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Metallurgy and Ceramics

A DETECTOR FOR SUB-SURFACE CRACKS

by

L. E. Goodwin
Instrument Development Division

August 1954

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By Authority of
TID 1147 Vol. 13 #7 4-15-57
Name Title Date
3-19-58
8/2/79

E. I. du Pont de Nemours & Co.
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ABSTRACT

An instrument was developed to detect cracks within 1/8 inch of the surface of cylindrical uranium fuel slugs. The instrument measures changes in eddy currents that are induced at a frequency of 2 KC.

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TABLE OF CONTENTS

LIST OF FIGURES

[redacted]

A DETECTOR FOR SUB-SURFACE CRACKS

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INTRODUCTION

A crack in a cylindrical uranium slug may produce a failure under the conditions of pile irradiation; therefore, a non-destructive method of detecting such cracks is desired. Previous work by others[1] had indicated that a commercial instrument called the Cyclograph[2] could be used to detect sub-surface cracks. However, the poor response of the instrument at low frequencies limited the depth of examination in the slug. This report covers an adaptation of the Cyclograph that is not subject to the above limitation.

SUMMARY

An instrument was developed to detect cracks in bare cylindrical uranium slugs. Eddy currents are induced in the slug by passing it through the coils of an oscillator operating at 2 KC. Cracks or inhomogeneities in the slug change the magnitude of the current flowing in the coils by interfering with the eddy currents. The change in current is amplified and presented on a recorder. An initial evaluation of the instrument verified that it detects sub-surface cracks. A more complete evaluation is forthcoming in Report No. DP-67.

PATENT SITUATION

The Cyclograph is covered by Patent No. 2,477,384, dated July 26, 1949.[3] The detector for sub-surface cracks does not appear to infringe any of the claims made in the Cyclograph patent.

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DISCUSSION

GENERAL THEORY

The detector for sub-surface cracks is basically a sensitive push-pull oscillator of which the test coils are a part. Its operating frequency is determined by the test coils, which are wound for the desired frequency. When the oscillator is operating, a magnetic field is set up in the test coils. Under this condition, both the energy output of the oscillator and the amplitude of oscillation are constant. When a uranium slug is placed in the test coils, the magnetic field induces circumferential eddy currents in the slug, the magnitude of the eddy currents being dependent upon the conductivity of the slug and the frequency of oscillation. The induced eddy currents cause energy to be lost from the oscillator, due to I^2R losses, and change the amplitude of oscillation. The energy losses may be so large that the positive feedback must be increased in order to maintain oscillation. The energy losses change the effective impedance of the test coils.

If the uranium slug is homogeneous throughout its entire length, the slug may be moved back and forth within the coils without affecting the amplitude of oscillation. At the location of a crack, the conductivity of the sample is changed, eddy current losses are less, and the amplitude of oscillation increases. This increase is recorded as a deviation from the almost straight-line response given by a normal, uniform slug.

The coil arrangement used is most sensitive to open longitudinal cracks. Seams, short or shallow flaws, small radial cracks, and pinholes affect the circumferential currents to a lesser degree, and the resulting field distortion produces relatively small changes in the amplitude of oscillation.

The frequency is chosen so that the effective depth to which the eddy currents penetrate is sufficient to detect cracks that lie within 1/8-inch of the surface. The depth at which the magnitude of the current decreases by a factor of 1/e, or about 36.9 per cent of its value at the surface, is given approximately by,

$$d = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

[redacted]

where: σ = conductivity in mhos/meter = 3.47×10^6 mhos/m
μ = permeability in henrys/meter = 4×10^{-7} henry/m
f = frequency of oscillation in cycles/second = 2000 cycles/sec
d = effective depth of penetration = 6.12×10^{-3} meters (= 0.241 inch.)

Thus, the depth of penetration is sufficient to give good sensitivity to defects occurring within the first 1/8-inch.

INSTRUMENT CIRCUIT

Figure 2 is a circuit diagram of the electronics with the exception of the Brown recorder. The assembled equipment is shown in Figure 9.

Description

Power Supply The power supply consists of a conventional full-wave rectifier with an output of 380 volts under load. There is also a regulated 220-volt output.

Oscillator The oscillator, of which the detecting test coils are a part, is a push-pull oscillator. The coils are bifilar wound with 400 turns of No. 36 Formvar coated wire. Coil specifications appear in Figure 3. These coils give a frequency of operation of approximately 2 kilocycles.

Cathode Follower The cathode follower acts as a buffer stage between the oscillator and the amplifier.

Amplifier The amplifier consists of two 6V6's in push-pull.

Detector The output of the amplifier is fed to a balanced detector. Two 6H6 tubes are used for this purpose.

Second Cathode Follower The second cathode follower serves as a buffer between the detector and the recorder. One-half of the second cathode follower output stage is used to supply a reference voltage so that the output may be adjusted to buck out most of the DC component.

Recorder The recorder (Model No. 153X18V-X-118N4) is a Brown recorder with a 1-second response and a chart speed of 8 inches per minute.

Initial Adjustments

Feedback Controls The coarse feedback control (refer to Figure 10) consists of two ganged switches. It controls the amount of positive feedback in the oscillator section of the circuit. This is a chassis adjustment, not available to the operator.

The fine feedback control is a 10,000 ohm helipot common to the cathode circuit of each triode section of the 6SN7 oscillator tube. It is an external control located on the front of the upper panel.

Chassis Adjustments (All chassis adjustments are made before installation.)

a. 2,000 ohm pot - this allows the bias of one of the 6V6 tubes to be adjusted so that the pair may be balanced.

b. 100,000 ohm pots - these two ganged pots provide gain control. They control the input to the 6V6 tubes.

c. 200 ohm pot - this pot adjusts the DC output of the cathode follower so that the range of the recorder (0-100 millivolts) is not exceeded. This pot is a sensitivity control and may be adjusted, if required. Too much sensitivity, however, increases instability and does not improve the indication caused by a crack.

d. 500,000 ohm pot - this pot controls the amount of regulated output voltage. It is adjusted to give 220 volts in the output of the regulator. (Refer to Figure 11.)

Associated Equipment In addition to the electronic equipment, a semi-automatic feeder, designed and built at ANL, was provided to feed the slugs through the concentric coil at a uniform rate. The feeder with the coil assembly in place is shown in Figure 9.

Operating Instructions

Terminals

a. Input The input terminal to the oscillator (refer to Figure 1 for a block diagram of the instrument) is a Jones plug located on the front of the top panel. The test coils supplied with the instrument are plugged into this Jones connector. The test coils must be firmly connected to the input cable.

b. Output The output terminal from the detector is located on the back of the chassis of the top panel. The output terminal should be connected with the proper polarity to the input terminal of the Brown recorder.

Starting Procedure

a. There are two power cables at the back of the cabinet. One cable supplies power for the Brown recorder and the other cable supplies power for the remaining circuitry. Plug both power cables into a nominal 115 volt, 50 to 60 cycle power line.

b. Insert a slug in the coils. The coils should be about half-way between the ends of the test sample.

c. Throw the power switch to the "on" position. This is the sole switch on the first panel above the Brown recorder.

d. Open the recorder door. There is a knob to the right of the chart paper. Turn this knob counterclockwise and pull. Almost the entire recorder assembly swings out of the case. At the back of the recorder assembly, there is a switch on the far right just below center. Throw this switch to the "on" position. Swing the recorder assembly back into position and turn the knob mentioned above in a clockwise direction to lock the assembly in its case.

e. Allow several minutes for the equipment to warm up. Although the unit can be used after 2 or 3 minutes of warm-up, it is desirable to allow about 10 minutes warm-up time, if possible.

f. Throw the switch on the front of the recorder assembly to the "on" position. This switch is located on the right of the chart paper.

g. Adjust the knob on the top panel until the recorder pin is in the center of the chart paper. The crack detector is now ready for operation.

h. With the coil properly adjusted in the feeder, start the feeder by turning the switch located on top of the metal box on the feeder. Run the slugs through the concentric coil, end to end, allowing as little air gap as possible between adjacent slugs. This reduces end effects. Choose one slug as a standard. Run this slug through the coil periodically to make sure the instrument is stable. (Refer to the discussion below for an analysis of the recordings.)

INITIAL RESULTS

Of the approximately 500 slugs run through the instrument, 12 slugs were chosen for further examination on the basis of deviations from the response given by a normal slug. The 12 slugs were retested three times and three were chosen for sectioning on the basis of their pronounced deviation from the nearly straight response given by a normal slug. Figures 4, 5, 6, 7, and 8 present strip chart recordings and photographs of the cracks. Slugs B, F, and G were chosen for sectioning. Slugs A through E gave almost identical chart indications. One of these slugs (B) was sectioned to determine the cause of the six peaks. The position of each peak was measured from the numbered end on the chart paper, and the position along the length of the slug corresponding to the peaks was marked using the conversion factor,

$$\frac{\text{the length of the slug}}{\text{length of chart indication for that slug}} .$$

The other two slugs were marked in a similar manner for their single indications. In the eight sections that were made, only four defects were actually found. The four cuts which revealed no defect were four of the six made on Slug B. It cannot be said conclusively that there were no cracks at the location where the section was made because the crack may have been destroyed or missed in the sectioning process.

A more extensive evaluation of the instrument can be found in DP-67.

L. E. Goodwin
Instrument Development Division

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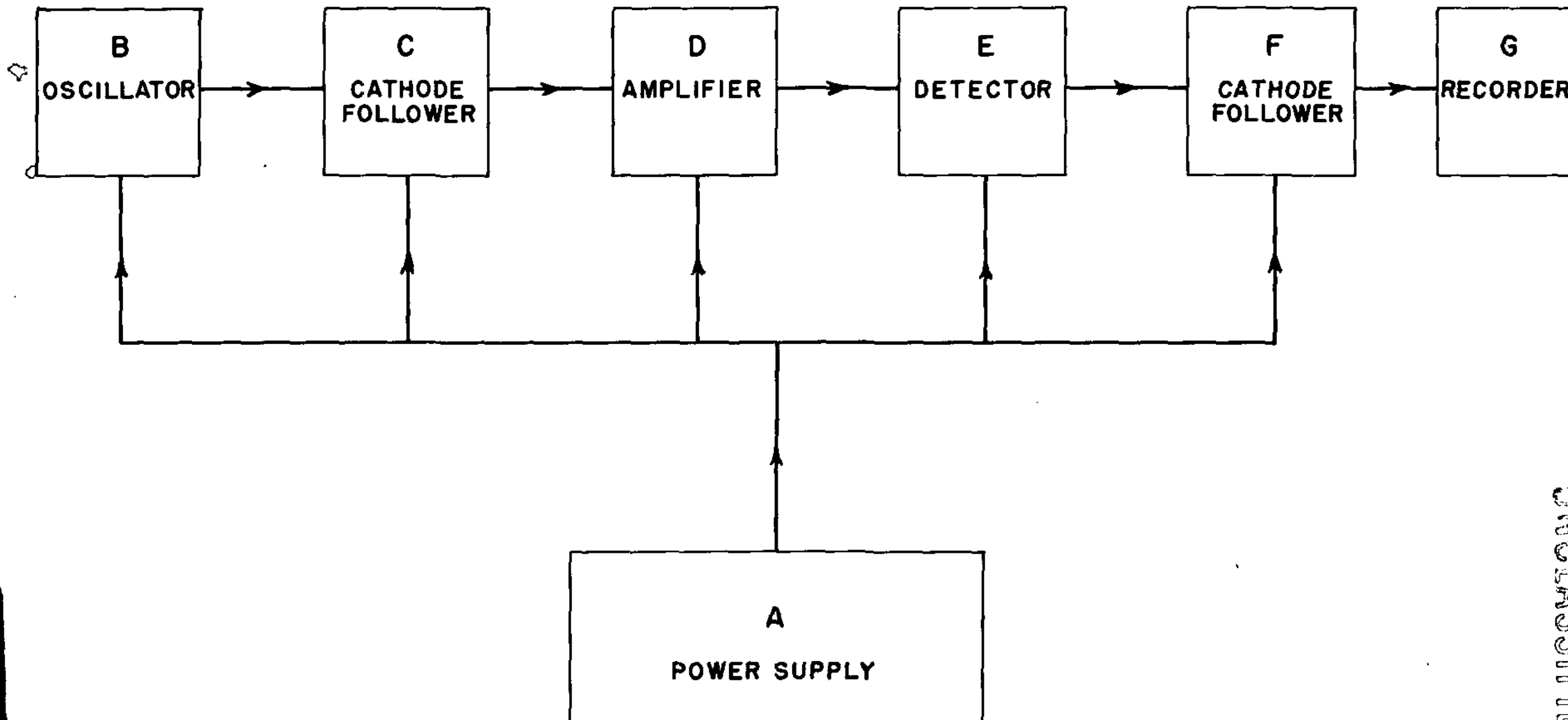
[redacted]

Figure 1



BLOCK DIAGRAM OF SUB-SURFACE CRACK DETECTOR

[redacted]

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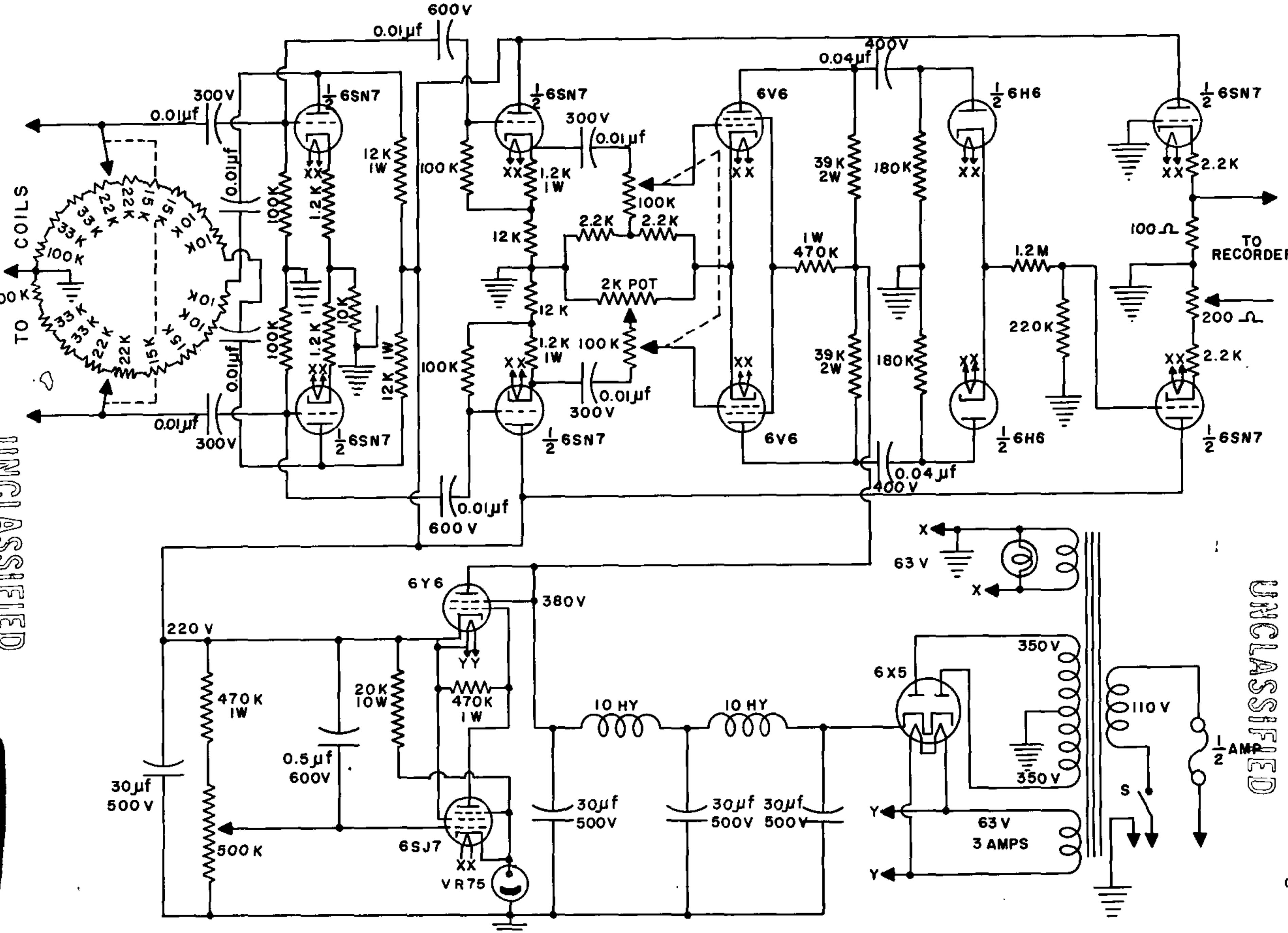
[redacted]

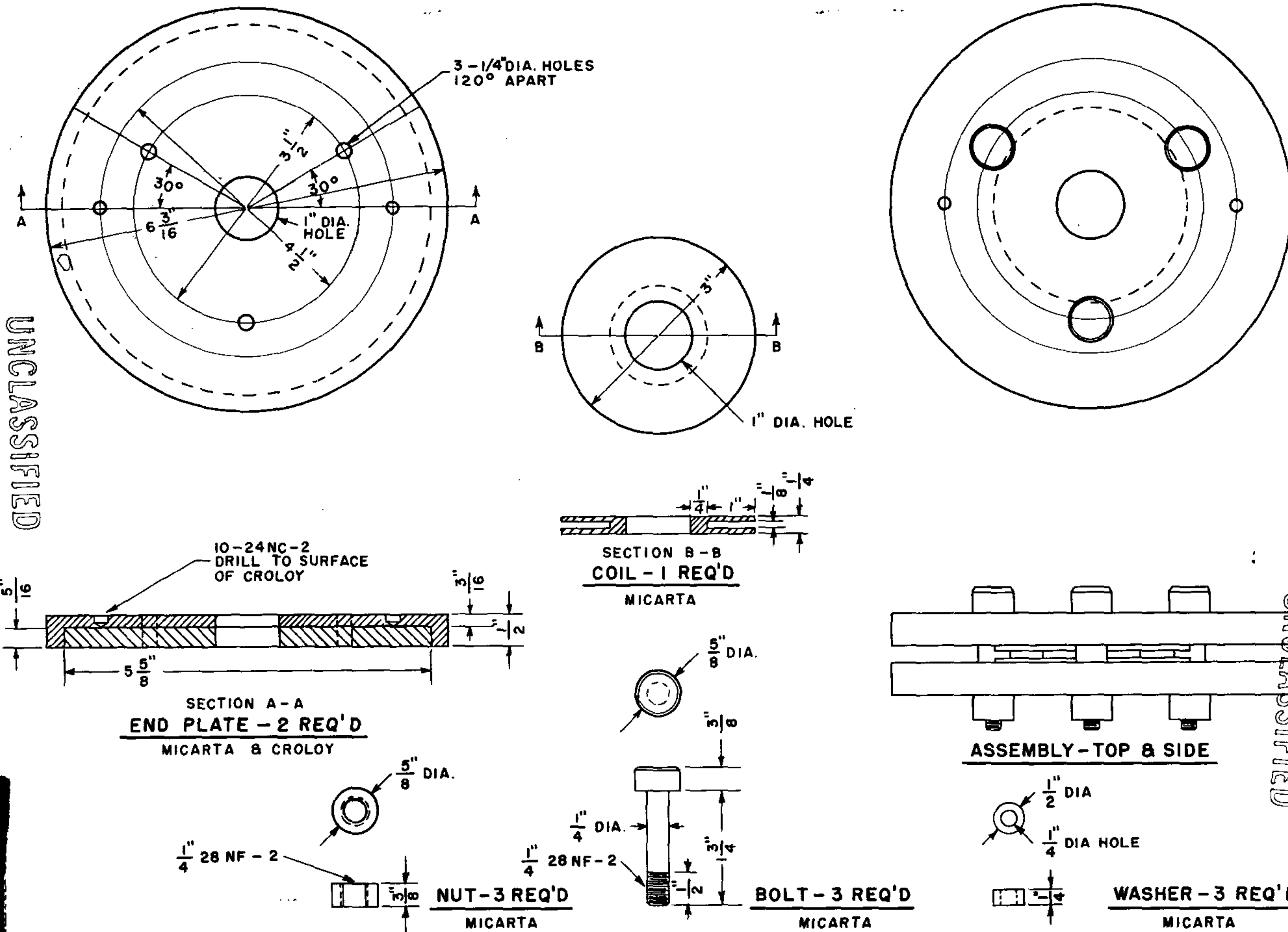


CIRCUIT DIAGRAM OF SUB-SURFACE CRACK DETECTOR

Figure 2

[redacted]

[redacted]



CROLOY COIL FORM WITH COIL

Figure 3

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Figure 4

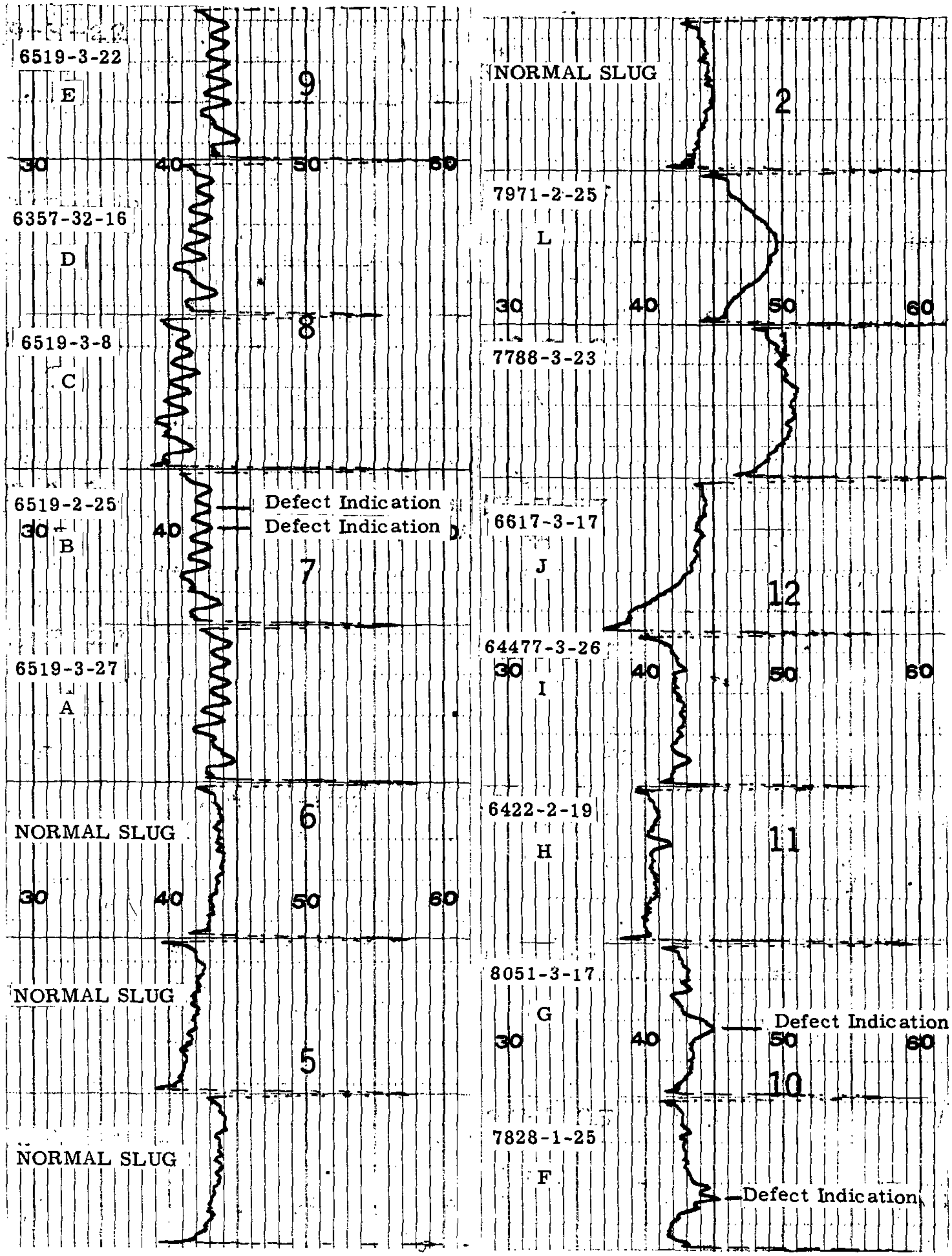

CHART RECORDS

[redacted]

[redacted]

Figure 5

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SLUG 6519-2-25 SECOND DEFECT FROM
NUMBERED END MAGNIFIED 250 TIMES

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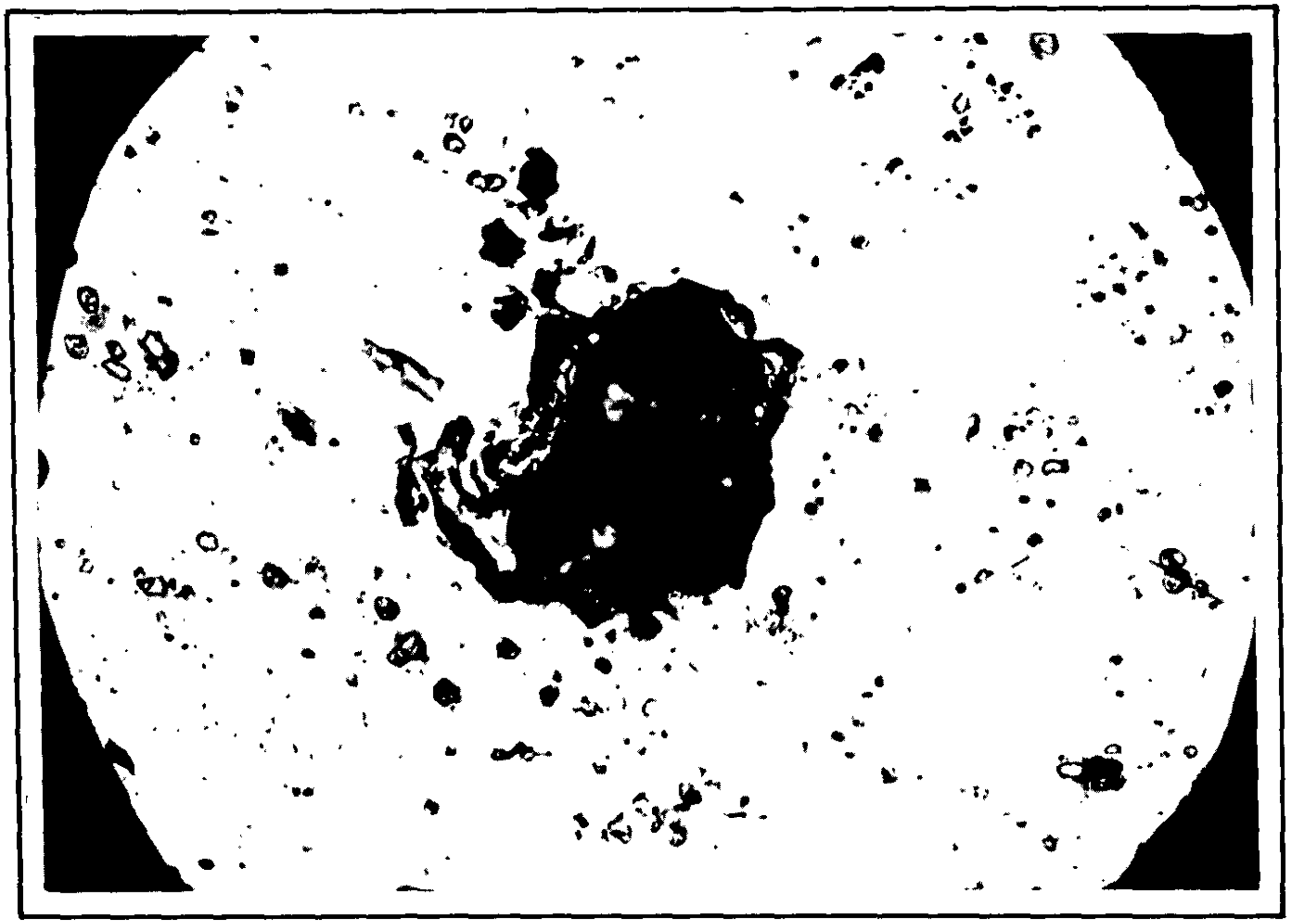
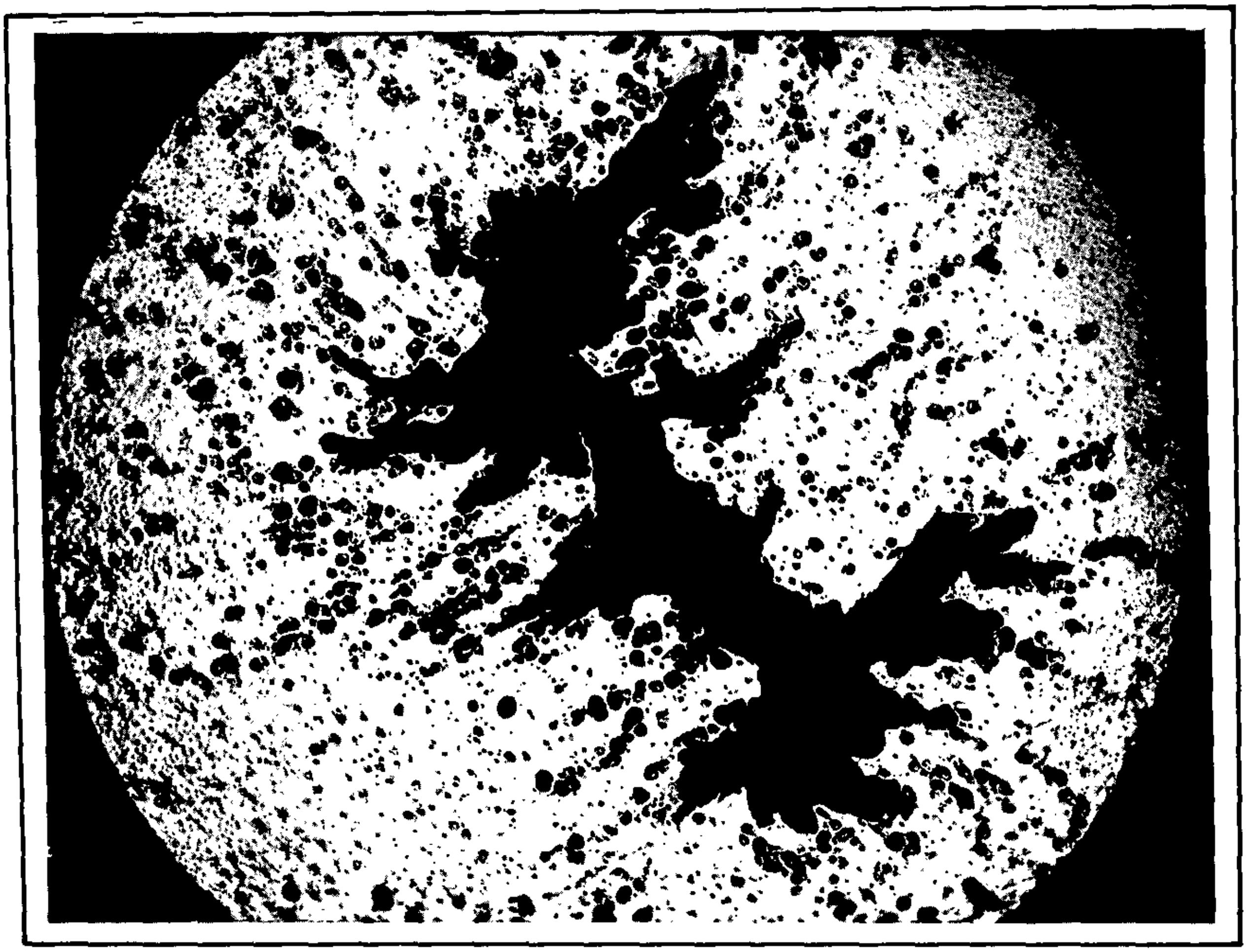
Figure 6



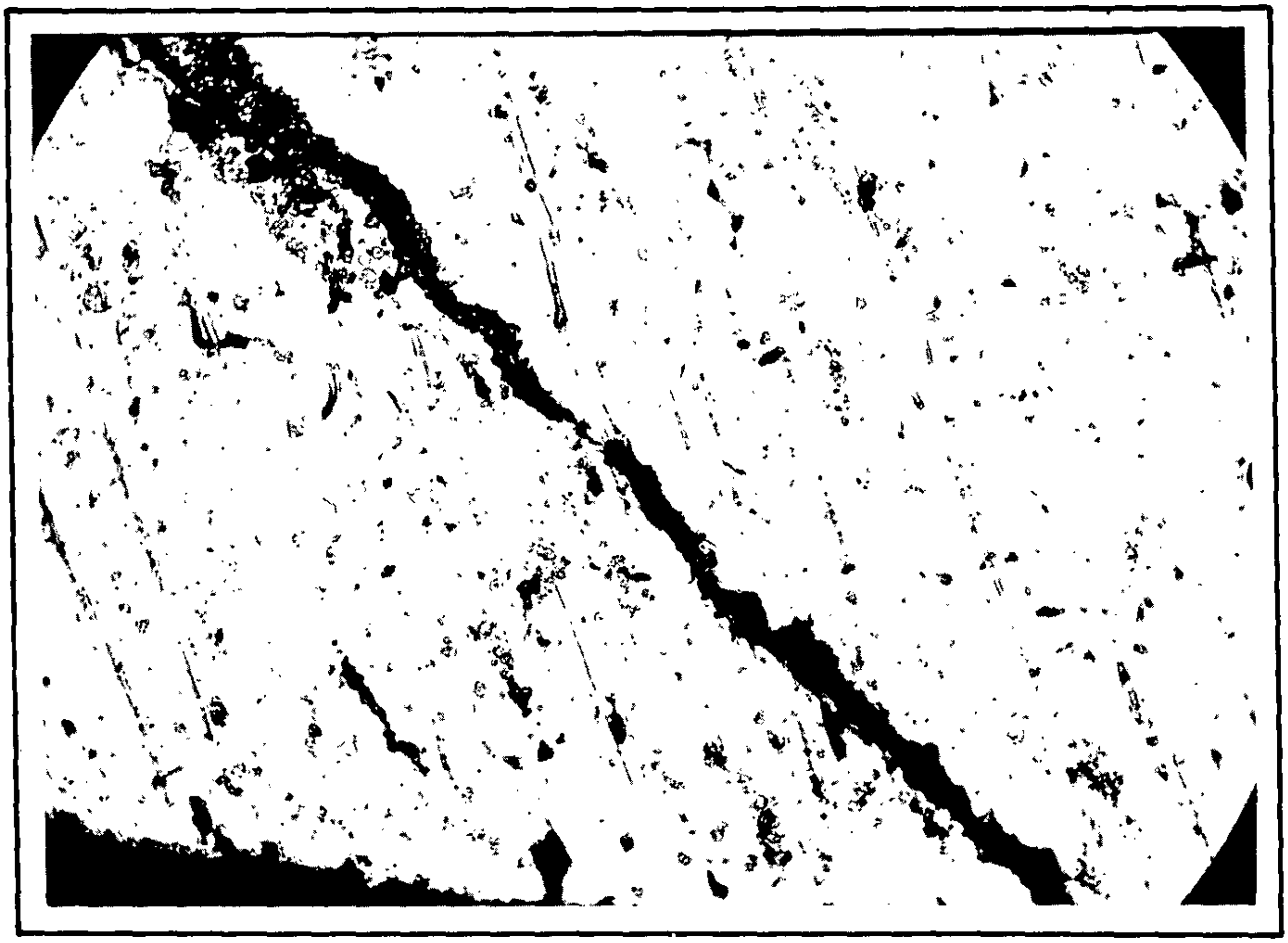
SLUG 6519-2-25 THIRD DEFECT FROM
NUMBERED END MAGNIFIED 250 TIMES

[redacted]

Figure 7

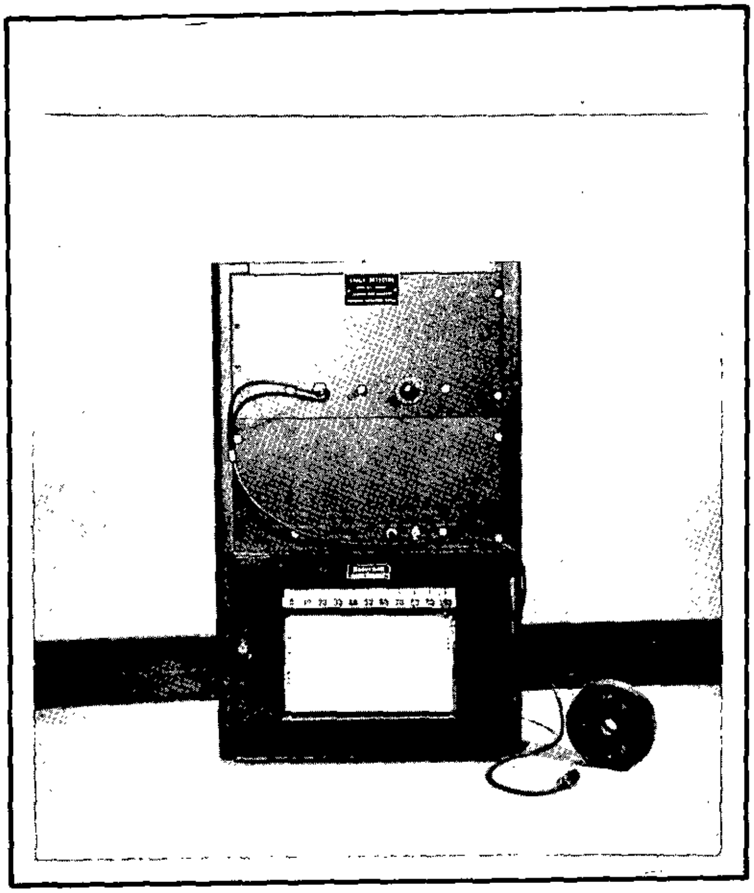


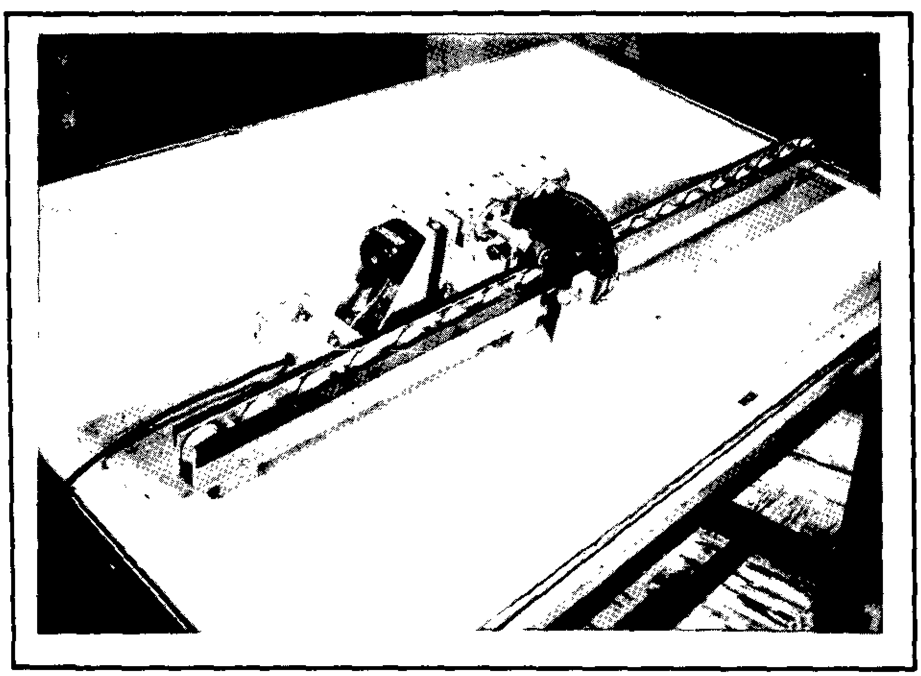
SLUG 7828-1-25 DEFECT MAGNIFIED 250 TIMES



SLUG 8051-3-17 DEFECT MAGNIFIED 150 TIMES

[redacted]





EQUIPMENT ASSEMBLY

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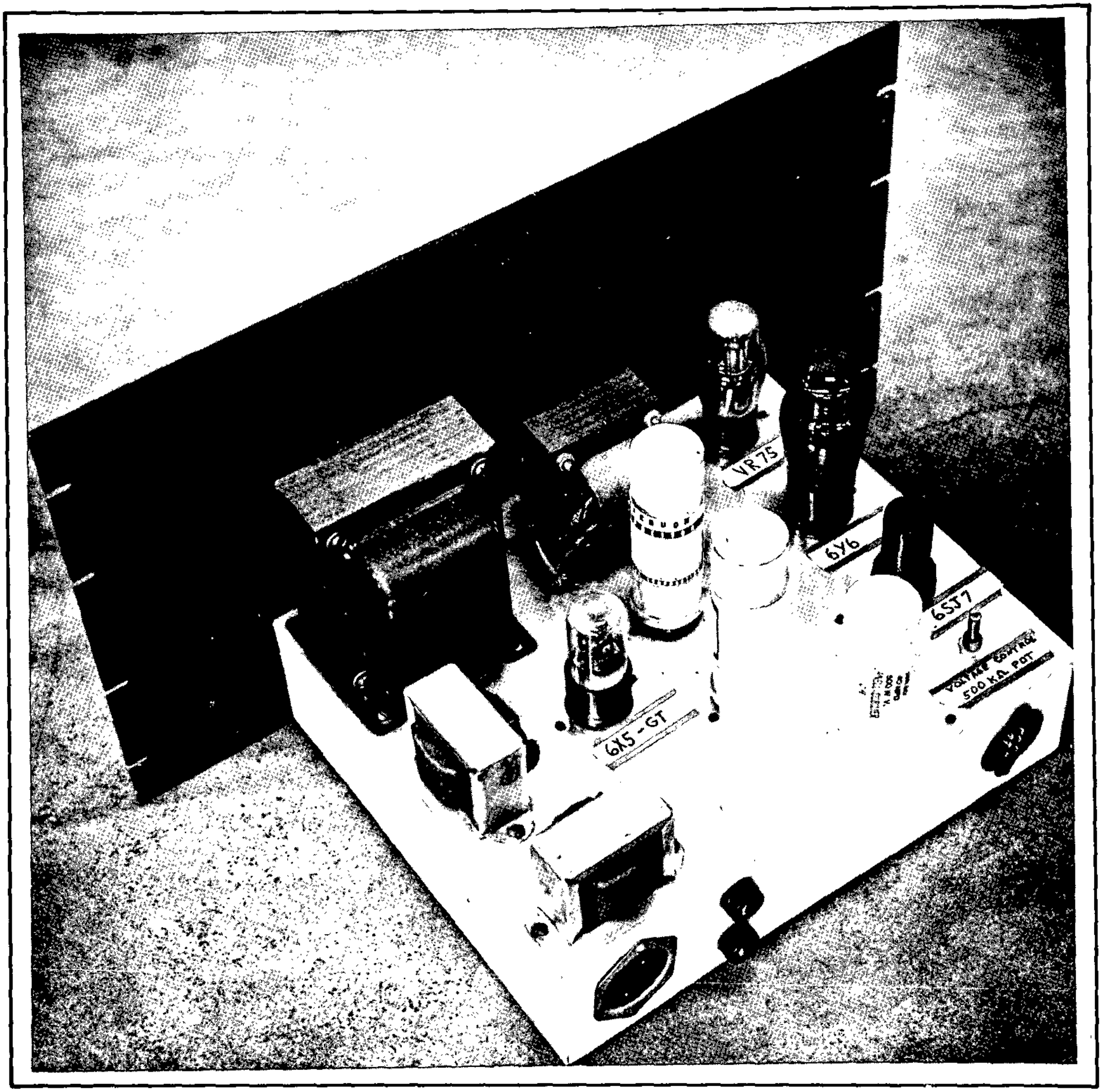
EQUIPMENT CHASSIS



EQUIPMENT CHASSIS

APPENDIX

MAINTENANCE

No special maintenance is required. All maintenance and servicing is done with ordinary laboratory tools. The tubes should be tested periodically. If the 6V6's are replaced, it may be necessary to adjust the 2,000 ohm potentiometer to balance them. This is done by placing the circuit in operation and observing independently the wave-forms across the 39,000-ohm resistors that serve as plate-load resistors for the 6V6's. This must be done with a scope which has an above-ground input. The two wave-forms should be of the same amplitude and undistorted.

The Brown recorder contains a dry-cell battery which must be replaced periodically. Exhaustion of the cell is indicated by a pointer on the left side of the recorder.

Defective components can be localized by making routine voltage checks using the circuit diagram shown in Figure 2.