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EDDY CURRENT INSPECTION OF GUN TUBES

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JULY 1992

US ARMY ARMAMENT RESEARCH,
DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
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13. ABSTRACT *(Maximum 200 words)*

This report describes the work done by the author to develop an eddy current system to inspect the inside diameter surface of gun tubes.

The report begins by explaining the basic theory of eddy current inspection. Next, the experimental work, which was done to test the feasibility of using this test method for gun tube inspection, is described. Finally, the system, which was developed as a result of this experimental work, is described in detail.

The system is capable of automatically performing inside diameter surface inspection of a gun tube in less than five minutes and is currently being tested as a replacement for the pre-swage magnetic particle inspection of gun tubes.

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Mr. William Sullivan for his expertise in electrical engineering and his moral support; Mr. John Atchinson for his expertise in the area of nondestructive testing; and Mr. John Moss for designing the mechanical modifications to the system.

In addition, the assistance of many other individuals, too numerous to mention here, who contributed to the success of this project is greatly appreciated.

OBJECTIVE

Traditionally, inside diameter (ID) inspection of gun tubes is done using a fluorescent magnetic particle solution with a black light borescope. The inspection, which takes approximately 30 minutes per tube, has four major limitations:

1. Because the inspection is manual, it is possible that an inspector could fail to inspect the entire tube surface.

2. The determination of a defect relies on the interpretation of an inspector.

3. The process is fatiguing to an inspector.

4. No permanent record is automatically produced indicating the defect locations.

The objective of this project was to develop a system that would eliminate the four problems encountered with magnetic particle borescope inspection. An additional objective was to reduce the time required to inspect the ID surface of a gun tube.

BACKGROUND AND INTRODUCTION

Of the various methods of nondestructive testing available, eddy current testing most appropriately meets the objectives of this project. It is an easily-automated process and a rapid means of inspection. One limitation of eddy current testing is that it is basically a surface inspection. Because of this, defects that do not come to the ID surface cannot be located. However, this is not a serious limitation for gun tube inspection, since the type of defect encountered after heat treatment is usually a quench crack, which, in most cases, comes to the ID surface.

The principle behind eddy current inspection is depicted in Figure 1. The oscillator represents the electronics used to produce an AC voltage across the coil at a given frequency. "I" represents the electric current flowing in the coil at one instant in time. The current in the coil produces a magnetic field, the strength of which is proportional to the number of coil turns (N) multiplied by the current. The magnetic field produced by the current is shown in Figure 1 by the arrow labeled H_1 (magnetic field strength of the coil). This creates a magnetic flux that causes currents to flow in the test material located adjacent to the coil. These currents, because of their tendency to flow in a circular path, are called eddy currents and are produced by magnetic induction. The eddy currents flowing in the material labeled I_E, produce a magnetic field counter to the original magnetic field. As shown in Figure 1, since the magnetic flux is a function of the voltage (E), frequency (f), and number of coil turns only, then the magnetic field strength of the coil must increase to maintain the flux. The increase in magnetic field strength is produced by an increase in the current. A crack in the test material decreases the magnitude of the eddy current, because the current must now travel around the crack resulting in a decrease in the magnetic field strength of the eddy current and the magnetic field strength of the coil current. The decrease in the magnetic field strength of the coil is produced by a decrease in the value of the current in the coil. The decrease or change in the current can be readily measured and is a way to detect cracks in the test material. The depth to which the eddy currents penetrate the test material is shown in Figure 1. Since the depth is inversely proportional to the relative permeability of the material, the currents do not penetrate nearly as deep in steel as they do in a nonmagnetic material such as aluminum. Thus, eddy current inspection of magnetic materials is basically a surface inspection.

Because this is essentially a surface inspection, there is one potential problem when inspecting an as-forged tube. The surface condition of an as-forged tube can be rough due to loose scale breaking away and leaving an irregular surface. However, since the ID surface is inspected after the tube is machined, if it could not be used effectively on the as-forged tube, it could replace the magnetic particle inspection on a rough-machined tube prior to swage.

APPROACH

The initial effort of this project was to modify an eddy current inspection system (Reluxtrol) previously purchased. The Reluxtrol was designed to locate ID defects. It uses an eddy current sensing coil slightly smaller than the tube's ID. The sensing coil is mounted at the end of an assembly with an electric motor to drive the coil down the tube bore. The system was modified in an attempt to overcome problems previously discovered. These problems were operation at a frequency that was too high and poor impedance matching of the sensing coil with the driving circuit. To eliminate these problems, a lower range frequency module was purchased, and the number of coil turns was changed to match the driving circuit impedance.

Tests were conducted using the modified system on production gun tubes and on sample sections of tubes that contained quench cracks. According to these tests, the system was not sensitive enough to locate quench cracks. The type of sensing coil used produced eddy currents that circulated around the circumference of the ID surface. The change in impedance produced by a quench crack was not enough to cause a significant change in the signal. Additional problems were encountered with the drive system, including slippage between the drive belts and the tube surface and failure of the drive belts.

To improve the sensitivity, tests were conducted using a small "pencil"-type probe (see Figure 2) using the setup shown in Figure 3. A pencil probe was mounted adjacent to the ID surface of a section of a gun tube. The section of tube was rotated by a motor to produce relative motion between the probe and test surface. The Reluxtrol instrument was used to process the signal from the sensing probe.

The test results were encouraging. Figure 4a shows the recording from a 105-mm tube section containing three quench cracks: one large crack and two smaller cracks. Figure 4b shows the recording from a 105-mm section with a heavily-scaled ID surface without quench cracks. Both recordings were taken at 100 kHz, 20 mV/division, and a passband filter setting of 10 to 30 Hz. The probe was held fixed as the sample rotated. The recording in Figure 4a shows two closely-spaced quench cracks and a larger quench crack approximately 180 degrees from the smaller ones. Figures 5a through 5c show recordings obtained at three different frequencies: 250, 100, and 30 kHz. As seen, the change in frequency had no significant effect on the signal. Figure 6 demonstrates the effect of filtering on the signal produced. Figure 6a shows the signal produced from a section containing three quench cracks and a scale pocket approximately 0.5 inch in diameter formed when an area of scale separated from the ID surface. The pocket depth is approximately 0.035 inch, and the quench cracks are from 0.1 to 0.5 inch deep. Filtering was set at 3 to 30 Hz passband. The signals in Figures 6a and 6b have been rectified and clipped for a more legible recording. Figure 6b shows the same recording at an increased chart speed to differentiate the wavelength between the quench crack and the scale pocket signal. Figure 6c shows the recording at a passband filter setting of 10 to 30 Hz. The indication from the scale pocket was filtered out. The results of these tests were encouraging at the time, since they indicated that filtering would effectively remove the unwanted indications from scale pockets on the recorder trace.

Figure 7 shows the recorder trace from a tube section containing four quench cracks and one scale pocket. In this case, the difference in amplitude between the signal produced from a 0.5 and a 0.2-inch deep quench crack can be seen. Although the amplitude of the signal is not directly proportional to the crack depth, a deeper crack did produce a larger amplitude signal. Figure 8 shows the results of a test conducted using a section containing three quench cracks. The remaining surface was rough due to scaling. Despite the noise signal produced from the rough-scaled surface, the signal-to-noise ratio was still very good.

As a result of the tests conducted using the pencil probe, the following was concluded:

- The frequency was not an important factor in determining the quality of signal produced in the 30 to 250-kHz range. Tests conducted below 30 kHz showed a deterioration of the signal-to-noise ratio.

- Filtering effectively reduced the signal produced from surface roughness.

- The pencil probe produced a signal far superior than that from the full diameter coil.

Further testing was conducted by two eddy current system manufacturers on sample sections of gun tube material containing quench cracks. They were asked to determine if eddy current was a practical method of locating quench cracks in as-forged gun tube material. The results are given in Appendices A and B. Both contractors, using a pencil probe, found that eddy current was an effective method of locating quench cracks.

The results of the work accomplished up to this point were used as the basis to develop a specification for the purchase of an automated eddy current inspection system. The system was required to have the following features:

- An oscilloscope display of the eddy current signal.

- A strip-chart recorder.

- The ability to detect defects as small as 0.001 inch wide, 0.1 inch deep, and 0.5 inch long. (The system purchased can detect defects as small as 0.1 inch long.)

- The ability to inspect each tube in five minutes or less.

- A rotating sensor mounted on a mandrel driven by a motor external to the probe assembly.

RESULTS

The automated eddy current inspection system (Magnetic Analysis) is shown in Figures 9a and 9b. Figure 9a shows the system with the control panel in the center of the photograph. Figure 9b shows a gun tube supported by adjustable stands located at the end of the mandrel assembly. The probe assembly is mounted on the end of a mandrel driven into and out of the tube bore by an electric motor. The probe, located near the middle of the probe assembly (see Figure 10), spins at 600 rpm to provide relative motion between the tube surface and probe. Mandrel translational speed is adjustable within 1 to 10 inches per second. The signal readout is given on a strip-chart recorder (see Figure 11). Channel one gives the eddy current signal, and channel two indicates whenever channel one exceeds a threshold value. The threshold value is set at a minimum defect depth, so that channel two is triggered whenever the preset value is exceeded.

The instrument can operate at 200, 400, or 600 kHz, with six different filter bands available. It also incorporates electronics that can amplify signals above a preset value and attenuate signals below a preset value. This feature further enhances the signal-to-noise ratio, and thus produces a clearer indication whenever a defect is detected. A phase control is used to select the proper signal phase angle to enhance the signal from a crack.

The varying ID and the out-of-roundness of the as-forged gun tubes necessitate incorporating circuitry to compensate for the variation in spacing between the probe and the tube surface. The compensation circuit operates in the 0.015 to 0.150-inch range. The compensation circuitry essentially works to electronically maintain the amplitude of the signal produced from a defect at a constant level within the given range based on the signal from a sensor located adjacent to the eddy current sensor.

The eddy current sensor is adjustable to provide the proper air gap for use with the 105-mm, 120-mm, and 155-mm gun tubes. The operation is automated via a programmable controller. The inspection is initiated by positioning a gun tube onto stands, with the muzzle end of the tube butted against the end of the machine (see Figure 9b). When the operator presses the cycle start button, the probe is driven into the gun tube and reverses direction after traveling a programmed distance (220 inches for the 105-mm M68 tube). On the return path, the signal from the eddy current sensor is processed and recorded. Inspection time for the 105-mm M68 tube is less than four minutes per tube.

Tests conducted with the Magnetic Analysis System on as-forged gun tubes demonstrated that the system can effectively locate quench cracks. However, tubes containing areas on the surface from which scale has separated can produce false indications.

Figure 12a shows the recorder trace obtained from the inspection of a 120-mm tube. The upper trace (channel one) is the signal from the eddy current sensor, and the bottom trace (channel two) is triggered whenever the amplitude of channel one exceeds the threshold value. This tube contained numerous quench cracks located from the breech end to six feet away. In this case, the signal obtained from the quench cracks is quite obvious. This tube, although in the as-forged state, has an ID surface without loose scale. Figure 12b shows the trace obtained from a 155-mm tube without quench cracks, but it did have an ID surface with loose scale on the breech end of the tube. The indication from scale pockets (see Figure 13) is indistinguishable from the quench crack indications.

In an attempt to examine the signals more closely, those obtained from quench cracks and scale pockets were digitized at a sampling rate of 10,000 Hz. The results are shown in Figures 14 and 15, respectively. Unfortunately, this closer examination of the signals did not reveal a discernible difference between the two signals. At that point, a decision was made to concentrate on preparing the system to inspect tubes after rough-machining in the before-swage condition. Tubes in this condition have a machined ID surface, therefore the problem of scale pockets encountered with the surface condition on as-forged tubes would not be present. Further attempts to develop methods capable of discriminating between scale pocket and defect signals require funding and efforts in excess of this project.

Tests were conducted on five different 105-mm M68 tubes in the before-swage condition containing bore defects. Each tube had quench cracks that were previously identified using magnetic particle inspection. These tests were conducted to determine optimum settings for the eddy current system. The following settings were used:

Frequency	400 kHz
Filter	F2
Phase	15 degrees
Vertical enhancement	in
Sensitivity	60
Reverse speed	1 inch/second

The varying air gap between the sensor and the material surface (within the 0.015 to 0.150-inch range) was compensated for by an electronic circuit. However, the compensation affected the amplitude of the signal only. At 200 kHz, there was a sufficient phase shift produced by the air gap variation to rule out using this frequency. At 400 kHz, the phase shift was minimal within the compensation range. There was a desire to use the lowest frequency possible to increase the penetration of eddy current within the material. Thus, 400 kHz was used rather than 600 kHz, despite the fact that both produced a minimal phase shift within the compensation range.

The F2 filter setting corresponds to a band-pass of 13 to 160 Hz. This setting produced the least attenuation of the quench crack signal. The 15-degree phase setting was selected to produce the maximum defect signal. Despite the minimum phase shift produced at 400 kHz between the defect and noise signals, the signal-to-noise ratio was still in excess of 5 to 1 at this phase setting. The vertical enhancement feature provides a decrease of any signal below unity gain and an increase of any signal above unity gain, both in a logarithmic fashion. Therefore, this feature artificially increases the signal-to-noise ratio. The sensitivity setting was based on the tests conducted on tubes containing previously identified defects. The minimum setting was used that would trigger channel two of the recorder when the sensor was positioned over the smallest defect identified using magnetic particle inspection. In other words, the sensitivity setting was selected to ensure that the eddy current inspection would indicate a defect at every location that the magnetic particle inspection indicated a defect.

The tests conducted on rough-machined tubes using the distance-compensated probe revealed a problem, namely, that the compensation provided by the electronic circuit is nonlinear. The probe assembly tends to sit closest to the bottom surface of the gun tube due to its own weight. This produces a variation in distance between the sensor and the tube surface as the sensor rotates. The nonlinear distance compensation results in an amplitude response when a crack is encountered that depends on how the tube has been placed on the supports. Figure 16 shows two results from tests on a 105-mm tube containing quench cracks. In Figure 16a the quench crack indications near the center of the recording are large enough in magnitude to trigger the threshold channel, which indicates defects are present. Figure 16b shows the recording obtained with the tube rotated 180 degrees from its position in Figure 16a. This change in amplitude is a result of the nonlinear response of the compensation circuit.

A new sensor design, the surface ride probe, was tested to eliminate the need for the distance-compensated circuit. The sensor, shown in Figure 17, uses "shoes" that ride on the surface of the test material. The "shoes" are designed to hold the eddy current sensor coil at a fixed standoff distance (approximately 0.030 inch) from the test material. A test using a 105-mm tube (S.N. 2664) is shown in Figure 18. The upper trace shows the eddy current indications obtained from quench cracks that existed on the ID surface of the tube from 90 to 135 inches from the breech end. The lower trace is the threshold channel, indicating that the threshold voltage has been exceeded. The fixed-distance contact sensor eliminated the problem of varying response when the tube was rotated. Also, the signal-to-noise ratio was somewhat better than with the distance-compensated probe. The following settings were used:

Frequency	200 kHz
Filter	F3 (30 to 263 Hz)
Phase	250 degrees
Vertical enhancement	out
Sensitivity	65
Reverse speed	1 inch/second

Since all the tests conducted up to this point were with tubes containing longitudinal quench cracks, i.e., cracks parallel to the long axis of the tube, additional tests were conducted on a tube segment with a circumferential slot. The slot was produced using electrical discharge machining (EDM) and measured 0.1 inch deep, 1.0 inch long, and approximately 0.01 inch wide. Results of the tests are shown in Figure 19. This figure shows the signal obtained with the rotating sensing coil positioned over the EDM notch. The trace represents a repeating signal obtained each time the sensing coil passes over the notch. The signal level obtained exceeded the threshold value, indicating that a circumferential defect can be detected with this eddy current system if the coil passes over the end of the defect. The signal obtained occurred as the sensor passed the end of the EDM notch. The eddy current sensor requires the change in surface-to-probe distance to produce a detectable signal.

Two characteristics of the surface ride probe were observed during testing, which although undesirable, would not limit its use as an inspection tool. One characteristic is the false signal produced when the sensor is riding on a tapered surface. This occurs on the rough tubes at the lead-in angle of the breech end. However, the tapered section is ultimately removed from the tube. The signal is produced because the taper allows the sensor to come closer to the test material than on the constant diameter surface. The second characteristic is a tendency to produce a false signal due to metal filings produced after repeated inspections with the surface ride probe. In normal use, this would not occur, since false signals were not produced until approximately 50 test runs were completed on the same tube. It does, however, indicate the need to have a clean ID surface before the eddy current inspection.

As with any operation in which there is metal-to-metal contact, some wear of the "shoe" material was encountered. After 75 tube inspections, the amount of wear measured approximately 0.002 inch. The shoe material used was tool steel, with a hardness of 62 Rc. Currently, a sensor with a titanium carbide coating is being tested. Thus far, it has been used to inspect over 100 tubes without showing measurable wear.

Presently, the automated eddy current inspection system is being used concurrently with magnetic particle to inspect production 120-mm M256 rough-machined gun tubes. Thus far, the two inspection methods have been in agreement except for two tubes in which the eddy current system detected discontinuities that were not found during magnetic particle inspection. In both cases, when examined using a white light borescope, the discontinuities were judged to be tool marks. This demonstrates the high degree of sensitivity obtainable with eddy current inspection. Early on in the inspection of 120-mm tubes, some false indications were produced during eddy current inspection due to interference from the honing solution, which remains on the bore surface after the tube is honed. This has necessitated cleaning of the tube's bore surface prior to the eddy current inspection.

CONCLUSION

In its modified form, the eddy current inspection system can effectively and reliably locate ID surface defects, such as quench cracks, on rough-machined gun tubes. The inspection time is less than four minutes for a 105-mm M68 tube and less than five minutes for a 120-mm M256 tube. Automation of the inspection process eliminates the possibility of failing to inspect a section of the tube, the effect of inspector fatigue, and the need for interpretation by the inspector. The use of a strip-chart recorder provides a permanent record of the inspection. Work is in progress to computerize the inspection results. A computer could provide more detailed information than the strip-chart recorder, such as clock position of the defect, and it would eliminate the need to store paper recordings.

EPILOGUE

A method to distinguish between the defect and scale pocket signals is presently being investigated. The use of artificial intelligence has been proposed, whereby an algorithm would examine numerous examples of defect and scale pocket signals so that it could "learn" to tell the difference between the two types. Another area to investigate is the use of filtering to eliminate the scale signal discussed in this report. Filtering was effective during preliminary testing. It is possible that the use of a filter with a smaller band-pass would effectively reduce the scale pocket signal. The possibility of incorporating a descaling operation before inspection is also being considered. Descaling would not only allow eddy current inspection before the rough-machining operation, but it would also help the machining operation by reducing tool wear and machine maintenance.

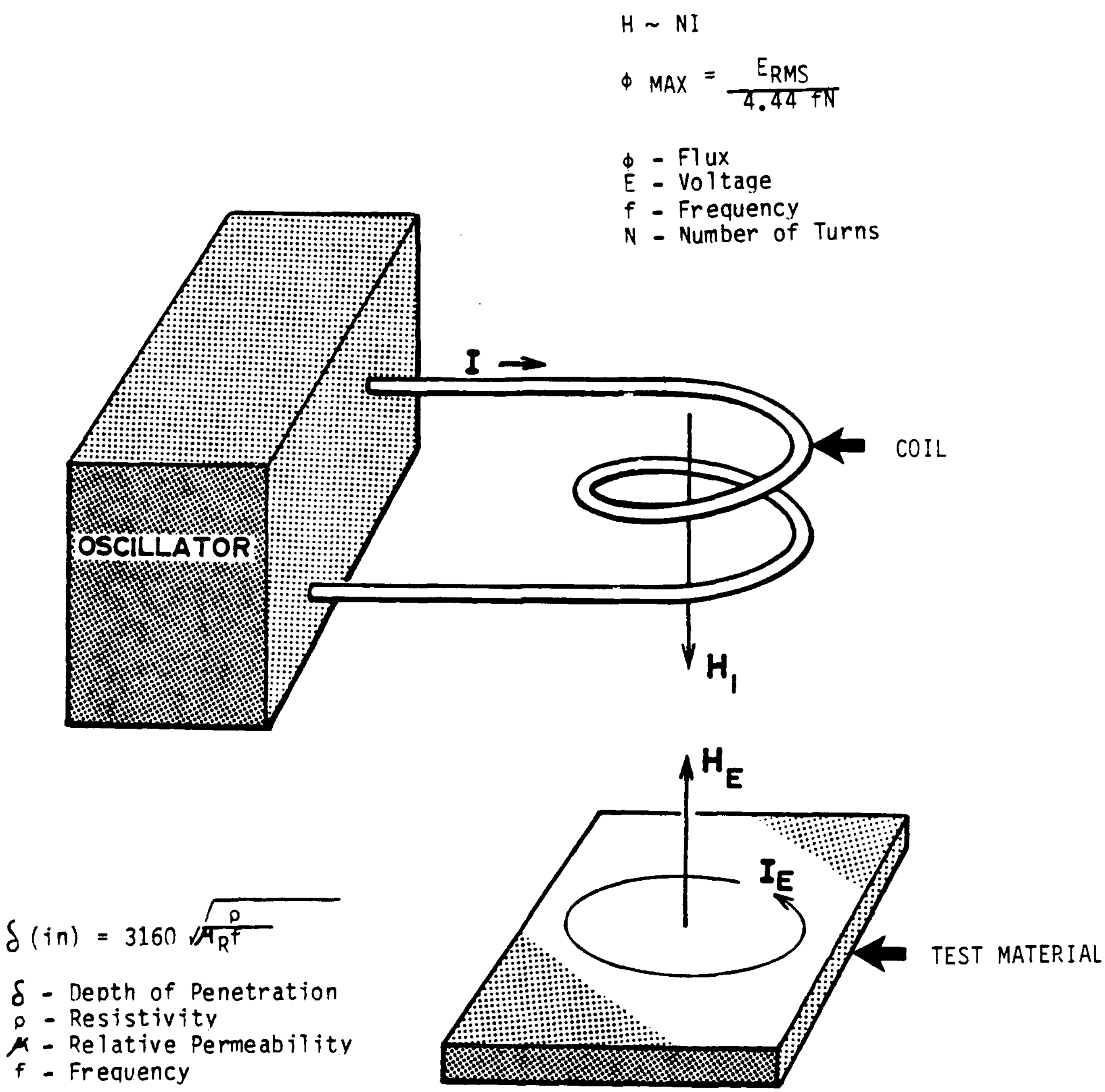


Figure 1. Basics of eddy current inspection.

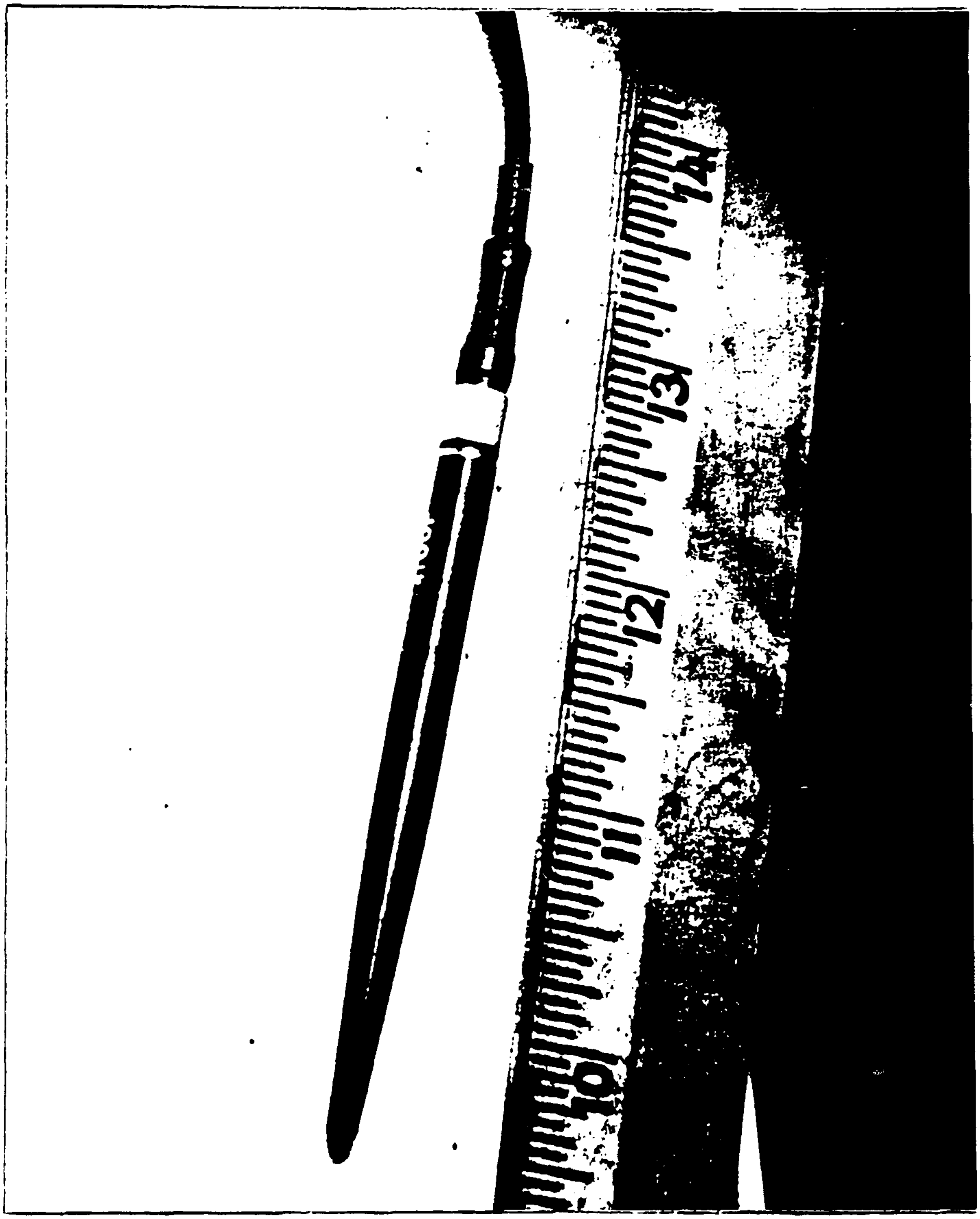


Figure 2. Pencil probe.

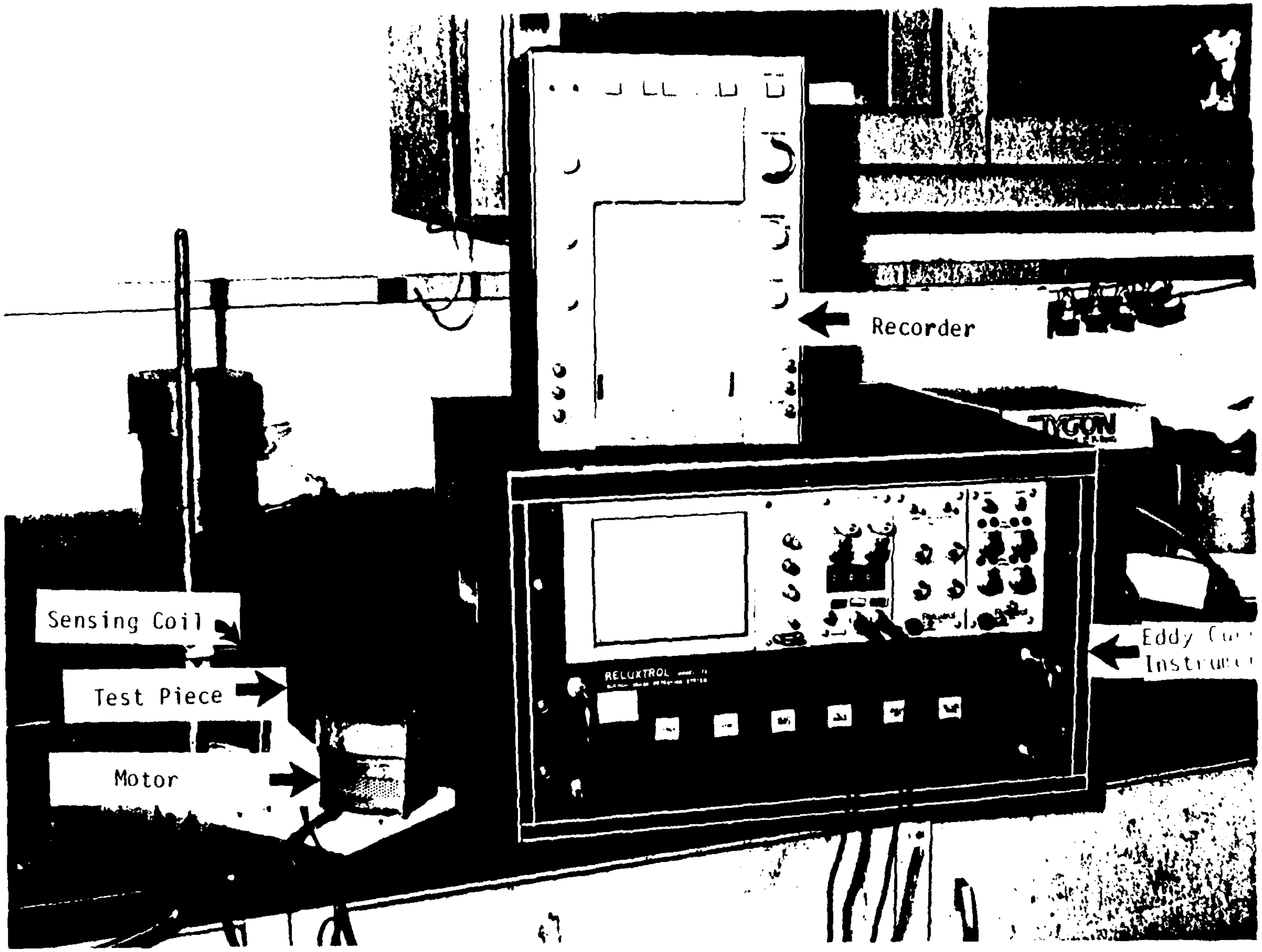


Figure 3. Eddy current test setup with pencil probe.

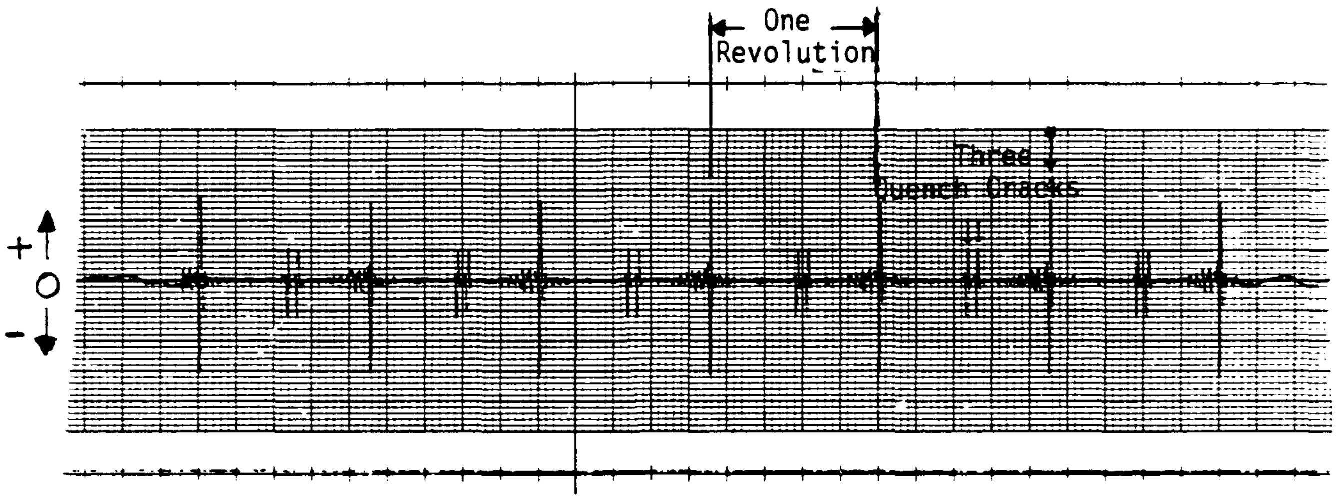


Figure 4a. Recording signal from a 105-mm section containing three quench cracks.

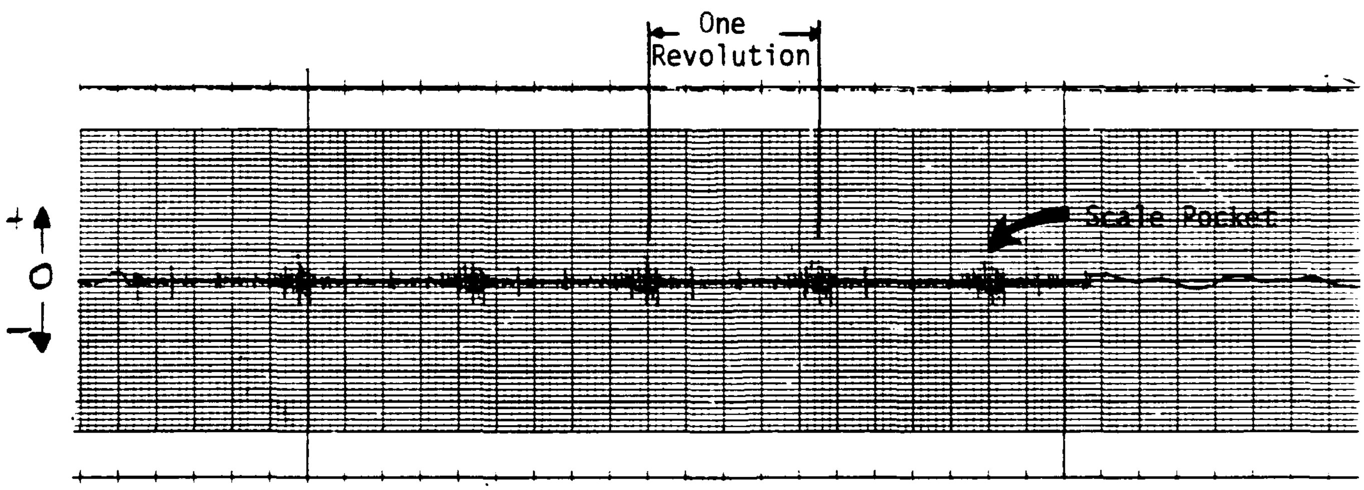
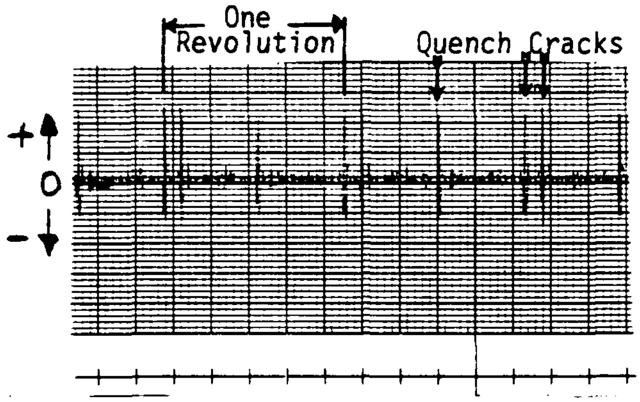
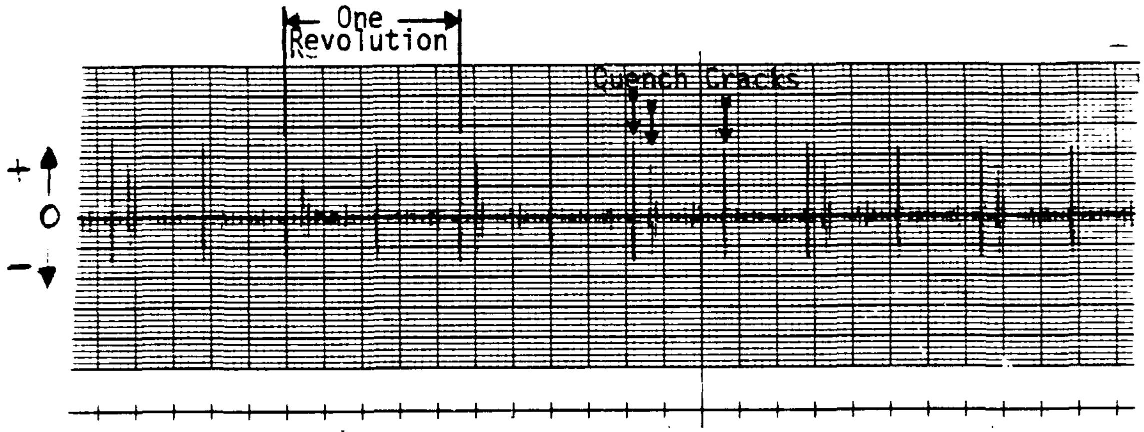


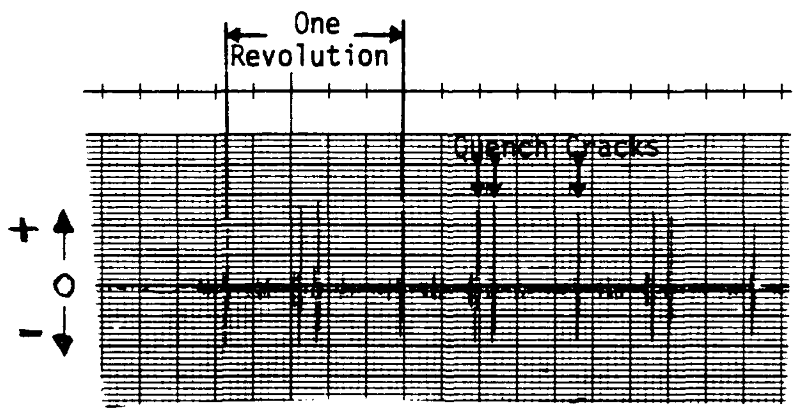
Figure 4b. Recording signal from a 105-mm section with a heavily-scaled surface without quench cracks.



a. 250 kHz signal.

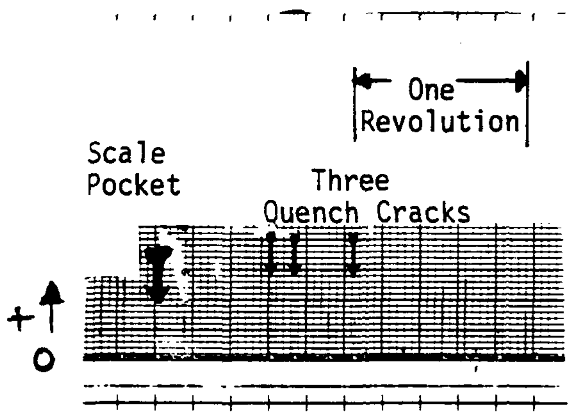


b. 100 kHz signal.

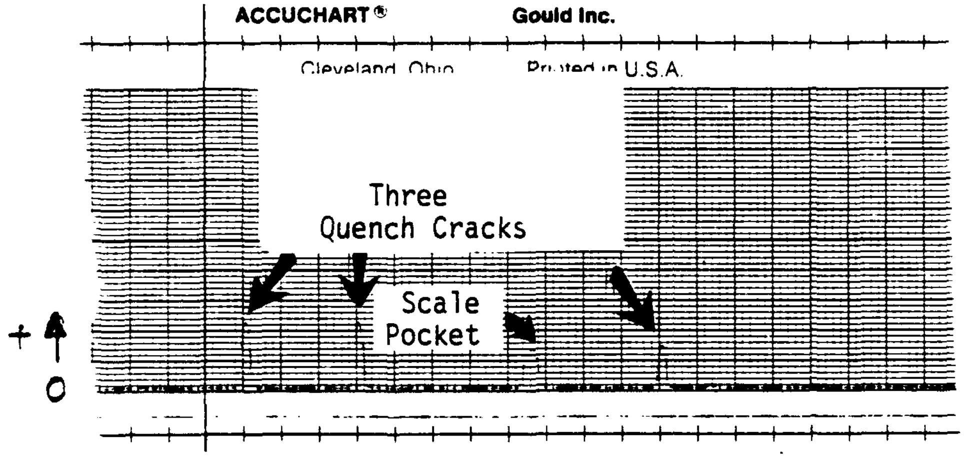


c. 30 kHz signal.

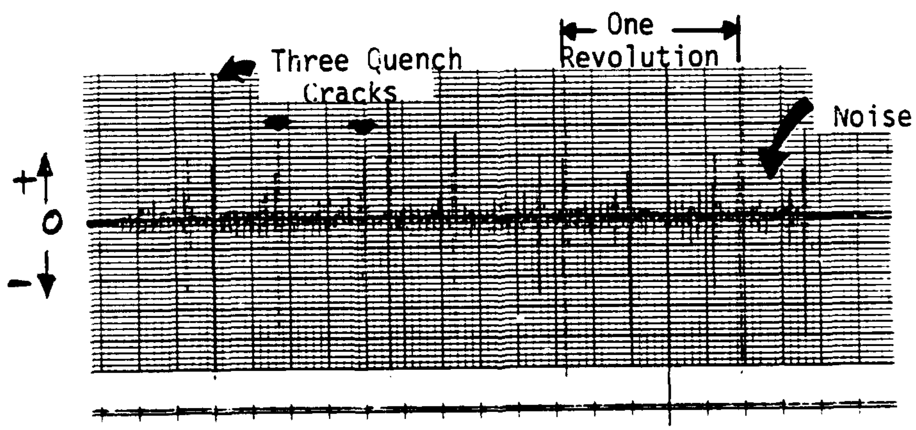
Figure 5. Recording signals from a 105-mm section containing three quench cracks.



a. 3 to 30 Hz passband, chart speed 5 mm/sec.



b. 3 to 30 Hz passband, chart speed 25 mm/sec.



c. 10 to 30 Hz passband.

Figure 6. Effects of filtering on signals.

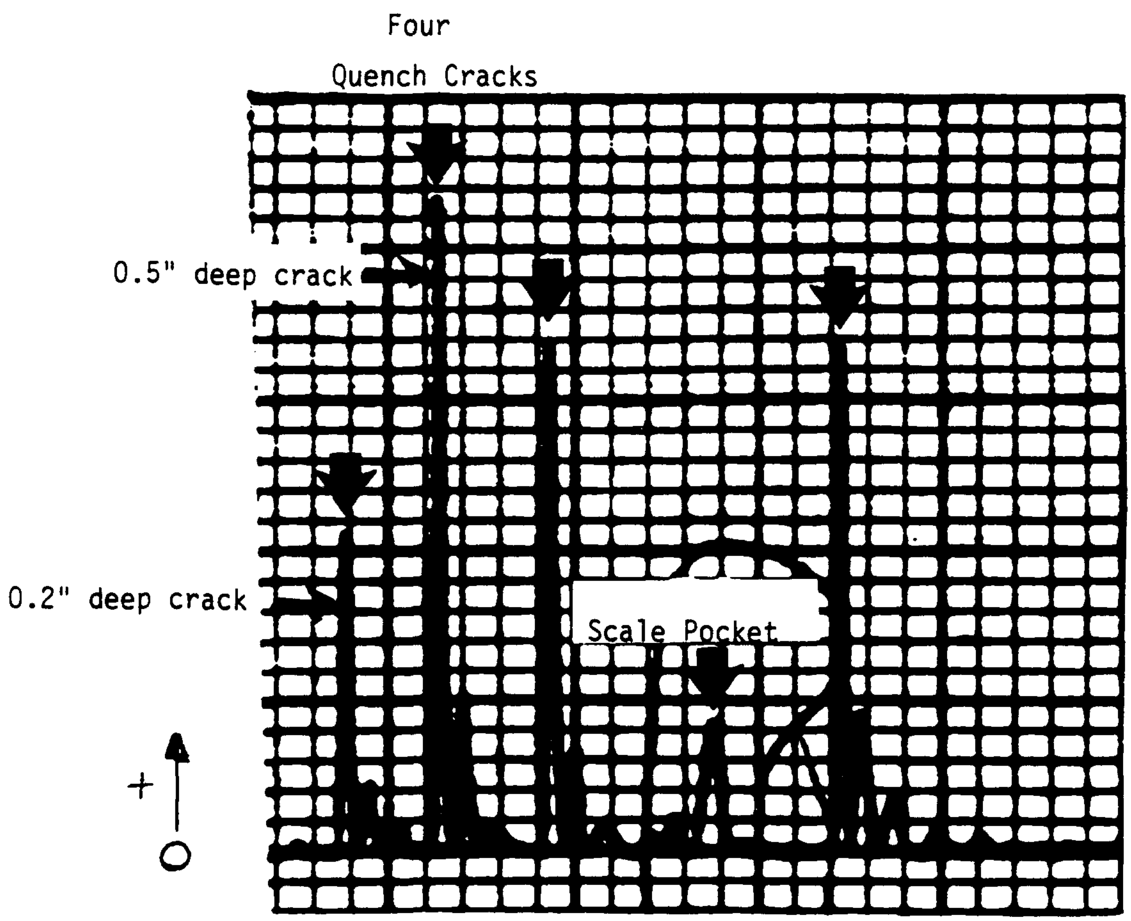


Figure 7. **Comparison of crack and scale signals at different crack depths. Chart has been magnified (5X) to show the difference between the magnitude of signals from different crack depths.**

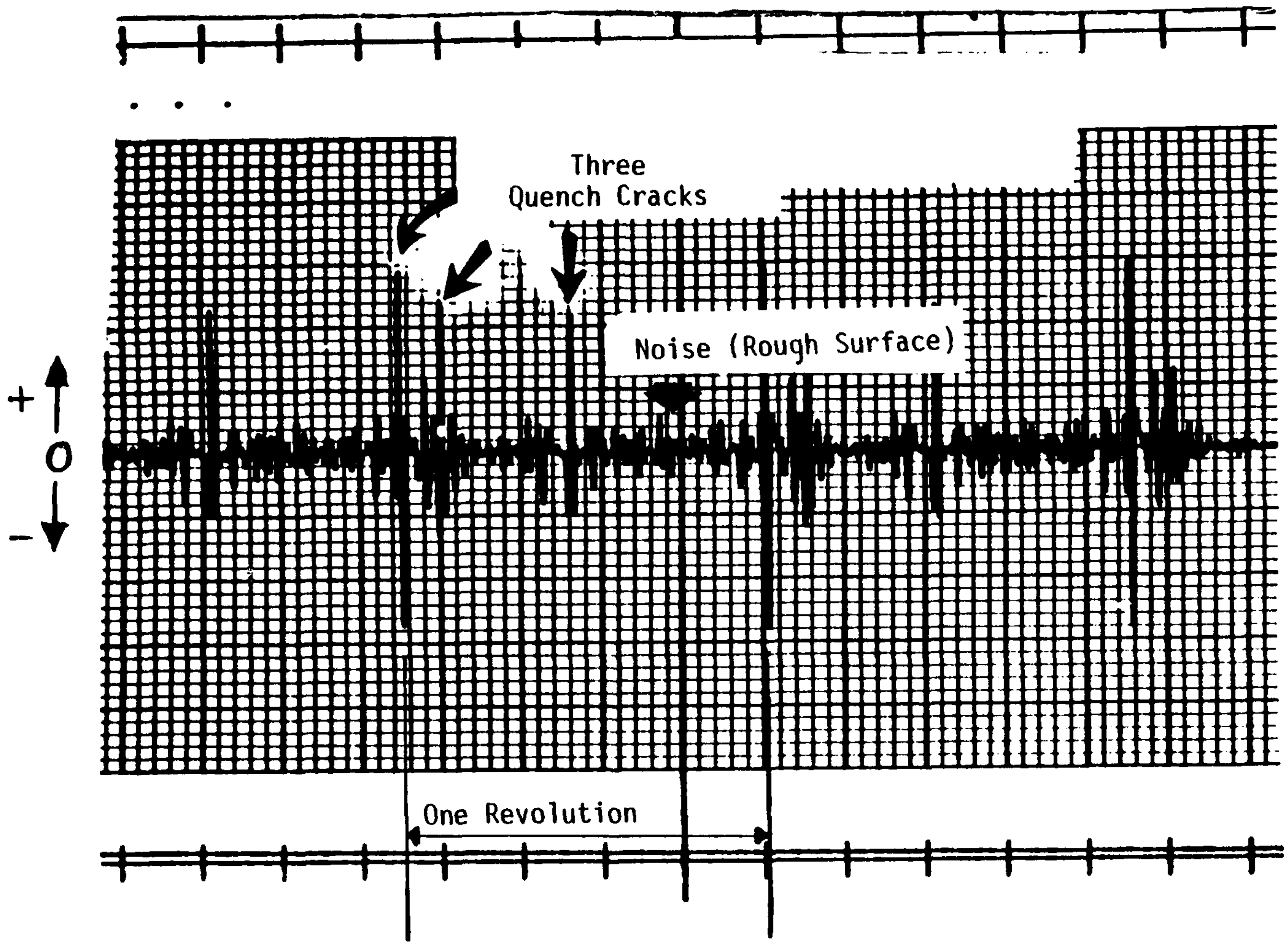


Figure 8. Three quench cracks on a rough surface.

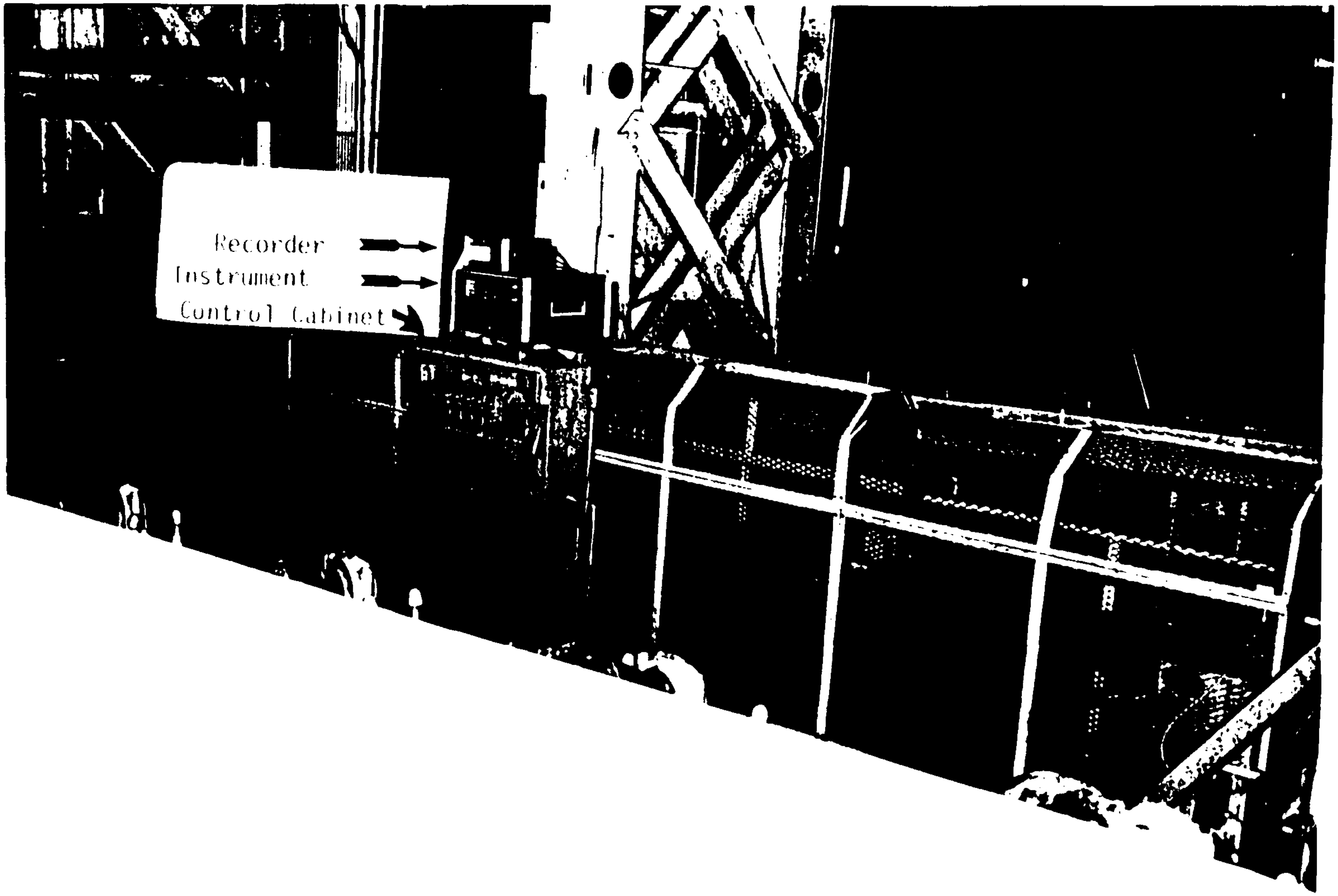


Figure 9a. Eddy current inspection system

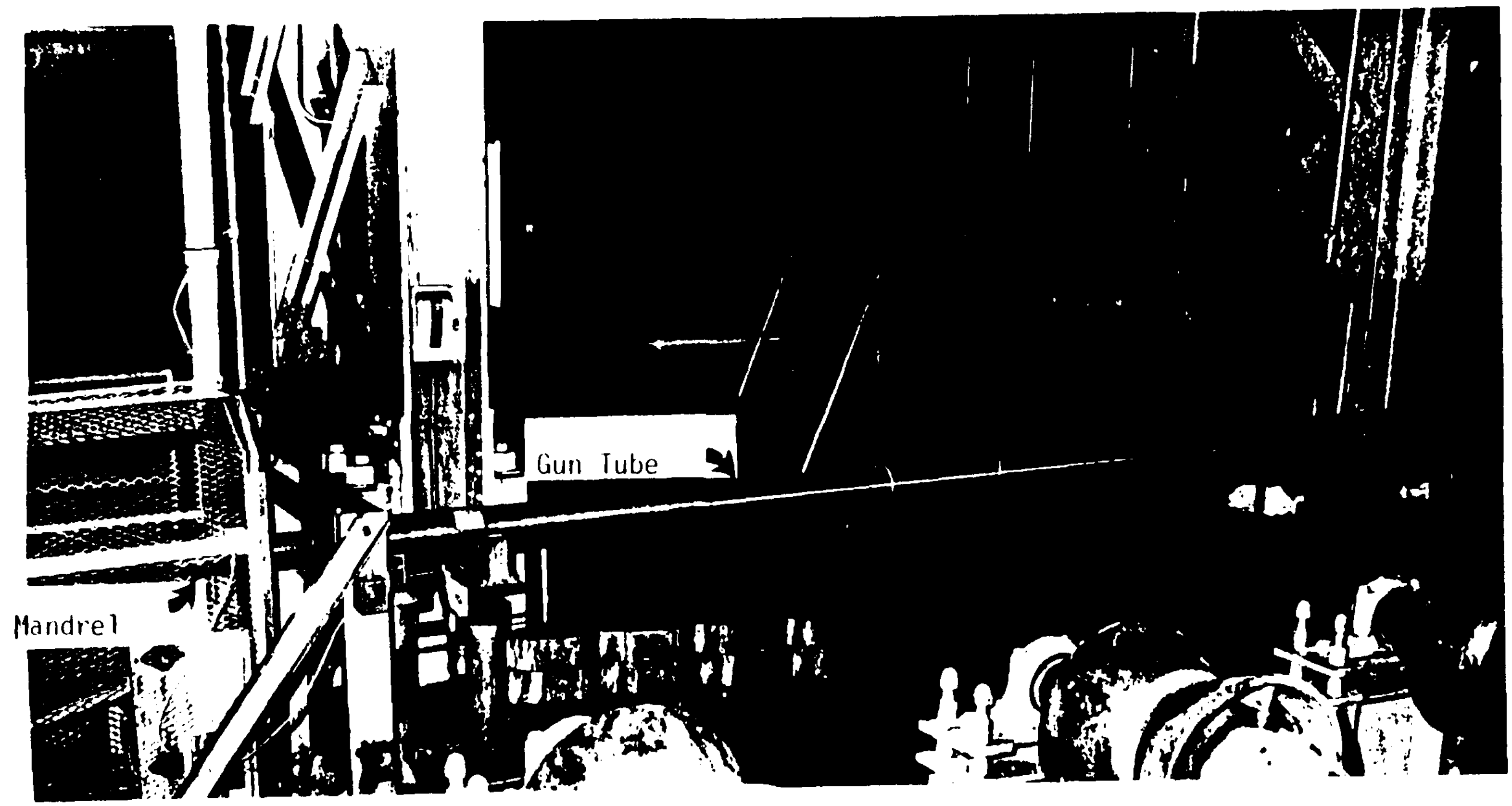


Figure 9b. Gun tube supported by adjustable stands.

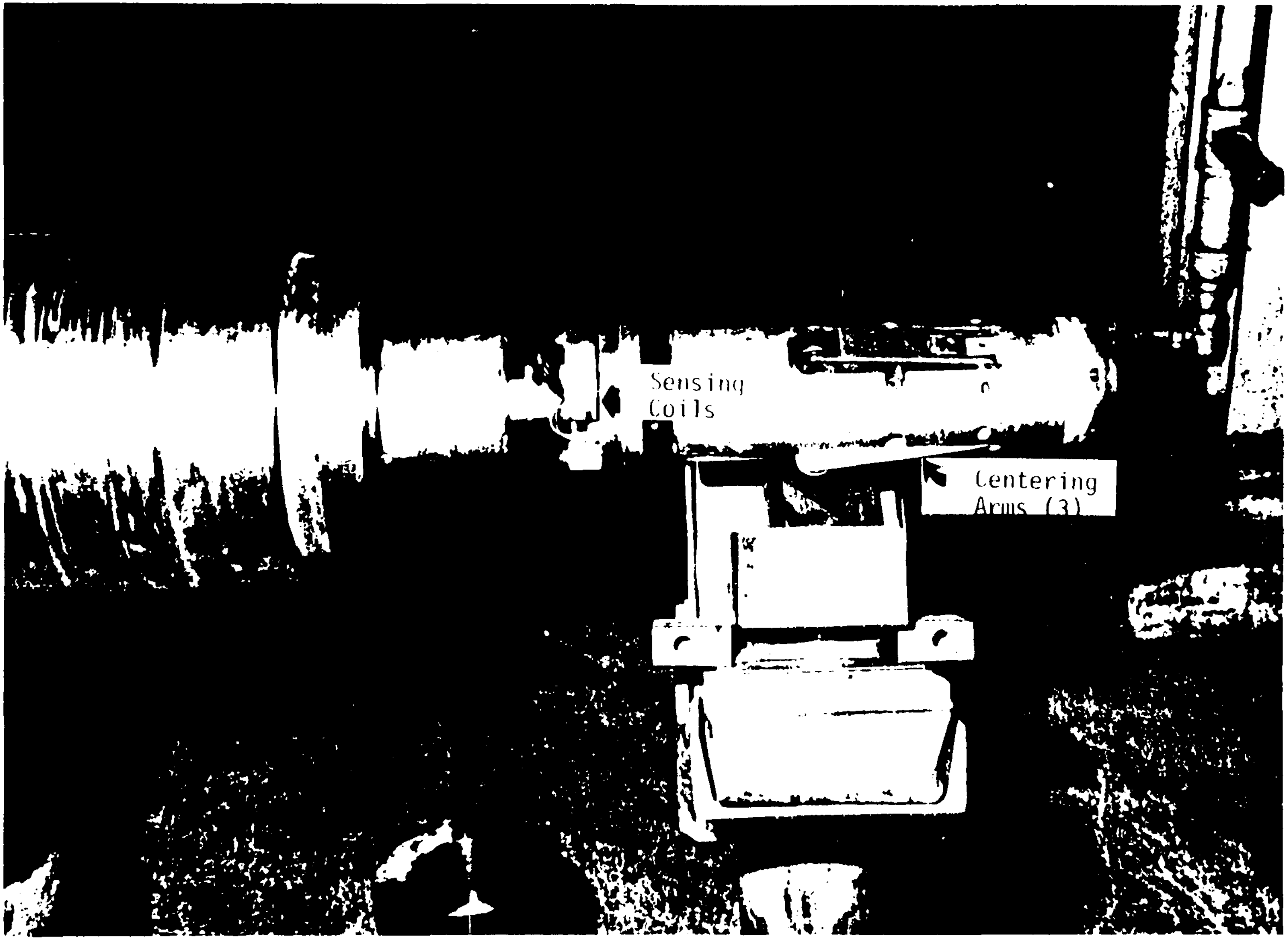


Figure 10. Probe assembly.

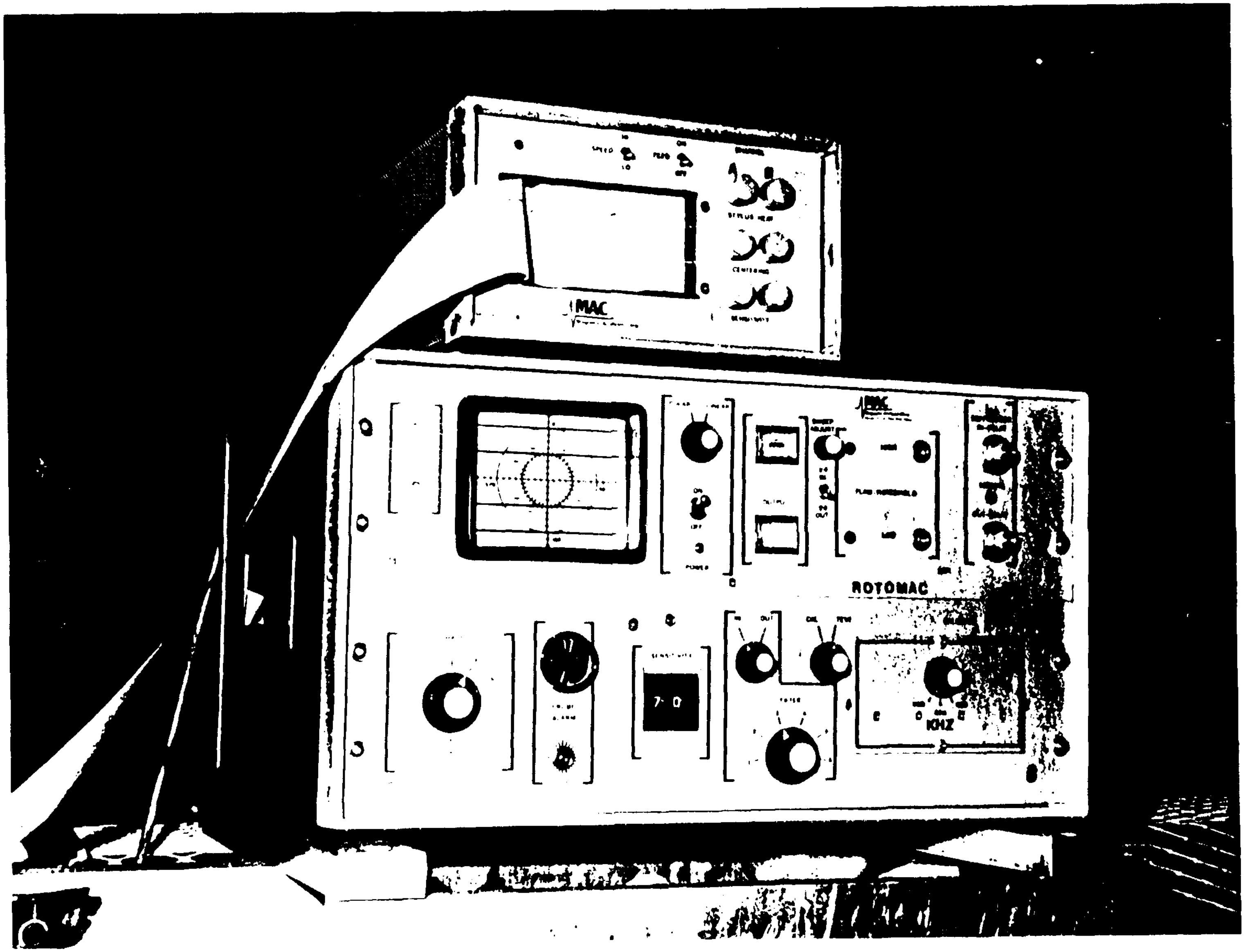


Figure 11. Strip-chart recorder and eddy current instrument.

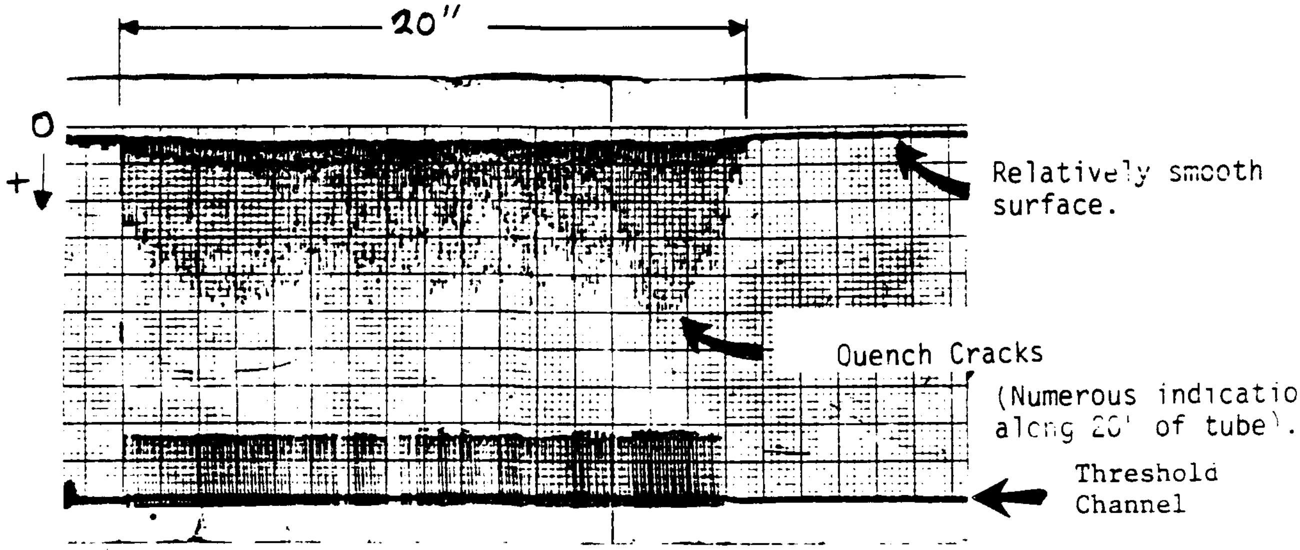


Figure 12a. Recording from a 120-mm tube containing numerous quench cracks and no scale pockets using the Magnetic Analysis System.

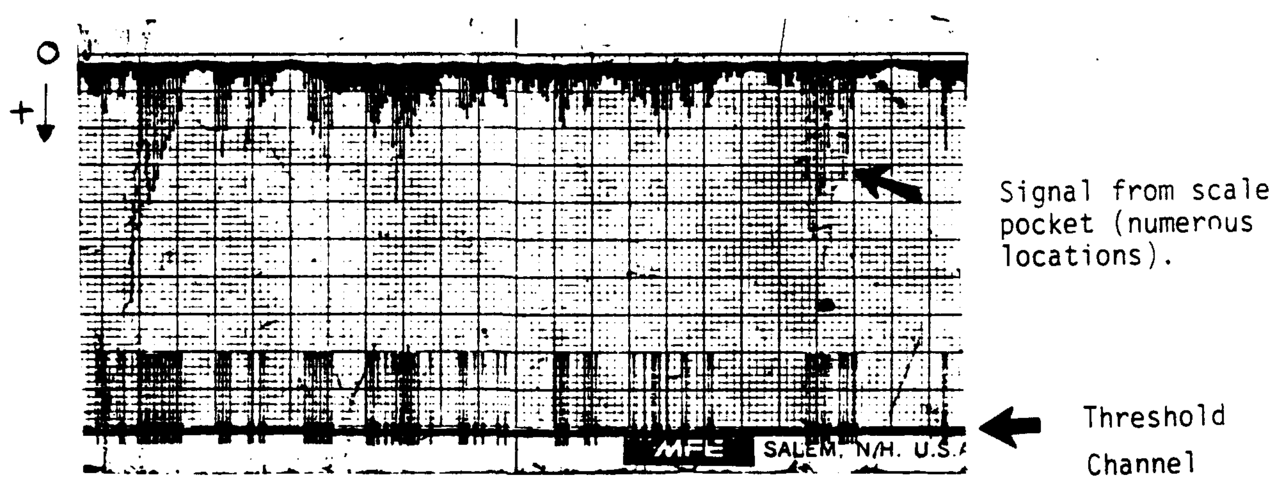


Figure 12b. Recording from a 120-mm tube with scale pockets and no quench cracks using the Magnetic Analysis System.

Figure 13. Scale pocket of a 155-mm tube.

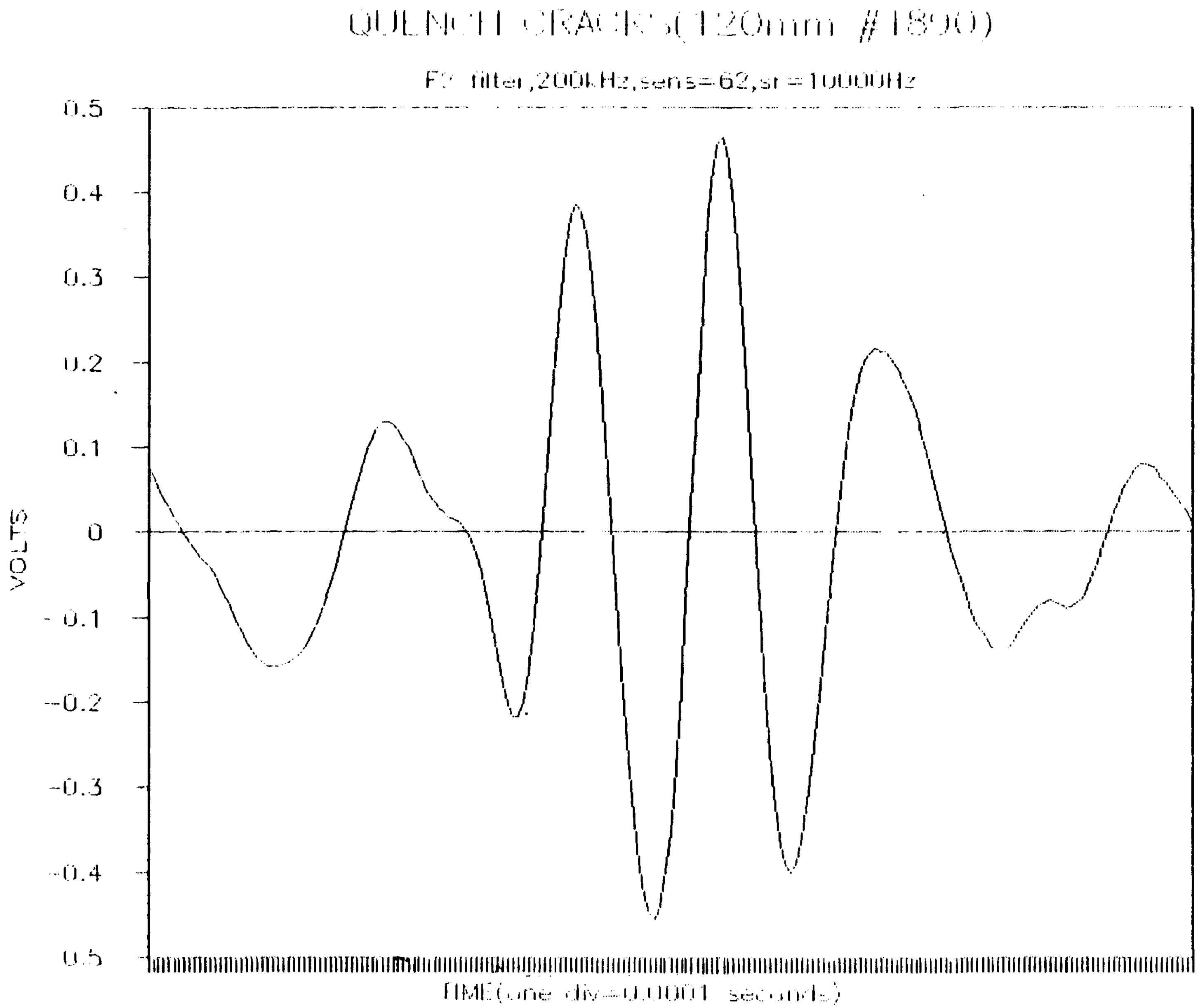


Figure 14. Signals obtained from quench cracks digitized at 10,000 Hz.

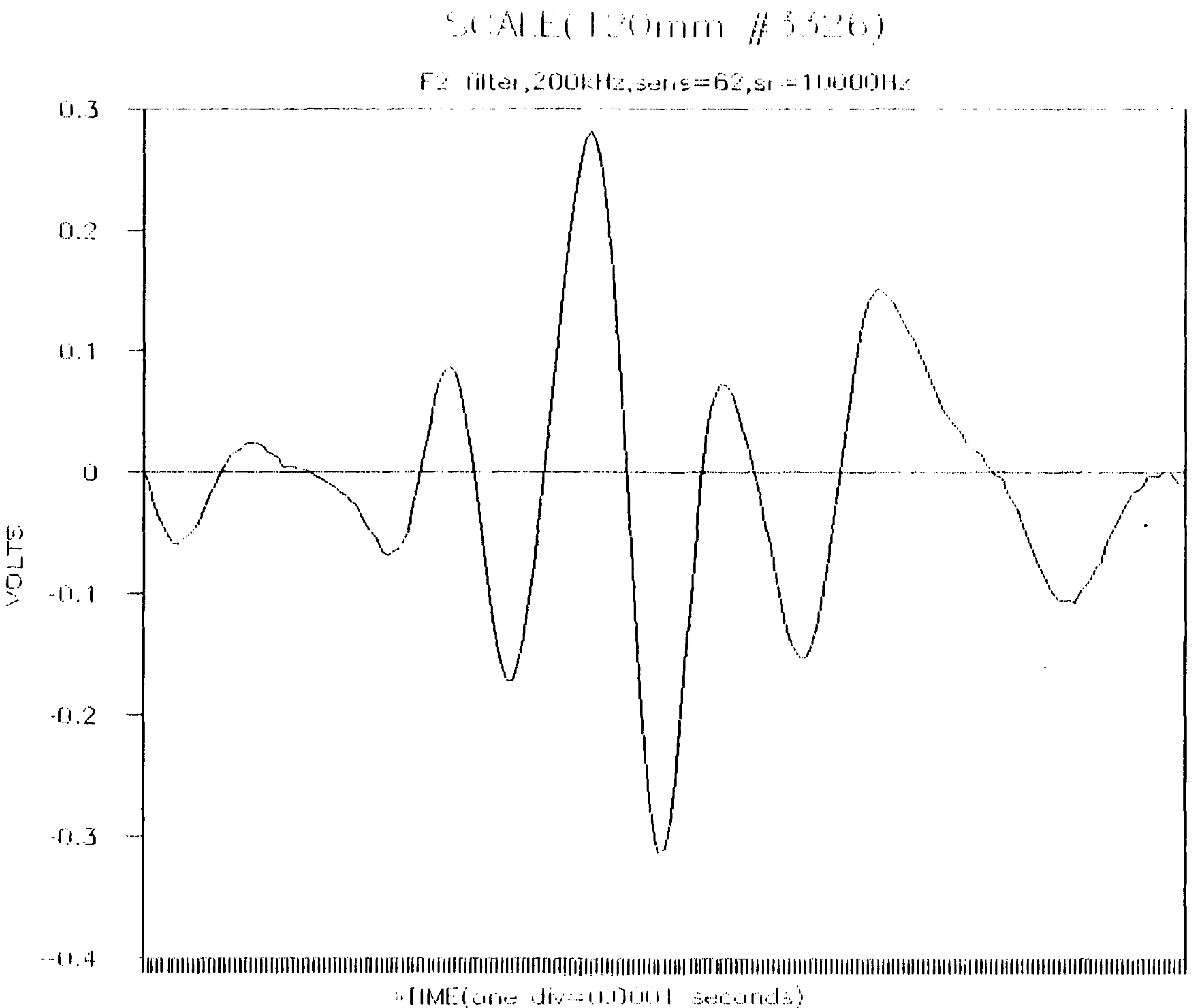
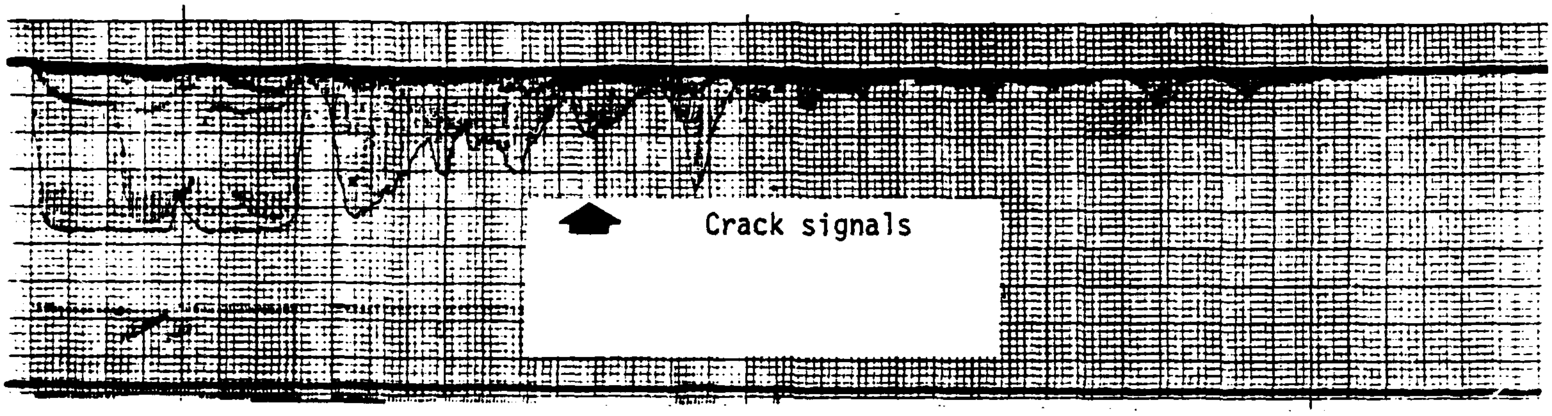
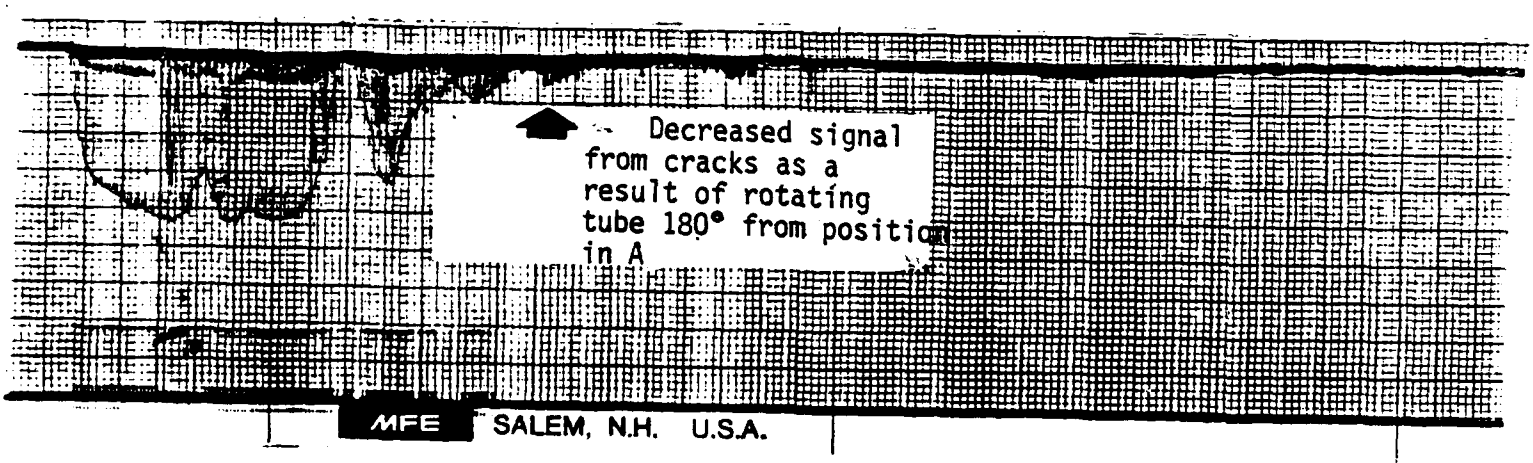


Figure 15. Signals obtained from scale pocket digitized at 10,000 Hz.



a.



b.

Figure 16. Effect of tube rotation on crack indication using the distance-compensated probe.

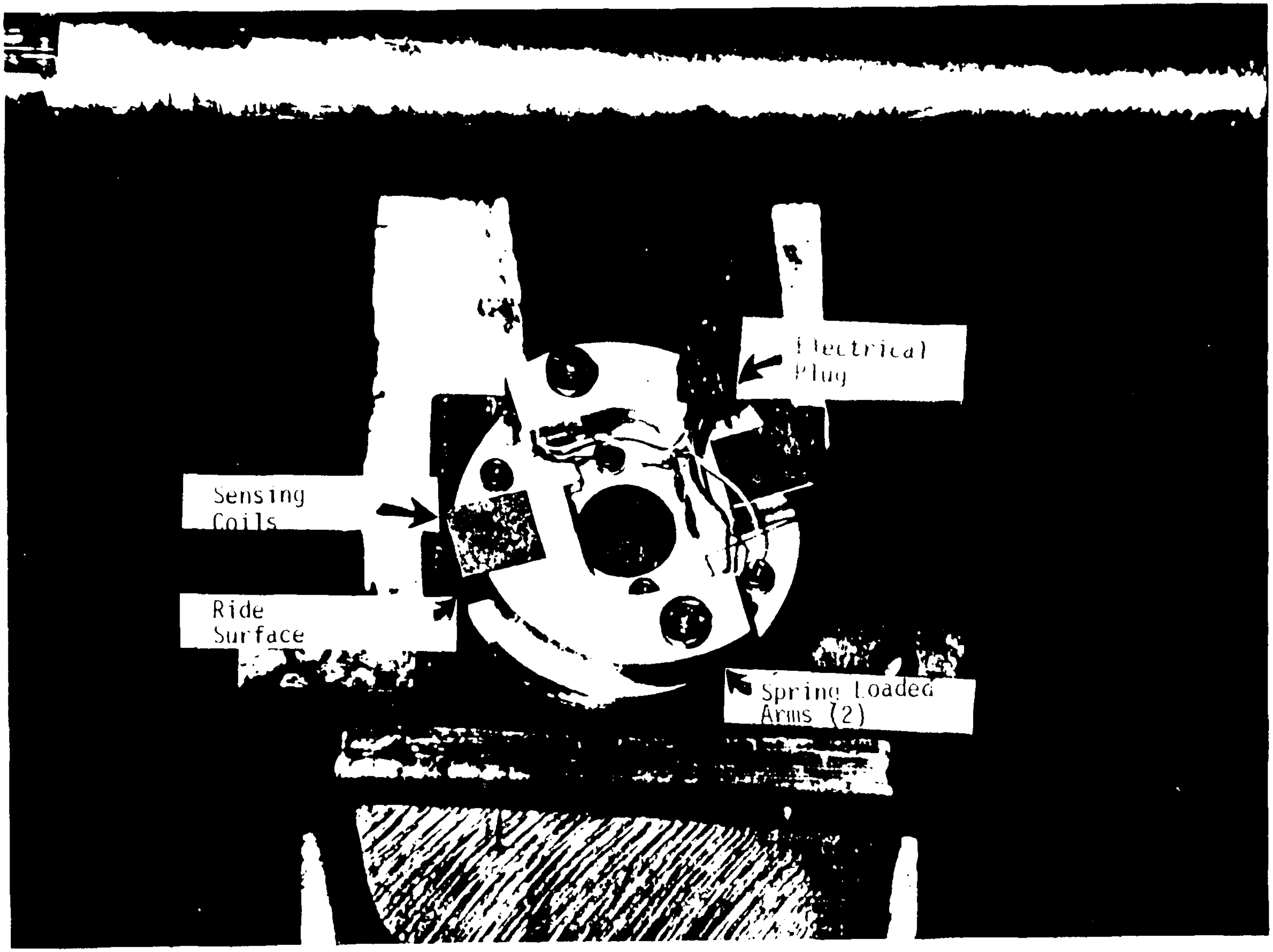


Figure 17 Surface ride probe

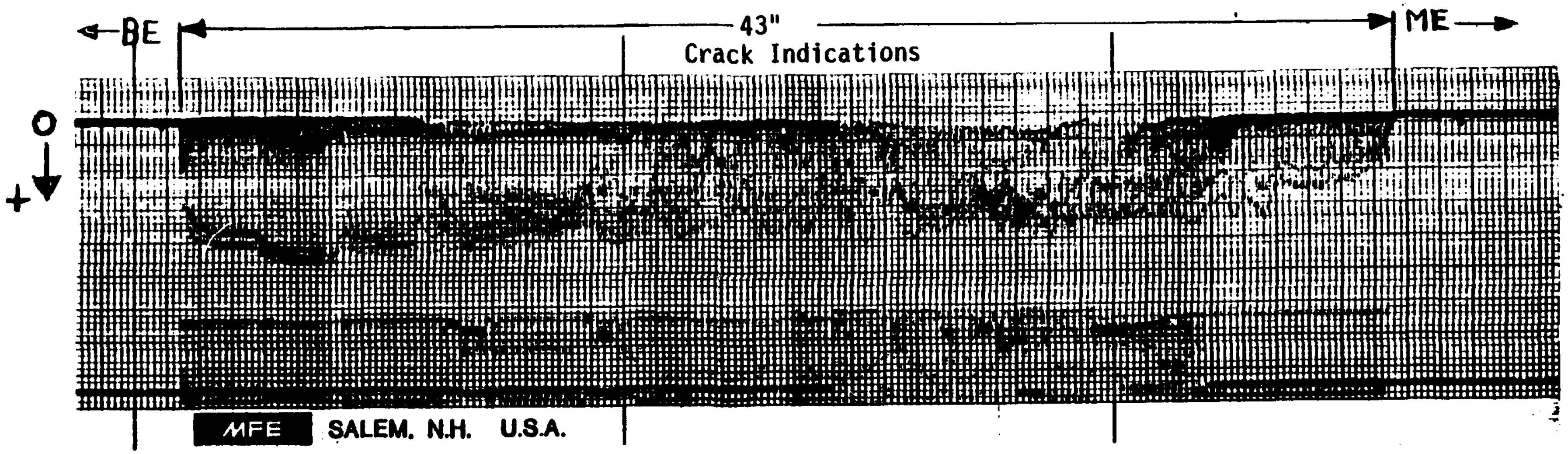


Figure 18. Test results using the surface ride probe on a 105-mm tube (S.N. 2664).

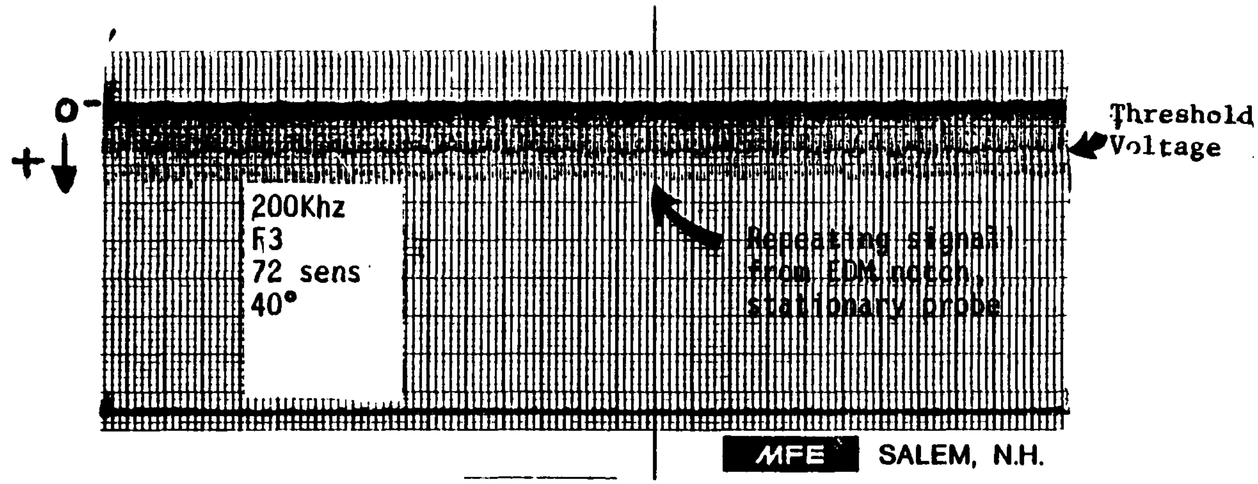


Figure 19. Circumferential EDM notch indications (0.1 inch deep) using the surface ride probe.

HENTSCHEL INSTRUMENTS, ANN ARBOR, MICHIGAN

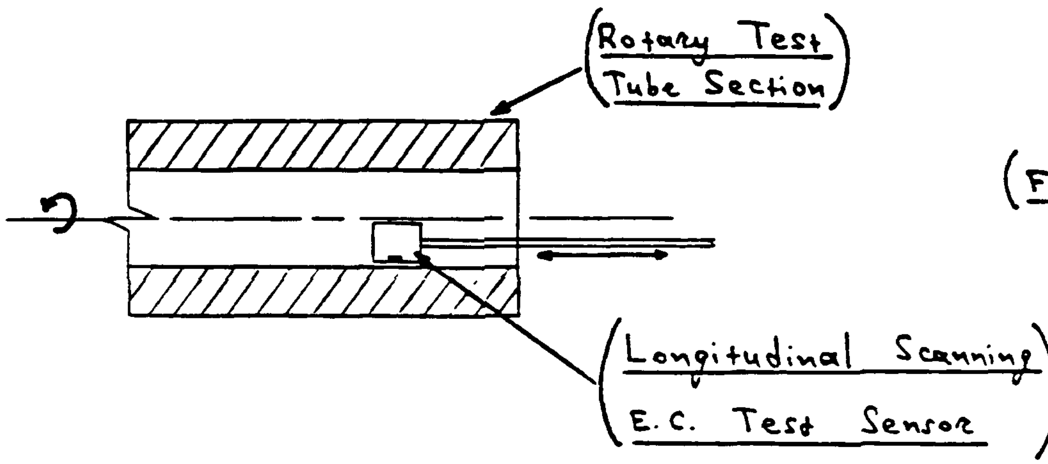
APPLICATIONS PROJECT TEST FORM 1.1

APPENDIX A

AP-NO. 850571
TEST NO. ______

CUSTOMER :	Watervliet Arsenal	DATE :	2/5/86
PART :	Sections of 105 mm M68 Gun Tubes	PERSONNEL:	O.J.V.
OBJECTIVE:	Crack Detection	CHK'D BY :	

Test Set-Up:



(Figure 1)

Test Instrument:	DE-300
Test Sensor:	ZFP-3.3
Test Frequency:	100 kHz
Lift Off:	~0.050"
Angular Speed:	~150 rpm

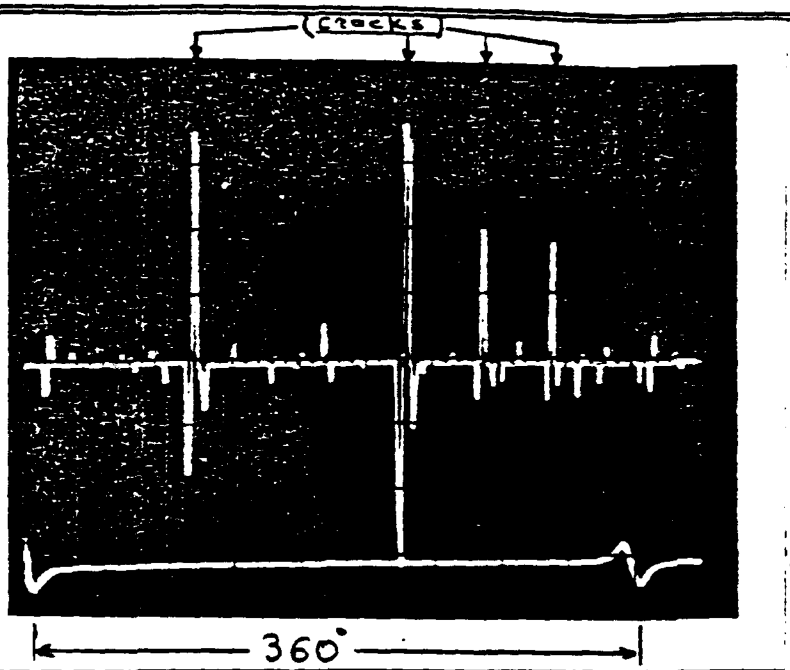
HENTSCHEL INSTRUMENTS, ANN ARBOR, MICHIGAN

APPLICATIONS PROJECT TEST FORM

AP-NO. 850571
TEST NO. ______

CUSTOMER : Watervliet Arsenal
PART : Sections of 105mm M68 Gun Tubes
OBJECTIVE : Crack Detection

DATE : 2/5/86
PERSONNEL : O. J. V.
CHK'D BY : ______



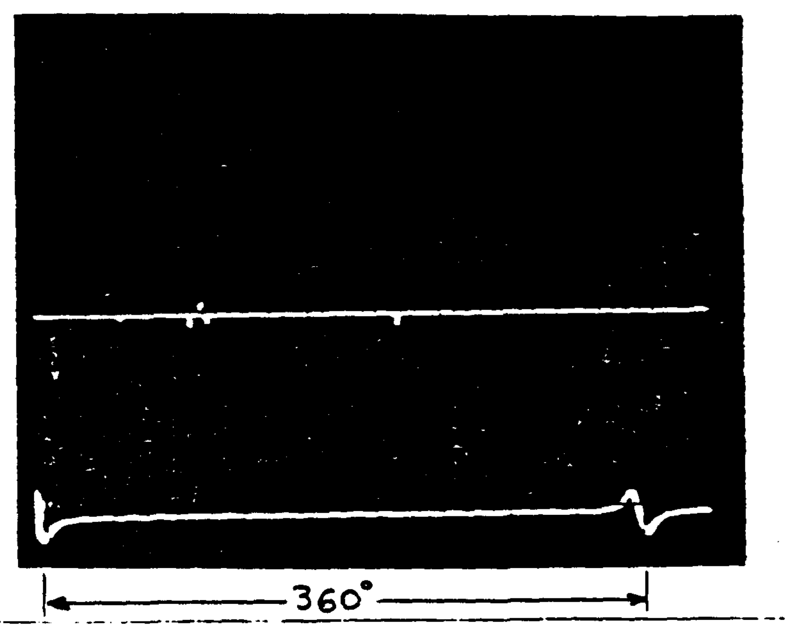
Cracked Tube Section:

f = 100 KHz

← (Eddy Current Response Signal 2 Volts / Division)

← (Reference SYNC. Signal)

(Figure 2)



Good Tube Section:

f = 100 KHz

← (Eddy Current Response Signal 2 Volts / Division)

← (Reference SYNC. Signal)

(Figure 3)

CC. WSG
FEB
J. DeM.
P.S.
D. Bugden 1/10/86
E.S.'s FILE

APPENDIX B

To: MAC
From: E. Spierer
Subject: Watervliet Arsenal
Re: Eddy current testing of 105 mm gun tubes
Contract DAAA 22-86M-3146

Two (2) sections of 105 mm gun tubes were received from the above arsenal for eddy current-defect evaluation.

One (1) section contained natural I.D. quench cracks. The other section, free of any I.D. quench cracks, contained both machined & unmachined I.D. surfaces.

The section not containing any natural quench cracks was sent out for E.D.M.ing per contract specs. & our dwgs. Three (3) std. notches (.100", .15 & .200" dp) x 1" length were put into both the machined & unmachined I.D. surfaces (6 E.D.M. notches in total). The locations & certifications of the E.D.M notches are herewith attached.

Testing of both sections were done by rotating the pcs in a lathe, automatically withdrawing the eddy current probe and recording the results. Surface & air ride of the probe was used.

Eddy current test results are as follows:

a) Section 1 – Natural Quench Crack Section

Attached recording dated 12/17/85 shows the section to be full of natural quench cracks of varying depth.

The smaller recording below, also dated 12/17/85, shows that for a complete revolution (probe not being retracted) the noise level between successive indications for a quench crack is extremely low. That is the remaining wall is good & no signal is obtained.

An air ride test was used so as to minimize surface noise.

b) Section 2 – I.D. Machined surface – E.D.M. standards
All standards detected with excellent S/N.
Depth correlation
Air ride used.
See recording dated 1/3/86

c) Section 2 – I.D. Unmachined surface – E.D.M. standard
All standards detected with excellent S/N.
Depth correlation bet. .100 & .150 good.
Surface ride used as I.D. out of round.
See recording dated 1/3/86

d) Section 2 – I.D. Machined Surface – E.D.M. standards
Tests conducted with Flux Leakage Enhancement to Eddy current.
All standards detected with excellent S/N.
Excellent depth correlation

Light surface ride used.
See recording dated 1/7/86

Conclusions:

It appears that the standard notches and natural quench cracks are readily detectable by eddy current means.

Fairly good correlation was obtained for .100 to .150 depth with standard eddy current techniques.

Eddy current with flux leakage enhancement gave excellent correlation between .100, .150, & .200 dp std. notches.

Either air or surface ride of the probe can be used.

WESTERN PROFESSIONAL, INC.
3460 BRADY CT. N.E.
SALEM, OREGON 97303

CUSTOMER MAGNETIC ANALYSIS CORP.

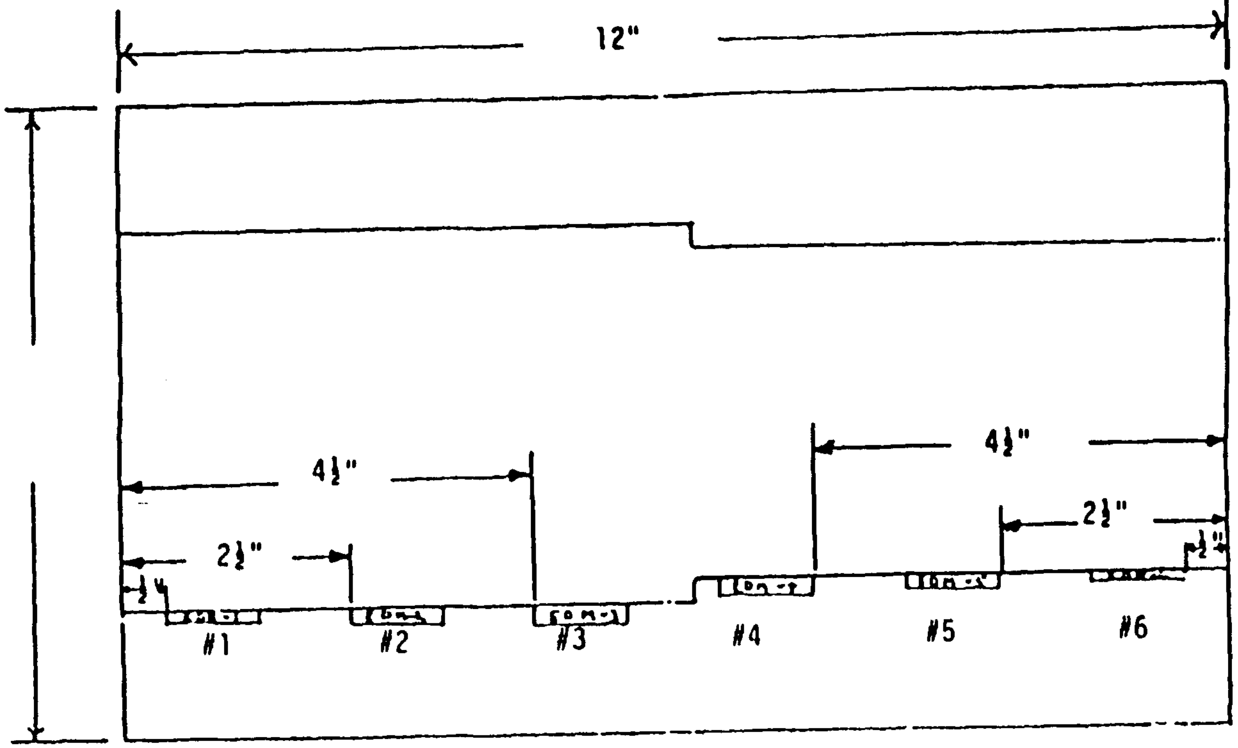
STANDARD NO.

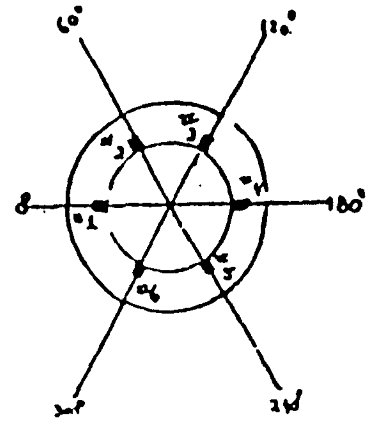
DIAMETER 6-3/4" Ø X 1-3/8" W X 1-5/8" W X

MATERIAL Steel

P.O. NO. 17818

DATE 12-20-85

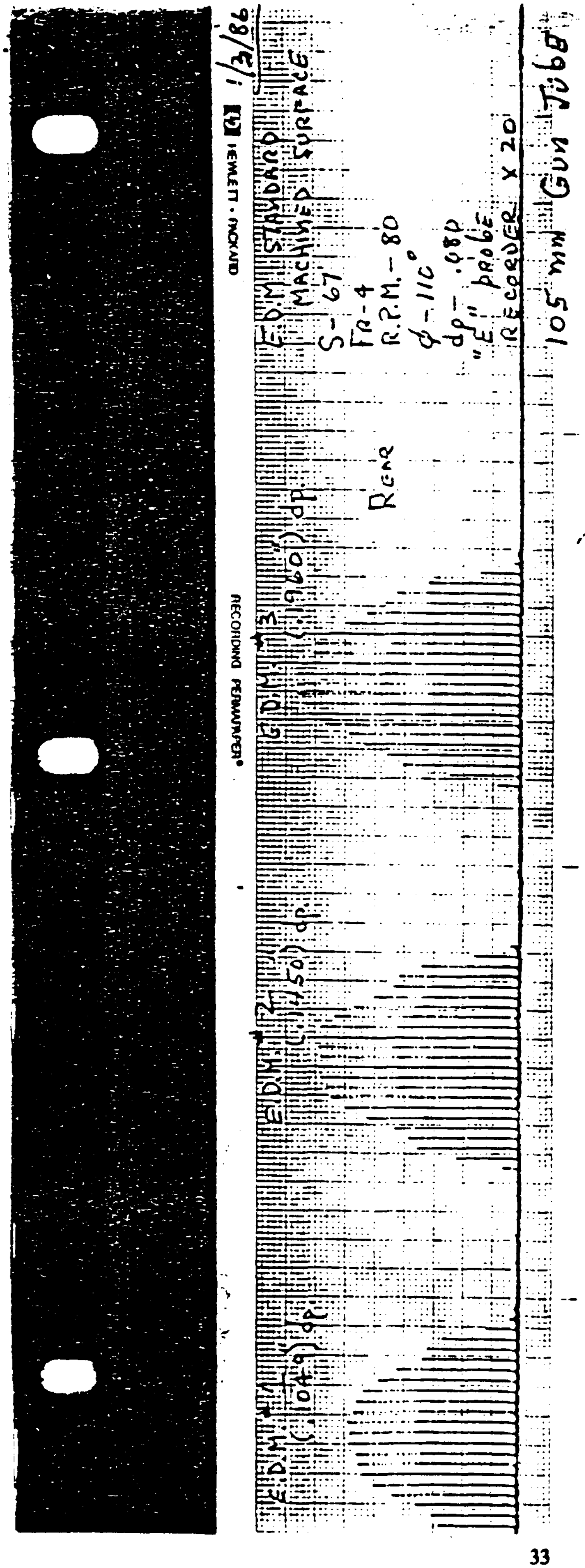


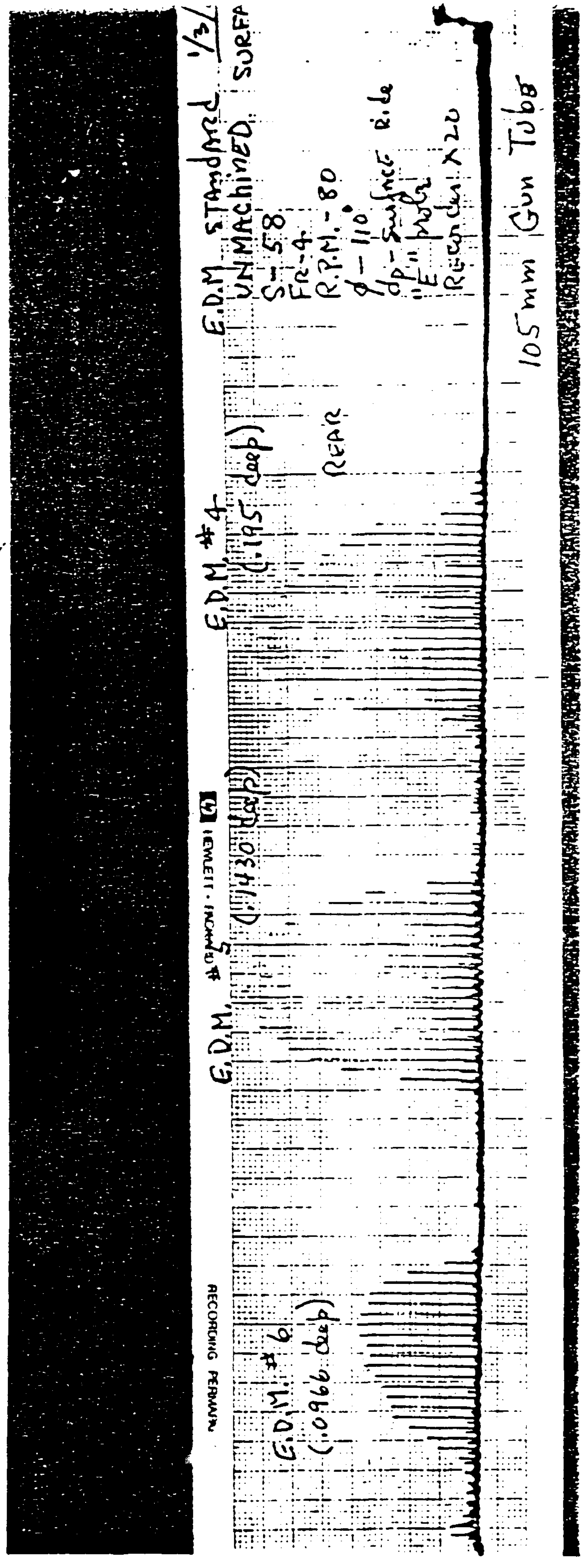


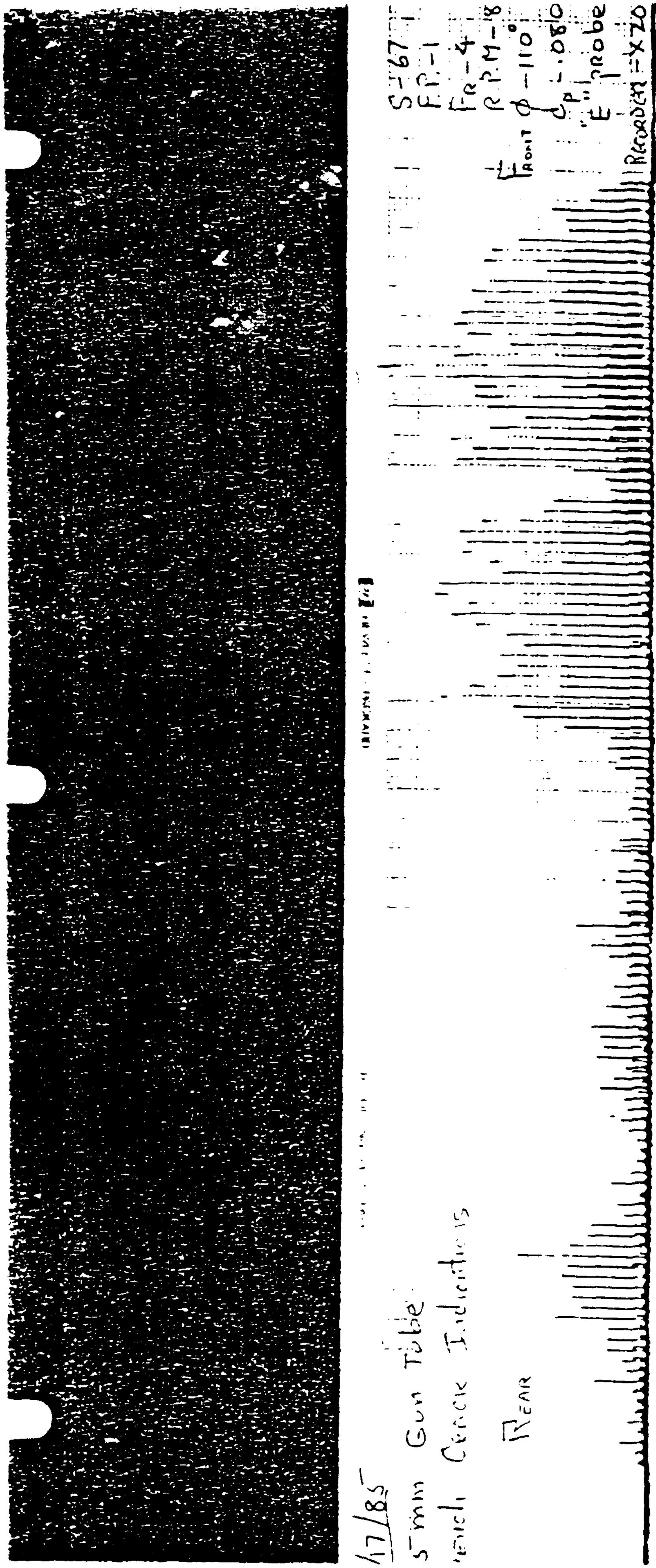
DEFECT DIMENSION				LOCATION		ORIENTATION	
NO	DEPTH	LENGTH	WIDTH	ID	OD	LONG	TRANS
1	.1049"	.9947"	.0101"	X		X	
2	.1450"	.9940"	.0102"	X		X	
3	.1960"	.9933"	.0100"	X		X	
4	.1950"	.9980"	.0120"	X		X	
5	.1430"	.9942"	.0087"	X		X	
6	.0966"	.9958"	.0098"	X		X	

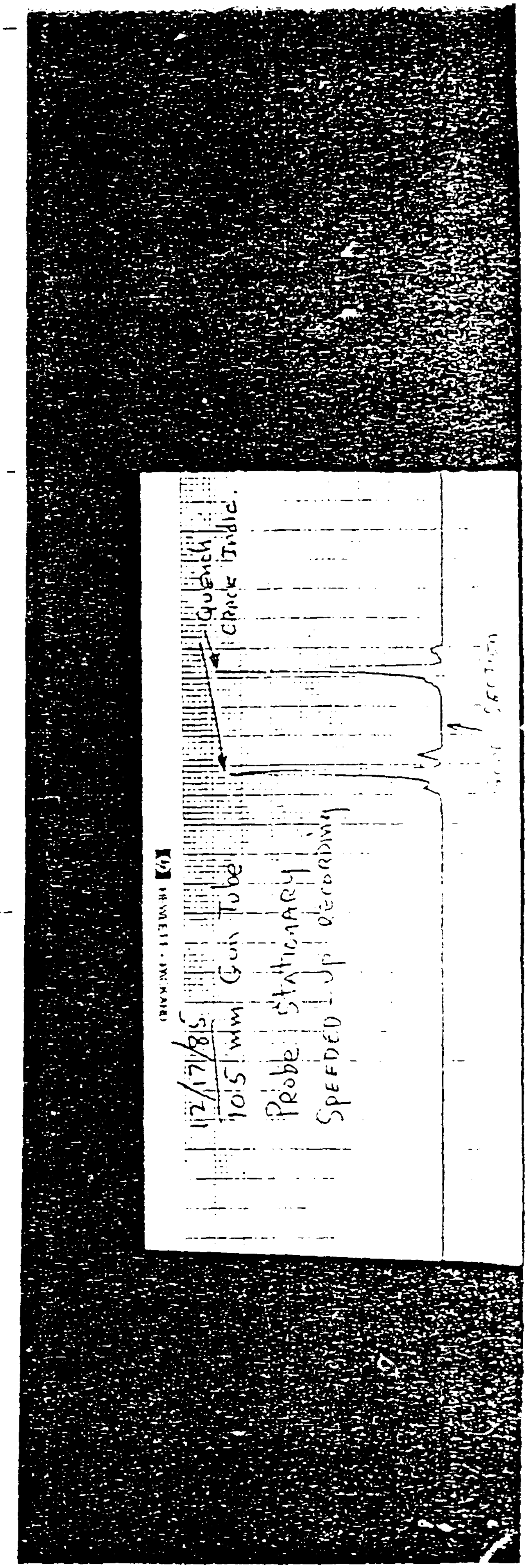
Fabricated by S. Chamberlain

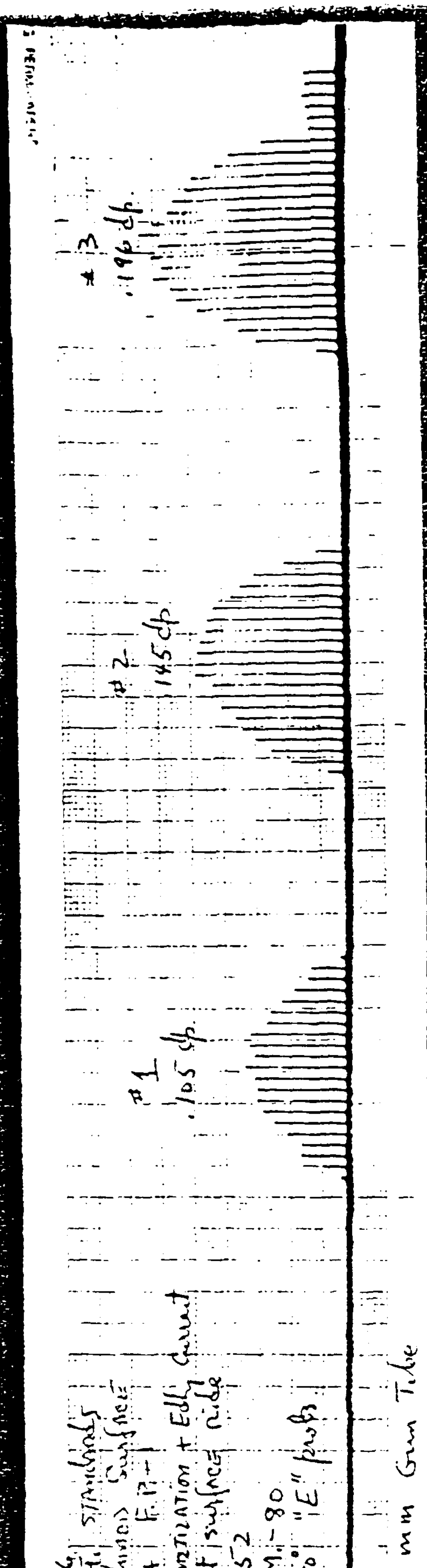
Approved by [signature]

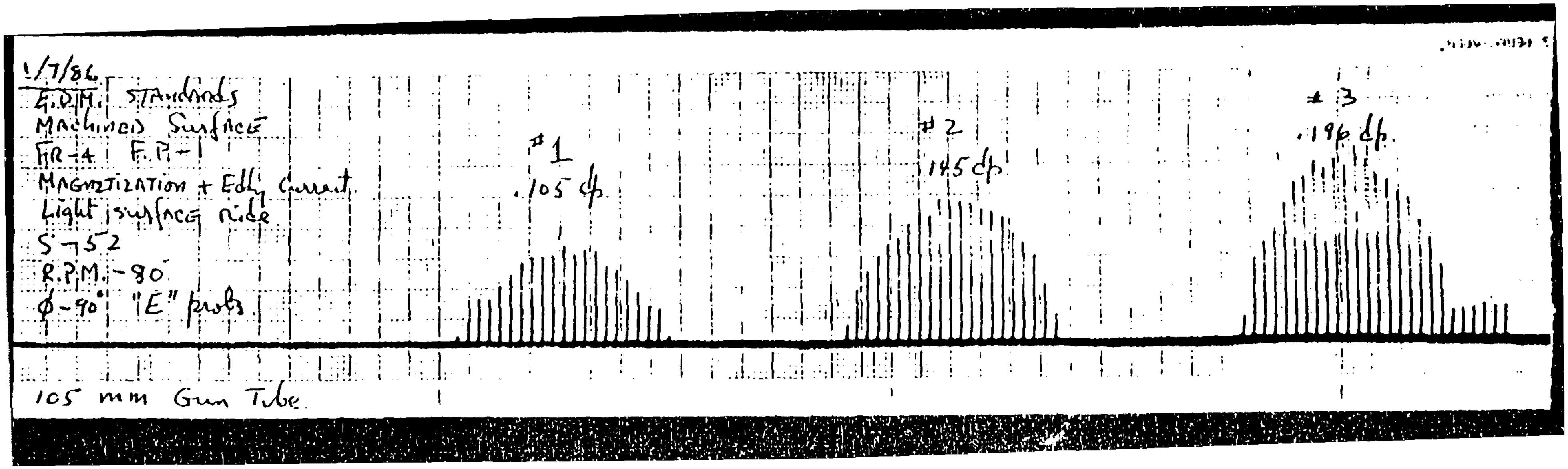

HEWLETT · PACKARD
RECORDING PERMAPAPER®
E.D.M. STANDARD
MACHINED SURFACE
1/3/86
S-67
FR-4
R.P.M.-80
ϕ-110°
dp-.080
"E" probe
RECORDER X 20
105 mm Gun Tube
REAR
E.D.M. #3 (.1960) dp.
E.D.M. #2 (.1150) dp.
E.D.M. #1 (.1049) dp.


HEWLETT · PACKARD
RECORDING PERMAPAPER
E.D.M. standard
UNMACHINED SURFA
1/3/
S-58
FR-4
R.P.M.-80
ϕ-110°
dp-surface ride
"E" probe
Recorder X20
105 mm Gun Tube
REAR
E.D.M. #4 (.195 deep)
E.D.M. #5 (.1430 deep)
E.D.M. #6 (.0966 deep)


/17/85
5"mm Gun Tube
Crack Indications
Rear
Front
S-67
FP-1
FR-4
RPM-8
φ-110°
"E" probe
Recorder=X20


12/17/85
105 mm Gun Tube
Probe Stationary
Speeded Up Recording
Quench Crack Indic.


1/7/84
E.D.M. Standards
Machined Surface
FR-4 F.P.-
Magnetization + Eddy Current
Light surface ride
S-752
R.P.M.-80
ϕ-90° "E" probe
105 mm Gun Tube
#1
.105 dp.
#2
.145 dp
#3
.196 dp.


1/7/86
E.D.M. Standards
Machined Surface
HR-4 F.P-1
Magnetization + Eddy Current
Light surface ride
S-52
R.P.M. - 80
ϕ - 90° "E" probe
#1
.105 dp
#2
.145 dp
#3
.196 dp.
105 mm Gun Tube

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