited value as a sole means of wire rope inspection. However, visual inspections are simple and do not require special instrumentation. When combined with the knowledge of an experienced rope examiner, visual inspection can provide an indispensable tool for evaluating many forms of rope degradation.

ELECTROMAGNETIC INSPECTION

EM wire rope inspection gives detailed insight into the condition of a rope. Its reliability has made EM testing a universally accepted method for the inspection of wire ropes in mining, for ski lifts, and many other applications.

EM rope inspection methods were developed over the past eighty years. EM inspection systems use coils or permanent magnets to induce a dc or an ac magnetic flux in a section of the rope. Any anomaly in the rope causes a change of the magnetic flux in the rope and especially of the leakage flux that surrounds the rope. Sensors, such as coils or Hall generators, produce analog

signals in response to these flux variations. The analog signals are then used to identify and evaluate defects in the rope.

To detect and classify defects of the LMA and LF type, two distinct EM inspection methods have evolved:

Loss-of-Metallic-Area Inspection (LMA Inspection) gives a (quantitative) measure of loss of metallic cross-sectional area caused by external and internal rope deterioration.

Localized-Flaw Inspection (LF Inspection) pinpoints the location of a wide variety of external and internal localized flaws.

Like the rag-and-visual method, LF inspection is suited only for the detection of localized flaws, especially broken wires. Therefore, small hand-held LF instruments have been called *electronic rags*.

The LMA inspection method detects and measures changes of the metallic cross-sectional area caused by wear and corrosion. More reliable than visual diameter checks, LMA inspection can replace diameter measurements made with a caliper. Therefore, LMA instruments could be called *electronic calipers*.

All EM rope testers can perform either LF-inspections or LMA-inspections. Modern instruments are of the dual function type and can perform combined LF/LMA inspections.

The operation of dual-function LF/LMA instruments is illustrated by Figures 4 and 5.

For LF inspection, the so-called flux-leakage method -- illustrated by Figure 4 -- is used. A section of the steel rope is magnetically saturated in the longitudinal direction by strong permanent magnets. Any discontinuity in the rope -- such as a broken wire or corrosion pitting -- locally distorts the magnetic flux in the rope and the leakage flux that surrounds the rope.

Sensor coils or Hall generators are placed close to the rope. The relative movement of the rope causes the flux leakage to change and to induce voltages in the sensors. Note that sensors used for LF testing are of the differential type. This means that they can sense only changes of the magnetic flux and not the flux itself. Therefore, flaw detection depends on a rapid change of magnetic flux along the rope, typically caused only by broken wires and corrosion pitting.

Figure 5 illustrates the principles used for LMA testing. As for the LF method, strong permanent magnets induce a longitudinal magnetic flux in the rope. When the rope is magnetically saturated, the longitudinal flux is proportional to the rope's metallic cross-sectional area. Therefore, any LMA can be determined by measuring changes in the longitudinal flux, which can be accomplished by several different methods.¹⁰ For example, in Figure 5, an annular concentric coil surrounds the rope. Any change of the metallic cross-sectional area A of the rope causes a change of the longitudinal main flux Φ_M in the rope. Hence, as the rope moves, the changing main flux induces voltages in the test coil that are proportional to the derivative of the magnetic flux Φ_M . The induced voltages are integrated by the integrator circuit, whose output voltage V_I is then directly proportional to the changes of the longitudinal main flux Φ_M . Hence, since Φ_M is proportional to the rope's cross-sectional area A , V_I is a measure of A . Because this approach measures directly the magnetic main flux in the rope, it has been called the *magnetic main flux method*.⁴

The detection of SFs (structural flaws) poses special problems for electromagnetic inspections. For example, loose wires are often caused by LMA that can be detected. However, loose wires do not carry load. So, the actual condition of a rope is often worse than an LMA reading of an electromagnetic inspection indicates. Loose wires with rather small LMA can cause disproportionate reductions of rope strength. Also, rather than directly identifying martensitic embrittlement, EM inspections will only

detect cracked wires caused by this type of damage. Therefore, visual inspections are an important adjunct of EM inspections for the identification and evaluation of such deterioration.

EM INSPECTION RESULTS

Figure 6 shows the sensor head of a dual-function LMA/LF electromagnetic rope inspection system during inspection of a mooring rope. The following paragraphs show chart recordings that illustrate the results of EM inspections.

Example 1:

Figure 7 is an EM inspection chart recording of a 30 mm die-formed multistrand diving bell hoist rope. The rope shows periodic groups of broken wires, probably at crossover points on the winch drum. The maximum LMA was 1%. The broken wires could be identified visually. This rope section is subjected to the full in-air weight as the bell is lowered and raised. On the basis of the EM inspection, a decision was made to cut and reterminate behind the first defect about 58 m from the diving bell.

Example 2:

Figure 8 shows the results of the mooring rope inspection depicted in Figure 6. The chart recording indicates a severe breakup of the internal wire rope core, which is strong evidence of heavy tensile fatigue loading. In addition, the chart indicates severe corrosion, including corrosion pitting. Note that corrosion products are clearly visible in Figure 6.

WIRE ROPE RETIREMENT CRITERIA

The formulation of retirement criteria that are geared to EM inspections is intricate, and requires a sound appreciation of rope deterioration mechanisms and phenomena.

The knowledge of a rope's metallic cross-sectional area and strength play a crucial role in formulating these retirement criteria. To eliminate confusion, it is useful to discuss these concepts first.

The averaging length⁴ or quantitative resolution³ of an EM instrument is important. The LMA channels from all instruments show a loss of metallic cross-sectional area that is averaged over a certain rope length. Therefore, the quantitative resolution or averaging length of all instruments is greater than zero. An accurate LMA measurement always requires a minimum flaw length.

The EM inspector must therefore recognize the difference between indicated LMA, as determined by the EM rope tester, and estimated LMA, an estimate of the actual LMA (or simply LMA) of a rope. Dependent on the averaging length of the instrument, some judgment is necessary in estimating the actual LMA from the indicated LMA.

The following definitions of rope strength are useful:

Breaking Strength (Actual Strength)

The maximum load sustained by a wire rope (or wire) during a monotonic test to total failure.

Aggregate Strength

The sum of breaking strengths of all individual wires in a rope.

Rope Efficiency

A factor obtained by dividing a rope's breaking strength by its aggregate strength. Depending on construction and other factors, the efficiency of ropes is usually in the 70 to 90% range. The rope efficiency of multistrand ropes is typically in the 70 to 80% area.

The function of discard criteria is to ensure, with a sufficient degree of confidence, that a rope will not fail before the next inspection.

A rope breaks when the applied tensile load exceeds its breaking strength. Depending on its operating conditions and construction, a rope will deteriorate throughout its entire service life by one or several degradation mechanisms. That means, its breaking strength will eventually decline to a point where extreme service loads are sufficient to cause failure. Thus, it is to be expected that discard criteria are often defined, either directly or indirectly, by a maximum permissible loss of breaking strength.

However, significant variations in the pattern of changing strength during the lifetime of a rope complicate this apparently straightforward concept. In particular, breaking strength can increase appreciably during the first part of service life. A combination of factors can increase strength:

- (i) During a break-in period, a general bedding in and balancing of the load distribution between the different elements of a rope takes place.
- (ii) In any rope under load, radial forces are transmitted through contact zones between individual wires. In these zones, locally high Hertzian contact stresses compound axial tensile stresses, causing a loss of rope efficiency. During bedding-in, local wear and plastic deformation occur at the wire contacts. This mechanism increases the contact areas, over which the radial forces in the rope are transmitted between wires. The resulting reduction of the Hertzian contact stresses can lead to increases in rope strength.
- (iii) Furthermore, consider a -- hypothetical -- perfectly lubricated rope under tensile loading. Each wire in such a rope would experience a uniform tensile stress. The contribution to axial load from a given wire at any point along the rope is reduced according to its inclination to the rope axis. This is

by far the most significant factor influencing rope efficiency. An increase in frictional coupling between wires -- caused by lubricant degradation or corrosion, for example -- alters this model and increases strength. (Note that a rope with theoretically perfect adhesion would have a rope efficiency of 100%.)

Thus, paradoxically, an increase of breaking strength is a sign of rope degradation. Under no condition should this phenomenon be interpreted or used as an added safety factor.

Depending on construction and operating environment, strength changes during the service life of a rope can be highly variable. However, in the final stage of rope life, breaking strength will always decay rapidly. The objective of discard criteria should be to predict and identify, well in advance, the onset of this final stage.

EM inspections help the inspector in several ways:

- (i) They assist in identifying visible local flaws. Thus, they relieve the rope inspector from the need to concentrate over extended periods.
- (ii) They can identify hidden internal damage.
- (iii) They provide a quantitative indication of loss of metallic area along the full inspected length.

The first two features above will increase the reliability of detecting sections of a rope that are damaged. If considerable lengths of rope must be examined, EM inspections will significantly improve the speed and quality of the inspection. The third item provides quantitative information that is a valuable supplement to the judgment and experience of the examiner.

Interactions between deterioration mechanisms are complex. Therefore, EM

inspections do not eliminate the need for visual inspections. On the other hand, wire rope discard criteria should recognize and use the quantitative information provided by EM inspections.

LMA provides a valuable measure of rope deterioration. However, there are exceptions. For example, wires with martensitic embrittlement can have full metallic cross-sectional area but, at the same time, decreased breaking strength.

Loose wires pose special problems. Because they do not carry load, loose wires with rather small LMA can cause considerable reductions of breaking strength. Therefore, if loose wires are present, the actual condition of a rope is often worse than an LMA reading of an electromagnetic inspection will indicate.

To summarize, in the absence of certain unusual conditions -- like loose wires or martensitic embrittlement -- LMA is a useful measure of wire rope deterioration. It should be incorporated into rope discard criteria and used as supplementary information by inspectors.

These ideas are gradually being accepted by the wire rope community. For example, the proposed US Code of Federal Regulation uses LMA to formulate retirement criteria that are geared to EM inspections.⁴ The Lloyd's Code for Lifting Appliances recognizes the value of EM inspection in discard criteria¹.

SUMMARY AND CONCLUSIONS

For most offshore ropes, inspection solely by visual methods is either unsafe or not practical. On the other hand, electromagnetic (EM) inspections at regular intervals can significantly increase confidence in the integrity of offshore ropes. EM inspections are particularly effective when they are combined with visual examinations as part of a comprehensive inspection program.

Electromagnetic and visual wire rope inspections complement each other. Both are essential for safe rope operation. For a thorough inspection, all aspects of a rope's condition must be considered, including:

- (1) the findings of a visual inspection,
- (2) the results of an EM rope inspection,
- (3) the rope's operating conditions and damage mechanisms, and
- (4) the history of the rope under test and that of its predecessors.

A program of periodic inspections is especially effective. In particular, periodic EM inspections allow the documentation of a rope's deterioration over its entire service life.

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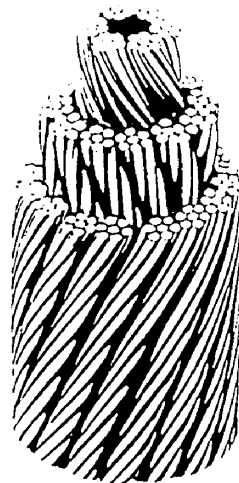


Fig. 1—Construction of multistrand ropes.



Fig. 2—Second layer of die-formed multistrand rope after fatigue.

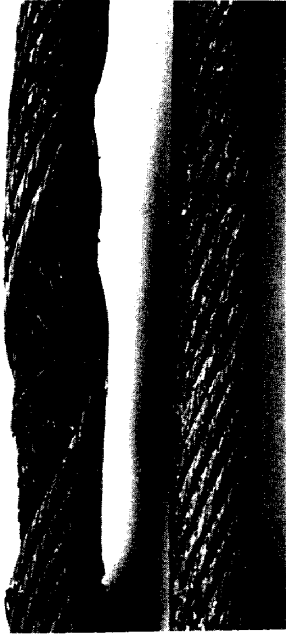


Fig. 3—Combined action of fretting, fatigue, and corrosion on multistrand rope.

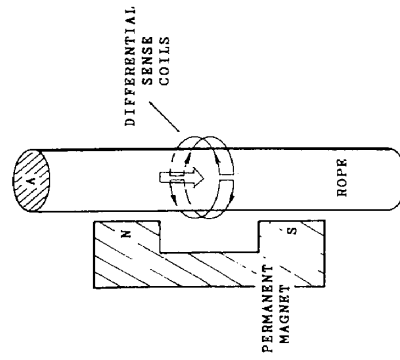


Fig. 4—Leakage flux method with differential coils.

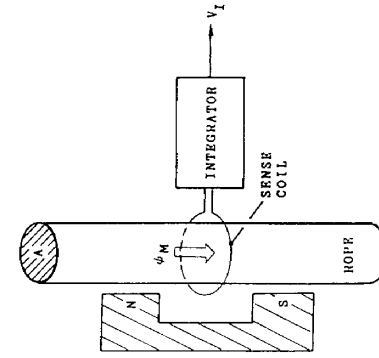


Fig. 5—DC main flux method with sense coil on rope.

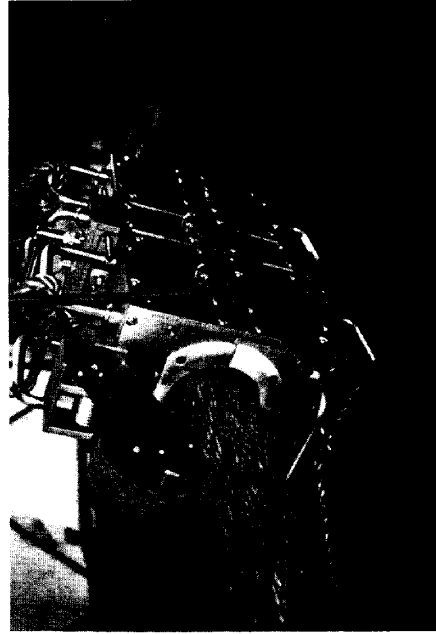


Fig. 6—Dual-function EM rope tester during inspection.

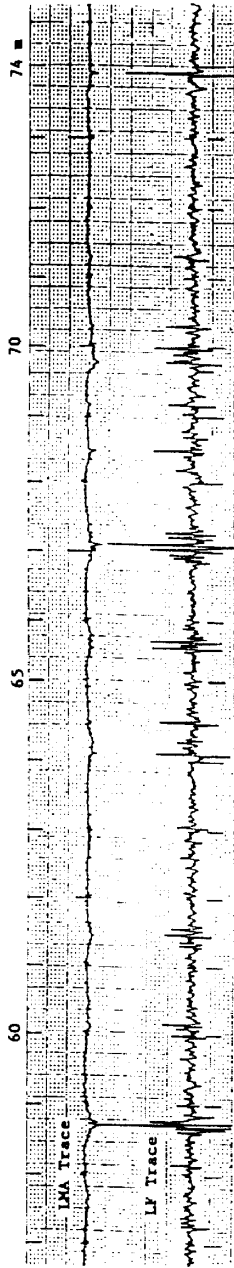


Fig. 7—Chart of diving bell hoist rope.

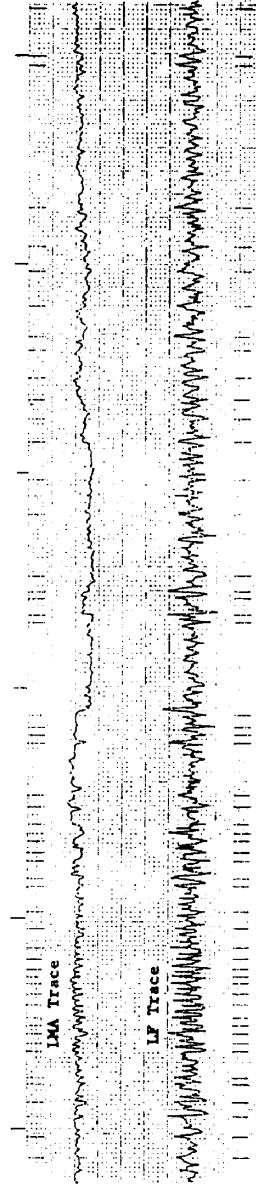


Fig. 8—Chart of mooring rope inspection.