Diving Bell Lift Wire Assessment
Summary

This report details an investigation of the processes of degradation occurring during the service life of diving bell lift ropes.

Two retired ropes, from ESV IOLAIR and SSV UNCLE JOHN, have been inspected in detail using electromagnetic NDT, overall external and full internal visual examination of selected sections, and a range of mechanical tests. Both the ropes examined were of spin-resistant deformed multistrand construction and manufactured from 200 grade galvanized wire, supplied by British Ropes Ltd.

The findings identify the importance of zinc galvanising in controlling corrosion and corrosion fatigue. One end of the Iolair rope appeared to be unused whilst the other showed a total absence of zinc, which is thought to be due to the rope operating in a sacrificial role when the vessel's impressed current system was turned off during diving operations. Both ropes showed signs of external damage in the highly loaded regions, most probably caused on the winch. Fatigue was not identified as a significant factor, although the onset of internal fatigue damage was observed which is consistent with the low number of bending cycles experienced. Re-lubrication had not penetrated far beyond the outer strands, hiding some internal lubricant degradation and making visual inspection almost impossible. The NDT systems tried were found to be highly effective in locating external damage.

Recommendations are made with regard to the importance of galvanizing and its protection, the need for a cut-and-slip of the heavily loaded part, regular pressure re-lubrication and, where practicable, end-for-ending. It is also recommended that the use of NDT inspection devices should be strongly encouraged. The effectiveness of NDT in identifying the internal damage, which is a characteristic of bending fatigue in multistrand ropes, should be the subject of a further investigation.

It is also recognised that any move towards the adoption of the above recommendations will necessitate the development of more appropriate discard criterion for this application.
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INTRODUCTION

Diving bell operations put great onus upon the integrity and performance of the ropes used for lowering and raising manned diving bells. The arrangement of diving bell lifting mechanisms and the nature of offshore operations ensure that diving bell hoist ropes have entirely different loading and environmental exposure conditions to onshore lifting applications using the same rope constructions. Current statutory requirements and guidelines regarding maintenance and discard for diving bell hoist ropes are sketchy and inadequate. New operating guidelines on maintenance and inspection procedures and discard criteria are required which should be based on a sound understanding of rope behaviour and operational experience.

In response to this need the Department of Energy commissioned British Ropes Ltd. to perform a series of bending-over-sheaves (BOS) fatigue tests on six different multistrand rope constructions (British Ropes (1987)), four of which were later examined at Reading University to assess the type and degree of damage (Chaplin and Walton (1987)). These tests showed that ISO 4309 - 1981 discard criteria based on numbers of visible external broken wires gave insufficient warning of imminent failure and were therefore both dangerous and inappropriate for multistrand rope constructions. Examination of sections of the failed ropes identified distinct differences between the rope constructions in the type of internal damage sustained and modes of degradation.

In the light of this work it was proposed to examine retired multistrand diving bell hoist ropes used and discarded in accordance with current operating practice to:

(i) determine the prime causes of rope degradation;
(ii) determine which sections of the rope suffer the most severe degradation;
(iii) evaluate the extent to which variations in operational duty cycle can influence the pattern of degradation; and,
(iv) comment upon the safety and applicability of maintenance/inspection criteria, recommending alternatives as necessary.

LOADING AND ENVIRONMENTAL EXPOSURE CONDITIONS

2.1 Lifting Mechanism Conditions

In general, diving bell hoists appear to conform with the utilization and loading state requirements for Class M5 lifting mechanisms in accordance with ISO 4301 - 1980, Lifting Appliances - Classification. These requirements are summarised in Table 1, though the relevant criteria for diving bell hoists are:
(i) Regular use at a heavy state of loading
   - up to 3200 hours total use
   - frequently subjected to the maximum load and normally to loads of heavy magnitude

(ii) Regular intermittent use at a moderate state of loading:
   - up to 6300 hours total use
   - fairly frequently subjected to the maximum load, but normally to rather moderate loads.

Table 2 sets out minimum recommended load factors of safety and D/d ratios for ropes operating on each class of lifting mechanism, as specified in ISO 4308 – 1981, Cranes – Selection of Wire Ropes. For Class M5 lifting mechanisms the recommended minimum factor of safety on loads is 4.5 and D/d ratios for winches and pulleys are 18 and 20 respectively.

It is standard practice for diving bell hoist ropes to operate with a minimum factor of safety (FOS) of 5 such that the maximum allowable load is MBL/5 (MBL is the rated minimum breaking load of the rope). The safe working load (SWL), i.e. maximum normal working load, as defined in DSM 17/1982, (Appendix B), is the total weight of the diving bell in air at water level (i.e. including maximum cable weight) when operationally manned. DSM 5/1982 (Appendix B) specifies the maximum allowable load (i.e. test load) to be 1.5 x SWL such that in air the rope will be operated at a FOS in excess of 7.5. When submerged, the buoyant weight of the diving bell is about 10% to 20% of its weight in air, thus providing an effective FOS during subsea operations usually in excess of 35.

2.2 Operational Fatigue Loading

In diving operations, the diving bell hoist rope will be subjected to three principal forms of fatigue loading along its length:

(i) Moderate – Heavy BOS Fatigue
   - lifting operations with the bell in air
   - moderate load factor of safety of about 7.5 – 10 with bending over 'fairly tight' pulleys of D/d's of about 20

This will affect the length of rope nearest the diving bell.

(ii) Low Load BOS Fatigue
   - lifting operations with the bell submerged
   - very low loads (FOS ≥ 35) with bending over "fairly tight" D/d's of about 20

Most of the hoist rope will be subject to this Light loading.

(iii) Heavy Bending-Tension (B-T) Fatigue
   - lifting operations with the bell passing through the water surface
   - large load ranges (up to 20% MBL) with small associated bending lengths (i.e. rope stretch) around tight D/d ratios due to buoyancy effects; plus dynamic amplification of these loads due to waves and vessel motions

This will have the most severe effect on the short length of rope at the contact with the first sheave above the bell when the bell
is passing through the water surface but will affect, to a lesser extent, sections of rope at all the sheave contacts between the bell and winch drum. In systems with complex reeving arrangements (especially where a heave compensator is incorporated) this will involve a significant proportion of the rope length between the bell, when at the water surface, and the drum.

Bending-over-sheave (BOS) fatigue occurs when a rope passes over a pulley at constant tension. Long lengths of the diving bell rope are subject to this flexural fatigue which is the classic form of fatigue loading for most running rope applications.

Bending-tension fatigue occurs when very short lengths of rope (usually less than one lay length) are subject to flexure on and off a pulley in phase with fluctuating tensile loads. Very few tests have been performed to model this form of fatigue loading, however it is considered to be a more severe regime than BOS fatigue.

It should be pointed out that for diving bell hoists fitted with heave compensators, or diving bells operating through moon pools, the severity of bending-tension fatigue when the diving bell is at the water surface would be reduced.

Bending-tension fatigue may also occur when the diving bell is fully raised and the hoist rope lifts against a stop, thus stretching the rope around pulleys with increased tension.

2.3 Environmental Exposure Conditions

North Sea diving operations usually only occur in long periods of fair weather, which confines most operations to summer diving seasons. During this period diving may occur at regular time intervals to maintain continuous subsea shifts. Diving bell hoist ropes are only subject to short periods of raising and lowering (i.e. BOS fatigue) although they may be submerged in seawater for long periods of time during these diving operations.

Cathodic protection of diving vessels may be by two means: sacrificial anodes or impressed current systems. Diving bell hoist ropes are usually galvanized for corrosion protection in the marine environment, although curiously enough galvanizing is not a statutory requirement. Wetted hoist ropes may stay fully wound on winches for prolonged periods between dives or in off-seasons. When submerged in seawater, ideally the hoist rope should be further protected by the 'throw' of the vessel's cathodic protection system.

2.4 Statutory Period of Service

There does not appear to be any maximum allowable period of service for diving bell hoist ropes specified in the Health and Safety Act - Diving Operations at Work Regulations (SI 399 (1981)), nor do there appear to be any such requirements set out in Diving Safety Memoranda (DSM) issued by the Department of Energy. Robertson (1986) has advised that the current requirements are not particularly specific and rely heavily on the classification societies and 'competent persons'.
DSM 5/1982 and DSM 17/1982, which superseded it, required examination and testing of the lifting system to be carried out on initial installation, after any major repair or alterations to the plant or equipment, and at six monthly intervals. On these occasions the hoist rope was to be test loaded to a specified proof load of 1.5 x SWL.

British Ropes Ltd. have written guidance notes on socketing installation and maintenance of diving bell hoist ropes (British Ropes (1986)) which were later issued to the diving industry by the Department of Energy for consideration. These guidance notes recommend that:

(i) diving bell hoist ropes are replaced every two years, irrespective of service;
(ii) ropes are not 'end-for-ended' during this period, but tailed and re-terminated every six months (the length to be tailed being determined by a 'competent person');
(iii) before being re-socketed, approximately a 2 metre length is to be cut off adjacent to the socket for later detailed examination and tensile testing to establish the residual breaking strength; and,
(iv) frequent dressings should be applied manually or by automatic system, e.g. every 10/14 days and on every occasion prior to diving operations being suspended for a period of time.

Robertson (1986) points out that a third year's service is recommended if the rope has been pressure lubricated throughout its service life, although no standard for pressure lubrication is specified. Such a standard would need to define the dressing to be used, the degree of penetration and the frequency of applications.

It is believed that a common operating practice is to 'end-for-end' the diving bell hoist rope each year, in addition to six or twelve monthly tailing and re-terminating. By 'end-for-ending' after a year, each end of the diving bell hoist rope would be subject to moderate-heavy BOS fatigue loading for only half of the rope's total service life. The British Rope's (1986) guidelines recommended against this practice since the operations associated with 'end-for-ending' (i.e. winching the rope on and off reels a number of times) could often damage rotation resistant rope constructions by introducing torque imbalances (e.g. birdcaging or waviness) if not carefully controlled. And, as such, end-for-ending was considered impractical for the offshore industry due to space and equipment limitations on diving vessels and other associated problems making it difficult to perform this operation without damaging the rope in the process.

3. 
EXAMINATION OF RETIRED DIVING BELL HOIST ROPES

3.1 
Rope Origins and Scope of Examination and Testing

By arrangement with MaTSU and the Diving Inspectorate, two recently retired diving bell hoist ropes of known origins and service
history, from diving vessels operating in the UK sector of the North Sea were provided to the investigators for detailed examination and testing.

The two diving vessels were:

(i) ESV Iolair operated by BP; and,

(ii) SSV Uncle John operated by Houlder Comex Offshore.

The retired hoist ropes (minus terminations) were delivered on spools to British Ropes Ltd., Doncaster, within a few weeks of being replaced on the diving vessels. At British Ropes, electromagnetic non-destructive testing (NDT) of the ropes was performed using Polish-manufactured Meraster Defectoscope devices from Aberdeen University, BP Research and British Ropes Ltd. The operational principles and details of these devices are set out in Appendix A. Mechanical rope spooling facilities were used in this operation. The purpose of NDT testing was to identify areas of significant damage along the ropes which were marked for later sectioning as test samples or more detailed examination.

Selected representative lengths of rope were subject to detailed visual examination at Reading University to determine the state of lubrication, degree of corrosion and type, location and severity of damage to wires. The rope sections were degreased and dismantled with some constituent wires tested for:

(i) tensile strength and torsional properties; and,

(ii) remaining thickness of zinc coating.

An additional aim of this exercise was to correlate the level of damage in the rope with the NDT signal trace obtained earlier.

Also three samples from different locations along the length of each rope were tested to determine residual breaking strength. These tests were carried out at British Ropes Ltd., Doncaster.

3.2 Hoist Rope from ESV Iolair

3.2.1 Rope and System Details

3.2.1.1 Rope Specification

The diving bell hoist rope retired from the ESV Iolair was a 30 mm diameter Dyform 34 LR (RHO) rotation resistant multistrand rope (Figure 1) manufactured by British Ropes Ltd. It was made using galvanized 200 grade wires with a nominal tensile strength of 200 kgf/mm² (1960 N/mm²) and the manufacturer's rated minimum breaking load (MBL) of the rope was 75.6 tonnes. A breaking strength test on a sample of the rope, as supplied, resulted in an actual ultimate breaking load (UBL) of 70.1 tonnes, some 7 per cent down on the rated minimum breaking load.

3.2.1.2 Rope Service History

The hoist rope was installed in January, 1984 and used for the following three diving seasons (i.e. 1984, 1985 and 1986): then
discarded in accordance with recommended operating practice. It arrived at British Ropes Ltd. for inspection in October 1986.

Information supplied by MaTSU from the Diving Inspectorate put the number of known dives during this period as:

- 1984 - 231 dives
- 1985 - 340 dives
- 1986 - 247 dives

Total - 818 dives

BP reported that the rope was in service for 838 dives (effectively the same number) at an average duration of six hours per dive totalling some 5000 hours in seawater. The average depth of dives was 120 metres and the distance from the top sheave to the water level was 17.2 metres. The hoist winch was in operation for about 38 minutes per dive, of which about 12 minutes of that total were at maximum loading, when the diving bell was raised or lowered in air.

The diving bell weighed 7 tonnes in air but with the cursor, within which the bell was lowered below sea level, and divers and associated equipment, the combined weight was 8.9 tonnes in air. The average submerged weight of the bell with divers and equipment was about 1 tonne. The operational SWL of the system was 9.2 tonnes. The maximum allowable load was set at 14 tonnes – an FOS of 5 on the UBL of the rope.

The lifting system layout for the ESV Iolair diving bell hoist is set out in Figure 2. The rope is wound on a lebus winch drum, passes through a heave compensator consisting of some five pulleys and then to a socket attached to the diving bell. From the information supplied the total rope length from winch drum to water surface has been calculated to be 43 m. The winch drum diameter was 520 mm (equivalent to a pitch D/d = 18.3) and the pulley diameters on the heave compensator were 590 mm (equivalent to pitch D/d = 20.7). The heave compensator is believed to have been inoperative although the hoist rope still ran round the pulleys.

Thus the total number of bending cycles during the service life of the rope amounts to some 16400 \(2 \times 2 \times 5 \times 818\) at a D/d of 20 and FOS of 7.5.

### 3.2.1.3 Rope Maintenance Practice and Testing

Information supplied indicated that neither 'cut-and-slip' nor 'end-for-ending' were carried out. Upon installation and at six monthly intervals the rope was proof-loaded to 1.5 x SWL (13.8 tonnes) in accordance with DSM 5/1982. There is one report of the rope being re-terminated in December 1984, after a year's service. No details have been received of the length tailed or residual strength tests having been performed on this, or other, occasions. No details were available on the frequency or means of re-lubrication.
3.2.1.4 Length of Hoist Rope

The original length of hoist rope purchased was 440 metres, however only some 250 metres was received for inspection. While no explanation for the missing 190 metres was given, a likely explanation is that a cut-and-slip policy has been employed with the lengths discarded being somewhat in excess of the 43 m from drum to water level.

3.2.2 NDT Examination

The rope was passed through the magnetic inspection devices several times to set up the equipment and check the repeatability which was found to be very good. The most useful trace was obtained from the Meraster GP-1 head which, although operating at the lower limit of its rope size range, was still able to pick up areas of rope damage.

The difference in corrosion between the two ends of the rope did not show up on the trace. The trace showed activity in the first 40 m of rope and in a small section of rope 80 m - 84 m (all measurements taken from the corroded end of the rope). Figures 3(a) and 3(b) show a section of the trace at 20 m and 230 m which demonstrates the difference in the two levels of activity. Two sections of rope, 80 m - 84 m (a corroded section with NDT trace activity) and 178 m - 182 m (an uncorroded section) were cut out and brought back to Reading. The two traces, Figures 4(a) and 4(b), indicate wire breaks and damage on section 80 m - 84 m but no obvious damage on 178 m - 182 m. The remainder of the rope was subsequently despatched by road to Reading.

3.2.3 Visual Examination

With regard to external corrosion, the two ends of the rope were totally different. At one end of the rope there was an almost total loss of zinc, which had led to the development of a marked degree of corrosion, with corrosion products evident in the lubricant. This level of corrosion affected approximately half of the rope (about 120 m) with a decreasing level over the next 60 m. The remaining 70 m of the rope was in a clean state, showing no signs of corrosion, and being effectively in 'as new' condition.

The entire rope was well-lubricated on the outside which, combined with corrosion products, made the visible identification of wire breaks more difficult. On stripping down the samples later it was found that the rope was lubricated internally, but this lubrication was starting to dry out near the core.

Sample 178 m - 182 m, from the uncorroded part of the rope, showed very little activity on the NDT trace (Figure 4(a)) and upon examination no external or internal damage was found.

Sample 80 m - 84 m showed more activity on the NDT trace (Figure 4(b)) and, after cleaning, several areas of external damage were found. The damage was due to plastic wear (crushing and flattening) and varied from moderate, where fibrillation of the wires was starting to occur (Figure 5), to heavy, where severe fibrillation had occurred (Figure 6). There was one missing wire (Figure 7) which:
was probably where a damaged wire had been cut out. On stripping down the rope to its constituent strands and cleaning, no internal damage was found apart from normal inter-wire contact wear.

When the remainder of the rope from ESV Iolair arrived in Reading from Doncaster four 1.5 m sections were selected from the area showing high activity on the NDT trace, i.e. the first 40 metres of the corroded end. Two samples (3.7 m and 10.8 m) had no discernible exterior damage apart from slight wear on the crowns and two slightly displaced wires (Figure 8) on the 3.7 m sample. Internally no damage was found apart from contact point wear scars. The other two samples (17.4 m and 20 m) showed a degree of plastic wear on the crowns. On stripping down and cleaning the individual strands, corrosion pitting was found on the inside of the outer wires (Figure 9). On the wires from the second layer strands there was heavy wear at the inter-wire contact points with outer strand wires. This wear had caused splits running longitudinally to the wire axes (Figure 10). These splits occurred regularly along the section of rope examined at approximately every 160 mm, the measured lay length at this section being 210 mm. The inner strand and core strand wires exhibited normal slight contact point wear and no split wires were found.

3.2.4 Galvanizing

As mentioned in Section 3.2.3, 180 m of the rope was corroded with 120 m being severely corroded. Figure 11 shows three groups of wires, one from the bright end of the rope, one from the lightly corroded section and the third from the most severely corroded end—the difference is very marked.

To assess the amount of zinc left on the rope, wire samples from the above mentioned three samples were tested using antimony trioxide in hydrochloric acid in accordance with BS 443: 1982. Although the original mass of zinc per square metre is not known, BS 2763: 1982 gives a minimum for Class Z galvanizing for round wires and is used as a basis for comparison. The results are tabulated in Table 3. For the clean end of the rope the outer and middle wires were slightly below the minimum for Class Z (90% and 70% respectively) while the middle filler, inner and core strands are above the minimum values. For the partially corroded section the outer strand wires were well below minimum, the middle strands having about half (48%) the minimum, the middle filler having above the minimum (131%) and the inner and core strands being just below (86% and 92% respectively). The corroded end of the rope had very little galvanizing left throughout the cross-section (8 - 14%).

3.2.5 Mechanical Testing

3.2.5.1 Breaking Load Tests

To assess any changes of strength three samples (one from the clean end, one from the partially corroded section and one from the corroded end) were sent to British Ropes Ltd., Doncaster, for breaking load tests. The results of all the ultimate strength tests are summarised in Table 4.
Sample (1), taken from the corroded end of the rope, broke at 82.19 tonnes with premature wire breaks audible from 79.4 tonnes to failure.

Sample (2), from the partially corroded section of the rope, broke at 75.9 tonnes with premature wire breaks audible from 70.6 tonnes.

Sample (3), from the clean end of the rope, broke at 71.32 tonnes with premature wire breaks from 67 tonnes.

All three samples broke away from the sockets in a manner indicative of a valid test. It is of note that only the corroded and partially corroded samples reached the quoted MBL of 75.6 tonnes, although all three attained strengths in excess of the strength measured when the rope was supplied (70.1 tonnes).

3.2.5.2 Tensile Wire Tests

Samples of 1.86 mm diameter core wire were tested (to BS 4545: 1970) in a JJ 20 kN tensile testing machine. Outer strand core wires were chosen as they are round and not dyformed. The three wires broke at 5500 N, 5360 N and 5500 N (Figure 12) giving a mean ultimate stress of 2001 N/mm², compared with a nominal wire grade of 1960 N/mm².

3.2.5.3 Torsion Test

Torsion tests (to BS 4545: 1970) were performed on samples of wires from the outer strands from two sections of rope, one set from the clean end of the rope (178 m - 182 m) and the other set from a more corroded part (80 m - 84 m). Samples were twisted and the number of turns to failure counted. The wires tested were dyformed and not round as they should be for a torsion test but the results (see Figure 13) are still indicative of the relative state of the two samples. The wires from the clean end failed above the 21 turns to failure which is the minimum for 200 grade wire given in BS 2763: 1982, whilst the corroded samples all failed below this figure.

3.3 Hoist Rope from SSV Uncle John No. 2 Diving Bell

3.3.1 Rope and System Details

3.3.1.1 Rope Specification

The second rope examined from the No. 2 diving bell on the Uncle John was a 26 mm diameter Dyform 34 LR (RH0) rotation-resistant multistrand rope manufactured by British Ropes Ltd. - the same construction as the ESV Iolair hoist rope. With galvanized 200 grade wire, the manufacturer's rated MBL was 58.7 tonnes. The UBL on a sample of new, as supplied, rope was 56.7 tonnes, some 3.4% down on the rated MBL, a similar deficiency to that noted for the hoist rope on the ESV Iolair.

3.3.1.2 Rope Service History

The rope was installed in April 1983 and retired in January 1987 after four seasons work. It was delivered to British Ropes Ltd. for inspection in April 1987.
Information supplied by Houlder Offshore Ltd. puts the total number of dives during this period at 763. The dive depth varied from 32 m to 300 m with the majority in the 120 - 140 m range. The height of the top sheave to water level was approximately 11 m.

The lifting system layout is as Figure 14 with the bell and cursor being lowered together to below sea level and then the bell being lowered by itself from there. With the bell/cursor combination just below the water level, the total length of rope from the bell back to the drum is approximately 50 m.

The weight of the bell alone was approximately 9.6 tonnes in air and 2 tonnes in water (Macadam, 1987). For the purpose of winch design the weight of the bell and cursor was taken as 15 tonnes which, with a 3 : 1 fall and 0.8 tonnes added to allow for friction, gave a working load of 5.8 tonnes. This figure represents a rope factor of safety of 10 based on the MBL. Once the bell and cursor were lowered to below sea level the bell was then lowered by itself. With a bell weight in water of 2 tonnes, the rope was then operating with a factor of safety of 29.

The pulleys used at the cursor end had a diameter of 590 mm, giving a pulley to rope (D/d) ratio of 22. The diameter of the winch, however, is not known.

Thus the total number of bending cycles during the service life of the rope amounts to a minimum of 15,300 (2 x 2 x 5 x 763) at a D/d of 22 and FOS of 10.

3.3.1.3 Rope Maintenance Practice and Testing

During its life the rope was reported to have been 'end-for-ended' and re-terminated annually with various unspecified lengths cut off. The only re-test certificate available shows that, when tested at British Ropes Ltd. on 13th November 1985, the rope broke at 59.75 tonnes. No details of any visual examination are recorded. It is stated that the rope was re-lubricated at frequent intervals.

3.3.1.4 Rope Length

Delivery records indicate that a rope length of 450 m was supplied but, by the time the rope was re-tested on 13th November 1985, at British Ropes, the length had been reduced to 291 m. When the rope was examined using the NDT equipment after discard, the length was measured as 256 m. As with the Iolair it seems most probable that lengths have been discarded after each season which include the more heavily loaded first 50 m.

3.3.2 NDT Examination

The rope was examined at British Ropes, Doncaster, using both the Meraster GP-1 equipment (as used previously) and a Meraster GP-2 head with a Gould high speed chart recorder. The GP-2/Gould combination was found to give a far superior indication of damage. Figure 15 shows the relative positions of damage indicated, all distances being measured from the most severely damaged end of the rope. The trace shows a significant level of damage for the first 35 m (Figure 16), then a lesser degree of damage, apart from two spikes at 87 m and 93 m (Figure 17) and one at 244 m.
This examination demonstrated that, using NDT equipment with the correct-sized head for the rope and with a superior recorder, an even more informative trace was given than in the previous examination of the ESV Iolair rope. Individual missing wires could be more confidently identified as such and then located on the rope.

3.3.3 Visual Examination

The lubrication on the outside of the rope was patchy over its entire length with severe loss of zinc and zinc corrosion products evident in the valleys between the outer strands (Figure 18). The level of corrosion was fairly consistent throughout the entire length, supporting the statement that the rope had been 'end-for-ended'. The rope had been re-lubricated but the new lubricant had only penetrated to the outer/second strand layer interface — further into the rope the original lubricant was drying out and losing its effectiveness.

Some wire damage was visible even before the rope was degreased and pressure washed. A lot of damage was found on the rope end which showed activity on the NDT trace. The external damage identified consisted of missing sections of wires, plastic wear and displaced wires. The missing sections of wires (Figure 19) are, most probably, due to damaged wires being snipped out during previous examinations whilst in service. The plastic wear (Figure 20) ranged from light to severe with resulting wire splitting and fibrillation. There are also numerous wires displaced or 'plucked out' (Figure 21) throughout the first 100 m (measured from the bell end).

Upon stripping down a one metre sample (located 20 m from the end) which showed extensive external damage, no internal broken or split wires were found. Wear at interwire contact points was minimal apart from on the filler strand wires which showed moderate wear (Figure 22) on the outside (i.e. outer/second strand layer interface).

3.3.4 Galvanizing

Surface corrosion was evident on the external surface of the rope with zinc corrosion products in the strand valleys. The appearance was constant throughout the length of the rope. Wires from each of the strands were tested for residual zinc in accordance with BS 443: 1982. The results (Table 5) show the residual zinc increasing from 9% (of the Class Z minimum) on the outside strands to 14% on the core strand.

3.3.5 Mechanical Testing

3.3.5.1 Breaking Load Tests

Four rope samples were sent to British Ropes Ltd., Doncaster, for breaking load tests (Table 4). Two samples, 21 m - 23 m and 23 m - 25 m, were from the most severely damaged section of the rope, and samples 64 m - 66 m and 66 m - 68 m which showed no exterior damage. The two damaged sections broke at 57.7 tonnes (with premature wire breaks from 40.5 tonnes) and 53.6 tonnes (with premature wire breaks from 32.5 tonnes) whilst the undamaged ones broke at 60.4 tonnes (with premature wire breaks from 55 tonnes) and 59.7 tonnes (with premature wire breaks from 48.5 tonnes). All breaks were clear of the sockets.
3.3.5.2 Tensile Wire Tests

Core wires from one of each of the strands of each strand layer were tested in a 20 kN JJ testing machine. The samples, as for the torsion tests, came from section 20 m - 21 m. Figure 23 shows the load-extension plots and Table 6 lists the wire details and failure loads. The results in the table fall into two groups: the higher group at the nominal wire grade strength, 1960 N/mm², and the lower group exhibiting strengths characteristic of 1770 N/mm² grade wire.

3.3.5.3 Torsion Tests

Samples from all three strand layers were tested. The number of turns to failure of the outer strand wires which were damaged were well down (Figure 24) on the minimum of 21 turns to failure set by BS 2763: 1982. The other wires from the interior were well above the minimum. The low values recorded for the outer wires were due to the torsional failures being focused to positions along the length of the sample which had been most severely weakened by wear.

3.4 Rope Examination Summary

The two ropes used in similar applications differed markedly in external appearance when examined at Reading. The ESV Iolair rope was bright and clean for one third of its length with the external corrosion increasing steadily until there was no visible sign of galvanizing left. By contrast the Uncle John rope appeared uniformly corroded over the entire length of the rope. This apparent loss of galvanizing was confirmed chemically and, where corrosion was significant externally, the internal zinc loss was also severe.

Both ropes had been re-lubricated but the amount of lubrication on the outside of the rope was patchy on the Uncle John rope. The service relubrication had only penetrated to the outer/second strand layer interface and the original lubrication further inside the rope had dried out, allowing corrosion to occur, most probably accelerated by trapped seawater. The working of a rope causes a certain displacement of lubricant; also, over a period of time the lubricant tends to degrade, becoming thicker and more viscous. These two processes result in a progressive increase in internal voids, particularly between strands rather than within the strands. These voids would initially be filled with lubricant but, once the lubricant has been displaced, will then be filled to some extent by seawater when the bell is lifted and the rope wound onto the drum. Given time and reasonable ventilation the water will largely evaporate but, if the rope surface is relubricated before drying out, the water and some air will be trapped within the rope, creating an environment for internal corrosion to proceed, no signs of which will be externally apparent.

External damage on the ESV Iolair rope was not very extensive and consisted of areas of plastic wear leading in some cases to fibrillation of the wires. The only internal damage found consisted of longitudinal splits in wires at the contact points on the outside of the second strand. On the Uncle John rope plastic wear was more severe at one end, with several missing wires where damaged wires had been clipped out during previous rope examinations. There were...
numerous wires displaced or 'plucked out' on the outside of the rope. No significant internal damage was found, only normal wear at interwire contact points.

Most of the tensile tests on wires from both ropes gave the ultimate stresses expected of the grade of wire used (200 grade) and the wires, apart from damaged external wires, exceeded the minimum number of turns to failure in torsion tests. The residual ultimate strength tests for the ESV Iolair rope gave results of 82.19, 75.9 and 71.32 tonnes for corroded, partially corroded and clean samples. Of the Uncle John rope samples, the damaged section samples broke at 53.6 and 57.7 tonnes and the nominally undamaged section samples broke at 59.7 and 60.4 tonnes.

4. DISCUSSION

4.1 Limitations Resulting from Incomplete Information

The investigation has been handicapped to some extent by difficulties experienced in obtaining complete operational details. Comprehensive details of the rope rigging system were provided for the Uncle John rope but some doubt remains concerning the cursor arrangements for the ESV Iolair. Unfortunately we were unable to obtain any information on the results of the periodic visual examination of the ropes which, along with the discarded lengths of the original rope, would have provided valuable additional information.

Because of the uncertainties regarding the cut-and-slip policies implemented, it is clear that some reservations must be expressed regarding conclusions relating to the sections of rope immediately adjacent to the bell, which have probably only experienced the more severe local loading for a proportion of the full service life, i.e. the sections of each rope attached to the bell have only been in that position since the re-tailing operation prior to final discard.

4.2 Condition of the Ropes related to their Service History

The two diving bell hoist ropes were used in similar applications so it is surprising to find such a marked difference in external appearance. To find a possible reason for this it is necessary to look at the vessels' respective cathodic protection systems. The operation of the vessels' cathodic protection system will affect the degree of corrosion of the ropes. It is known that the SSV Uncle John maintains an impressed current system at a maximum of -0.8 V (to a silver chloride reference electrode) which is not switched off during diving operations. Unfortunately it is not known if the cathodic protection system on the ESV Iolair was kept switched on during diving operations although there have been some informal indications that it was not. If it were switched off then the galvanizing on the rope would, in effect, become the sacrificial anode for the entire vessel, which is consistent with the severe loss of zinc from the bell end of the Iolair rope.

The operational procedure of end-for-ending would also affect the distribution of corrosion along the length of the rope. Although the

*(It is known that current practice on the Iolair is to maintain the impressed current throughout diving operations).*
practice of end-for-ending a rope is no longer recommended (British Ropes, 1986) since it may result in rope damage, it would ensure that each extreme was subject to immersion for only half its life (contingent upon the cut-and-slip policy). It is obvious from the 'as-new' end of the ESV Iolair rope, the winch end, that it was not. However, the relative uniformity of corrosion throughout the length of the Uncle John rope was consistent with it having been end-for-ended. Note that end-for-ending may result in wetted rope being transferred to the inner layers on the drum, possibly exacerbating the corrosion problem.

Although the Uncle John rope had an even degree of corrosion along its length consistent with the rope being end-for-ended, the mechanical damage was concentrated at one end. The reason for this may lie in the fact that we only received about 60% of the original length of rope and the heavily loaded section, which would have been at the drum end after end-for-ending, has been discarded.

The mechanical damage found at one end of the Uncle John rope and, to a lesser extent, on the Iolair rope is consistent with the rope periodically running over a hard obstruction. The 'plucking', however, is more representative of damage caused on the winch drum either as a result of severe fleet angles or Lebus winding problems.

No significant fatigue damage was found on either rope although some internal longitudinal splitting of wires was present. This splitting is likely to be a function of the wire metallurgy and residual stress state in combination with the onset of fatigue damage.

The noted absence of significant fatigue damage is consistent with the number of bending cycles experienced by both ropes. The full estimated number of bending cycles for the Iolair rope is 16,400 (at FOS of 7.5 and D/d of 20), and for the Uncle John 15,300 (at FOS of 10 and D/d of 22). These numbers may be compared with British Ropes (1987) test results for 14 mm dyformed 34 LR with a mean life of 39,500 under more severe loading (FOS of 5 and D/d of 20). Note end-for-ending and tailing would each reduce the number of cycles experienced at the full load.

The breaking load test on the 'as new' part of the Iolair rope gave a strength effectively the same as the installed value which was less than the MBL. A similar short fall in initial strength was apparent for the Uncle John rope. Work by Davidsson (1955) has indicated that successive flexing of a new rope over pulleys can improve the load distribution with the rope and so increase strength. This effect may be expected to be more noticeable in ropes of multistrand construction with 200 grade wire. However, where corrosion and loss of lubricant are also involved, a further strength enhancement may be expected due to the increased coupling between wires (Chaplin and Tantrum, 1985). This latter effect helps to explain the significant strength enhancement observed for the corroded Iolair rope samples.

The ultimate load tests on damaged samples from the Uncle John showed that even in the worst case the strength had fallen only 3.5% below the initial strength value thus maintaining an adequate FOS on the safe working load.
The individual wire test on the ESV Iolair rope gave a mean ultimate stress value of 2001 N/mm² with all three values being above the minimum for 200 grade wire (1960 N/mm²). The tests on the Uncle John rope, however, gave two values in the 180 grade class and two values in the 200 grade class. Although unusual it is not unknown for rope manufacturers to mix grades in a rope as long as the finished rope meets the specification.

The torsion tests clearly demonstrate the difference between the clean end and the damaged, corroded end of the ESV Iolair rope with the wires of the latter failing at significantly fewer turns than the former. The effect of damage is also shown up by the difference between performance of outer wires and inner wires of the Uncle John rope with, again, the outer wires failing below the specified minimum and the inner wires above.

4.3 Problems Associated with Wire Rope Examination and Discard

The normal method of examining ropes is by visual inspection and the criteria for discarding ropes are based either on the presence of a pre-determined degree of wire degradation within a stated length of rope or by setting a fixed limit on its service life, measured either by time per se or by hours worked. If the life of a rope is based solely on time then the rope is usually retired much sooner than it need be due to the essential conservatism inherent in such an approach. However, some form of visual examination is also required to detect mechanical damage and corrosion which could necessitate ending a rope's life before expiry of the normal service life.

Most industries which have traditionally used wire ropes, e.g. mines, docks, etc., have their own standards for the examination and discard of wire ropes. ISO 4309 - 1981 and BS 6570: 1986 detail discard criteria primarily for lifting applications and sets maximum numbers of visible external wire breaks per given number of rope diameters as well as covering the assessment of wear, corrosion and deformation. These standards depend heavily upon the 'competent person' and his ability to examine the rope thoroughly and consistently.

There are numerous problems in the visual inspection of ropes. The first and perhaps the most serious is that it is very difficult, if not impossible, to examine satisfactorily the inside of a rope. Short lengths of smaller diameter rope may be examined by clamping jaws to the rope a short distance apart and twisting the rope in the opposite direction to the lay. This is virtually impossible with larger diameter ropes and with multistrand ropes one can only expose the second layer of strands and not the inner layers, whilst running the risk of upsetting the torque balance of the rope at that point.

In order to perform a thorough visual inspection of the outside of a rope it needs to be cleaned first, since it is very difficult to spot damaged wires under a layer of dirty grease. Even after cleaning it is still very time-consuming and fatiguing to inspect a length of rope which, in the case of a diving bell hoist rope, can be 450 m long. One method commonly used to aid inspection is to hold cotton waste around the moving rope and watch for broken wires snagging the cotton. This method is unlikely to indicate anything other than protruding broken wires.
The construction of dyformed multistrand rope which gives the rope its beneficial properties for diving bell hoist applications (low rotation, high strength, flexibility and wear resistance), also makes inspection and assessment of fatigue performance more difficult than with conventional six strand rope. Figure 25 shows the difference between a conventional 6 x 19 classification rope and the dyform 34 LR rope. A greater surface area of the strands of the 6 x 19 rope is exposed for visual inspection with only the core totally obscured. The multistrand rope has a much greater proportion of its mass hidden from view by the outer strands.

In bending fatigue the dyform multistrand rope has a greater fatigue life (approximately 75% greater) than an equivalent six strand rope, but the broken wires that signify the approach of the end of the rope's life occur in different positions due to different failure mechanisms (Chaplin and Walton, 1987). When a rope is fatigued over sheaves it is a common misapprehension that a rope acts like a steel bar with the greatest stresses at the surface of wires furthest from the pulley axis. Because of the low shear transfer between the wires, they tend to bend more-or-less independently and stresses may be predicted with reasonable accuracy on this basis (Wieck, 1973). However, the severe transverse loading associated with pulley groove contact exacerbates the bending stress component and in six strand ropes this is the most common location of fatigue failures. The equal lay construction within the strands of a six strand rope provide a reasonable line contact for re-distribution of these transverse load components. However, in multistrand ropes the situation is quite different with the proportionately smaller strands crossing each other with high radial loads, leading to sawing motions and additional radial bending (sometimes called secondary bending). These wear patches are most severe at the outer/second strand contact points. Damage at these locations cannot be detected by visual examination of the rope, thus rendering the ISO and BSI discard criteria based on external, visible wire breaks wholly inappropriate, in that the criterion may only be reached at failure (British Ropes, 1987).

4.4 The Use of Electromagnetic NDT in Rope Examination

The use of electromagnetic NDT equipment, although not very widespread in this country, is used extensively in other countries, such as France and Canada, where for certain applications their use in rope examination is mandatory. NDT examination using suitable instrumentation and a trained operator has several advantages over visual inspection:

(i) it is much quicker and more convenient and as a result inspection can be carried out at more frequent intervals;
(ii) the effectiveness is not influenced by rope coverings such as grease or plastic sealing material;
(iii) interior damage can be quickly assessed over the total length of the rope without risk of damage;
(iv) a permanent and objective record of the rope condition is available;
(v) by removing the inspector from the immediate vicinity of
the rope the danger of personal injury is avoided;

(vi) the quality of the trace produced is not subjected to the
short attention span of the human inspector and the
assessment of the degree of damage can be carried out, away
from what may be a hostile environment.

Frequent use of NDT equipment would provide information on the
progressive degradation of a rope and would also contribute
significantly both to operational confidence and to the pool of
knowledge on rope behaviour. The NDT record which is not influenced
by the inspector's subjective assessment and a log of the rope
application and history would create a data base of causes and effects
which would provide information for the future development of ropes
and their maintenance.

For the operator, NDT examination offers a quicker and, in some
instances, far cheaper method of inspecting ropes. It would enable a
rope to be discarded before becoming hazardous and would reduce the
number of ropes being discarded too prematurely. The cost of the
capital outlay is recouped by a saving in man hours and a reduction in
down time. In an extreme case, where it is critical to keep down time
to a minimum, it may be justifiable to install the NDT equipment as a
permanent fixture and carry out NDT examination at frequent intervals
to help planned maintenance.

Although NDT examination has a number of advantages over visual
inspection it is not suggested that it should completely replace the
human eye. The two systems can be employed together advantageously by
using the NDT trace to pin-point areas for closer visual inspection.
This can be achieved by having a paint sprayer activated automatically
by the rope damage monitor.

At the moment there is no official guidance on the use of NDT
examination in the UK. Neither ISO 4309 - 1981 nor BS 6570: 1986 make
any mention of NDT. It is hoped that suggestions concerning the use
of NDT (Potts, 1987) be at least partially incorporated into the
present revision of ISO 4309 - 1981 (ISO/DIS 4309 - 1987), as Industry
as a whole is becoming more aware of the benefits of NDT. British
Coal has taken NDT seriously enough to develop their own NDT equipment
based on an earlier Plessey prototype discussed by Marchant, 1979,
which is at present undergoing certification for intrinsic safety.

The adoption of NDT equipment as an accepted tool for rope
examination will, in turn, necessitate the development of appropriate
discard criteria, especially for multistrand ropes.
CONCLUSIONS AND RECOMMENDATIONS

QUALIFICATION

The conclusions and recommendations presented here are based on assumptions that there are no significant differences between the condition of the lengths examined and the parts presumed to have been discarded. No specific information has been made available regarding the difference between the lengths received for examination and the original lengths purchased. This unsatisfactory situation clearly introduces an element of uncertainty into those conclusions and recommendations presented here which relate to the degree of degradation induced over the service life, particularly where damage is localised.

5.1 Conclusions

(i) The ropes examined showed some damage but had been discarded well before any serious loss of strength had occurred.

(ii) The prime causes of degradation were corrosion and mechanical damage. The corrosion had occurred at one end of the Iolair rope which had not been end-for-ended and, to a lesser extent, throughout the length of the Uncle John rope which had. It was considered most likely that the loss of zinc from the Iolair rope was induced by an inoperative cathodic protection system. Apart from leading to accelerated steel corrosion the loss is also important due to the zinc's influence in controlling rope corrosion fatigue.

(iii) A secondary cause of degradation was the onset of fatigue damage at the outer strand/second strand layer interface. However, both ropes had been retired before accumulating significant numbers of fatigue cycles. On the assumption that cut-and-slip of the heavily loaded parts has been carried out, the implication is that this low level of fatigue damage will only be maintained with such a policy.

(iv) Both the mechanical damage and onset of fatigue damage were essentially concentrated in those parts of the ropes exposed to the full weight of the bell when running on and off the winch drum and over sheaves.

(v) In the ropes examined the relubrication had only penetrated as far as the interface between the outer and second layer of strands, but must be considered moderately effective in that it had reached the region where fretting is most severe. Pressure relubrication should penetrate further than hand relubrication. However, care needs to be exercised to avoid the entrapment of seawater during relubrication.
(vi) Ultimate strength tests showed the corroded section of the Lolair rope to have an enhanced strength while the more severe damage to the Uncle John rope had reduced the strength to a value only marginally below the initial strength accepted for rating purposes.

(vii) NDT devices were demonstrated to be effective in identifying individual surface wire breaks and areas of local damage.

5.2 Recommendations

(i) The use of galvanized ropes should be mandatory for diving bell ropes.

(ii) To reduce rope corrosion and preserve the wire-galvanizing, the vessel's impressed current protection system should not be switched off during diving.

(iii) Pressure relubrication helps prolong the useful working life of a rope but should be carried out regularly from the beginning of service. An investigation into ways of increasing the lubricant penetration and avoiding seawater entrapment could be usefully carried out.

(iv) Although there is some evidence to suggest that some operators are already doing it, a six monthly cut-and-slip policy as recommended should be a specific requirement, with the amount removed being at least the rope length from winch drum to water surface. An examination and ultimate strength test should be carried out and the results recorded. Where an annual six month diving season is the practice, consideration should be given to annual cut-and-slip prior to the recommencement of each new season.

(v) By distributing the effects of corrosion over the full length of the rope end-for-ending would extend the useful service life, but only provided that it can be done without damage to the rope, and action is taken to avoid seawater entrapment within the inner layers.

(vi) A review of the winch system should be carried out to isolate and rectify the causes of the mechanical damage, particular attention being paid to Lebus grooves and fleet angles.

(vii) A detailed study should be made of the effectiveness of electromagnetic NDT systems in identifying both external and internal damage in multistrand ropes, with a view to developing appropriate discard criteria.

(viii) Periodic visual inspection should be supported by NDT to identify areas requiring more rigorous inspection. This policy could be usefully implemented even before the more detailed study has been performed.
(ix) Future changes to operational regulations for diving bell hoist ropes should provide for the opportunity to extend service where justified by improved maintenance and inspection techniques.

In the short term regulations should include requirements for:

(a) cut-and-slip of specified lengths at prescribed intervals with test and inspection reports of the discarded lengths;

(b) the maintenance of an adequate log of the lift rope service history detailing installation, lengths tailed, lubrication, inspection reports and other relevant information.

In the longer term regulations should incorporate allowances for:

(a) electromagnetic NDT at minimum prescribed intervals using approved equipment;

(b) pressure relubrication of the dry rope at prescribed intervals using approved dressings, equipment and procedures (any drying process must be controlled to regulate rope temperature to a level approved by the manufacturer).

(x) In the light of the uncertainties concerning various details of diving bell lifting operations that have been encountered during this investigation, it would seem appropriate that any future study should include a survey of current operational practice and bell deployment configurations.
REFERENCES


<table>
<thead>
<tr>
<th>State of Loading</th>
<th>Nominal Load Spectrum Factor, $K_a$</th>
<th>$T_0$</th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_5$</th>
<th>$T_6$</th>
<th>$T_7$</th>
<th>$T_8$</th>
<th>$T_9$</th>
<th>Remarks on State of Loading of Lifting Mechanism</th>
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<tbody>
<tr>
<td>L1 - Light</td>
<td>0.125</td>
<td>M1</td>
<td>M2</td>
<td>M3</td>
<td>M4</td>
<td>M5</td>
<td>M6</td>
<td>M7</td>
<td>M8</td>
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<td>Very rarely subjected to the maximum load, and normally to light loads</td>
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<td>L2 - Moderate</td>
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<td>M2</td>
<td>M3</td>
<td>M4</td>
<td>M5</td>
<td>M6</td>
<td>M7</td>
<td>M8</td>
<td></td>
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<td>Fairly frequently subjected to the maximum load, but normally to rather moderate loads</td>
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<td>L3 - Heavy</td>
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<td>M2</td>
<td>M3</td>
<td>M4</td>
<td>M5</td>
<td>M6</td>
<td>M7</td>
<td>M8</td>
<td></td>
<td></td>
<td>Frequently subjected to the maximum load, and normally to loads of heavy magnitude</td>
</tr>
<tr>
<td>L4 - Very Heavy</td>
<td>1.00</td>
<td>M2</td>
<td>M3</td>
<td>M4</td>
<td>M5</td>
<td>M6</td>
<td>M7</td>
<td>M8</td>
<td></td>
<td></td>
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<td>Regularly subjected to the maximum load</td>
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<table>
<thead>
<tr>
<th>Total Duration (hrs)</th>
<th>200</th>
<th>400</th>
<th>800</th>
<th>1600</th>
<th>3200</th>
<th>6300</th>
<th>12700</th>
<th>25000</th>
<th>50000</th>
<th>100000</th>
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<tbody>
<tr>
<td>Remarks on Utilization of Lifting Mechanism</td>
<td>Irregular Use</td>
<td>Regular Use</td>
<td>Regular Intermittent Use</td>
<td>Irregular Intermittent Use</td>
<td>Intensive Use</td>
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</tbody>
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TABLE 2
MINIMUM FACTORS OF SAFETY AND D/d RATIOS FOR
LIFTING MECHANISM CLASSIFICATIONS
- ISO 4308 (1981)

<table>
<thead>
<tr>
<th>CLASSIFICATION OF LIFTING MECHANISM</th>
<th>COEFFICIENT OF UTILIZATION ( Z_p )</th>
<th>SELECTION FACTORS</th>
<th>STATIONARY ROPES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COEFFICIENT OF UTILIZATION ( Z_p )</td>
<td>DRUMS ( h_1 )</td>
<td>PULLEYS ( h_2 )</td>
</tr>
<tr>
<td>M1</td>
<td>3.15</td>
<td>11.2</td>
<td>12.5</td>
</tr>
<tr>
<td>M2</td>
<td>3.35</td>
<td>12.5</td>
<td>14.0</td>
</tr>
<tr>
<td>M3</td>
<td>3.55</td>
<td>14.0</td>
<td>16.0</td>
</tr>
<tr>
<td>M4</td>
<td>4.0</td>
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<td>M5</td>
<td>4.5</td>
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<td>20.0</td>
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<td>M6</td>
<td>5.6</td>
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<td>M7</td>
<td>7.1</td>
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<tr>
<td>M8</td>
<td>9.0</td>
<td>25.0</td>
<td>28.0</td>
</tr>
</tbody>
</table>

COEFFICIENT OF UTILIZATION \( Z_p = \frac{F_o}{S} = \frac{\text{Rope MBL}}{\text{Max. Rope Tension}} \)

i.e. \( Z_p = \text{FACTOR OF SAFETY or LOAD FACTOR} \)

SELECTION FACTORS \( h = \frac{D}{d} \)

\( D = \text{Pitch diameter of winch drum or pulleys} \)

\( d = \text{Rope diameter} \)

N.B. Stationary ropes are fixed at both ends and are not subject to winding on a drum.
<table>
<thead>
<tr>
<th>WIRE POSITION WITHIN ROPE</th>
<th>SAMPLE POSITION ALONG ROPE</th>
<th>Clean End</th>
<th>Partially Corroded</th>
<th>Corroded End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Strand</td>
<td></td>
<td>90</td>
<td>7</td>
<td>7</td>
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<tr>
<td>Middle Strand</td>
<td></td>
<td>70</td>
<td>48</td>
<td>8</td>
</tr>
<tr>
<td>Middle Filler Strand</td>
<td></td>
<td>224</td>
<td>131</td>
<td>14</td>
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<tr>
<td>Inner Strand</td>
<td></td>
<td>102</td>
<td>86</td>
<td>8</td>
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<tr>
<td>Core Strand</td>
<td></td>
<td>207</td>
<td>92</td>
<td>8</td>
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**TABLE 3** - Percentage of the Minimum Mass of Zinc for Class Z remaining in the rope.
<table>
<thead>
<tr>
<th>ROPE AND CONDITION</th>
<th>BREAKING LOAD (TONNES)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ESV IOLAIR</strong></td>
<td></td>
</tr>
<tr>
<td>MBL (catalogue value)</td>
<td>75.6</td>
</tr>
<tr>
<td>As delivered to operator</td>
<td>70.1</td>
</tr>
<tr>
<td>Discarded - Corroded end</td>
<td>79.4</td>
</tr>
<tr>
<td>Partially corroded end</td>
<td>75.9</td>
</tr>
<tr>
<td>Uncorroded end</td>
<td>71.3</td>
</tr>
<tr>
<td><strong>SSV UNCLE JOHN</strong></td>
<td></td>
</tr>
<tr>
<td>MBL (catalogue value)</td>
<td>58.7</td>
</tr>
<tr>
<td>As delivered to operator</td>
<td>56.7</td>
</tr>
<tr>
<td>Retest after two years' service</td>
<td>59.75</td>
</tr>
<tr>
<td>Discarded - Damaged</td>
<td>57.7 &amp; 53.6</td>
</tr>
<tr>
<td>Undamaged</td>
<td>60.4 &amp; 59.7</td>
</tr>
</tbody>
</table>

**TABLE 4 - Rope Breaking Loads**
<table>
<thead>
<tr>
<th>Strand Position</th>
<th>Outer</th>
<th>Middle</th>
<th>Middle Filler</th>
<th>Inner</th>
<th>Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of original minimum zinc coating for Class Z left</td>
<td>9</td>
<td>24</td>
<td>28</td>
<td>45</td>
<td>146</td>
</tr>
</tbody>
</table>

TABLE 5 - Percentage of Minimum Mass of Zinc for Class Z remaining, for Uncle John Rope

<table>
<thead>
<tr>
<th>Wire Position</th>
<th>Wire Diameter (mm)</th>
<th>Load at Failure (N)</th>
<th>Failure Stress (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Strand Core</td>
<td>1.62</td>
<td>4096</td>
<td>1987</td>
</tr>
<tr>
<td>Middle Strand Core</td>
<td>1.60</td>
<td>3616</td>
<td>1798</td>
</tr>
<tr>
<td>Filler Strand Core</td>
<td>1.22</td>
<td>2272</td>
<td>1944</td>
</tr>
<tr>
<td>Inner Strand Core</td>
<td>1.60</td>
<td>3584</td>
<td>1780</td>
</tr>
</tbody>
</table>

TABLE 6 - Details of Tensile Wire Tests on Uncle John Rope
Rope Construction: Dyform 34 LR (RHO)
- 34 Dyformed strands, core strand with round wires
- limited rotation rope, i.e. 'torque balanced' construction
- right hand ordinary outer strands
- preformed strands

Number of Strands per Layer: 16/6 + 6/6/1
Direction of Lay: RHO/LHL/LHL/LH
Wire Grade: 200 grade, Class 2 galvanizing

Nominal Wire Tensile Strength, UTS = 200 kgf/mm$^2$ = 1960 N/mm$^2$

Mass of drawn zinc coating for each wire size in accordance with BS 2763 (1982)

<table>
<thead>
<tr>
<th>Diving Vessel</th>
<th>Nominal Rope Diameter (mm)</th>
<th>Area of Steel $A_s$ ($\text{mm}^2$)</th>
<th>Fill Factor $F = A_s/\pi d^2$</th>
<th>Aggregate Breaking Load $ABL = A_s \times UTS$ (tonnes)</th>
<th>Rated Minimum Breaking Load $MBL$ (tonnes)</th>
<th>Spinning Loss Factor $K = MBL/ABL$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncle John</td>
<td>26</td>
<td>377</td>
<td>0.71 (0.68)</td>
<td>75.4</td>
<td>58.7</td>
<td>0.78 (0.75)</td>
</tr>
<tr>
<td>ESV Tolair</td>
<td>30</td>
<td>504</td>
<td>0.71 (0.68)</td>
<td>100.8</td>
<td>75.6</td>
<td>0.75 (0.75)</td>
</tr>
</tbody>
</table>

( ) Bracketed values specified in British Ropes Ltd. catalogues

Figure 1 Specification of the two multi-strand diving bell hoist ropes.
FIGURE 2 RIGGING PLAN FOR ESV. IOLAIR DIVING BELL ROPE
Figures 3(a) & 3(b) sample NDT traces from the corroded and the clean ends of the ESV IOLAIR rope.
FIGURES 4(a) & 4(b)  NDT TRACES FOR SAMPLES 80-84 & 178-182 FROM THE ESV IOLAIR ROPE

(i) severe fibrillation as in fig 6
(ii) missing wire as in fig 7
Figure 5    ESV Iolair rope - start of wire fibrillation

Figure 6    ESV Iolair rope - severe wire fibrillation
Figure 7  ESV Iolair rope - missing section of wire

Figure 8  ESV Iolair rope - slight wear on crown and slightly displaced wires.
Figure 9  ESV Iolair rope - corrosion pitting on inside of the outer wires.

Figure 10  ESV Iolair rope - longitudinal split on second layer wire.
Figure 11  ESV Iolair rope – variation in degree of corrosion along rope
FIGURE 12  TENSILE WIRE TEST ON ESV IOLAIR ROPE
Figure 13  Torsion Test Results for ESV IOLAIR Rope
FIGURE 15  POSITION OF DAMAGE ALONG THE UNCLE JOHN ROPE

DISTANCE FROM WINCH TO WATER ASSUMING NO LOSS ON DISCARD
FIGURE 16  NDT TRACE FOR UNCLE JOHN ROPE (0-30m)

(i) area of fibrillated wires as in fig 20
(ii) missing wire as in fig 19
Figure 18  Uncle John rope - external corrosion

Figure 19  Uncle John rope - missing section of wire
Figure 20  Uncle John rope - external plastic wear

Figure 21  Uncle John rope - displaced wires
Figure 22  Uncle John rope - contact wear point on filler wire

Local wire area reduction in the order of 10%
FIGURE 23 TENSILE WIRE TEST ON UNCLE JOHN NO. 2 ROPE
Figure 24: Torsion Test Results for Uncle John No. 2 Rope
FIGURE 25 COMPARATIVE CROSS-SECTIONS OF MULTISTRAND AND SIX STRAND ROPES
APPENDIX A - ELECTROMAGNETIC NDT OF WIRE ROPE

1. Principles of Operation for Electromagnetic NDT Device

"As no physician of today would ignore the X-ray apparatus, so no engineer who has ropes in his care can afford to neglect modern methods of electronic rope testing".

This 'timely' quotation, referring to electromagnetic NDT techniques for examining the condition of wire ropes, was in a paper by Harvey and Kruger in 1959.

Since then a number of more sophisticated electromagnets NDT devices: have been developed and there is widespread and well-established experience in using these devices to monitor the condition of wire ropes in service. Some national regulations require periodic inspection using NDT devices; such as for cable cars and ski-lifts in France and Switzerland and for mine hoist ropes in Poland, Canada, South Africa and the USA. There are a number of proven devices on the market from Canada, France, Poland, South Africa, Belgium, Switzerland, Germany, Netherlands and the USA. Plessey also developed a device in the UK a number of years ago (discussed in Marchant, 1979) but did not market it due to patent difficulties. British Coal has developed its own device based on the Plessey prototype which is currently being certified for intrinsic safety. Some time ago the Health and Safety Executive (HSE) performed a detailed evaluation of a number of different devices then available.

There are three methods of electromagnetic testing of wire ropes: the AC method, DC method and DC device incorporating some means of measuring change in metallic cross-sectional area.

(i) AC devices were developed as early as 1907. These instruments use AC magnetization of the rope such that the wire rope acts as a ferrous core of a coil or transformer (Figure A1(a)). The output from a secondary search coil is proportional to the magnetic flux flowing through the metallic cross-section of the rope and as such changes in the metallic area can be measured by variations in the magnetic flux and voltage. These devices are somewhat unreliable as remnant magnetism in the wire rope and the presence of metallic oxides will adversely affect their operation. Local faults such as broken wires are not detected.

(ii) The first practical DC devices for the inspection of wire ropes were developed in approximately 1935. DC devices use strong electromagnets or permanent magnets to saturate the measured section of the rope (Figure A1(b)). Any discontinuity in the rope (i.e., localized fault), such as a broken wire, a broken core, corrosion or abrasion distorts the magnetic flux and causes it to leak from the rope. The movement of the rope causes the leakage flux to change and induce voltages in the sensors. The output signal of the sensing coil depends on the size of the faults and rope speed (although speed compensation circuitry is now common).
(iii) There are two main types of DC devices that incorporate some means of measuring changes in metallic cross-sectional area: return flux and main flux instruments. Return flux instruments measure magnetic flux density returning from the rope through the air gap to the permanent magnet using either Hall effect sensors (Figure A1(c)) or flux gate sensors. The flux density in the air gap is an approximate measure of the average metallic cross-sectional area of the rope section between the poles. Main flux instruments measure the main flux in the rope directly.

Some sample traces obtained from the Plessey prototype device, a DC device incorporating Hall effect sensors, are set out in Figure A2. They illustrate the capability of these devices.

The two forms of DC devices are considered to be the most useful instruments for examining wire ropes. Of course, the more sophisticated DC devices incorporating metallic cross-sectional area detectors are more expensive; however, for most applications, a basic DC device to locate localised faults is all that would be necessary and would greatly assist the rope inspector in assessing the condition of the rope. More detailed visual inspection of the rope where the device has detected flaws would be expected.

Electromagnetic NDT inspection of wire ropes has a number of major advantages over purely visual inspection:

(i) the devices can continuously gauge both internal and external damage of the rope without requiring stop-start examination of the rope with untwisting at each location;

(ii) a permanent and objective record of the rope condition is readily available;

(iii) electromagnetic inspection is more convenient, less time consuming and less dangerous (i.e. less likelihood of goring one's hand with protruding broken wires) for the inspector than purely visual methods.

It should be pointed out that suitable instrumentation and a trained operator are required to get such results.

In common with all non-destructive testing devices these DC devices have limitations which, once understood, should not significantly affect their value as a flaw detector. Although some experience will be necessary before an operator can utilise the information with confidence, the presence of obvious flaws such as broken wires can be quickly and reliably established. It would be of extreme value for the operator of the lifting appliance if consecutive chart records could be examined for change, as in this way broken wires and structural changes in the rope may be monitored and the maintenance personnel kept aware of potential trouble spots.

2. Specifications for NDT Equipment used on Diving Bell Hoist Ropes

A number of electromagnetic NDT devices of the DC type were used in this study with varying success, including:
(i) Meraster GP-1 magnetic head with an MD-12 rope damage recorder from BP Research Centre;

(ii) Meraster GP-2S magnetic head with an MD-10P rope damage monitor from Aberdeen University;

(iii) Meraster GP-2 magnetic head with a Gould Brush chart recorder from British Ropes Ltd; and,

(iv) Meraster GP-3A magnetic head with an MD-12 rope damage recorder from BP Research Centre.

Manufacturers' fact sheets for these devices are included, following the figures, setting out the performance details for these devices.
(a) AC Method Device

(b) DC Method Device

(c) DC Device incorporating Hall-Effect Sensors

Figure A1 - Schematic Layout of Electromagnetic NDT Devices
(a) Trace from haulage rope with known defects, in particular:
   - presence of a splice
   - missing wires in one section of splice
   - wear and corrosion corresponding to about 1% change in steel area

(b) Trace from small haulage rope with known defects, in particular:
   - presence of splice
   - removal of wires corresponding to losses of 5 and 7% of steel area

FIGURE A2 - TYPICAL TRACES FOR ROPE DEFECTS USING HALL EFFECT DEVICE.

APPENDIX B

Department of Energy
PETROLEUM ENGINEERING DIVISION
Thames House South
Millbank London SW1 4QJ
Telegram Energy London SW1

Your reference

Our reference
PET 1226/114

Date
24 August 1982

Dear Sir

DIVING SAFETY MEMORANDUM NO 17/1982 – EXAMINATION AND TESTING OF LIFTING EQUIPMENT
HEALTH AND SAFETY DIVING OPERATIONS AT WORK REGULATIONS 1981

Diving Safety Memorandum No 5 of 1982 pointed out that Regulation 13(1)(c) and
Regulation 13(2) requires the examination and testing of lifting equipment used in
the launch and recovery system for diving operations to be carried out on initial
installation, after any major repair or alterations to the plant or equipment and
at six monthly intervals.

"Tested" is not defined in the legislation but the following should be considered as
guidance to the competent authority carrying out such examinations and tests.

On the first installation and thereafter after repair or alteration, the test should
be an "overload" test. Acceptable "standards" will include those published by
classification societies and other relevant bodies having experience in this type of
work and those contained in documents such as ship building regulations.

At other times (every six months) and subject to acceptance by the competent person,
a functional or operational test to maximum normal working load will satisfy the regula-
jons.

"Standards" vary in detail but in all cases the maximum normal working load of, for
example, a diving bell is the total weight of the bell in air at water level
(i.e. including maximum cable weight) when operationally manned.

Legislation places considerable importance on the role of the competent person and in
particular circumstances he should use his judgement which should follow the
philosophy of this guidance.

This memorandum cancels Diving Safety Memorandum No 5/1982.

Yours faithfully

COMMANDER S A WARNER
Chief Inspector of Diving
Dear Sir

DIVING SAFETY MEMORANDUM NO 5/1982 - SAFETY APPARATUS/LIFTING EQUIPMENT
HEALTH AND SAFETY DIVING OPERATIONS AT WORK REGULATIONS 1981

Regulation 13(1)(c) and Regulation 13(2) requires the examination and testing of
lifting equipment used in the launch and recovery systems for diving operations
to be carried out on initial installation, after any major repair or alterations:
to the plant or equipment and at six monthly intervals.

The following is issued as guidance to the competent authority carrying out such
examinations and tests.

Test load equals 1.5 x SWL.

Static brake test equals 1.25 x SWL.

Dynamic brake tests equals 1.1 x SWL.

The safe working load (SWL) should be the total weight of the system in air at
the water level (i.e. including maximum cable weight) when operationally manned.

British Registered Merchant Ships and other ships in general tend to have their
lifting gear checked annually. Diving systems onboard such vessels operating in the
U.K. sector should have the lifting systems checked inw SI 399 as above.

Yours faithfully

[Signature]

COMMANDER S A WARNER
Chief Inspector of Diving
1981 No. 399

HEALTH AND SAFETY

Diving Operations at Work Regulations 1981

Made - - - 12th March 1981
Laid before Parliament 25th March 1981
Coming into Operation 1st July 1981

ARRANGEMENT OF REGULATIONS

1. Citation and commencement
2. Interpretation
3. Application of these Regulations
4. Duty to ensure compliance with these Regulations
5. Diving contractors
6. The diving supervisor
7. Divers
8. Diving team
9. Diving rules
10. Qualifications of divers
11. Certificate of medical fitness to dive
12. Plant and equipment
13. Maintenance, examination and testing of plant and equipment
14. Exemption certificates
15. Transitional provisions
16. Revocations and modification

Whereas the Health and Safety Commission has submitted to the Secretary of State under section 11(2)(d) of the Health and Safety at Work etc. Act 1974(a) ("the 1974 Act") proposals for the making of Regulations after the carrying out by the said Commission of consultations in accordance with section 50(3) of the 1974 Act:

And whereas, under section 80(1) of the 1974 Act it appears to the Secretary of State that the revocation of the Offshore Installations (Diving Operations) Regulations 1974(b) and the modification of the Merchant Shipping (Diving Operations) Regulations 1975(e) which are made by Regulation 16 below are expedient in connection with the other provisions of these Regulations and whereas in accordance with section 80(4) of the 1974 Act he has consulted such bodies as appear to him to be appropriate:

(a) 1974 c. 37. (b) S.I. 1974/1229. (c) S.I. 1975/116.
Maintenance, examination and testing of plant and equipment

13.—(1) The plant and equipment specified in Regulation 12(1), (2) and (5) shall not be used in any diving operation unless—

(a) it is maintained in a condition which will ensure so far as is reasonably practicable that it is safe while it is being used;

(b) the register maintained under paragraph (4) contains—

(i) a certificate by a competent person that it complies with Regulation 12(4), and

(ii) in the case of a surface compression chamber or a diving bell, sufficient information, including information relating to the materials used in its construction, to enable it to be safely used, repaired or altered;

(c) there is in force a certificate issued under paragraph (2) by a competent person that it has been examined and tested and that it may be safely used;

(d) it has been examined by a competent person within the six hours immediately before the diving operation commenced.

(2) The certificate referred to in paragraph (1)(c) shall—

(a) state—

(i) the plant and equipment to which it relates,

(ii) that the competent person has examined it,

(iii) that it has been tested by him or under his close supervision,

(iv) the pressure, depth or other conditions under which it can be safely used, and

(v) the period during which it can be safely used which shall not exceed six months;

(b) cease to be valid—

(i) when any repair or alteration has to be made to the plant or equipment which affects its safe working,

(ii) on the expiration of six months or such shorter period as may be certified under sub-paragraph (a)(v) above.

(3) For the purposes of paragraph (2)(a)(iii) the competent person need not cause a pressure leak test or an internal pressure test to be repeated—

(a) in the case of a surface compression chamber or a diving bell—

(i) if a pressure leak test to a safe working pressure has been carried out and certified within the previous two years, or as the case may be,

(ii) if an internal pressure test has been carried out and certified within the previous five years;

(b) in the case of a seamless gas cylinder not taken under water if either a pressure leak test to a safe working pressure or an internal pressure test has been carried out and certified within the previous five years;

(c) in the case of any other item of plant or equipment which will be subjected to an internal pressure in excess of 300 millibars above external pressure, if either a pressure leak test to a safe working pressure or an internal pressure test has been carried out and certified within the previous two years.

(4) The diving contractor shall—

(a) enter in, attach to or insert into a register kept for the purpose, the certificates and information required by paragraph (1)(b) and (c);

(b) retain each such register—

(i) in the case of a register containing certificates relating to any surface compression chamber or diving bell or seamless gas cylinder not taken under water, for at least five years from the date of the last such certificate,

(ii) in any other case, for at least two years from the date of the last certificate it contains.
System Chart of MERASTER Inspection Equipment for NDT of Steel Wire Ropes

<table>
<thead>
<tr>
<th>MEASURING HEADS</th>
<th>SENSORS</th>
<th>ANCILLARY EQUIPMENT</th>
<th>MEASURING EQUIPMENT</th>
<th>STANDARD INTERFACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROPE SIZE (m/m)</td>
<td>стандарт</td>
<td>GP-1</td>
<td>GP-1</td>
<td>MD 12 ROPE DAMAGE RECORDER</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GP-2S</td>
<td>GP-2S</td>
<td>ANALOG RECORDER</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GP-3A</td>
<td>GP-3A</td>
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<td>20-60</td>
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<td>8 - 15</td>
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</tbody>
</table>

**SPECIAL DESIGNS**

- For cable cars installations: GP-2
- For lifts & multiple rope installations: GP-5

**Contents**

- Standard in 1923 and Otta in 1936 pioneered research for suitable physical methods of non-destructive testing (NDT) of steel wire ropes (SWR).
- In 1946, Grasow Mining and Metallurgy Academy started research on a reliable method for field applications - the magnetic test method (MTM).
- Consequently, testing apparatus (TA) and the method of evaluation of its records have been developed and introduced by MERASTER on world wide market.
- MTM tools supplied by MERASTER enable practical inspection of SWR and its internal damages such as broken wires, cavitation in blocked-out SWR.
- MTM is approved in Poland as a standard for cable cars, skilifts, mining boats (Mines Safety Regulations) and passenger lifts.
- The first industrial generation of the TA, Defectograph MD 6 is supplied by MERASTER on a commercial basis for more than two decades in Europe, North and South America and Asia.

**Non-destructive magnetic equipment for non-destructive inspection and monitoring of steel wire ropes** is divided into the following categories:

- **Sensing equipment** which includes: magnetic measuring heads GP 1, GP 2, GP 3A, appropriate inductions and half-affected zones of steel wire ropes with diameters from 35 mm.
- **Inspection equipment** which includes: specialized recording instruments - a MD 12 Defectograph (link marking model), and MD 17 Rope Damage Recorder (blasted through marking model).
- **Monitoring equipment** which includes: analyzing and specifying unit MD 100 Rope Damage Monitor, which examines multiple and..
For magnetic, non-destructive testing of Steel Wire Ropes (SWR), some different Measuring Heads have been designed, covering diameters from 8 to 85 mm, for nearly all domains of applications.

Generally the technical structures of GP-1, GP-2, GP-2-S and GP-3A are similar. All of them are fitted with grip handles for transport facilitation and lugs for fixing of length transducer (roller) and spray-marker. All above-mentioned measuring heads can be delivered with roller fixed on a swinging arm, with the adjustable helical spring exerting pressure against the tested SWR.

GP-4, GP-5, GP-6 heads are recommended for testing SWR of smaller diameters, 8 to 25 mm, in cranes and lifts.

As an interesting, unique solution, applicable for simultaneous inspection of SWR in multi-rope passenger and goods lifts are MH of GP-6-4 (four-ropes) and GP-6-6 (six-ropes) types recommended.

The complete system chart of sensing equipment supplied for Magnetic Inspection of steel wires ropes is shown at table.

---

**GP - 1h**
- Rope dia 30-85 mm.
- Measuring coils dia 100 and 130 mm.
- Weight 66 kg.

**Inspection of the ropes in hoisting machines and aerial ropeways.**

**GP - 2**
- Rope dia 20-60 mm.
- Measuring coils dia 80 and 115 mm.
- Weight 46 kg.

**Inspection of the hoisting ropes in hoisting machines, carrying ropes of aerial ropeways and guiding ropes in shafts.**

**GP - 2Sh**
- Symmetrical head.
- Rope dia 20-80 mm.
- Measuring coils dia 80 and 115 mm.
- Weight 58 kg.

As GP - 2, but high sensitivity of measurement.

**GP - 3Ar**
- Rope dia 10-35 mm.
- Measuring coils dia 50 mm.
- Weight 16 kg.

**Inspection of the ropes in drilling hoists and pulling ropes in aerial ropeways and funiculars.**

**GP - 4**
- Rope dia 10-26 mm.
- Measuring coils dia 35 mm.
- Weight 6.3 kg.

**Inspection of the hoisting ropes in cranes, lifts, elevators and pulling ropes in aerial ropeways and funiculars.**

**GP - 5**
- Rope dia 10-15 mm.
- Measuring coils dia 20 mm.
- Weight 5 kg.

**Inspection of the hoisting ropes of all types.**

**GP - 6 - 4**
- Rope dia 8-14 mm.
- Measuring coils dia 20 mm.
- Weight 8.5 kg.

Four rope measuring head for testing and inspection of the ropes in multi-rope passenger and goods lifts.

**GP - 6 - 6**
- Rope dia 8-14 mm.
- Measuring coils dia 20 mm.
- Weight 12.5 kg.

Six rope measuring head for testing and inspection of the ropes in multi-rope passenger and goods lifts.
Inspection Equipment for Non-destructive Testing of Damages in Steel Wire Ropes

MD-12
Rope Damage Recorder

Centrum Naukowo-Produkcyjne Systemów Sterowania
Scientific and Manufacturing Centre of Control Systems
MD-12 Rope Damage Recorder is designed for systematic, cyclic inspections of SWR.

The MD-12 compatible with measuring heads of GP series and with RI Length Transducer delivers the most precise and reproducible records of inspection courses, taken periodically, according to safety regulations or standards. MD-12 is a specialized thermal-marking recorder.

It provides facilities for:

- simultaneous recording of single defects of the SWR, detected with the inductive sensor, as well as the integral of the number and magnitude of discontinuities on the definite SWR section
- location of inner and outer rope defects
- simultaneous record of testing of two ropes with inductive sensors
- recording of pulse mode test results and – simultaneously – the permanent reduction of the cross-section of SWR detected with the Hall-effect sensor

Technical Characteristic of MD-12 Rope Damage Recorder

Record mode: thermal marking
Sensitivity: 2 mV/1 mm to 64 mV/1 mm
Input Impedance: 20 kohm
Rope Speed Range (with RI Transducer): 0.1 m/s to 3 m/s
Frequency Response: DC to 60 Hz - 5% non-linearity
DC to 100 Hz - 15% non-linearity
Record Width: three channels - 15 mm
Rope Speed To Chart Speed Ratio (m/s:mm/s): 1:1, 1:10, 1:20
Rope Length Counter Capacity: 9999 m
Integration range: 0.6 to 4 metres
Outputs: to Spray-Marker 30V DC 1A
Operating conditions:
- temperature range: +5° to 40°C
- humidity: 10 - 90%
- atmospheric pressure: 53.3 - 106 kPa
- power supply: 220 V ±10% or 110 V ±10% at mains frequency 50 - 60 Hz
Power consumption: 130 VA
Dimensions: 395 x 290 x 150 mm
Weight with power lead: 12.5 kg

*1 Replaces MD-8 Defectograph manufactured by MERASTER

PRODUCER
Centrum Naukowo-Produkcyjne Systemów Sterowania System Study & Manufacturing
ul. Krów Chorzowska 169
40-100 Katowice
Phone: 88 206 597 626
Fax: 88 214 658 merast pl
Inspection Equipment for Non-destructive Testing of Damages in Steel Wire Ropes

MD-10P
Rope Damage Monitor

Centrum Naukowo-Produkcyjne
Systemów Sterowania

Scientific and Manufacturing
Centre of Control Systems
The MD-10 P Rope Damage Monitor is an instrument suitable for inspection and monitoring of defect in steel wire ropes (SWR).

It is compatible with all magnetic measuring heads of GP family, and suitable for SWR diameters from 8 to 85 mm and digital length transducer described in separate leaflet.

It has been designed for quick measurement (max. SWR velocity in respect to the measuring head is 5 m/s) and periodic routine control of SWR.

Instant results, marking of the damage suspected part of SWR using the Spray Marker S-1, printer output, combined with easy systematic use of the MD-10P Rope Damage Monitor provide statistical data for forecasting of SWR life and for inspection report. MD-10P Rope Damage Monitor may also be used for quality control of SWR production. MD-10P allows classification of rope damages into five levels in two modes:

- pulse mode i.e. classification and counting of each rope damage which can be resolved by measuring head
- integration mode i.e. classification and counting of summation results of the magnitude and number of damages

MD-10P Defectoscope is equipped with additional sockets which enable output of the results in analog form to a recorder or tape recorder. The results in a digital form are output to an alphanumeric printer.

MD-10P Rope Damage Monitor can be used as an "intelligent" terminal for detecting of steel wire rope damages utilizing the optional P2 serial interface p.c. board.

Technical Characteristic of MD-10P Rope Damage Monitor

Counters capacity
1999 defects and 1999 metres

Integration range
0.06 to 5.99 metres or seconds

Inputs
MEASURING HEAD two sensors:
input impedance 10 kohm
max. input voltage ±15 V
bandwidth up to 250 Hz (-0.5 dB)
attenuation range 0 to 49 dB

LENGTH CONVERTER (digital):
12 V standard, direction sensitive, resolution: 100 pulses per metre, two pulse trains.

Outputs
SPRAY-MARKER
voltage: 30V DC, 1 A
ANALOG OUTPUT
voltage: max. 5 V
connector: BNC
PRINTER OUTPUT
Data: 7 bit ASCII, parallel, TTL std, with strobe and acknowledge pulses
software control: Line Feed
columns: 24
min. data rate: 1800 Hz
connector: DB-25 S

<table>
<thead>
<tr>
<th>signal</th>
<th>pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>STROBE</td>
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</tr>
<tr>
<td>DATA 1 to DATA 7</td>
<td>2 to 8</td>
</tr>
<tr>
<td>ACKNOWLEDGE</td>
<td>10</td>
</tr>
<tr>
<td>BUSY (printer)</td>
<td>11</td>
</tr>
<tr>
<td>GND</td>
<td>13</td>
</tr>
<tr>
<td>TWISTED PAIR GND</td>
<td>14 to 24</td>
</tr>
<tr>
<td>+5 V</td>
<td>25</td>
</tr>
</tbody>
</table>

Others
- optical and sound alarms
- direction sensitive defects counting with cut off of negative displacement of SWR

Operating conditions:
- temperature range: 0 + 55°C
- humidity: 10 – 90%
- atmospheric pressure: 53.3 – 106 kPa
- power supply: 220 V ±10% or 110 V ±10%
  at mains frequency 50 – 60 Hz

Power consumption: 80 VA
Dimensions: 420 x 270 x 160 mm
Weight with power lead: 10 kg

* Equivalent of the MD-10P Defectoscope

** any printer ex. Centronics Microprinter, Axiom Ex 8001P, Victor Data Products 5080, Epson MX-80
MD-10P
Rope Damage Monitor
Netzunabhängiger 2 Kanal
Standard - Direktschnittschreiber

- Netzunabhängig durch eingebaute Akkumulatoren
- Eingebautes Ladegerät, ermöglicht auch Pufferbetrieb
- Tragbare, sehr robuste Ausführung
- Empfindlichkeit 50 mV F.S.
- Eingang symmetrisch, geschirmt
- 6 umschaltbare Papiergeschwindigkeiten
- Durch Kompensationsverfahren Meßgenauigkeit > 99,5 %
- Frequenzbereich > 30 Hz für Voltausschlag
- Brillantes Schriftbild durch Drucktinte-Schreibverfahren

Einlegen einer neuen Papierrolle ist in wenigen Sekunden möglich, die Vorratskassette nimmt eine ca. 90 m-Rolle Hochkontrast- oder eine ca. 130 m-Rolle Standard Papier auf.

Austauschbare Tintenpatrone; Inhalt einer Patrone reicht für ca. 1 Jahr

### Bestellinformationen

<table>
<thead>
<tr>
<th>Modellnummer</th>
<th>Zusätzliche Netzspannungsadapter für:</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-6325-00</td>
<td>115 V AC</td>
</tr>
<tr>
<td>15-6325-01</td>
<td>230 V AC</td>
</tr>
<tr>
<td>15-6325-02</td>
<td>12 V bis 33 V DC</td>
</tr>
</tbody>
</table>

### Verbrauchsmaterialien

- **Registrier Papier (standard), 122 m**
- **High-Kontrast-64m**
- **Feder für Schreibkanal**
- **Feder für Eingangskenal**
- **Tintenpatrone**
- **Ersatz- Akkumulator**

### Lieferbares Zubehör

- **Betriebsbeginn-Zubehör**
  - 12 Rollen Reg.-Papier, Federwaage, 2 Justierschlüssel, Staubdeckel, Ersatz-Packung (12 Rollen Reg.-Papier, je 2 Federn für Schreib- und Markierer, 1 Tintenpatrone)
  - 1 sec-Tastgeber
  - Papierauflöschevorrichtung
  - Einzelmarken (Zwischenkanal)

### Sonstiges

Der Prospekt des Brush 222 wurde mit freundlicher Genehmigung der Firma Gould Advance GmbH., Hauerstr. 3-5, 6453 Seligenstadt, reproduziert.

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