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TITLE: TEST AND EVALUATION OF THE MAGNOGRAPH™ UNIT — A NONDESTRUCTIVE WIRE ROPE TESTER

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NOTE

TECHNICAL

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

°F   -40   0   32   98.6   212 °F
°C   -40   -20   0   20   37   40   60   80   100 °C

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The nondestructive wire rope test device, a unitized AC/DC Magnograph, was tested for operational characteristics prior to acquisition by Naval field activities and start of inspection programs. The Magnograph was tested for loss of metallic area (LMA) and local fault (LF) detection accuracy. Wire ropes 1/2, 3/4, 1-1/8, 1-1/2, 2, and 2-1/2 inches in diameter were tested on a wire rope test track to find the accuracy of the unit. Two mining wire ropes, guy wires of a 1,000-ft-tall tower, and wire rope for 400-, 250-, and 30-ton cranes were used to determine operational characteristics of the Magnograph.

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The nondestructive wire rope test device, a unitized AC/DC Magnograph, was tested for operational characteristics prior to acquisition by Naval field activities and start of inspection programs. The Magnograph was tested for loss of metallic area (LMA) and local fault (LF) detection accuracy. Wire ropes 1/2, 3/4, 1-1/8, 1-1/2, 2, and 2-1/2 inches in diameter were tested on a wire rope test track to find the accuracy of the unit. Two mining wire ropes, guy wires of a 1,000-ft-tall tower, and wire rope for 400-, 250-, and 30-ton cranes were used to determine operational characteristics of the Magnograph.

CONTENTS

INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) previously conducted
a study on nondestructive evaluation (NDE) equipment for wire rope
inspection*, which compared conventional equipment (individual AC/DC
units) to that of newly developed equipment (a unitized AC/DC unit, the
Magnograph). The operational features of the two types of equipment
were reviewed, and a limited test program was conducted to compare the
results. The report recommended that the Magnograph equipment be pur-
chased for Navy applications because it was found to be more versatile
than the AC/DC units; e.g., data were recorded simultaneously on strip
chart paper for both local fault (LF) defects and loss of metallic area
(LMA) recordings and the equipment could be operated at slow speeds, to
0 fpm, and still detect LF and LMA data. This report presents results
of a test and evaluation program conducted on the Magnograph unit before
Navy field activities acquire the units and start field inspection
programs.

Preliminary Testing With Broken Wire

The original two objectives of the program were: to define broken
wire signals for producing a pictorial defect catalog and to determine
the accuracy of the LMA data. The results would assist inspectors in
interpreting data from field tests on wire rope. As testing progressed,
it became clear that a defect catalog could not be developed. The LMA
readings were found to be outside the manufacturer's accuracy specifica-
tions. A method for obtaining accurate LMA readings was developed,
however, and is available to inspectors who take special effort to
calibrate the equipment. The new calibration method is presented in
this report.

The interpretation of LF data on broken wires requires experience
to understand both gross and subtle meanings. Often signals of back-
ground noise are difficult to distinguish from signals of broken wires.
The equipment sometimes does not give all the answers on broken wires;
the data sometimes only indicates the general condition of the wire
rope, especially if the wire rope is heavily worn or corroded. Some
broken wires give signals that indicate definite breaks, but other
broken wires give signals difficult to distinguish from background
noise. In the latter case, broken wires can go undetected.

One of the more important findings of this program is that every
broken wire does not produce an obvious broken wire signal.** Broken
wires having a small gap between the broken ends produce only small

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*Civil Engineering Laboratory. Technical Note N-1594: Nondestructive
   testing equipment for wire rope, by H. H. Haynes and L. D. Underbakke;
   Port Hueneme, Calif., Oct 1980.
**This finding also applies to the conventional DC-type equipment as well
   as to the Magnograph equipment.

defect signals which can be lost in the background noise. This limitation was first observed during a field test on an elevator wire rope taken from a mine and known to have a 1/8-inch gap. When the sensor head was moved slowly or rapidly over the broken wire, the break signal was totally lost in the background noise.

Further Tests

Consequently, a laboratory test track was built to accommodate a loop of wire rope 100 feet in length. Different sized wire ropes were tested that contained broken wires having various gap spacings. This work was planned for the defect catalog, but became an investigation of the minimum-sized gap which produces an observable break signal.

Field studies also indicated that used wire rope gave off considerably more background noise than new rope. It became apparent that a used wire rope would need to be taken apart to correlate the defect signals to the actual wire rope conditions. This work was done, and the results are presented in this report.

Magnograph Development

The Magnograph unit has only recently become available for purchase from the manufacturer (Heath and Sherwood Limited, Ontario, Canada). The manufacturer's discussion on engineering principles and operation of the equipment is presented in the Appendix (the manufacturer's operation manual).

It is important to mention that as limitations of this new equipment arise, the developers (Noranda Research Centre, Montreal, Canada) and Heath and Sherwood work to solve the problems. For example, during the NCEL tests it was observed that the LMA recordings were drifting with time. Part of the problem was an electronic component failure, but another part was the temperature sensitivity of the Hall sensors. Both developer and manufacturer solved the problem and have upgraded subsequent equipment.* Noranda has improved the calibration method for LMA readings. Thus, the equipment is evolving and improving as problems are noted and solved.

TESTING

Scope

New wire ropes of 6x25 right-regular-lay, fiber-core construction, having diameters of 1/2, 3/4, 1-1/8, 1-1/2, 2, and 2-1/2 inches, were tested with manmade broken wires. The broken wires had gap spacings that varied from 0 to 1/2 inch in 1/16-inch increments. A used wire rope of 6x31 regular-right-lay, fiber-core construction, having a 1-1/8-inch diameter, was tested and disassembled to compare LF signals with the actual condition of the wire rope. Other tests investigated signal size as a function of gap configuration, orientation, and rope speed.

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*NCEL's equipment has not been upgraded with this feature.

LMA accuracy was determined by adding individual wires to a wire
rope so that the known actual change in percent LMA could be compared to
the recorded change in percent LMA.

Test Setup

    A test track (Figure 1), designed to accommodate a 100-foot loop of
wire rope, was constructed to conduct tests on running wire ropes of
various diameters and constructions. Wire rope speed was infinitely
variable by means of a variable speed transmission powered by a 1-3/4-hp
electric motor. Rope speeds are variable from 0 to over 800 fpm.
    Each end support consists of three 1-foot-diameter sheaves that
simulate a 4-foot-diameter sheave. The larger sheave diameter was
needed to supply the larger wire ropes with an acceptable bend radius.

DISCUSSION

Gap Configuration

    A broken wire can have various shaped ends that produce gaps of
different configurations. A fatigue break gives square ends, while a
tensile break causes the ends to neckdown. Another condition occurs
when a wire is bent and pushed to the side (Figure 2d). A series of
tests was conducted on different gap configurations (Figure 2) to
determine the effective gap size. The results indicated that the signal
size depended on the clear air gap size in the longitudinal direction.
Hence, wires that are pushed sideways and are grossly displaced produce
a signal size that is dependent mainly on the longitudinal gap size.

Gap Orientation

    Gap orientation refers to the location of a wire break in relation
to the four Hall-effect devices that were located 90 degrees apart in
the sensor head. In these tests a wire break could be directly under a
Hall-effect device, while at other times a break could be oriented up to
45 degrees from the device.
    The test to determine the effect of gap orientation used a 1-1/2-
inch-diameter wire rope with two manmade wire breaks approximately 4
yards apart (A and B of Figure 2). Break A was a broken crown wire, and
Break B was a broken filler wire. On the test stand, a break appeared
at the same orientation after each complete loop. Hence, for this test
the sensor head was rotated from 0 through 90 degrees in 22.5-degree
increments. The LF data were compared to observe any changes in the
signal size.
    Figure 3 shows that the signal size changed considerably: between
the maximum and minimum signal, a 40% decrease for each wire break
signal was noted. The test was not designed to determine the orienta-
tion of the break in relation to the Hall-effect devices; however, the
data from break A revealed that for the minimum signal size, the probable
break orientation was 45 degrees from a Hall-effect sensor because the
signal size changed only once for the five readings. Surprisingly, the

data from break B changed signal size for each orientation. Regardless of the differences between breaks A and B, the signal size was dependent on gap orientation.

Gap Space

New Rope. A series of tests was conducted on new wire rope to determine LF signal size as a function of longitudinal gap space. A hammer and chisel were used to make wire breaks in crown wires. The initial gap space was about 1/128 inch, but a file was subsequently used to widen the gap spacings to 1/2 inch in 1/16-inch increments.

Tests were conducted on wire rope 1/2, 3/4, 1-1/8, 1-1/2, 2, and 2-1/2 inches in diameter. Rope speed was 200 ft/min in all cases, except for the 2-1/2-inch-diameter wire rope. For that rope, the sensor head was pulled over the wire rope because the drive wheel of the test stand could not develop sufficient traction to maintain movement of the rope.

A condensation of the data for the various tests is shown in Figures 4 through 9. From these data, LF signal-to-noise ratios were obtained for each gap space. The background noise was defined as an average of the peak values for each rope.

Figures 10 through 15 show LF signal-to-noise ratio as a function of gap space. Interestingly, the LF signal-to-noise ratios ranged from 2 to 4 for a gap space of about zero. Therefore, one would expect to easily detect a broken wire even when the gap space is extremely small, but this is not necessarily true because of two conditions: (1) the above data were collected on new wire rope, and (2) the background noise was the average of the peak values.

New wire rope is fairly clean of background noise; once surface corrosion occurs, however, background noise increases. As a wire rope is worked, the strands and wires seat themselves relative to one another. Internal and external wear, along with peening and nicking, is another cause for background noise. Heath and Sherwood propose to track the growth of background noise as an indication of the condition of the wire rope (see the Appendix). Data on the growth of background noise are not available, but it is expected that LF signals for small gap sizes would quickly be lost in the background noise.

The other condition -- that of using average peak values for background noise -- means that above-average background-noise signals can appear to be LF signals. Many times, confusion exists when studying a signal as to whether it is an LF or a background noise signal. This occurs most frequently in heavily used wire ropes.

In summary, LF signal size is dependent on the gap space, and broken wires with extremely fine gap spacings can be detected in new wire rope.

Used Rope. The difficulty of distinguishing between LF signals from small gap spacings and background noise was investigated by non-destructive testing and then by disassembling a used wire rope. A 1-1/8-inch-diameter, 6x31 fiber-core wire rope, which had been retired from a mine elevator hoist, was used in the test. A 100-foot-long section was mounted on the test stand. Magnograph data were obtained at

a rope speed of 200 ft/min; raw data are shown in Figure 16. Several large LF signals indicate broken wires, but the intermediate-sized LF signals take more experience to define.

The first 36 feet of the rope were disassembled for a detailed study. Three crown wire breaks and five filler wire breaks were found (see Figure 17). As can be seen, several filler wire break signals were the same size as the background-noise signals. It appears that inexperienced inspectors would have a difficult task distinguishing between these types of signals.

Rope Speed

The Hall-effect devices, which detect broken wires by picking up a magnetic flux leakage field created by a discontinuity in the wire rope, are not dependent on rope speed to generate a signal.* It has been demonstrated that the Magnograph unit detected broken wires when the sensor head was moved slowly over breaks on wires. The LF signal remained even when the sensor head was at a standstill over the broken wire. However, it was noted during field tests that the LF signal size varied to a limited degree with rope speed, which led to further investigation.

A test was conducted on a 1-1/8-inch-diameter, 6x25 regular-right-lay, fiber-core rope to observe the effect of rope speed on LF signal size; break gap spacing was about 1/8 inch. Figure 18 shows that as the rope speed changed from 50 to 800 ft/min, the signal-to-noise ratio ranged from a maximum of 7 to a minimum of 2. As the rope speed increased, the background noise became larger, so the signal-to-noise ratio decreased. The manufacturer recommends testing at rope speeds of 50 to 600 ft/min, which is acceptable, but higher rope speeds are also acceptable.

Rope Guides

The Magnograph unit's sensor head can be used for wire ropes with diameters varying from 1/2 to 2-1/2 inches by using different-sized rope guides and adaptor tubes. The equipment uses five different rope guides to accommodate all wire rope diameters (see Appendix, Figure 4.3): four adaptor tubes handle ropes from 1/2 to 2 inches in diameter, and the larger rope diameters of 2 to 2-1/2 inches are handled without an adaptor tube.

Tight and loose fit were investigated for the effect on LF signal-to-noise ratio of a rope traveling through the sensor head. The manufacturer recommends rope guide C for wire ropes of 1-1/8 to 1-9/16 inches in diameter, and rope guide D for 1-9/16 to 2 inches in diameter. The 1-1/2-inch-diameter wire rope used in the test had a tight fit in rope guide C, but a loose fit in rope guide D. The LF signal-to-noise ratio for rope guide C was about 10 and for rope guide D about 6. When going from the tight to loose fit, the LF signal size decreased slightly and the background noise increased substantially. Consequently, the rope guide with a tight fit is recommended.

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*Conventional DC-type wire rope testers are dependent on rope speed to generate a signal.

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Accuracy of LMA

NCEL's Magnograph equipment was modified by Noranda during FY81 to simplify the calibration procedure for determining LMA. The original equipment used a calibration procedure that required knowing the mass per unit length of the wire rope. Many times this value had to be estimated, generating a source of error. The Noranda modification entailed some circuitry revision along with a new calibration curve. The new method eliminated the need for prior knowledge of the mass per unit length of the wire rope.

The accuracy of the LMA readings decreased with this modification. Tests to determine the accuracy were conducted on wire ropes of 1-1/8- and 2-inch diameter, 6x25 right-regular-lay, fiber-core construction. Extra wires (about 15 feet) were added to the wire rope by taping them into the valleys between the strands to simulate an increase of mass. Figure 19 shows that significant differences exist between the known change in LMA and the Magnograph readings. Revisions in the calibration curve would make some improvement in the accuracy, but that procedure by itself is not enough to improve the accuracy to meet the manufacturer's specifications.

Noranda has recently developed a self-calibrating system that does not require a calibration curve. The sensor head determines the mass of the rope by measuring the flux flow through the rope. A given voltage change (1 volt) from the zero condition represents a 10% loss or gain in metallic area. NCEL has tested this system, and its accuracy is ±0.05%. This self-calibrating system will probably be used for all future equipment.

NCEL's Magnograph equipment can be manually calibrated to simulate the self-calibrating process as described in the Appendix. The procedure is to start the calibration process before the sensor head is placed on the wire rope. In the self-calibrating procedure the following steps should be taken by the operator:

1. With a four-digit read-out Volt-Ohm-Milliamp (VOM) meter, plug the test leads into the LMA input receptacles of the Magnograph chart recorder.

2. Turn on the recorder and electronic sections.

3. On the electronic section, adjust the LMA zero potentiometer until 0 volt is obtained (have the VOM on the 2-volt scale).

4. Now place the sensor head on the wire rope and adjust the LMA gain potentiometer until +1.000 volt is obtained on the VOM.

5. Then go back to the LMA zero potentiometer and adjust until 0 volt is obtained.

By using this new method to calibrate the Magnograph unit, LMA accuracy is well within the ±0.5% accuracy by area specified by the manufacturer.

LMA for 30% Crown Wire Wear

The Magnograph equipment measures total LMA that results from wear and corrosion. Navy inspection criteria specify that a wire rope with 30% or more reduction in the diameter of the crown wires must be removed from service. The question posed is: what is the approximate LMA for 30% crown wire wear?

The crown wires of three different wire rope samples (1/2-, 1-1/8-, and 2-inch-diameter 6x25 right-regular-lay, fiber core) were abraded on a belt sander to simulate various degrees of wear. Physical samples had to be used because, for different degrees of wear, the number of crown wires showing wear at any given cross section varied. For example, for 5% crown wire diameter reduction, only one crown wire per strand showed wear; but for 30% crown wire diameter reduction, three crown wires showed wear. Using these data, calculations were made of LMA and are shown in Figure 20. It can be seen that for 30% crown wire diameter reduction, the LMA percentages were about 5.5, 4.0, and 2.0 for wire ropes of 1/2-, 1-1/8-, and 2-inch diameter, respectively.

To an inspector, significant wear is easily detected. The appearance of a wire rope with 30% crown wire diameter reduction is visibly startling in its impact because of the "used" or "poor" condition of the rope. Figure 21 is an example of a wire rope with 12% crown wire reduction and one broken wire. It is doubtful that many wire ropes stay in service until crown wire wear is 30%, solely because of the poor appearance of the rope.

Canadian mining practices require nondestructive evaluation of wire ropes and a 10% LMA is cause for removal of a wire rope from service. To reach 10% LMA, it is apparent that the effect of corrosion has to be more significant than that of wear. Assuming a rope of 1-1/8-inch-diameter, one can determine that reasonable wear can be about 2% LMA; therefore, corrosion would make up the other 8%. Corrosion is more insidious than wear because it can be hidden from view, and corrosion pitting causes stress risers in the wires. Wear is an easy condition to inspect for, but corrosion is a more significant cause for wire rope failures. The Magnograph equipment is an important tool in determining the degree of corrosion in wire ropes.

FINDINGS

1. The air gap between ends of a broken wire, as measured in the longitudinal direction of the wire rope, is the predominant factor governing LF signal size.

2. The orientation of a broken wire with respect to the four Hall-effect devices in the sensor head also influences the LF signal size.

3. Broken wires having a gap of less than 1/32 inch can be detected in new wire ropes, but with used rope the background noise is greater and can obscure the LF signal. Hence, not all broken wires can be detected by the Magnograph equipment.

4. LF signal size is very slightly influenced by rope speed (Figure 18).

5. A wire rope guide that provides "a best fit" on a rope should be used; a tight fit is better than a loose fit.

6. The accuracy of LMA readings for the Magnograph unit is outside the manufacturer's specifications; however, a new method has been developed by the manufacturer to improve the accuracy. New equipment will have a self-calibrating capability; NCEL's equipment can be manually calibrated. This method brings the LMA readings well within the manufacturer's specifications.

CONCLUSIONS

1. Broken wires with a small gap between the ends do not always produce an LF signal of sufficient size to be distinguished from background-noise signals.

2. At the present time, the Magnograph unit should be used as an inspection tool to augment the inspector's skills. It is valuable because the internal condition of wire ropes, particularly broken wires and corrosion, can be detected.

3. The Magnograph equipment provides considerably more technical data on the rope's condition than is available by using visual inspection and will indicate areas that require further inspection.

Figure 1. Test stand for wire ropes.
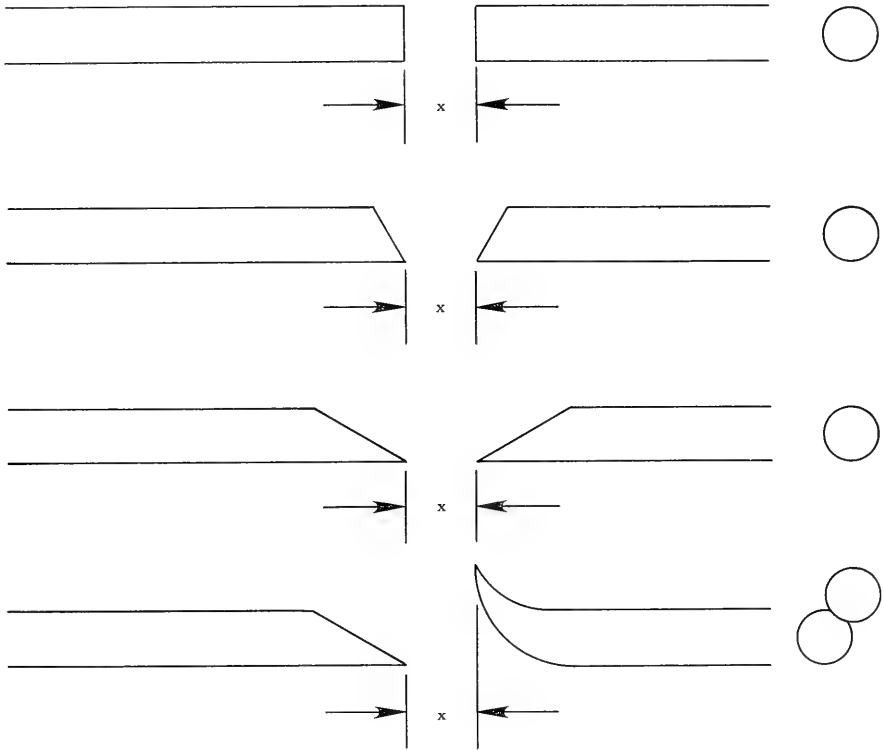
x = clear air gap space in longitudinal direction of wire rope
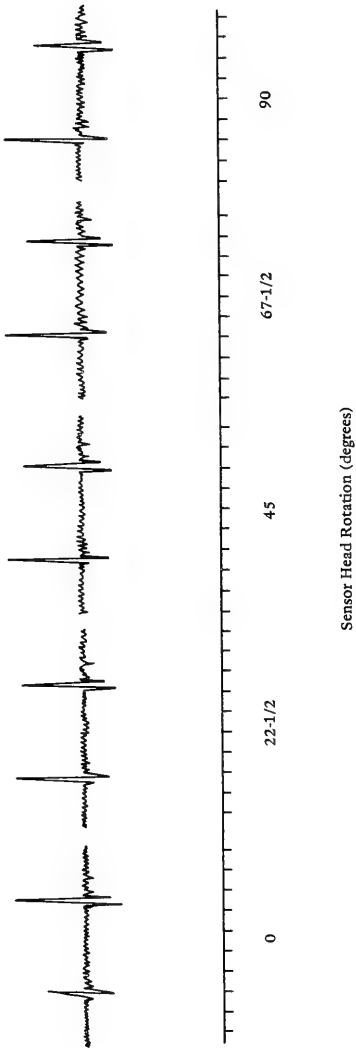
Figure 2. Gap configurations for wire rope.

Figure 3. Sensor head rotated about 1-1/2-in.-diam wire rope to determine signal size as a function of gap orientation.

Rope Guide #A (1/2 - 3/4 in.)
Wire Rope Speed = 200 ft/min
LMA 0 = 163   LF 0 = 500
LMA G = 20   LF G = 756
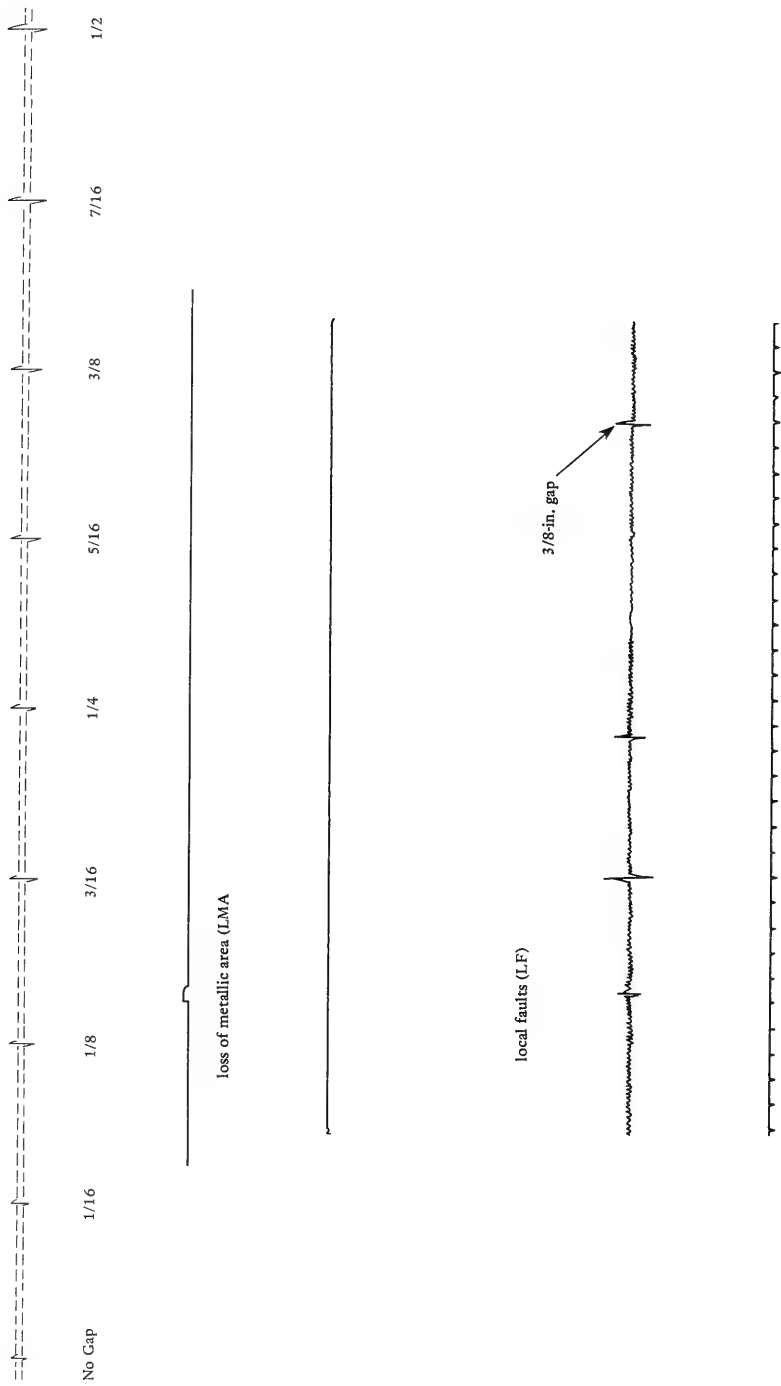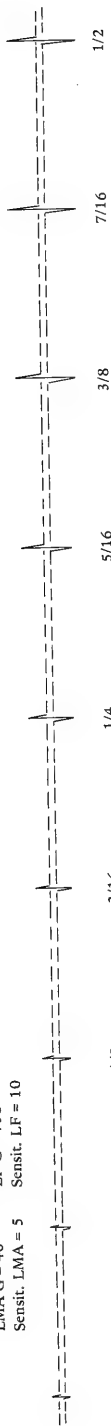Sensit. LMA = 5   Sensit. LF = 10

No Gap   1/16   1/8   3/16   1/4   5/16   3/8   7/16   1/2

loss of metallic area (LMA

local faults (LF)

3/8-in. gap

Figure 4. LF signal size as a function of gap spacing for 1-1/2-in.-diam wire rope.

Rope Guide #A (1/2 - 3/4 in.)
Wire Rope Speed = 200 ft/min

LMA 0 = 237	LF 0 = 556
LMA G = 40	LF G = 758
Sensit. LMA = 5	Sensit. LF = 10

No Gap   1/16   1/8   3/16   1/4   5/16   3/8   7/16   1/2

loss of metallic area (LMA)

local faults (LF)

3/8-in. gap

Figure 5. LF signal size as a function of gap spacing for 3/4-in.-diam wire rope.

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Rope Guide #B (3/4 - 1-1/8 in.)
Wire Rope Speed = 200 ft/min
LMA 0 = 387   LF 0 = 593
LMA G = 125   LF G = 750
Sensit. LMA = 5   Sensit. LF = 10
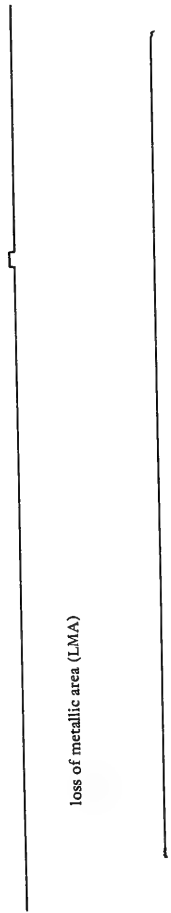
No Gap   1/16   1/8   3/16   1/4   5/16   3/8   7/16   1/2

loss of metallic area (LMA)
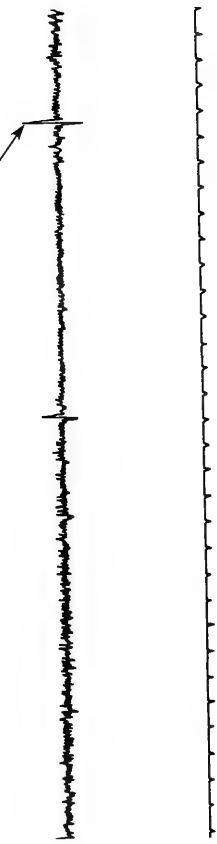
local faults (LF)

3/8-in. gap

Figure 6. LF signal size as a function of gap spacing for 1-1/8-in.-diam wire rope.

Rope Guide #C (1-1/8 - 1-9/16 in.)
Wire Rope Speed = 200 ft/min
LMA 0 = 605   LF 0 = 616
LMA G = 290   LF G = 750
Sensit. LMA = 5   Sensit. LF = 10

1/16   1/8   3/16   1/4   5/16   3/8   7/16   1/2

loss of metallic area (LMA)

local faults (LF)

1/4-in. gap
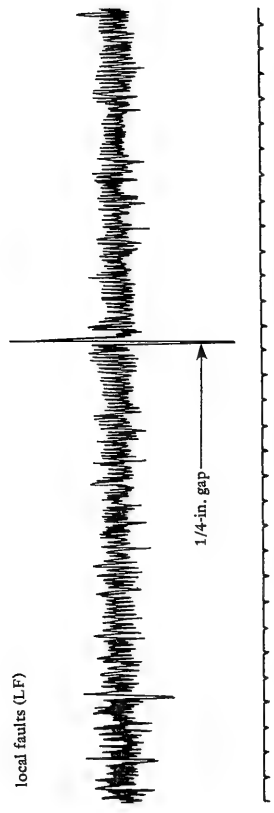
Figure 7. LF signal size as a function of gap spacing for 1-1/2-in.-diam wire rope.

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Rope Guide #E (2 - 2-1/2 in.)
Wire Rope Speed = 200 ft/min
LMA 0 = 605   LF 0 = 616
LMA G = 290   LF G = 750
Sensit. LMA = 5   Sensit. LF = 10

No Gap   1/16   1/8   3/16   1/4   5/16   3/8   7/16   1/2

loss of metallic area (LMA)
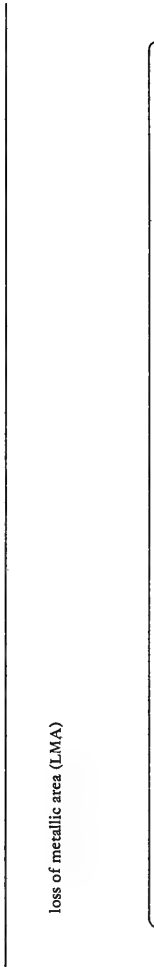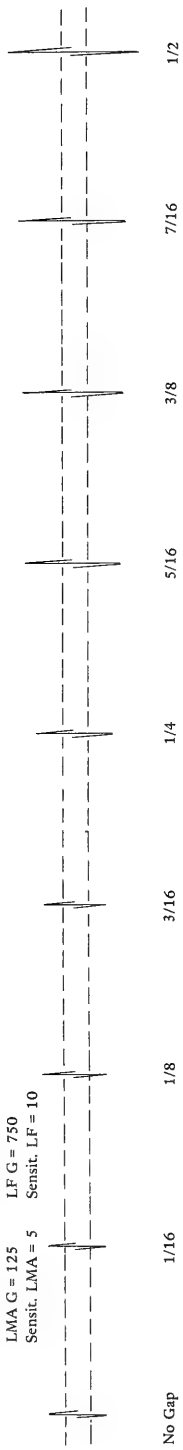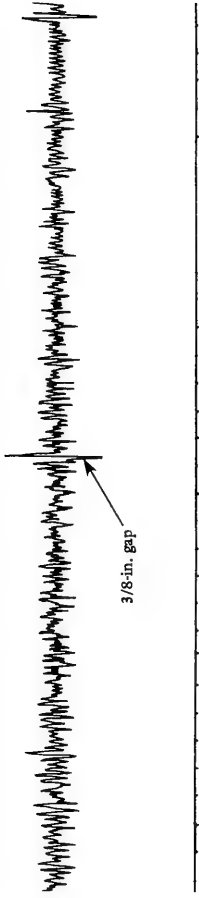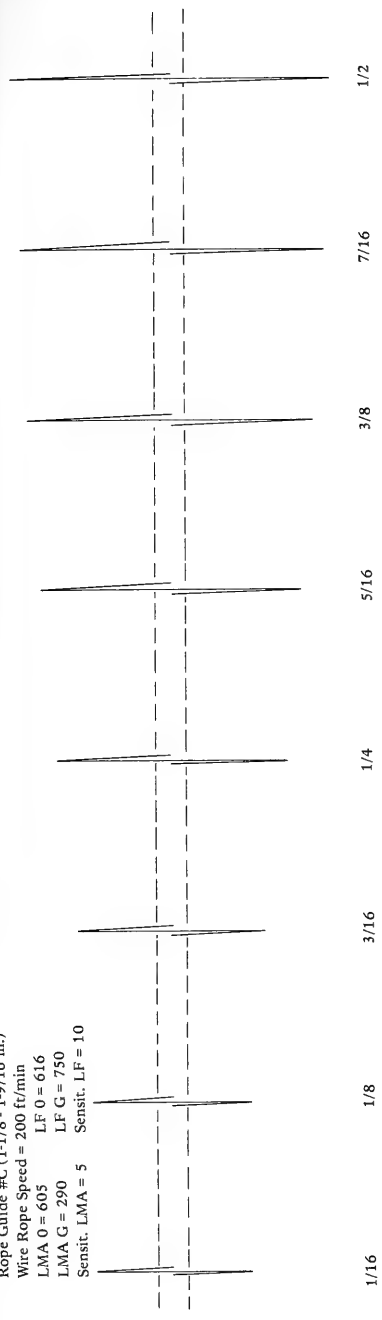
local faults (LF)

3/8-in. gap
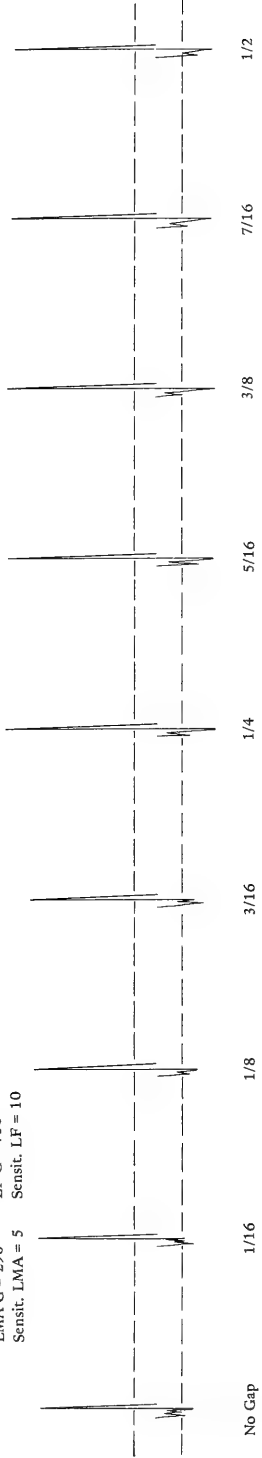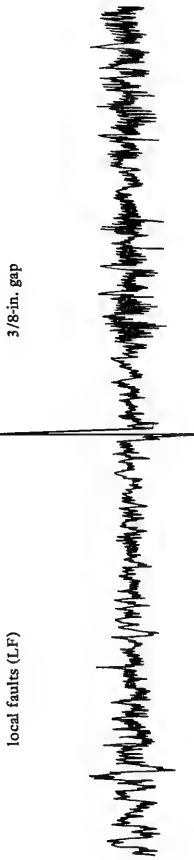
Figure 8. LF signal size as a function of gap spacing for 2-in.-diam wire rope.

16

Rope Guide #E (2 - 2-1/2 in.)
Wire Rope Speed = 200 ft/min
LMA 0 = 650   LF 0 = 530
LMA G = 540   LF G = 500
Sensit. LMA = 5   Sensit. LF = 10

No Gap   3/16   1/4   5/16   3/8   7/16   1/2

loss of metallic area (LMA)

local faults (LF)

3/16-in. gap
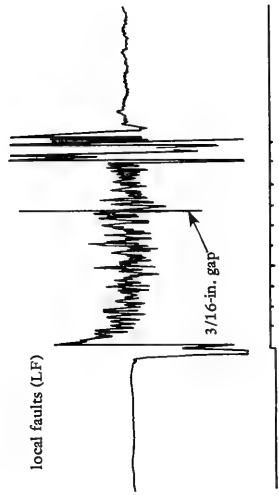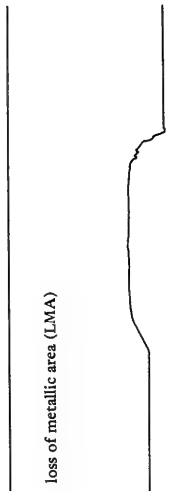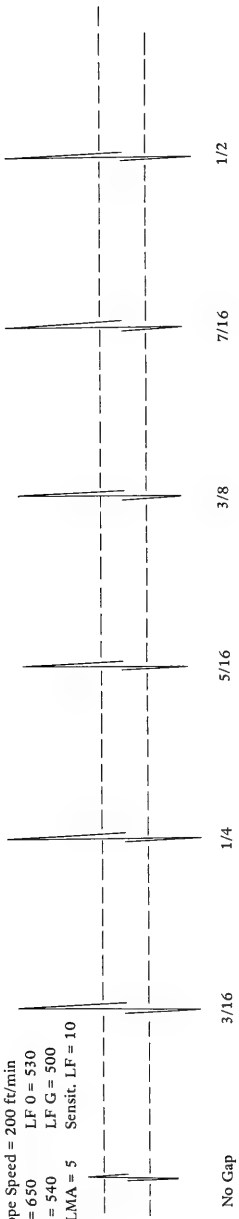
Figure 9. LF signal size as a function of gap spacing for 2-1/2-in.-diam wire rope.

17
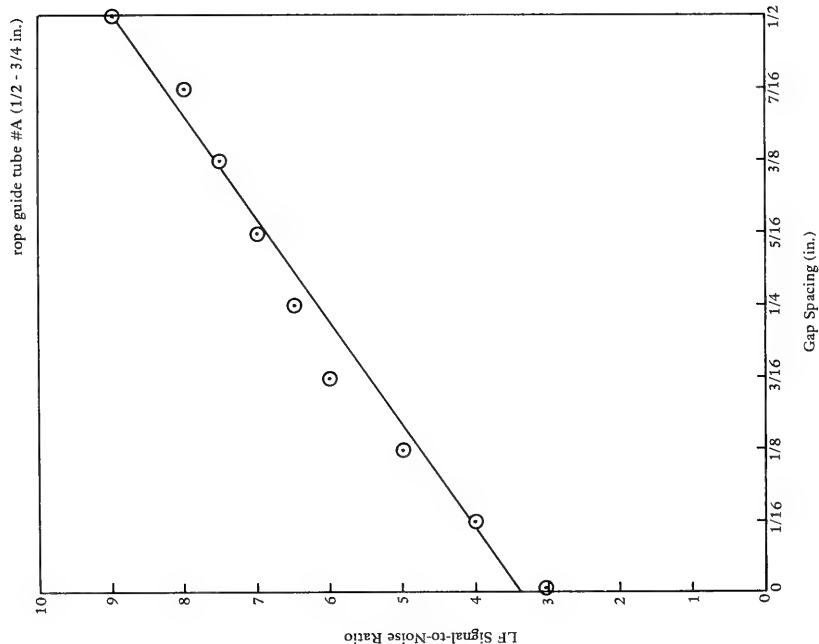
Figure 10. LF signal-to-noise ratio as a function of gap spacing for 1/2-in.-diam wire rope.
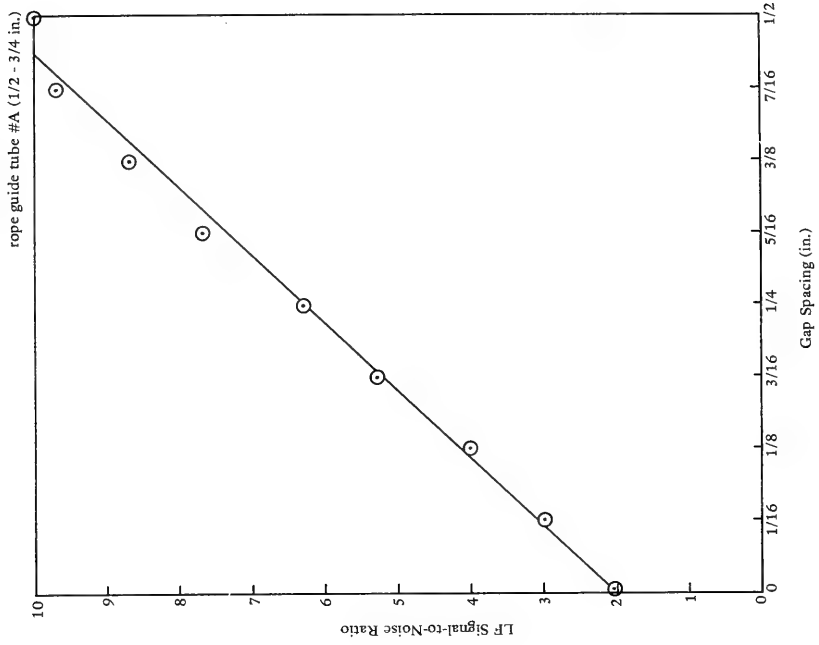
Figure 11. LF signal-to-noise ratio as a function of gap spacing for 3/4-in.-diam wire rope.

18
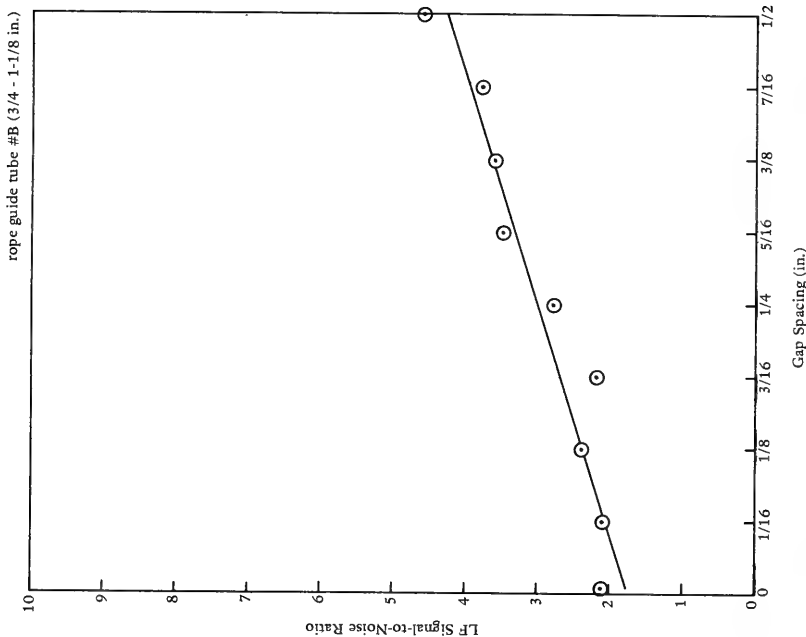
Figure 12. LF signal-to-noise ratio as a function of gap spacing for 1-1/8-in.-diam wire rope.
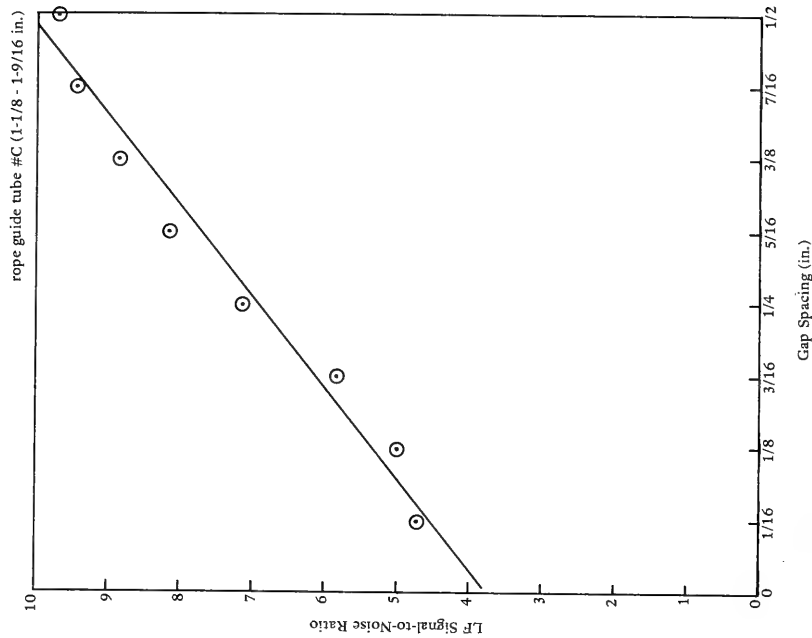
Figure 13. LF signal-to-noise ratio as a function of gap spacing for 1-1/2-in.-diam wire rope.

19

rope guide tube #E (2 - 2-1/2 in.)

LF Signal-to-Noise Ratio
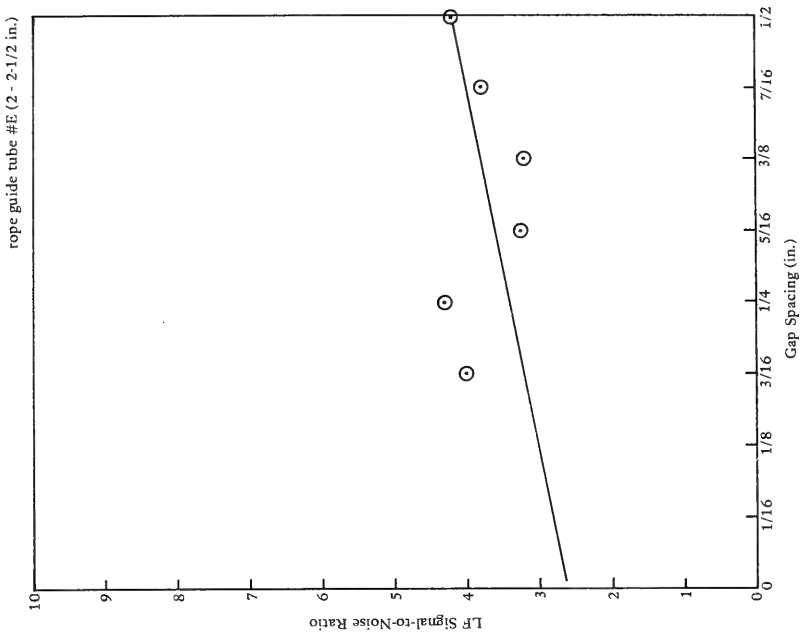
Gap Spacing (in.)

Figure 15. LF signal-to-noise ratio as a function of gap spacing for 2-1/2-in.-diam wire rope.

rope guide tube #E (2 - 2-1/2 in.)

LF Signal-to-Noise Ratio
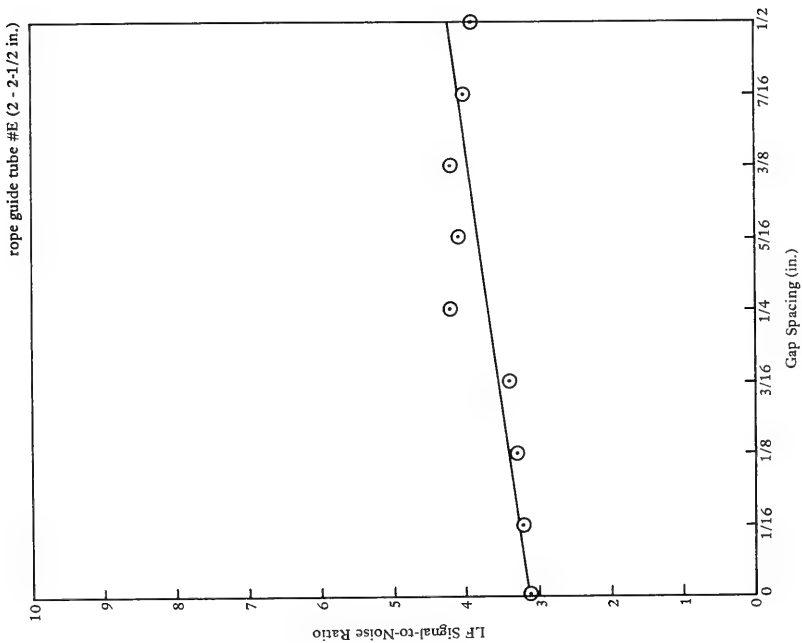
Gap Spacing (in.)

Figure 14. LF signal-to-noise ratio as a function of gap spacing for 1-in.-diam wire rope.

20

loss of metallic area (LMA)

5%

local faults (LF)
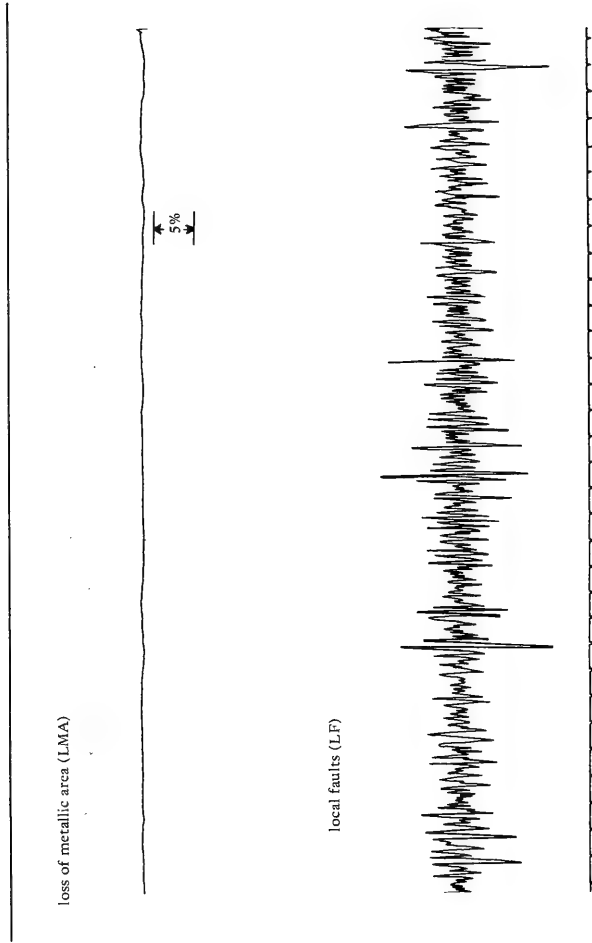
Figure 16. Raw data from a used mine elevator hoist rope.

21

crown wire

filler wire
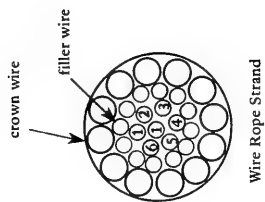
Wire Rope Strand

wire rope strand
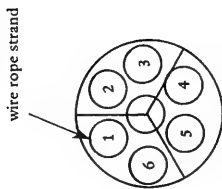
Cross Section Wire Rope

5%

loss of metallic area (LMA)

local faults (LF)

Ⓐ broken external "crown" wire

Ⓑ broken internal "filler" wire
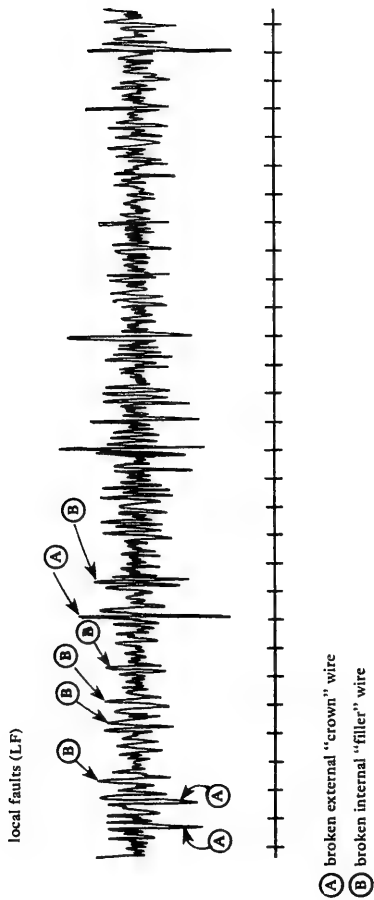
Figure 17. LF signal chart of used mine elevator hoist rope with broken wires found when taken apart.

22

Figure 19. Tests for accuracy of LMA readings.

Figure 18. LF signal size as a function of rope speed for new 1-1/2-in.-diam wire rope.

23
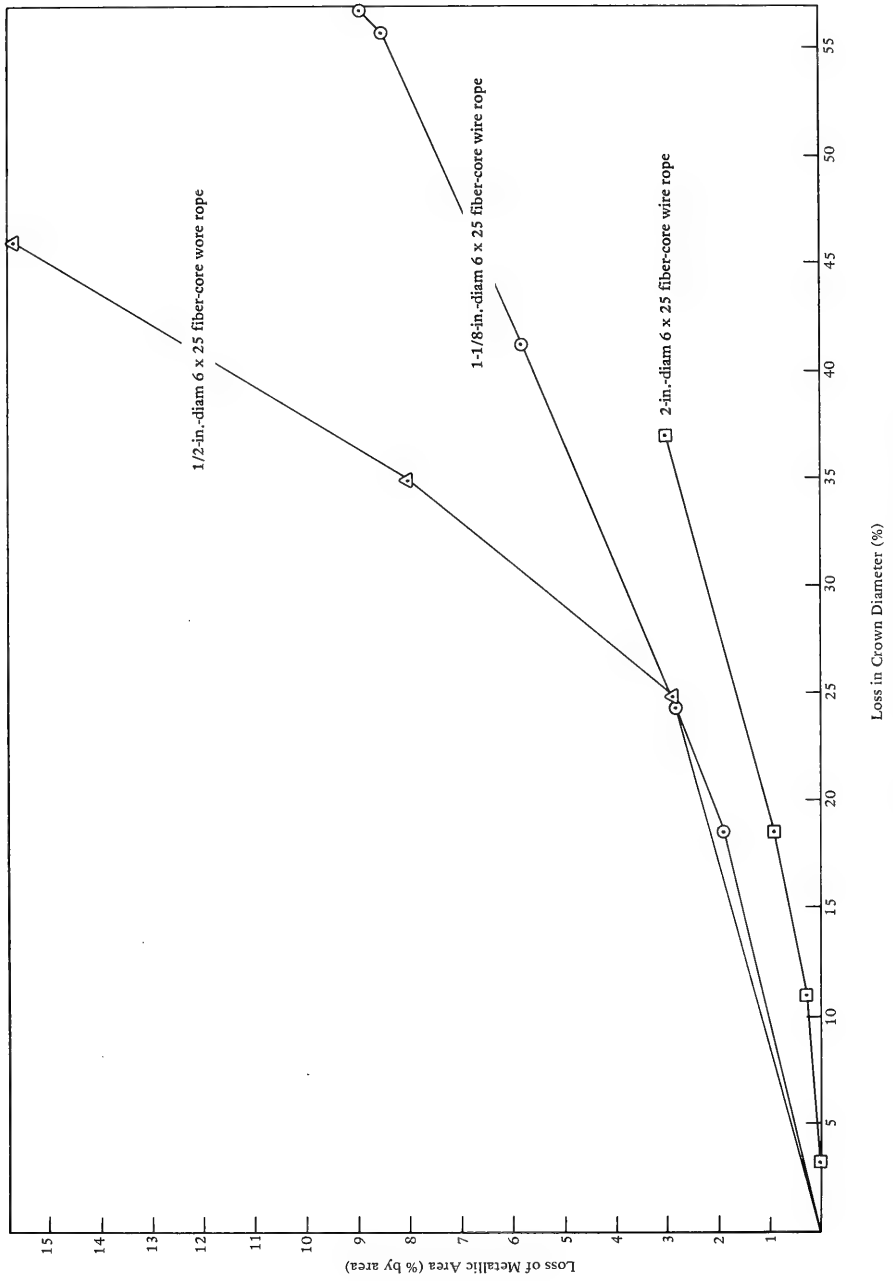
Figure 20. LMA as a function of crown wire wear.

Loss in Crown Diameter (%)

Loss of Metallic Area (% by area)

1/2-in.-diam 6 x 25 fiber-core wore rope

1-1/8-in.-diam 6 x 25 fiber-core wire rope

2-in.-diam 6 x 25 fiber-core wire rope

Figure 21. Wire rope 1-1/2-inch in diameter with 12% crown wire wear.
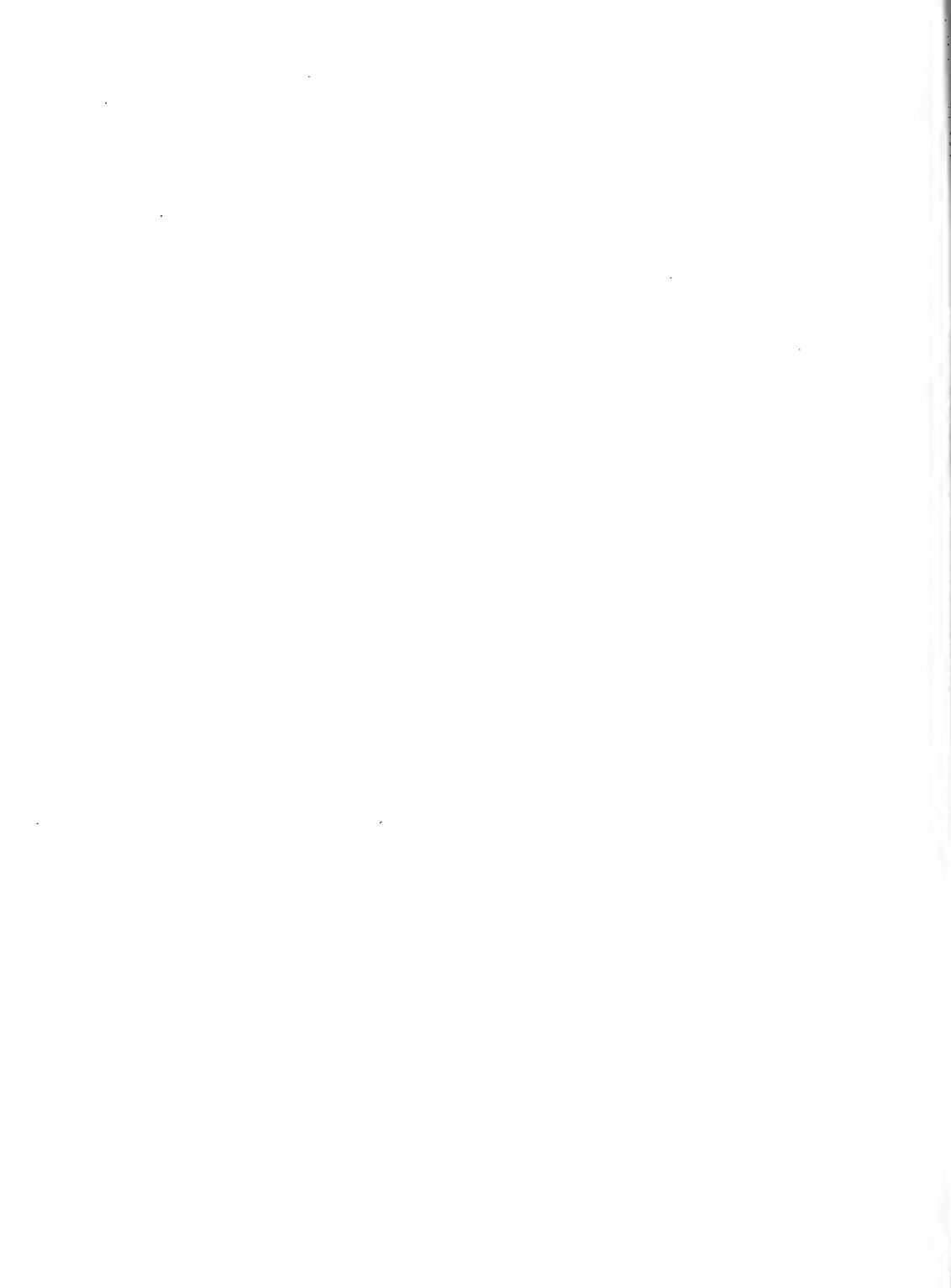
Appendix

MANUFACTURER'S OPERATING AND MAINTENANCE MANUAL FOR
MAGNOGRAPH MODEL MAG-1

This appendix presents a method for nondestructive testing of
wire rope as proposed by Heath and Sherwood in April 1981.

1.0   General Information

The MAGNOGRAPH^{TM} non-destructive wire rope tester uses Hall Effect Sensors and a strong static magnetic field to measure wear and breakdown of wire ropes. It will test ropes of any construction from 1/2 to 2 1/2 inches (12-64mm) in diameter at speeds from 0 to 600 ft./min. (0-3 m./s.)

The instrument gives simultaneous readings of a rope's metallic cross-sectional area and of localized faults such as broken wires, wire ends, wire nicks and corrosion.

The Magnograph consists of three major parts:

1) The Sensing Head - through which the rope is passed and which does the basic detection of the fault.

2) The Electronic Control Section -
which processes the Sensor Head signals and records the test on magnetic tape.

3) The Recorder Section -
which provides a strip chart visual representation of the rope test.

The complete Magnograph instrument, model Mag-1, is shown in Fig. 1.0.

SENSING HEAD
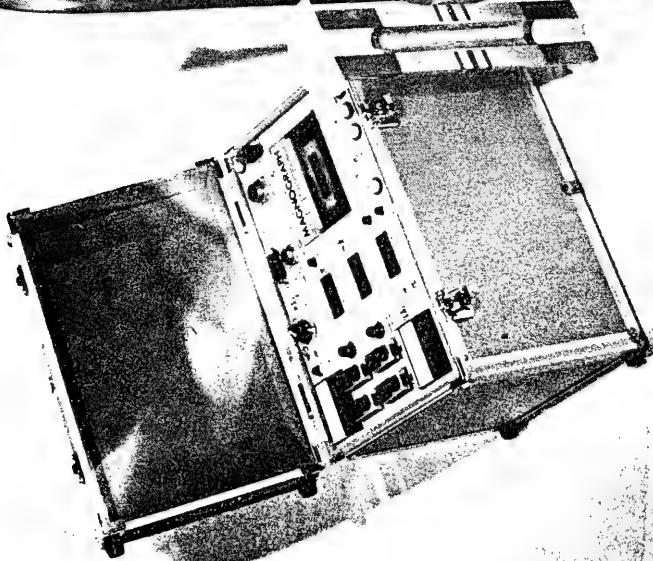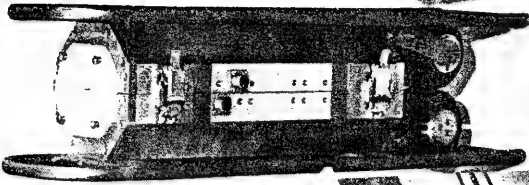
ADAPTER
TUBE
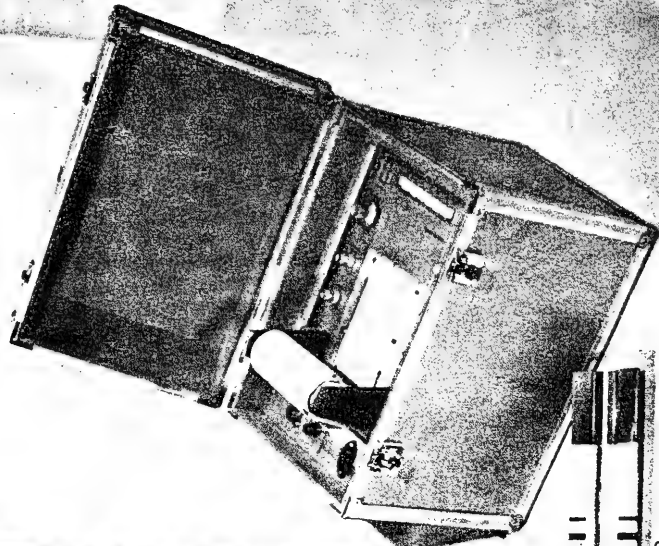
RECORDER

ELECTRONIC CONTROL

Fig. 1.0   Magnograph Non-Destructive Rope Tester

2.0   Specifications

The specifications listed below apply to Sensor Head
and Electronic Control Sections of this instrument when
operated and maintained as per this manual. These speci-
fications are subject to change without notice.

Specifications other than weight for the Chart Recorder
can be found in Gould manual No. 15-806325-00.

2.1   Electrical

Power Requirements -
Line Operation of Electronic Control Section and Battery
Charging

115VAC $\pm$ 10%, 50/60Hz   40   VA

                                           switch selectable

230VAC $\pm$ 10%, 50/60Hz   40   VA

Operation by external battery of 11.5-14VDC on Control
Section only. (Current consumption is approximately 2
amps) Internal Nicad battery in Control Section will
provide 8 hrs of continuous operation when fully charged.

2.2   Mechanical

Weight (lbs)		Dimensions (ins.)
Sensor Head -	105	28Hx8Lx8D
Electronic Control -	45	15Hx17Lx11D
Chart Recorder -	35	15Hx17Lx11D

2.3   Environmental

Operating and Charging

        Sensor Head - 20°c to + 40°c

                                        See Accuracy
Electronic Control - 0°c to + 40°c   Specifications

Storage Temperature

        Sensor Head - 40°c to + 55°c
Electronic Control - 40°c to + 55°c
 (batteries fully charged)

<u>Humidity</u>

Sensor Head - 100%, splash proof (oil and water) with
               cables connected (do not emerse)

Control Section - 100%

2.4   <u>Measuring Capabilities</u>

<u>Rope Size and Construction</u>
All steel wire ropes of any construction from 1/2 to
2 1/2 inches in diameter (12-64mm).

<u>Rope Speed</u>
0-600 ft./min. (0-3 m./s.) with 300-400 ft./min.
(1.5-2.0 m./s.) as a preferred testing speed

<u>Sensitivity</u>
LMA - $\pm$ .5% change in metallic area
LF - a discontinuity of .1% of nominal rope metallic
      area

<u>Accuracy</u>
LMA - $\pm$ 2.5% of reading for all rope sizes and con-
       struction from 0°c to +30°c
       $\pm$ 5.% of reading from -20°c to +40°c
LF - peak signal repeatable with $\pm$5% accuracy from
       0°c to +30°c and $\pm$ 10% accuracy from -20°c to
       +40°c.
 Accuracy specifications are referenced to readings at
+20°c.

<u>Detecting Length</u>
Metallic area reduction/increase will be detected with
the accuracy specified provided they exist over a length
of 24 inches (610 mm.).

3.2   The Magnetic Circuit

The heart of the magnetic circuit is the rare earth
magnets at each end of the sensing head. As shown in
Fig. 3.2 the magnetic circuit is completed through the
flux bar on one side and through the pole piece and
rope under test on the other side.

There are 4 sets of adapter tubes with various IDs
which fit against the pole pieces and which serve to
decrease the air gap between the pole piece and rope
under test. These are shown in Fig. 1.0.

The magnetic circuit in the Magnograph brings the por-
tion of the rope between the pole pieces to a high level
of static magnetic saturation. In this state the mag-
netic flux density will have a uniform distribution
throughout the rope within the sensing head and will
assume a constant value.

3.2.1   Metallic Area Measurement

As the magnetic flux density (B) within the rope is at a
constant saturation value the total magnetic flux passing
through the rope and pole pieces is directly proportional
to the metallic cross-section of the rope. This flux is
what is measured by the LMA Hall sensors.

When the metallic area of rope decreases or increases
along its length the LMA Hall sensors will show decreas-
ing or increasing voltage due to the change in metallic
cross-section. The voltages generated by the Hall
sensors are amplified and scaled in the electronic con-
trol section to produce outputs on the chart recorder
and magnetic tape recording. These outputs show changes
in the metallic area of the rope expressed as a percentage
of the nominal rope metallic area.

3.2.2   Local Fault Measurements

The magnetic flux induced into the rope under test will
be contained by the rope unless there are physical dis-
continuities within it. Physical discontinuities such
as broken or heavily nicked wires, pitting caused by
corrosion, or wire ends produce small dipoles, as shown
in Fig. 3.3. The resulting 'fringing field' of these
dipoles protrude outside the physical confines of the
rope.

3.0   Operating Theory

The intent of this section is to familiarize the user
with the basis on which measurements of rope condition
are made with the Magnograph. It touches on the magne-
tic principles involved and how they are applied to pro-
duce these readings. By necessity the analysis is sim-
plified to stress the major considerations and effects
of the principles involved.

3.1   The Hall Principle

The Hall Principle states that an electric potential will
exist across a flat conductor carrying current if the
conductor is subjected to a magnetic field. (refer to
Fig. 3.1)

Vh is proportional to:
    I.B

I - is the current
B - is the magnetic
      flux density
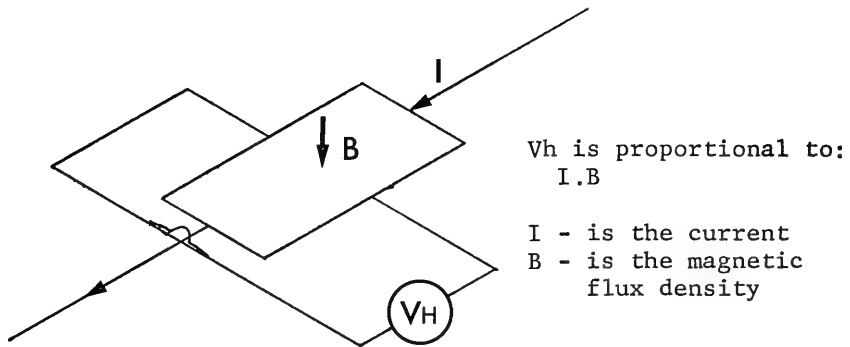
Fig. 3.1   Hall Principle.

The Magnograph uses this principle to measure metallic
area and localized faults. The semi conductor Hall
Effect Sensors used provide quite large and stable hall
voltages and allow very small changes in flux density (B)
to be measured whether they are static or dynamic in
nature. The magnetic circuit and the placement of the
Hall devices is shown in a cross-sectional view of the
Magnograph in Fig. 3.2.
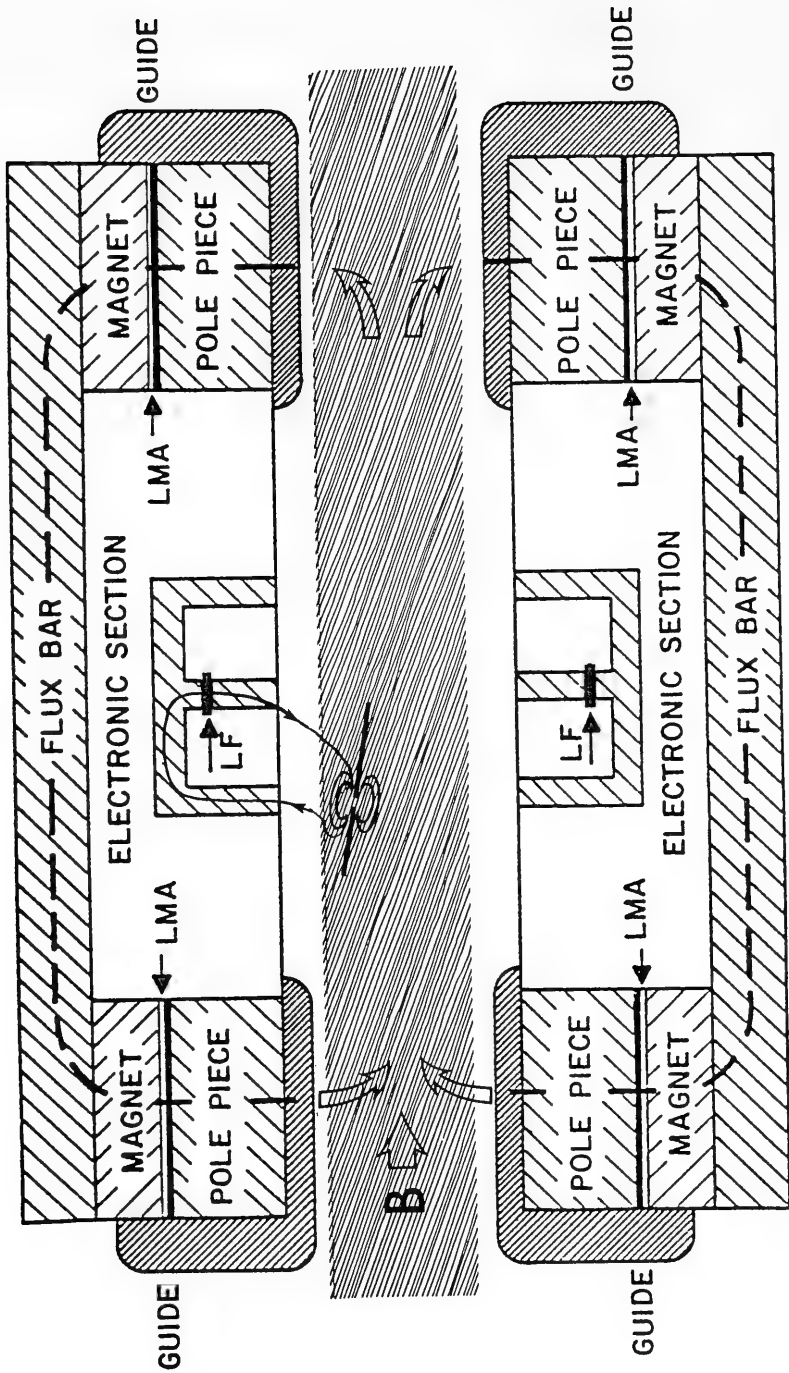
Fig. 3.2 Cross-sectional view of Magnograph sensor head. Shows LMA (loss of metallic area and LF (local fault) sensor placement and magnetic flux distribution within a rope under test.

This 'fringing field' passes the E shaped LF magnetic
circuit and induces a positive voltage in the Hall
sensors and then a negative voltage. This is illustrated
in Fig.3.4 (a) - (d)
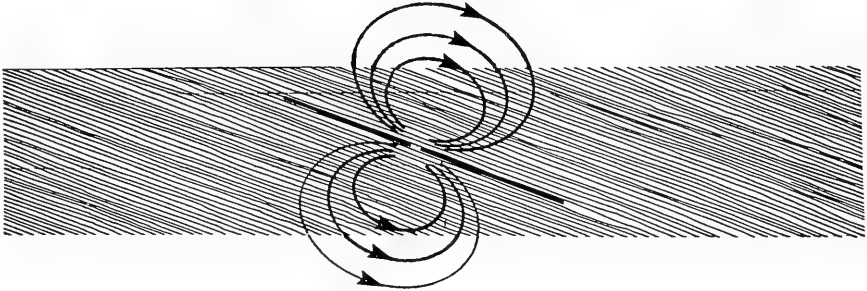
Fig. 3.3 Dipole & fringing field created by
broken wire
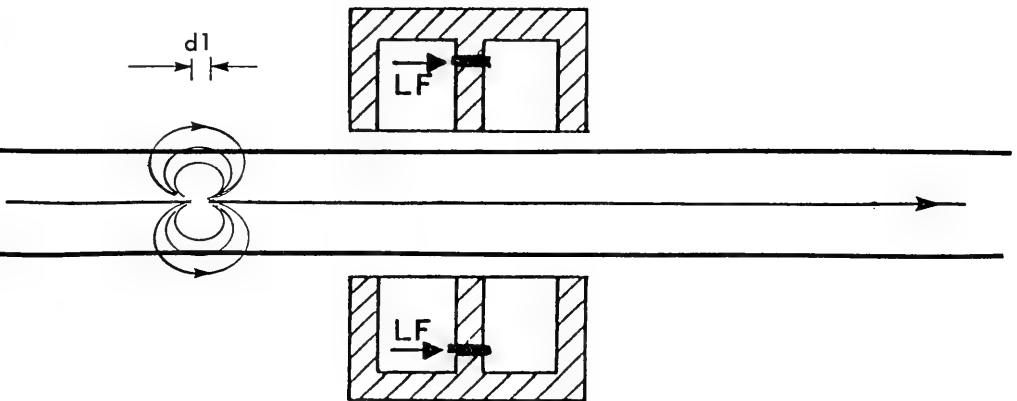
Fig. 3.4(a) Dipole fringing field before entering
LF section.
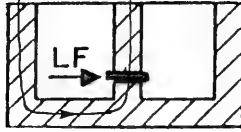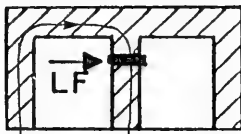
Fig. 3.4(b) Dipole fringing field entering
            first half of LF section
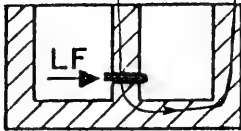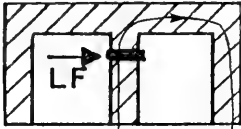
Fig. 3.4(c) Dipole fringing field entering
            second half of LF section
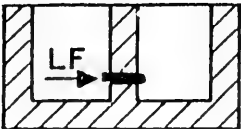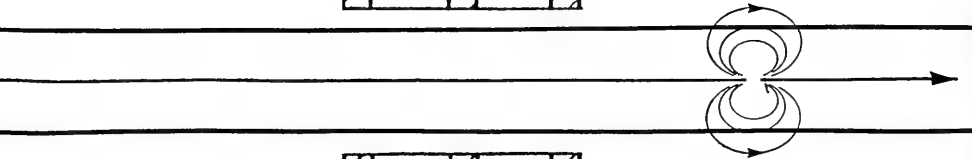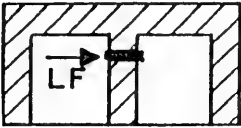
Fig. 3.4(d) Dipole fringing field leaving
            LF section

The resulting chart recorder trace for a broken wire
fault will appear as in Fig. 3.5.

The resulting chart record of Fig. 3.5 is typical of a
short dipole type of defect where dl is small. Defects
of this type are wire breaks, deep wire nicks, and
corrosion pitting. Wires which are missing in a cable
will produce a dipole which has a very large value for
dl. This will serve to stretch out the zero crossing
shown in Fig. 3.5 so that it will appear as in Fig. 3.6.
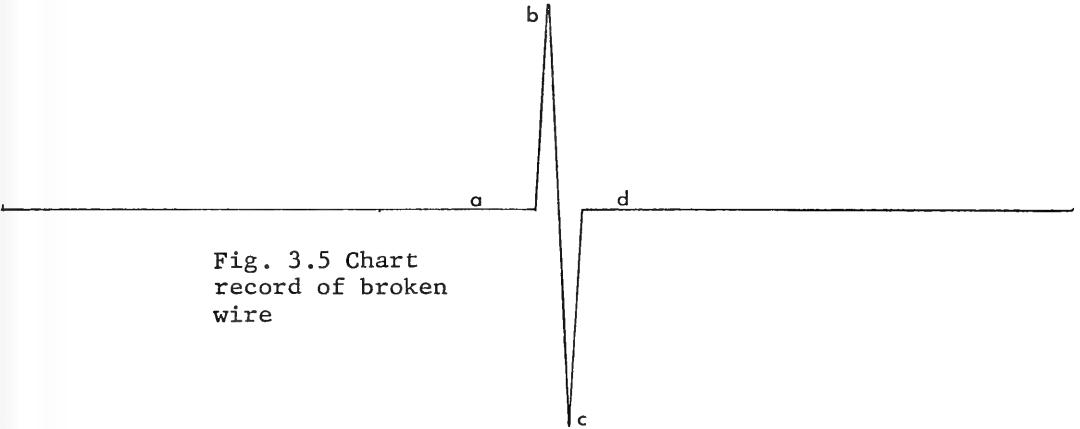
Fig. 3.5 Chart
record of broken
wire
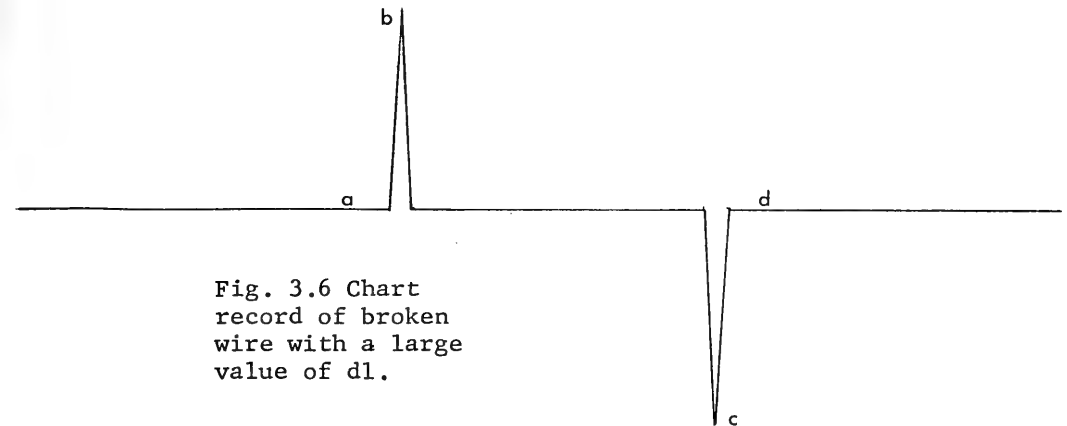
Fig. 3.6 Chart
record of broken
wire with a large
value of dl.

An example of a missing wire is shown in Fig. 3.7.
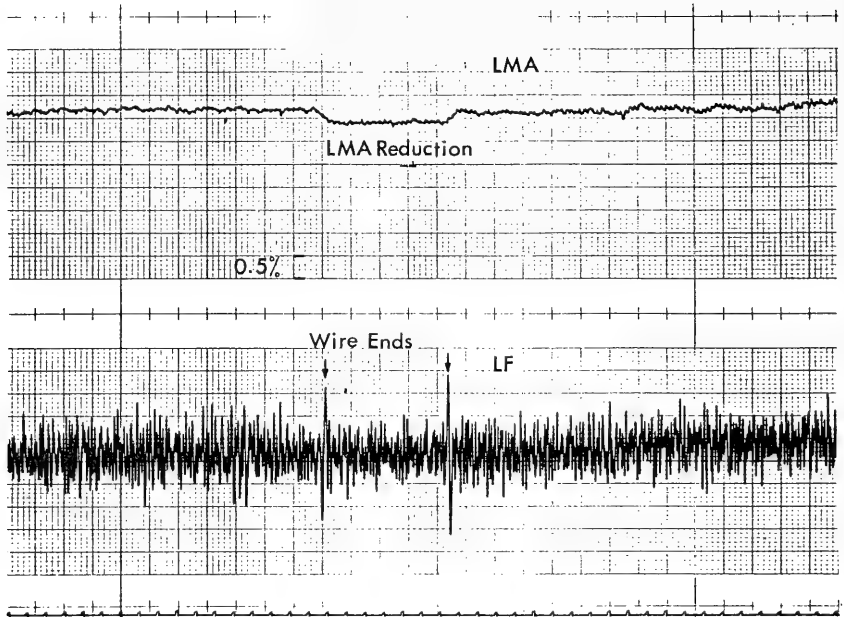
Fig. 3.7   Missing Wire in 1" full locked coil
            hoisting rope.

3.2.3 Static Measuring Capabilities

The Hall sensor measures field statically or dynamically.
This allows the Magnograph to be virtually insensitive
to rope speed. Maximum rope speeds are controlled by
the speed of response of the recording medium and the
bandwidth of the control instrumentation rather than
the magnetic circuit.

This ability is most useful when pin pointing local
faults as the sensing head can be brought very slowly
to a fault and stopped on it.

3.3   The Advantages of High Magnetic Saturation

3.3.1   The Magnetics of Materials

Wire ropes are made of carbon steel which exhibit
Ferromagnetism and Hysteresis. A magnetic induction
curve for this type of material is shown in Fig. 3.8.
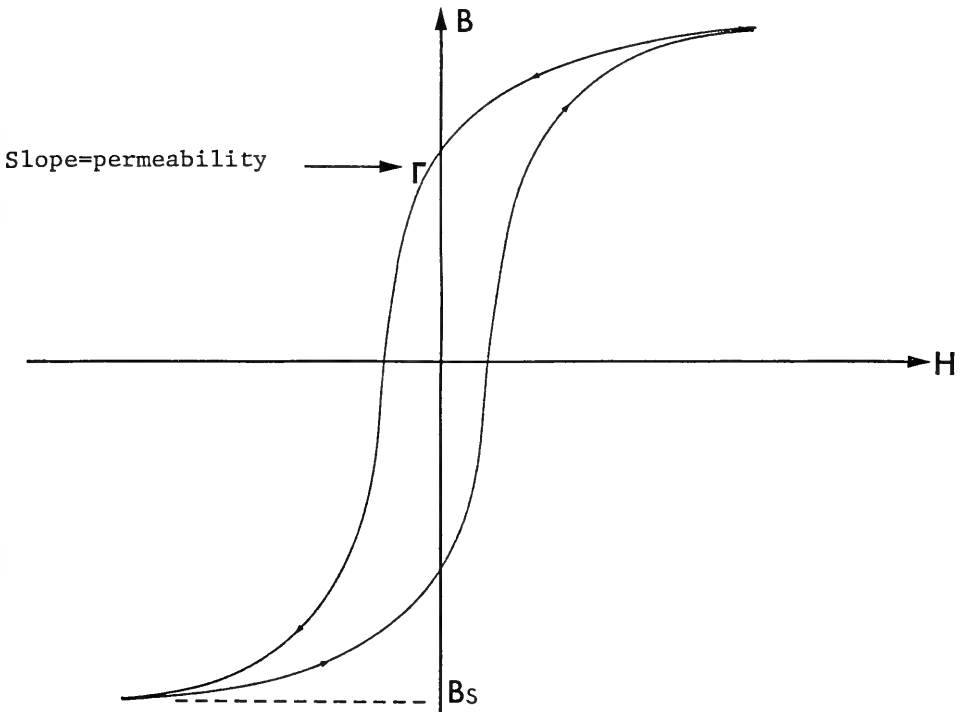
Fig. 3.8 Magnetic induction curve for carbon steel

The slope of the B-H curves at any point is called the
permeability μ =B/H.   The value of μ changes with the
slope of the B-H curve. At flux level Bs the material
is magnetically saturated and μ drops to a very low value.

The inverse of μ is related to the 'reluctance' R of the magnetic material:

$R = K/\mu$;   As μ decreases, R increases.

As R increases in a material it shows a higher resistance to the flow of magnetic flux (B) for a given Magneto Motive Force H. This is an advantage for the LF sensing section of the Magnograph as a dipole created by a local fault will experience a very small 'short circuit' effect by the surrounding wires. This allows detection of breaks deep within a large rope.

3.3.2   Permeability Changes in Magnetic Materials

The magnetic behavior of steel in wire rope is affected by factors other than the operating point of the magnetic circuit used to test it. Temperature and tension change the permeability of the steel and oxides associated with corrosion can contribute to the total flux flowing within a wire rope. The effects of temperature and tension on permeability are very pronounced at low values of magnetic flux density.

At very high levels of magnetic flux density the effects of temperature and tension are negligible. The contribution to the total flux within a rope under test due to corrosion is also negligible when compared with the total flux due to the steel alone. For these reasons, the metallic area readings of the Magnograph do not require 'interpretation' to remove the effects of tension, temperature or corrosion.

4.0   Operating Instructions

These operating instructions are intended as a guide to
the use of the Magnograph. It is aimed at familiarizing
users with the controls and procedures that will generally
be followed during a test. Users are encouraged to im-
provise and should contact Heath & Sherwood (1964) Limited
if there are any questions on application.

4.1   Transporting, Handling and Charging

The plywood containers used to ship the instrument are
designed to provide protection for it. They should be
used when the instrument is being transported over long
distances, shipped by air or when it will be subjected to
rough handling. The instrument should be considered as
sensitive electronic equipment and handled accordingly
during testing and transportation.

On receipt of the equipment it should be charged for 14
hours. This should also be done after 8 hours continuous
use or when the battery indicator shows a low battery
condition. (see section 4.2)

The battery charger has been designed to 'trickle charge'
the batteries and will not over charge them. For further
information on battery care, refer to section 5. of /this
manual.

Before charging is started the user should ensure that the
Electronic Control and Recording sections have been set to
the AC voltage that will be used. The AC voltage used to
charge the instrument is switch selectable by toggle
switches on the Electronic Control and Recording Section
chassis. Units will be shipped set for the AC voltage
requested by the customer.

4.2   <u>Front Panel Controls - Electronic Control Section</u>

<u>Refer to Fig.4.1</u>

1. Power ON/OFF Switch   - this should be off during
                               charging and when connect-
                               ing or disconnecting
                               sensor head.

2. AC Power Connector   - centre pin grounded to case.

3. Sensor Head Connector   - used to connect the Sensor
                               Head to the Electronic
                               Control Section.

4. Chart Recorder Connector - used to connect the Chart
                               Recorder to the Control
                               Section.

5. Battery Check Push Button- indicates battery voltage
                               on LMA meter when depressed.

6. LMA Meter   - indicates LMA on record or
                               playback
                       Note- this should be used as an
                               indicator only; accurate
                               readings should be taken
                               from the chart recorder.

7. Metric/English Switch   - In the 'Metric' Position:
                               -measured length is in
                                meters
                               -rope speed is in meters
                                per second
                               -meter marks are generated
                                on the chart recording.

                               In the 'English' Position:
                               -measured length is in yards
                               -rope speed is in feet per
                                minute
                               -Yard marks are generated
                                on the chart recording.

8. Rope Direction Switch   - changes direction of count-
                               ing on measured length
                               counter.

9. LMA Gain Potentiometer: -Set according to LMA
                              gain chart.
                              -calibrates chart record
                              to show metallic area
                              losses as a percent of
                              nominal rope metallic
                              area.

10. LMA Zero Potentiometer: -Used to zero the LMA
                              signal when starting a
                              test. Its setting is re-
                              lated to rope weight and
                              LMA gain by the LMA gain
                              chart.

11. LMA Calibrated Offset   -Used to shift the LMA sig-
                              nal by a fixed amount dur-
                              ing testing. (affects
                              chart recorder feed only).

12. LF Gain Potentiometer: -Sets the internal gain of
                              the electronic control
                              section for the LF channel
                              -setting depends on rope
                              size, construction and
                              condition.

13. LF Zero Potentiometer: -Used only in the 'static'
                              mode of testing to zero
                              the LF trace.

14. Compression Band Switch   -used to 'compress' lower
                              amplitude noise on the LF
                              trace
                              -this function is available
                              on record only.

15. LF Meter   -Used for zero adjustment
                              of the LF trace and as an
                              indicator of LF signal.

16. Static/Dynamic Switch   -Tests can be run in
                              'Dynamic' mode when rope
                              speeds are above 100 ft/
                              min (.35m/sec); below
                              this speed 'static' set-
                              ting should be used.

17. Measured Length Counter   -Shows distance from
                              starting point of the
                              test.

18. Wire Rope Speed   - shows speed of rope
                                   through the head.

19. Tape Counter   - shows position on
                                   cassette tape.

20. Record/Play Switch   - sets the electronic
                                   control section and tape
                                   transport in either re-
                                   cord or play mode.

21-25. Cassette Recorder Controls - ensure the 'Record'
                                   button is depressed
                                   when initiating record-
                                   ing.

26. Cassette Tape Transport.

27. External Battery Connection.

28. External Battery Indicator:- will illuminate when
                                   the external battery
                                   is connected with the
                                   proper polarity.

Prior to any testing the battery condition should be
checked. Depress the battery test switch and observe the
battery voltage on the LMA meter. The 'BATT' marking on
the meter corresponds to 11.V. If the battery condition
is at or below this level the batteries should be re-
charged. If necessary the Electronic Control and Chart
Recording sections can be run from an AC source. This
is not recommended where the AC is electrically noisy.
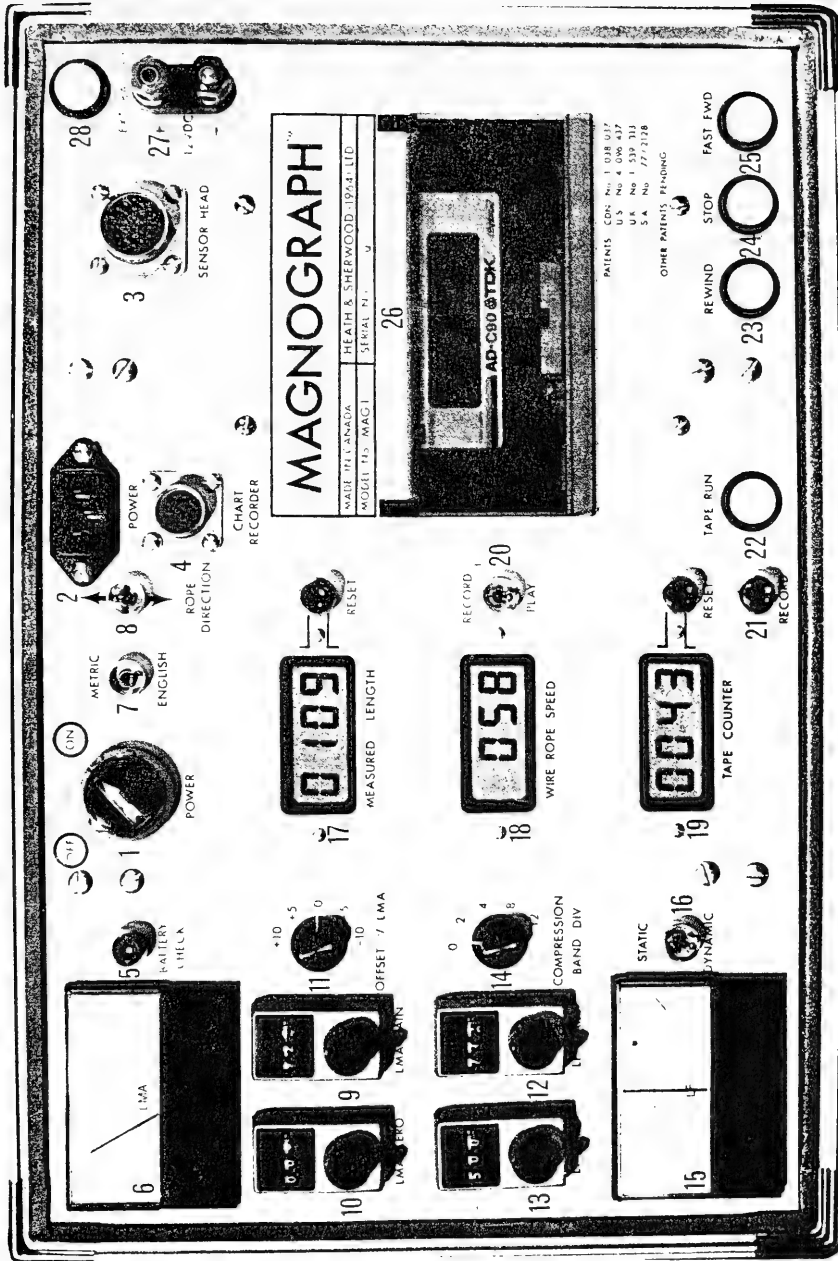
Fig. 4.1   Front Panel Controls Electronic Control Section

4.3   Front Panel Controls - Chart Recorder Section

Refer to Fig. 4.2

1.   AC Power Connector - centre pin grounded to case.

2.   LF Channel Output - LF signal present at these
                         terminals.
                       - also used for zeroing chart re-
                         corder LF Channel.

3.   LMA Channel Output - LMA signal present at these
                          terminals.
                        - also used for zeroing the chart
                          recorder LMA channel.

4.   Chart Speed Selector - Select 'Time Base' chart speed.
                            Used in 50 mm/sec. position
                            when 'Proportional Drive' is
                            used.

5.   Chart Recorder Connector - used to connect the Chart
                                Recorder section to the
                                Electronic Control Section.

6.   Proportional Drive Selector Switch - synchronizes
                                          chart speed to
                                          rope speed.
                                        - should not be
                                          used at speeds
                                          less than 10 ft/
                                          min. (.05 m./s.)
                                        - requires selec-
                                          tion of the 50
                                          mm/sec. time
                                          base on the re-
                                          corder.

The chart recorder controls for position and sensitivity
are used to adjust and calibrate the chart record. The
variable sensitivity potentiometers should be in the x1
position at all times. The multi position sensitivity
switches should be set as follows:

LF Channel   -   20 mv/mm when recording; higher
                    sensitivity may be used on 'Playback'

LMA Channel   -   5 mv/mm for a full scale LMA sensiti-
                    vity of 25%.
                -   2 mv/mm for a full scale LMA sensiti-
                    vity of 10%.
                -   1 mv/mm for a full scale LMA sensiti-
                    vity of 5%.

For further explanation of the chart recorder controls
refer to Gould manual No. 15-806325-00.
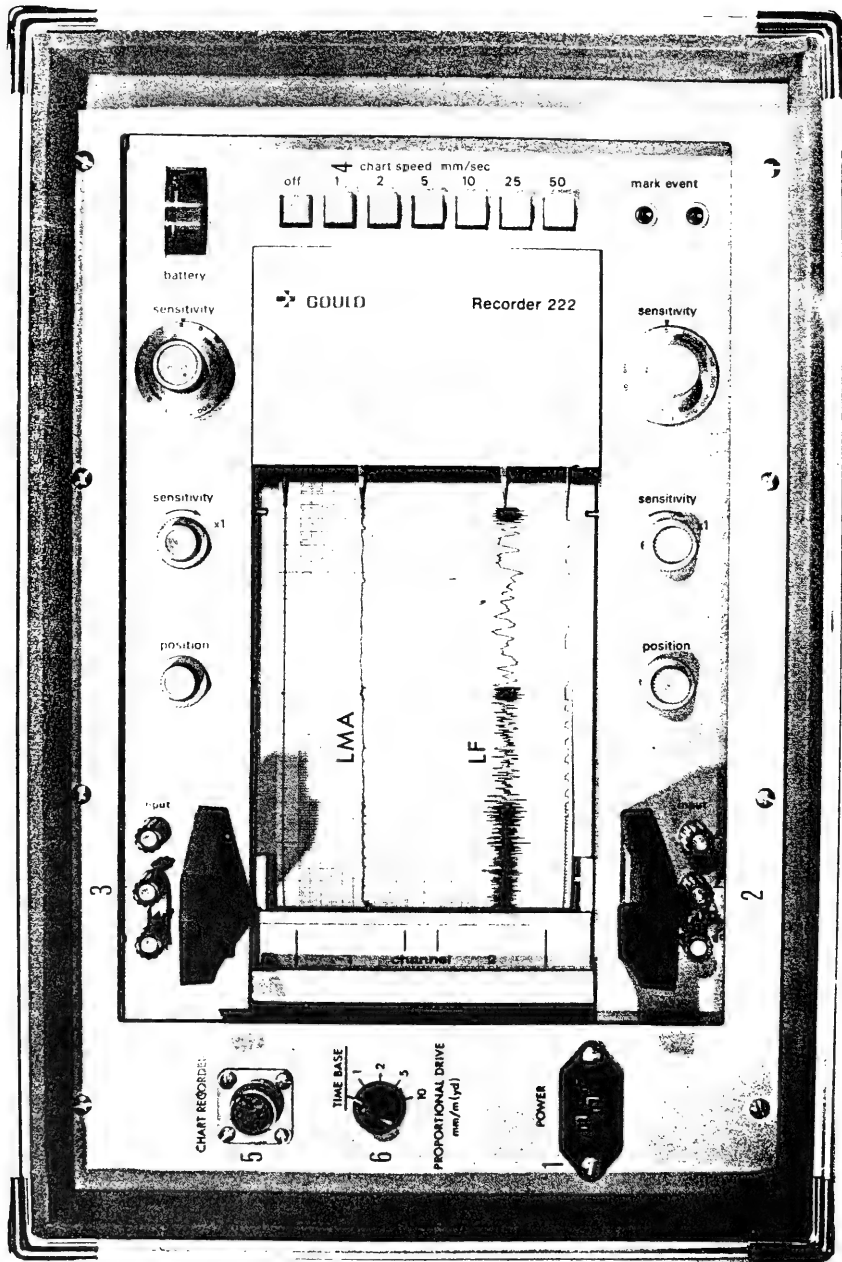
Fig. 4.2   Front Panel Controls, Chart Recorder

4.4   Conducting a Field Test

Choosing the Proper Rope Guide and Adapter Tube

The instrument is equipped with 5 sets of rope guides
and 4 sets of adapter tubes. The smallest set of guides
and tubes that will allow free movement of the rope
should be used in the sensor head when testing a rope.
Table4.1 gives a general guide line for the rope guides
used. Adapter tubes should be chosen to fit the rope
guide selected.

Table 4.1

Rope Guide   Rope O.D.

    A   1/2 - 3/4 in (12-20 mm)
    B   3/4 - 1 1/8 in (20-27mm)
    C   1 1/8 - 1 9/16 in (27-39mm)
    D   1 9/16 - 2 in (39-51mm)
    E   2 - 2 1/2 in (51-64mm).

Note - Rope Guide E does not require an adapter tube.

4.4.1 Installing and Changing Adapter Tubes
       (Refer to Fig. 4.3)

With the sensor head open undo the knurled screws hold-
ing the rope guides in place and remove the rope guides.

Insert a screw driver blade into the hole at the end of
the adaptor tube and pull one end up. The tube can then
be removed from the sensor head by hand.

To install the new adapter tube the same procedure is
followed in reverse. When installing the tube be sure
that the end of the tube is aligned with the end of the
sensor head so that the small 'locating' pins on the
adaptor tube will mate with the locating holes on the
head.

Note - The magnetic attraction of the head is very
       strong. Caution must be used to prevent injury.
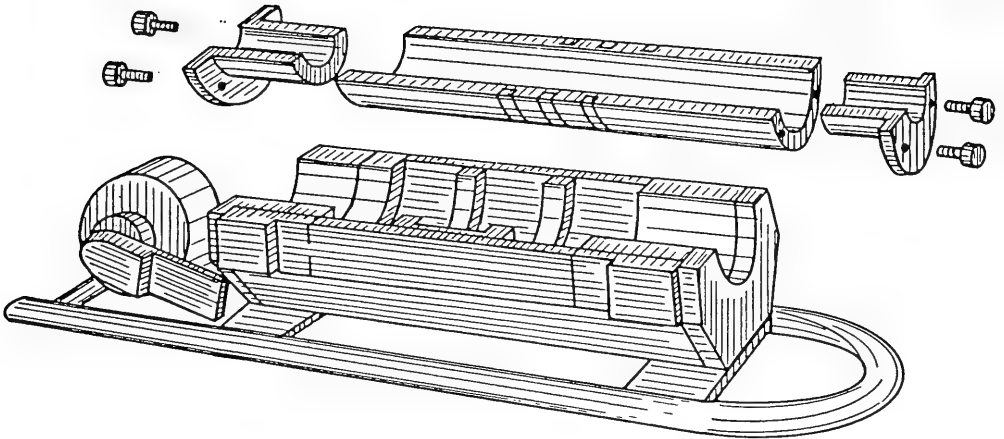
Fig. 4.3 Adapter tube and rope guide installation

4.4.2   Installing & Positioning the Sensor Head on the Rope

The sensor head can be mounted in any position for test-
ing. When positioning on the rope care should be taken
that the wheels are free to move and that the head is
secured to prevent it being carried away by lumps of
lubrication or protruding wires. The rope guides act
as slip planes between the rope and the head and are
capable of taking the weight of the head on them.

It is advisable to locate the head so that no large
pieces of metal are closer than one foot to it, the
sides in particular. This can cause some distortion
in the magnetic field which may compromise the readings.

A typical vertical testing arrangement is shown in Fig.
4.5
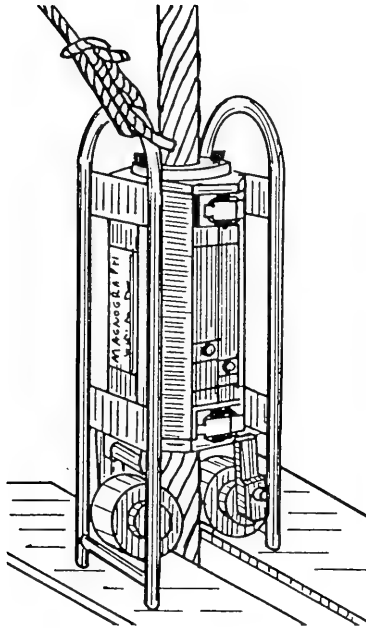
Fig. 4.5   Typical vertical testing arrangement

The cable which attaches to the sensing head has two 9
pin connectors and one 5 pin connector. The 9 pin connec-
tors connect to the receptacles on the side of the head
and the 5 pin connector to the arm of one wheel. The
cable should be routed as per Fig. 4.6 to allow the head
to be installed on the rope when the connectors are
attached.

CHART RECORDER CABLE

SENSOR HEAD CABLE

SENSOR HEAD THREE WAY CABLE

RECORDER SECTION

ELECTRONIC SECTION

SENSOR HEAD
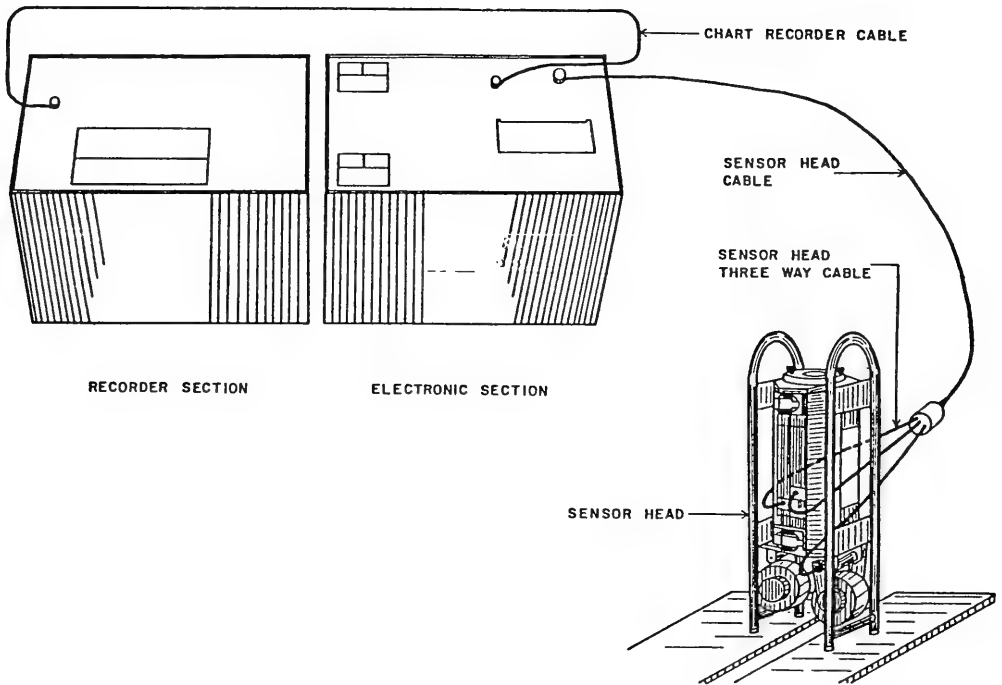
Fig. 4.6   Cable routing

With the cable connected to the head, install it on the rope by undoing the two clasps and bringing one half of the head to the rope so that the rope rests in the rope guides. Close the head and refasten the clasps.

<u>Note</u> - During connection and disconnection of the head the electronic control section should be turned off.

4.4.3 Running the Test

When the sensor head and recorder have been connected to the electronic control section it may be turned on. Allow it to warm up for 30 sec.

Adjusting the instrument for the rope being tested is carried out as follows:

i)   Start the chart recorder in the Time Base mode, at some convenient chart speed. (1mm/sec.)

ii) Set the multi position sensitivity switch on the LMA Channel for the desired LMA sensitivity. This should be done so that the highest and lowest LMA readings will remain on the chart. The sensitivity settings and their corresponding LMA sensitivity is shown in Table 4.2.

Table 4.2

Chart Recorder Sensitivity	LMA Sensitivity
5mv/mm	25% LMA full scale (.5% LMA/mm.)
2mv/mm	10% LMA full scale (.2% LMA/mm.)
1mv/mm	5% LMA full scale (.1% LMA/mm.)

iii) Zero both channels by using the shorting plugs provided in the LMA and LF Channel Outputs (See Fig.4.2) and by adjusting the chart recorder position controls. The LF channel should be zeroed in the centre of the trace and the LMA channel, 2 large divisions above the centre of the trace so that both positive and negative LMA changes may be kept on the graph.

iv) Switch the Record/Play switch to the 'Play' mode.

v) Adjust the LMA Zero Potentiometer to give the zero reference established in iii) or to show zero on the LMA Meter.

vi) Adjust the LMA Gain as per the graph in Fig. 4.8. Re-adjust the zero and gain if necessary.

vii) Select either 'Static'or 'Dynamic' on the Dynamic/Static switch depending on the rope speed anticipated. If the 'static' mode of operation is chosen adjust the LF Zero potentiometer to give the zero reference chosen in iii) or to show the centre of the scale on the LF meter. Adjust the LF gain as per the discussion in section 4.5.1.

viii) Set the position on the Rope Direction Switch to correspond to the rope direction (with the switch in the up position a rope moving from the top of the sensor head toward the wheels will cause the measured length counter to count up.)

ix) Set the Metric/English switch to the desired position, the Calibrated Offset to 0 and the Compression Band Switch to the desired amount of compression (see section 4.5.3 for further explanation of the use of this setting).

x) If a tape recording is to be made load a cassette into the tape transport. Press the red Record Button and the Tape Run button and allow the tape to advance passed the leader.

xi) Zero the Measured Length and the Tape Counter displays.

xii) Start the rope.
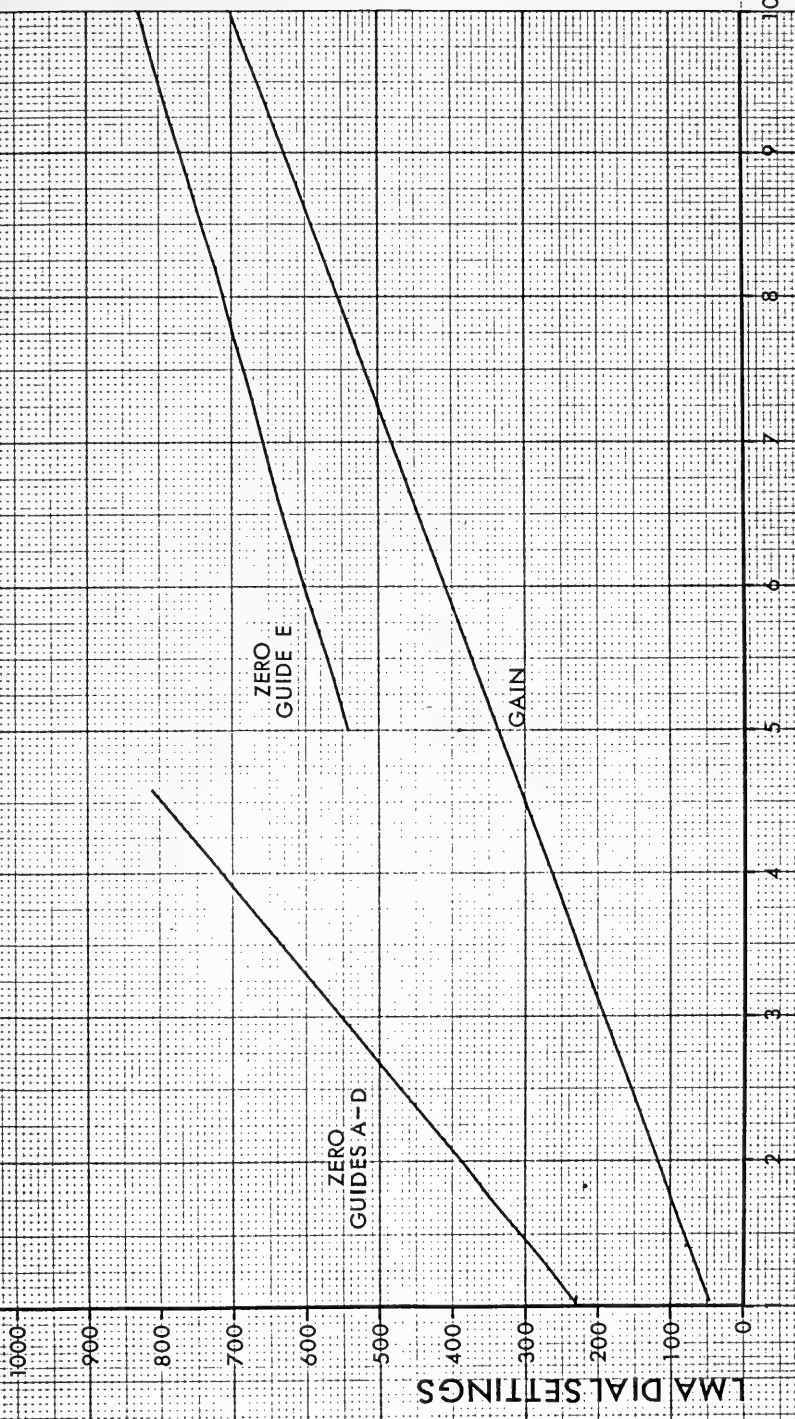
NOMINAL ROPE METALLIC WEIGHT (LBS/FT)

LMA DIAL SETTINGS

ZERO
GUIDE E

GAIN

ZERO
GUIDES A–D

4.5   General Considerations for Testing

It is best to start a test on a section of rope which is
known to be in good condition. This will give the best
calibration for nominal rope weight on the LMA trace and
will allow the LF trace to be calibrated for an area
where the LF signal will be relatively clean.

4.5.1   LF Signal Generation

The local fault (LF) reading is affected by many things.
Magnetic dipoles which the Hall sensors will detect are
formed by broken wires, nicks, corrosion and wear.
Broken wire dipoles and how they show on the chart record
is a function of how large the wire is and how large the
separation is between the ends of the break. In general
the magnitude of a broken wire signal will increase as
the separation between the ends increases to the point
where the zero crossing becomes a plateau as shown in
Fig. 3.6. Broken wires with the ends 'butted' together
will not show on the chart record as no dipole is pro-
duced. A large broken wire with the same end separation
will show a larger signal than a small wire.

Wire rope, when new, will show a low level local fault
signal associated with the lay of the rope. The ampli-
tude of this signal is a function of the size and con-
struction of the rope. The signal is higher for larger
ropes of the same construction and is higher for stranded
ropes than for locked coil ropes.

The lay noise and a broken wire signal are shown in Fig.
4.9 on the left. On the right of Fig. 4.9 is the chart
recording of the same rope in an area where the wear is
high and corrosion is present. The LF Gain is the same for
both sections of the graph.

As can be seen the LF 'background noise' increases dram-
atically with wear and corrosion on the rope and in this
case is assuming the magnitude of the broken wire signal
on the left part of the chart. As rope wear increases
the broken wire signal may become lost in this 'background
noise'.

The increase in the 'envelope' of the LF trace is an
important qualitative indication of rope condition. The
increase with time in the signal's 'envelope' is an im-
portant piece of rope history to keep track of as its
growth will accelerate as the rope nears the end of its
life.   A-30

Due to the many factors affecting the generation of LF
signals a graph of gain setting vs. rope size and con-
struction is of little use. The LF gain setting will
depend on the rope size, construction, and its state of
wear. Section 4.5.2 sets out general 'rules of thumb'
which should be followed to gain the most information
from the LF trace.
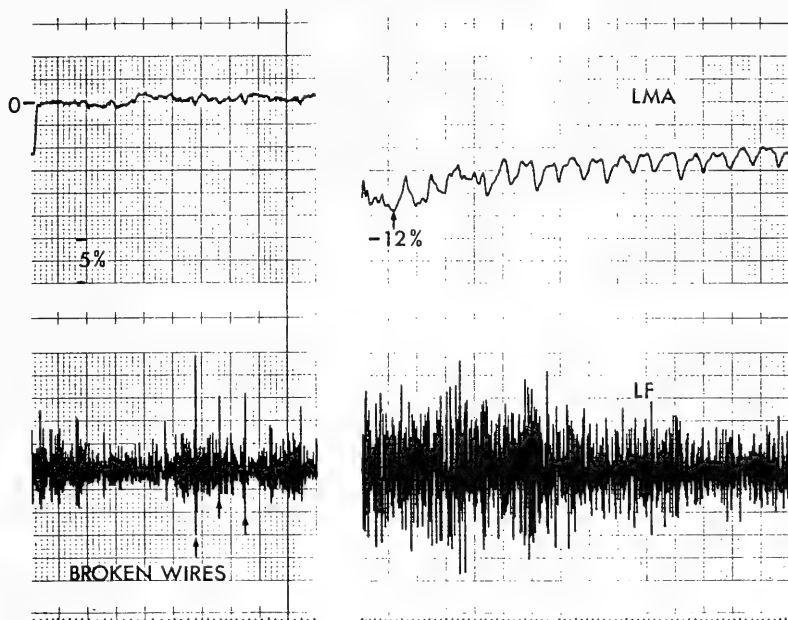
Fig. 4.9   1 1/8"   6x27 Hoisting Rope.

4.5.2   <u>LF Gain Potentiometer Setting</u>

On ropes with very little wear the LF Gain should be ad-
justed to show ± 3 small divisions of signal on the chart
recorder. This will allow significant local faults to
be quite visible. With rope wear this initial setting
will cause the LF trace to go off scale in sections where
corrosion and wear are heavy. The gain should be reduced
to ensure that these areas are mostly on the chart so
that only occasional peaks go off the chart limit.

Areas of the rope that have little wear and for which a
higher amplification can be used can be tested again at a
higher amplification or can be re-run from the tape with
a higher chart sensitivity (see section 4.6   ).

As the user becomes more familiar with the ropes under
test the setting of gain to keep the LF signal on the
chart will be quite straight forward.

The change from test to test of the LF trace should be
watched carefully and the gains used for successive
tests should be kept track of to establish the rate of
increase of the LF signal. In Fig. 4.10 the gain of the
LF amplifiers vs. the Gain Potentiometer setting is
shown. To relate the changes in amplitude of the LF
trace with successive tests, the amplitude change and any
gain change should be noted so that an increase in the
'envelope' of rope noise can be kept track of. To find
the total 'envelope' change take the change in the
'envelope' from the two tests and multiply by a factor of
New Gain/Original Gain. This change in the 'envelope' of
rope noise should form part of the history of the Rope.
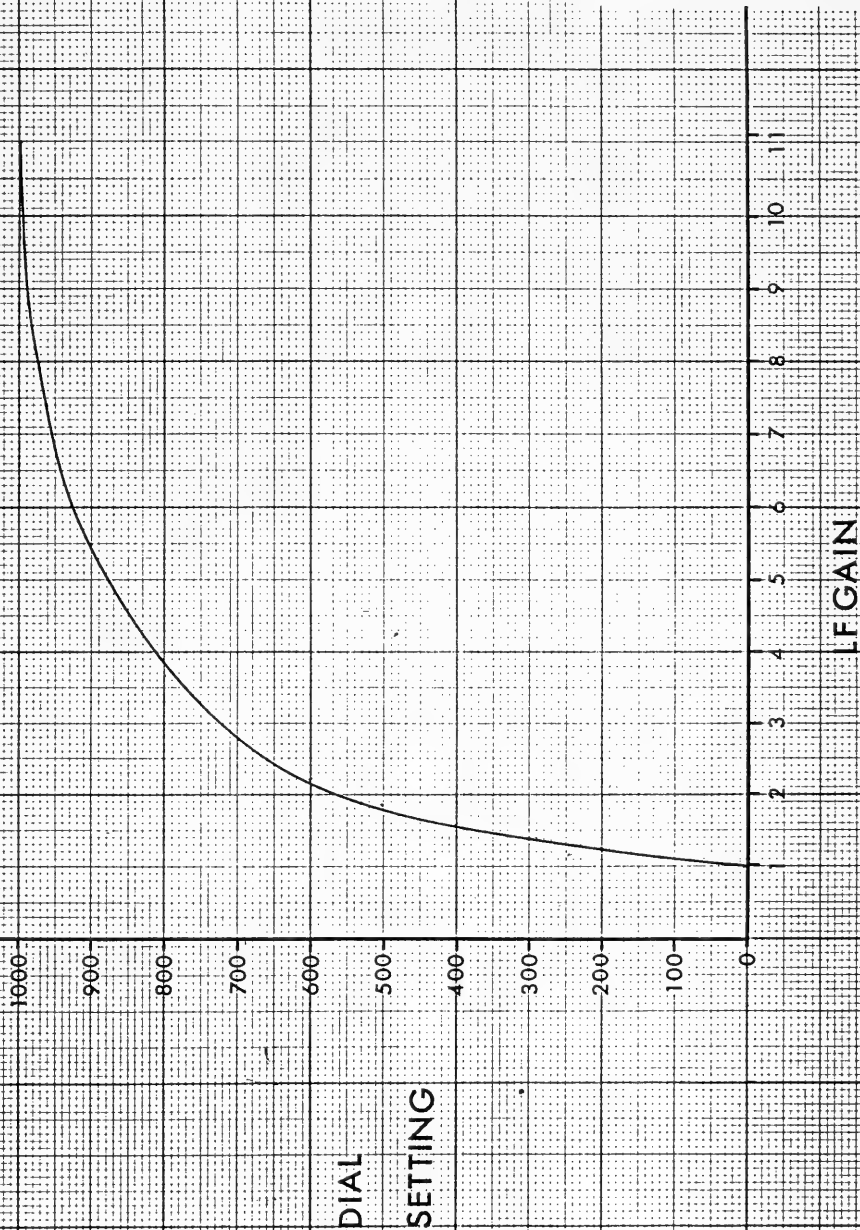
FIG. 4.10

4.5.3 Use of the Compression Band Switch

The compression band switch controls the amplification of the LF signal in a manner that will reduce signals with an amplitude below a certain number of divisions on the chart but will leave the gain unchanged for signals over this number. As an example, a setting of 4 on the Compression Band Switch will reduce signals of $\pm$ 4 small chart divisions by a factor of 10 but will leave signals above $\pm$ 4 divisions with their original gain. This feature is used to accentuate the higher amplitude LF signals. Caution is required in the use of the compression control and it should only be used when familiar with the instrument and the rope under test. The compression control works only in the 'Record' mode and the 'compressed' LF signal will be recorded on the tape. If uncertainty exists on what compression setting will be most valuable for a particular rope the compression switch should be left at zero as LF signals which are of interest but which have been 'compressed' are not retrievable from the tape recording of the rope.

4.5.4 Use of Proportional Drive Chart Control

The chart can be advanced proportionally with rope speed during a test or tape replay. To do this select a proportional drive setting on the Chart Recorder Section and depress the 50mm/sec. chart speed button. The chart will advance and 'sync' itself to the rope speed.

The proportional drive requires a few yards (meters) to lock into the rope speed and initial rope speeds will not be accurately represented.

4.5.5 Distance Markers on Chart Recorder

There are 2 event markers on the chart recorder which indicate distance travelled along the rope. The lower event markers (on the side of the LF trace) marks every yard or meter. The upper event marker (on the side of the LMA trace) marks every 50 and 100 yards or meters. The 50 y/m marks are short pulses and the 100 y/m marks are long pulses. The 50 and 100 y/m marks will only be indicated when the rope measured length counter is counting up. The y/m marks have 2 polarities as shown in Fig. 4.11.
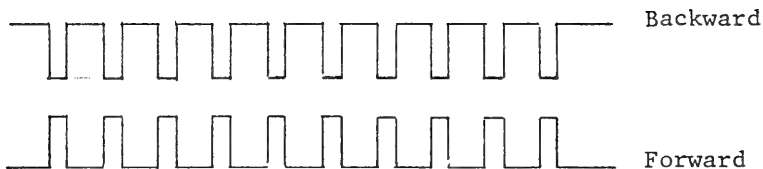
Fig. 4.11   Yard/Meter Marks.

The 50 and 100 y/m marks are ~~not~~ recorded on tape as the
y/m marks are and are used to locate distance along the
rope from the beginning of the test.

4.6   Running a Chart Record From Tape

Rope testing can be done without the Chart Recorder and
the information can be recorded on tape only. Conversely
a tape recording of a rope test is not essential but
forms a convenient way of storing rope data, and allows
replay of the rope test for further investigation.

When a tape is made of a rope test the LMA, LF and yard
or meter marks are recorded on the tape. This allows a
further investigation of the test using increased chart
speed or sensitivity. When a test is underway, areas of
the rope that warrant further information should be in-
dicated with the tape counter number so that they can be
located on the tape afterwards: The tape counter will
help to locate the area of the fault on the tape, but
will not pinpoint it exactly as there is some slippage
in the tape transport.

Note -   Do not allow tapes to come close to sensor head
         as the strong magnetic field will erase them.

To re-run a test from tape the following procedure is used:

i) Connect the Chart Recorder Section to the Electronic Control Section.
ii) Turn the Electronic Control Section on and set the chart recorder to the desired chart speed or proportional drive setting (see sections 4.3 & 4.5.4).
iii) Set the Record/Play switch to the 'Play' mode and insert the cassette.
iv) Zero the chart recorder channels as at the beginning of a rope test.
v) Use the tape transport controls to locate the area of interest and start the recorder with the 'Tape Run' button.

The zero references for the LMA and LF Channels may require repositioning with the chart recorder controls.

Note - High quality recording tape should be used. TDK type AD is recommended.

4.7   Rope Magnetization

The strong magnetic field within the Magnograph sensing head will leave remnant magnetism in the rope. This remnant magnetism decreases somewhat with time and working of the rope in use. The presence of remnant magnetism in the rope causes a shift in the LMA zero as a result of a redistribution of the magnetic flux from the auxiliary field outside the sensing head to the field inside the sensing head.

The effect of the presence of remnant magnetism on the LMA readings can compromise the readings of the LMA channel if not properly accounted for.

In Fig. 4.12 the sensor head and its associated magnetic fields are shown for a rope with no remnant magnetism in it. (There may be small amounts of remnant magnetism in the cable due to the earth's magnetic field but these will be insignificant).
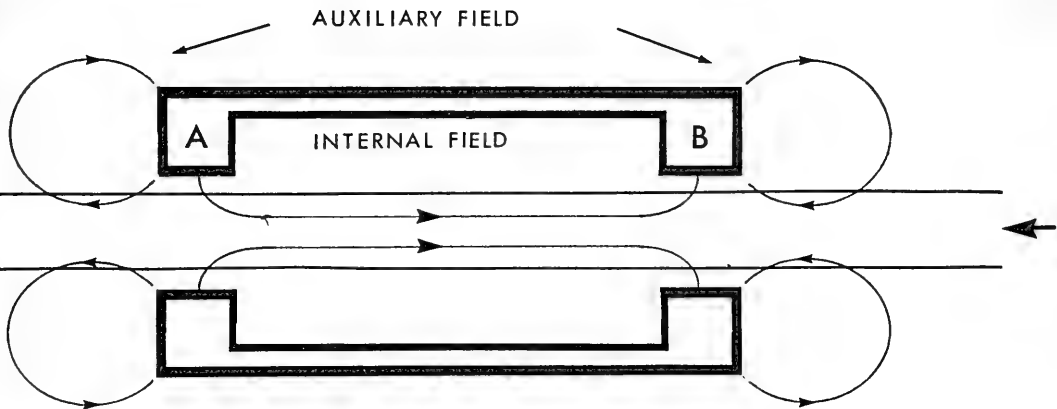
Fig. 4.12   Sensor head Internal and Auxiliary
            magnetic field

As the rope is moved the part of it leaving A will have
remnant magnetism in it. This remnant magnetism will
cause Aux. field A to decrease and Internal field A to
increase. This change will take place over the first
2-3 feet of rope movement. A previously zeroed LMA
chart record will show this increase as in Fig. 4.13.
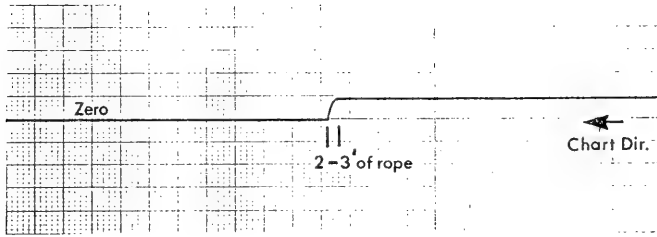
Fig. 4.13   LMA chart record showing zero increase
            with rope magnetization

This increase in the zero due to magnetization results in
a calibration error of the original gain setting by the
amount of the increase. ie. a 1% shift in the LMA zero
due to the rope being magnetized will mean that the LMA
gain setting is off by 1%. This may not be of concern
to the user and LMA zero shift due to magnetization on
smaller ropes is quite small. Larger ropes (2" plus)
may have a shift of 2-3%. With this amount of shift
recalibration for the new zero is advisable.

This can be accomplished in the following manner:

  i) Set up the instrument as described in section 4.4.3
     with the sensor head on good section of the rope.
 ii) Advance the rope by 3 feet so that the zero increase
     due to magnetization is seen on the chart.
iii) Rezero the chart with the LMA Zero Potentiometer
     and adjust the gain as per the LMA calibration chart.
 iv) Start the test.

The LMA zero increase caused by the magnetized rope leaving one end of the machine will also occur as the magnetized rope leaves the other end of the machine.

Once a test is completed the rope which has been run through the machine will be magnetized. If the rope is then run in the opposite direction an LMA zero shift will occur. This is as a result of magnetized rope leaving end B of the machine (see Fig. 4.12) and the Internal magnetic field B increasing. No change occurs in the field A as magnetized material is now entering the head at end A and the zero shift in the LMA due to this field redistributing has already occurred at end A on the previous test. If recalibration of the LMA gain is again desired it can be done by first advancing the rope by 3 feet on this 're-run' and adjusting zero and gain as previously described.

The LMA zero shift due to magnetization has a more important effect on measurements than calibration.

Rope tests are often carried out in two parts due to accessibility of the working length of the rope. Once one section of the rope has been tested care must be taken in testing the rest of the rope as the sensing head will ultimately meet the end of the first test and see the magnetic 'signature' created by the magnetization induced in the rope by the first test. An example is in order to explain this further.

Fig. 4.14 shows the working length of a rope as if it were completely stretched out. The first test was conducted between d1 and d2. To test from 0 to d1 the head should be installed with the same orientation on the rope as the first test. As d1 is approached and passed the sensing head will see a changing magnetic condition from unmagnetized rope entering it to magnetized rope entering it. This will create an LMA chart record as in Fig. 4.15.
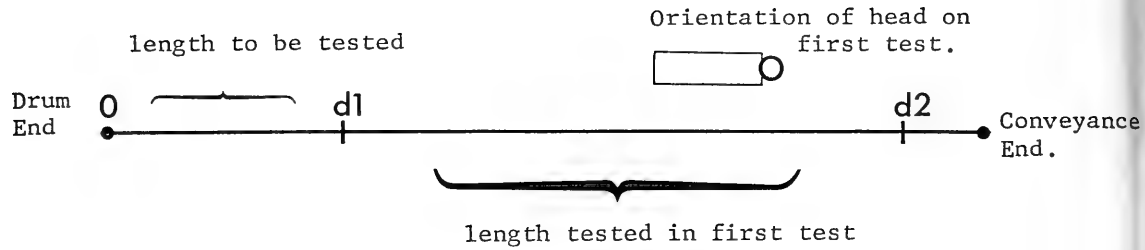
Fig. 4.14 Working length of Rope
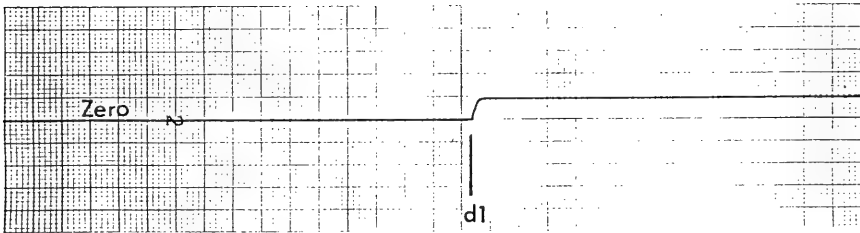
Fig. 4.15 Change in LMA zero when passing the start of
the first test.

The danger of this transition is that it may be mistaken
as an actual change in the rope condition. If there is
confusion as to where d1 is on the charts of the two
successive tests, the charts should be overlapped.

For similar reasons running past the end of an earlier
rope test (as would occur in retesting past d2) should
also be done with care. An example of running over a
previous test is shown in Fig.4.15. As can be seen the
magnetization ending from the previous test looks very
much like an LMA decrease due to wear. In this partic-
ular test there is no marked reaction in the LF trace
that generally accompanys an LMA decrease of this size.
This helps to pinpoint the end of the previous test.
As wear increases however, the LF trace will have a
larger amplitude and cannot be used effectively to
indicate the end of a rope test. Keeping track of
where tests start and finish and overlapping charts of
adjacent test is a more positive method.
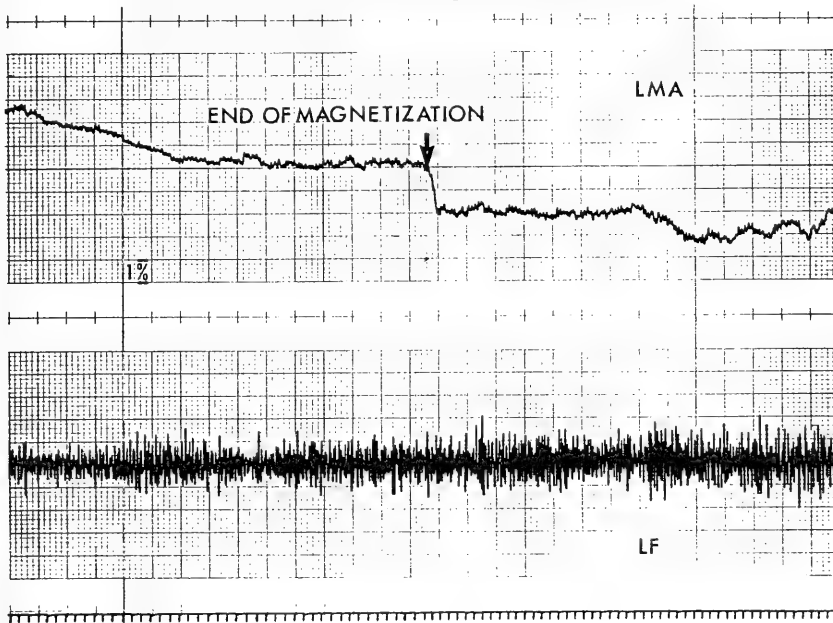
Fig. 4.16   Showing End of Magnetization from previous
            test.   (1 3/4"   6x27 Flattened Strand)

In Fig. 4.9 the LMA zero setting vs. nominal rope
weight is shown. This allows the rope weight to be
estimated by the zero setting. This graph represents
rope weight of 'magnetized' rope with 'magnetized'
indicating that the rope on either end of the machine
has been magnetized.

4.8 Testing Short Pieces of Rope

Short sample pieces of rope can be tested in the Magno-
graph. If calibrated LMA readings are required the
sample must protrude at least 5 feet on either side of
the sensing head. This is required to contain the
auxiliary magnetic field. The LF readings are quite
insensitive to this 'end effect' and short test pieces
may be used if LF readings are required.

4.9   Interpretation and Use of Readings

The readings obtained by the Magnograph should be used
to pinpoint areas of a rope which require further visual
inspection but should not be considered as a wholesale
replacement of visual inspection.

By keeping accurate histories of rope wear, problem
areas in the hoisting system or in rope usage will be-
come quite visible. Using this information will allow
for more efficient rope use.

4.9.1 Using Readings as a Rope Removal Criterion

The decision to remove a rope from service due to loss
of strength is an individual decision for each user.
Rope removal is governed by legislation in many count-
ries and users should be aware of how this affects their
individual situation.

The metallic area loss (LMA) on a cable is sometimes
used as a direct indication of loss of strength.
This is sometimes a good estimation or 'starting point'
but assumes that all ropes wear and lose strength in
the same manner. Even in countries where metallic area
loss is used as a direct indication of strength loss
considerable variation is found when this is compared
to the actual loss of strength. This is due to the
fact that many variables contribute to strength loss and
metallic area decrease is only one factor. If metallic
area loss were the only factor involved it too would
show considerable variation in loss of strength depend-
ing on where the loss has occurred in the rope.

To achieve some guidelines on the correlation of the
readings of the instrument and how strength is being
lost in ropes of specific usage it is suggested that
actual breaking tests be done on a rope once removed
from service. This will allow the user to derive a
pattern of strength loss for his specific situation.

5.0   MAINTENANCE AND TROUBLE SHOOTING

The purpose of this section is to provide: an under-
standing of the operation of the circuitry at a "block"
level; a schedule for regular maintenance to ensure
serviceability of the equipment for many years to come;
and a means of identifying faulty blocks, should a
problem arise.

5.1   Block Description

The "FUNCTIONAL BLOCK DIAGRAM" of Fig. 5-1 shows the
major divisions in the signal conditioning circuit
paths; Sensor Head, Analogue   , FM   , Digital
and Chart Recorder.

5.1.1 Analogue/Sensor Head

The analogue signals, LMA (proportional to cross-
sectional area of the rope) and LF (indicative of
irregularities in the rope) are derived in the SENSOR
HEAD by 8 LMA HALL SENSORS and 4 LF HALL SENSORS. These
sensors are excited by DC constant current supplies in the
ANALOGUE section of the Control Electronics. The signals
are summed, temperature corrected and amplified by two
preamplifier boards, one in each half of the SENSOR HEAD,
and transmitted up the cable to the Control Electronics.

The LMA signal is summed with LMA ZERO which cancels the
100% rope proportional signal and amplified by means of
LMA GAIN to normalize signal changes that they may be
expressed in percentage change. This normalized signal
is smoothed by a Low Pass Filter and made available to
the TAPE RECORDING circuitry, LMA panel METER, and
through additional LPF to the CHART RECORDER. At this
point the capability of inserting a fixed % OFFSET is
offered so that large area changes, up to 25%, may be
offset on the chart thus allowing use of optimum sensi-
tivity.

The LF signal is summed with LF ZERO to eliminate any DC
levels due to additive DC field components, then Low
Pass Filtered to eliminate high frequency transients.
(Note: LF ZERO is disabled in the DYNAMIC MODE of
operation).

The signal is subsequently amplified by LF GAIN to a
level dependant on rope condition, for optimum fault
measurement. A band of COMPRESSION (+) may be selected
within which the signal is attenuated by a factor of 10
(eg. background noise). If "O" is selected the signal
is unaltered. After this stage the LF signal is made
available to the TAPE RECORDING circuitry,   the LF
panel METER and   the CHART RECORDER.

5.1.2   FM

The LMA and LF data can be recorded on magnetic tape for
future processing or playback. The FM section consists
of voltage to frequency converters for the LF and LMA.
These converters produce frequencies above and below
their centre frequency of 3KHz in proportion to the
signal inputs. A third converter produces one of two
frequencies to correspond to its digital 0 or 1 input.
This Frequency Shift Keying (FSK) is used to code the
Yard or meter marks from the Digital Section.

These signals are recorded at a fixed amplitude on tape
and upon playback are decoded and reconstructed by two
frequency to voltage converters and a Phase Locked Loop
FSK demodulator.

A digital panel indicator allows approximate relocation
of any point on a recorded cassette by counting in res-
ponse to spindle rotation.

5.1.3   Digital/Sensor Head

The tachometer located in the rope guide roller on the
Sensor Head, with a fixed rotation to length ratio pro-
duces two square waves with a + or - 90º phase relation-
ship. The signals are transmitted up the cable to the
Control Electronics. The Digital section sharpens these
pulse trains and decodes their phase relationship to in-
dicate one direction of travel or the other. These
pulses are counted and a mark for each yard or meter of
rope travel is produced. The polarity of the mark is
determined by the rope direction.

These marks, whether in real time or decoded from taped
data are delivered to an event marker in the Chart
Recorder and are also counted to generate a combined
50 and 100 mark indicator which is fed to a second event
marker in the Chart Recorder.

The yard/meter marks are counted and indicated on the
panel display "MEASURED LENGTH".

A voltage proportional to the speed of the rope is also
derived from these marks. It is used to drive a panel
display of "ROPE SPEED" and to control the speed of the
paper chart recorder in proportion to the speed of the
rope. This feature requires that the rope travel at a
speed greater than a preset minimum and thus it is en-
abled by a motion sensor.

5.1.4 Chart Recorder

A two channel paper chart recorder is used to provide hard
copy of the data measured by the system.

The LMA and LF signals are delivered to the channel sensi-
tivity controls and attenuated for optimum results.

The YD/M marks and the 50/100 marks are isolated electri-
cally by means of a photo coupler the outputs of which
drive the two event marker pens.

The speed of the chart may be controlled either by the
internal TIME BASE or by the speed of the rope as selected
by the front panel PROP DRIVE switch.

5.2 Maintenance

Very little maintenance is required but adherence to a "clean-up" routine will further reduce the risk of failures.

5.2.1 Chart Recorder

After each day of use of the Chart Recorder any accumulated dust or dirt should be wiped off with a soft cloth. If used under very dusty conditions it may be necessary to remove the works from the cabinet and using low pressure compressed air,blow the dust from the equipment. Removal of the four bottom mounting screws is the only dissassembly required.

Paper wipers and rubbing alcohol should be used to remove any spilled ink from metal work.

Maintenance to the pen and ink supply, paper supply and chart or pen drive mechanisms should be done at regular intervals as specified by the manufacturer's manual (supplied herewith #15-806325-00).

5.2.2 Control

After each day of use of the Control any accumulated dust or dirt should be wiped off with a soft cloth or paper wipes and rubbing alcohol. If used under very dusty conditions it may be necessary to remove the works from the cabinet and using low pressure compressed air, blow the dust from the equipment. Removal of the four bottom mounting screws is the only dissassembly required.

Maintenance of the tape recorder heads and drive system should be performed at regular intervals according to the manufacturer's manual included herewith. (#78-2OEM-1A2)

The internal battery in the control should not be left inactive for periods exceeding three months. Every 90 days while in storage for periods of greater duration, the control should be operated by internal battery until the minimum voltage is reached, then allowed to charge for 24 hours. This will ensure long battery life and consistent discharge capacity.

5.2.3 Cables

The cables for interconnection of the components of the system contain multiple pairs of shielded conductors and should not be subjected to great compressive forces. Regular inspections should be made to ensure the integrity of the outer jacket and repairs made with self-vulcanizing silicone rubber tape as required.

After each use of the system the cable should be wiped clean of any grease or oil using a soft cloth dampened with varsol or mineral spirits, then wiped again with rubbing alcohol. This will ensure long life of the P.V.C. outer jacket.

Caution: Do not use solvents such as acetone or MEK as this will dissolve the material in the jacket.

5.2.4 Sensor Head

This component of the system is subjected to the worst abuse in regular service. It must be cleaned often using mineral spirits or varsol to remove the large amounts of grease and oil that accumulate on it.

When cleaning remove the plastic guides and metal inserts and wash them separately in a tray of cleaner using a small short bristled brush.

When cleaning the rest of the body particular attention should be paid to the roller assemblies to ensure they turn freely and are not restricted from good contact with the rope by accumulations of grease or dirt.

Caution: Great care must be taken to prevent damage to wires or connectors or the ingress of foreign matter into either the connectors or the electronics area of the head.

5.3   Trouble Shooting

The following section is intended to aid in the isolation
of faulty blocks in the event that a problem should arise.

Although these schedules are kept at a "block" level and
not "component" level, they should be performed only by
those familiar with and qualified to operate various
pieces of test equipment such as oscilloscopes, digital
voltmeters, soldering irons and other electronic test
equipment as may be required.

Reference to the following schematic drawings will be
necessary for full understanding in most cases.

```
D 7001-0001     MAG-1 Control
C 7001-0002     MAG-1 Recorder
C 7001-0007     MAG-1 Sensor Head
D 6000-0001     MAG-1 Sensor Head Cable
B 6000-0002     MAG-1 Recorder Cable
```

FIG 5-1 FUNCTIONAL BLOCK DIAGRAM MAG-1

HEATH & SHERWOOD (1964) LIMITED
KIRKLAND LAKE CANADA

A-50

No LMA/LF Output On Recorder

Refer to Schedule "B" Fig. 5-3

Cont.Batt Chk D.C. Fuse — Bad / OK

Select "Record" (1st) (2nd)

Replace ± 15V Power Supply Board — Bad

Check +15V At JH-Y, Z WRT. JH-U — OK

Replace Analog BD 1700-0001

Adjust LMA,LF Meters Zero: Move? — Yes / No

Apply Ext. Volts to JH- E,F,H,J WRT JH-D

Recorder Pens Move? — Yes / No

Meters Move? — No / Yes

Chk/Repair Wiring JH to J7

Check for 0.5 VDC JH-U to JH- — No / OK

Faulty Sensor Head

Check Head Cable — Bad / 2nd OK 1st

Repair or Replace Cable

Replace Analog Brd 1700-0001

Recorder BATT Indicator — OK / No

Plug into Line

Apply Ext. Volts to Recorder Inputs

Pens Move? — Yes / No

Repair or Replace Rec. Cable

Faulty Recorder

T.S. SCHEDULE "A"
Fig. 5-2

A-51

Short Control
Battery
Discharge
Life ⩽ 4Hrs.

Check AC
Fuses
Line Volts
Nom + 10%

No → Adjust
Using
Auto
T-Former

OK

Chk Charger
Vin ≈ 20v

No → Replace
Lambda

OK

V Bat After
14hrs on
Charge >13.7v

No → Check
Charger
Current
(1.8-2.2A)

OK → Replace
Battery

No → Replace or
Repair
Charger

OK → Battery
Temp

Warm → Adjust
Charger
Vmax =13.9v

Cool → Remove DC Fuse
(5A) Measure Operating
Current ⩽ 2.5ADC

No → Refer to
Schedule "C"
Fig. 5-4

OK → Replace
Battery

T.S. Schedule "B"
Fig. 5-3

A-52

AC Fuses Blow As Mains Cord is Connected

Control Draws Too Much Current (No Conns.)

DC Fuse Blows When Power Switch to On

Disconnect Power Plug P1 From Tape Deck

Tape Deck Faulty

If Fuses Still Blow Contact Factory.

Check +15 +15L.+$\bar{1}$2 +10v

Replace Faulty P.S. Board

Remove All Plug in Circuit Brds

Re-Install Brds One By One

When Fuse Blows Replace Faulty Board

If Fuse Still Blows Contact Factory

Is Voltage Selector Switch in Correct Pos.

Fuse Values Correct?

Correct Switch Replace Fuses

Mains Voltage Nominal ±10%

Correct Using Auto T-Former or Regulator

Remove K1: Fuses Still Blow?

Install New Relay (K1)

Replace LAMBDA Supply

If Fuses Still Blow Contact Factory

Labels: DC · AC · Fuse still blows · Fuse OK · OK · Bad · Still Blows · Fuse OK · No · OK · Yes · No · Yes · No

T.S. Schedule "C"

Fig. 5-4

A-53

```
┌──────────────┬──────────────┐
│No Rope Speed │ LF, LMA      │
│or Length     │ Functions    │
│Indication    │ Appear       │
│              │ Normal       │
└──────────────┴──────────────┘
        │
        ▼
┌──────────────┐                    ┌──────────────┐        ┌──────────────┐
│Ensure        │                    │Check         │  Bad   │Replace       │
│Sensor        │        OK          │+15L          │───────▶│Faulty        │
│Head Roller   │───────────────────▶│+10V          │        │P.S. Board    │
│Rotation      │                    │              │        │              │
└──────────────┘                    └──────────────┘        └──────────────┘
     │ No              OK                   │ OK
     ▼                                      ▼
┌──────────────┐    ┌──────────────┐   ┌──────────────┐      Yes
│Clean         │    │Ensure        │   │Recorder      │───────────▶┌──────────────┐
│Spring and    │    │Function      │   │Event         │            │Replace DVM Brd│
│Shaft Area    │    │Controls      │   │Marker        │            │1700-0007      │
│              │    │Correct       │   │Works?        │            │Counter Brd    │
└──────────────┘    └──────────────┘   └──────────────┘            │1700-0008      │
                        │ No                │ NO                    └──────────────┘
                        ▼                   ▼                              │
                    ┌──────────────┐   ┌──────────────┐            ┌──────────────┐
                    │See           │   │Replace       │            │If Problem    │
                    │Operating     │   │Digital       │            │Persists      │
                    │Instructions  │   │Brd           │            │Contact       │
                    │              │   │1700-0003     │            │Factory       │
                    └──────────────┘   └──────────────┘            └──────────────┘
```

T.S. Schedule "D"
Fig. 5-5

A-54

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