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Fifth Partial Report

on

EDDY CURRENT TYPE FLAW DETECTORS

APPLICATION TO INSPECTION OF ALUMINUM ALLOY PROPELLER BLADES

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ABSTRACT

The eddy current type flaw detector using a 60 cycle/sec exciting frequency has been applied to the inspection of aircraft propeller blades. The phase and amplitude sensitive vacuum tube circuit is described in detail. A motor driven scanner with suitable scanning jig is described for facilitating the scanning of the propeller.

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INTRODUCTION

(A) Authorization

1. This problem was authorized by the Bureau of Aeronautics Project 39/42 of June 25, 1941.

(B) Statement of Problem

2. To develop the eddy current type flaw detector and auxiliary scanning apparatus for application to the detection of flaws in propeller blades.

(C) Known Facts Bearing on the Problem

3. Three important factors connected with the frequency of the exciting current and the conductivity of the test material are:

(a). Sensitivity. In general, the higher the exciting frequency and the greater the electrical conductivity of the test material the greater will be the sensitivity of the detector to flaws.

(b) Penetration. (Depth of flaw in the test material to which the flaw detector is sensitive.) The higher the exciting frequency and the greater the conductivity of the metal the less will be the penetration.

(c) Edge effect. (The response of the detector to the proximity of an edge or discontinuity in the test specimen.) The higher the frequency and the greater the conductivity of the metal the less the edge effect.

4. Obviously, it is desirable to have high sensitivity, deep penetration and small edge effects. As noted above a high frequency increases the sensitivity and reduces the edge effects but it also decreases the penetration. Because the conductivity of the material and the exciting frequency are both involved in these three important factors they must be considered together.

5. Considering the comparatively high conductivity of the aluminum alloys used in aircraft propeller blades, the following conclusions are reached in regard to sensitivity, penetration and edge effects as they apply to propeller blade inspection.

(a) Sensitivity. Because of the good conductivity, sufficiently high sensitivity can be achieved by the use of a 60 cycle/second exciting frequency.

(b) Penetration. The high conductivity requires a relatively low exciting frequency to achieve good penetration.

(c) Edge effects. The expected fatigue crack in a propeller blade is a transverse crack some distance

from the tip of the blade, therefore, it is usually necessary to scan only in a direction parallel to the edges of the blade, and it is not necessary to approach very closely to the tip of the blade. Hence, edge effects do not introduce complications even at a low exciting frequency.

6. In view of the above considerations and the fact that the 60 cycles/second source from the power mains eliminates the necessity of a vacuum tube oscillator, an exciting frequency of 60 cycles/second is conveniently used for the flaw detector described in this report.

7. To prevent a large shift of the zero reading of the microammeter as the pickup unit is moved across the test specimen, it is necessary to keep the face of the pickup unit as nearly as possible parallel with the surface which is being scanned. The curvature of the propeller blade requires that the pickup unit be free to orient itself at any angle less than approximately 15° with the vertical. Uniform motion of the pickup unit gives a characteristic deflection of the meter so that it is easy to distinguish a deflection due to a flaw from a random or background motion of the microammeter which might be present. These considerations prompted the use of a motor driven scanning jig for scanning the propeller blade.

DESCRIPTION OF APPARATUS

(A) Pickup unit

8. The theory of the operation of the pickup unit has been presented in the NRL Report No. 0-1683 and in the NRL Report No. 0-1837. The pickup unit used is shown on Plate 1. The concentric cylinders and cores for the pickup coils are made of hot-rolled mild steel. The exciting coil has approximately 860 turns of No. 26 enamel covered copper wire with a resistance of 9 ohms and inductance of 55 millihenries. Each pickup coil has approximately 4250 turns of No. 38 enamel covered wire with a (resistance) of 130 ohms and an inductance of approximately 160 millihenries.

(B) Exciting current

9. The stepdown transformer Tr_2 shown in the diagram of Plate 3 provides an exciting voltage of 18 volts which gives a 60 cycles/second exciting current in the pickup head of approximately 180 milliamperes.

(C) Detector circuit

10. Plate 2 gives a closeup view of the detector unit. The complete circuit of the detector is given in the diagrams of Plate 3 and the circuit constants on Plate 4.

(1) Nature of pickup signal

11. The pickup signal from the pickup coils is the combination of the voltages induced in each of the pickup coils. Because the internal cylinder of the pickup unit does not give complete magnetic shielding to the pickup coils from the exciting magnetic field, there is a voltage induced in each of the pickup coils due to the exciting field of the exciting coil. It is necessary that these two voltages be 180° out of phase and equal in magnitude so that they will cancel each other at least to the extent that the remaining signal is less than the overloading signal of the 6SC7 vacuum tube. This signal will be referred to as the residual signal. As the pickup unit approaches a flaw in the test material the magnetic effects of the unsymmetrical eddy current pattern in the material induces a voltage in each of the pickup coils. These voltages are in phase so that they add together. This signal due to the flaw is therefore superimposed upon the residual signal and it is imperative that these combined signals always be less than the signal required to overload the 6SC7 vacuum tube if maximum sensitivity is to be achieved. The condensers C_1 and C_2 and the resistance R_1 serve to adjust electrically both in phase and amplitude the effective induced voltage due to the exciting field so that the residual signal is well below the overloading signal of the 6C7 tube.

(2) Phase and amplitude sensitive circuit.

12. The signal received by the 6SC7 is amplified by a factor of approximately 33 and this tube also serves as a phase inverter to apply the amplified signal in push-pull to one pair of control grids of the 6L7's. To a second pair of control grids of the 6L7's is applied a square wave signal of the same frequency as the exciting current and in phase with the flaw signal. This square wave permits the tube to respond to the flaw signal only during that half of the cycle in which it is positive. Plate 6 gives the relation between the flaw signal applied to grid 1, the square wave commutating signal applied to grid 2 and the resulting plate current for each of the 6L7 tubes as the pickup unit approaches and recedes from a flaw. Thus, when the flaw is being approached, tube T_1 has a greater plate current during one half of the cycle than does T_2. This results in a greater difference in potential between points A and B (Plate 3) than between B and C and hence point C is at a higher potential than point A during this half of the cycle thus giving a deflection (let us say) to the right on the microammeter M. As the pickup unit recedes from the flaw, tube T_2 has a larger plate current during one half the cycle than does T_1 with the result that point A is at a higher potential than point C during half of the cycle which gives a deflection to the left. When the pickup is directly over the flaw, the flaw signal is zero thus giving zero deflection of the microammeter. It is obvious that for greatest sensitivity the square wave should be in phase with the flaw signal. The proper phase relation is obtained by the phase shifting bridge composed of R_{22}, R_{23}, R_{24}, and C_{10} (Plate 3). The sine wave from the phase shifter is given a square wave form by the limiting tube 6SF5. This square wave is then applied to the second pair of control grids of the 6L7's.

The phase shift control R_{24}, is mounted on the chassis and the proper setting has been made for maximum sensitivity.

(D) Automatic scanning

14. Plate 7 shows the scanner which is useful in exploring propeller blades. The two rollers, F, support the pickup unit and jig and provide a small clearance between the face of the pickup unit and the propeller. The pickup unit has freedom to tilt at any small angle and the pickup unit can move vertically as a whole thus permitting the pickup unit to follow the contour of the propeller blade. In scanning a blade it is only necessary that the blade have its longitudinal axis approximately parallel and on the same level as the ways along which the scanning jig moves. The scanning jig has a sweep of 18 inches or less, the sweep length being determined by the positions of the adjustable stops, A. At the end of the sweep the motor is automatically reversed. Four inches of cross motion of the scanning jig is possible by means of the hand screw, B. The slot, C, permits a movement of 4 inches so a total of 8 inches cross motion is possible. The scanning jig moves with a speed of about 12 inches per minute and it requires approximately 6 seconds for the complete deflection of the microammeter as a flaw is traversed.

APPLICATION

(A) Edge effect

15. Plate 8 (A) gives the deflection of the microammeter as a function of the distance of the center of the pickup unit from the edge of a plate. The curve indicates that the pickup unit can be used to within 1 inch of the edge. It should be added that when the scanning is parallel to an edge no response is given by the detector to the presence of the edge.

(B) Typical response

16. Plate 8 (B) shows a characteristic deflection of the microammeter as a function of the distance of the center of the pickup unit from the flaw. The automatic scanner requires about 6 seconds to traverse the distance over which the pickup unit is sensitive. This comparatively slow characteristic deflection due to the flaw is easily distinguished from random movements of the microammeter which might be present.

(C) Response to total and surface flaws

17. All the flaws considered in the following discussion are longer than the diameter of the pickup unit. A total flaw is one which completely severs the material under test. A surface flaw is on the side of the specimen being examined but only partially severs the test specimen. Plate 9 curve (A) shows the microammeter deflection as a function of the depth of the surface flaw. Curve (B)

shows the microammeter deflection as a function of the depth of a complete flaw. It is to be noted that a surface flaw of 7/8 inch in dural is required to produce a deflection approaching that produced by an infinite flaw whereas a total flaw of only 1/4 inch will give a response approaching that of an infinite flaw. Curve (A) indicates that a surface flaw 1/32 inch in depth in duralumin can be easily detected if full sensitivity is used.

(D) Response to subsurface flaws

18. A subsurface flaw is a flaw that does not extend to the surface of the material under test. Plate 10 shows the microammeter deflection as a function of the depth of the flaw below the surface. The curve indicates that a flaw 3/8" below the surface can be detected if full scale sensitivity is used.

SUMMARY

19. An exciting frequency of 60 cycles/second has proven suitable as well as convenient for application of the eddy current type flaw detector to inspection of aircraft propeller blades. A vacuum tube circuit sensitive to both phase and amplitude changes of the pickup flaw signal with good stability and sensitivity has been presented. A motor driven scanner which moves the pickup unit with uniform speed and a scanning jig which keeps the face of the pickup unit parallel to the surface being scanned has been found useful.

20. It is shown that an edge or discontinuity in a duraluminum test specimen causes a deflection of the microammeter if the center of the pickup unit approaches within 1 inch of the edge. It is estimated that a surface flaw 1/32" deep or a subsurface flaw of large magnitude 3/8" below the surface can be detected in 24 S-T dural. These values will be different for materials of different electrical conductivity.

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1. An Eddy Current Method of Flaw Detection in Non-Magnetic Metals, R. Gunn. Journal. Applied Mechanics 8:A22(1941).

2. Eddy Current Type Flaw Detectors for Non-Magnetic Metals, I. Vigness, J.E. Dinger, and R. Gunn. Journal of Applied Physics 13:377-383(1942).

3. Second Partial Report on Magnetic Flaw Detector Stationary Pickup, Eddy Current Detector. Naval Research Laboratory Report #0-1683.

4. Third Partial Report on Eddy Current Type Flaw Detectors. Tests of Spot-Welds in Aluminum Alloys. Naval Research Laboratory Report #0-1792.

5. Fourth Partial Report on Eddy Current Type Flaw Detectors. Naval Research Laboratory Report #0-1837.

APPENDIX

Operating Instructions for NRL Model No. 4, Eddy Current Type Flaw Detector with Automatic Scanner.

Connections

1. Connect the cable of the pickup unit to its connector on the panel.

2. With the power switch off, connect the detector to 110 volts a.c. at the indicated connector on back of cabinet.

3. Best stability of the apparatus is obtained if the cabinet is connected to a good ground.

Adjustment of Scanner

4. Place the pickup unit in the jig, E, (Plate 7) on a plane surface and adjust the pickup unit so there is a clearance of about .002 inch between the face of the pickup unit and the plane surface when the rollers, F, are touching the surface. A sheet of paper provides a convenient guage for adjusting this clearance. It is very important that the pickup unit be placed in the jig so a plane passing through the two inside pole pieces is parallel to the direction of motion of the scanner.

5. At the start of a run it is convenient to have the cross feed screw, B, and the adjustable slot C so the pickup unit is as "close in" to the ways of the scanner as possible.

6. Clamp the cable D in the manner indicated in Plate 7 so tilting of the pickup unit will not be hindered by the cable.

7. Place the propeller blade on supports which put the axis of the blade approximately parallel and on a level with the ways of the scanner. At the start the pickup unit should be about 1/2 inch from the edge of the blade nearest the scanner.

8. Set the stops, A, for the desired length of the sweep of the scanner. The motor will automatically reverse when the carriage reaches these stops.

9. Connect the motor to 110 volts a.c.

Operation

10. Make certain the switch S_1, Plate 2, is in the position pointing to Meter unless an external meter is being used.

11. Set the Sensitivity control C_2 at zero.

12. Throw the power switch S_2 to ON position. The pilot light, P.L., should be lighted. Allow at least two minutes for the apparatus to warm up.

13. Turn the Sensitivity control C_2 to position 1 and then by means of the Zero Adjuster adjust the microammeter to the zero position.

14. The sensitivity control may now be turned up to any desired value. Plate 5 gives the relative sensitivity as a function of the position of this control.

15. Start the motor. It is suggested that in making the run the pickup unit be moved crosswise of the blade 1/2 inch each time the motor reverses. This is accomplished by 12 turns of the hand screw, B. This screw provides a total cross motion of 4 inches. The screw can then be run back and the scanning jig moved crosswise in the slot C, thereby allowing the scanning jig to be moved crosswise an additional 4 inches by means of the hand screw. An area 8 x 18 inches can thus be explored. At the speed which the motor drives the scanner it requires 25 minutes to scan such an area in this manner.

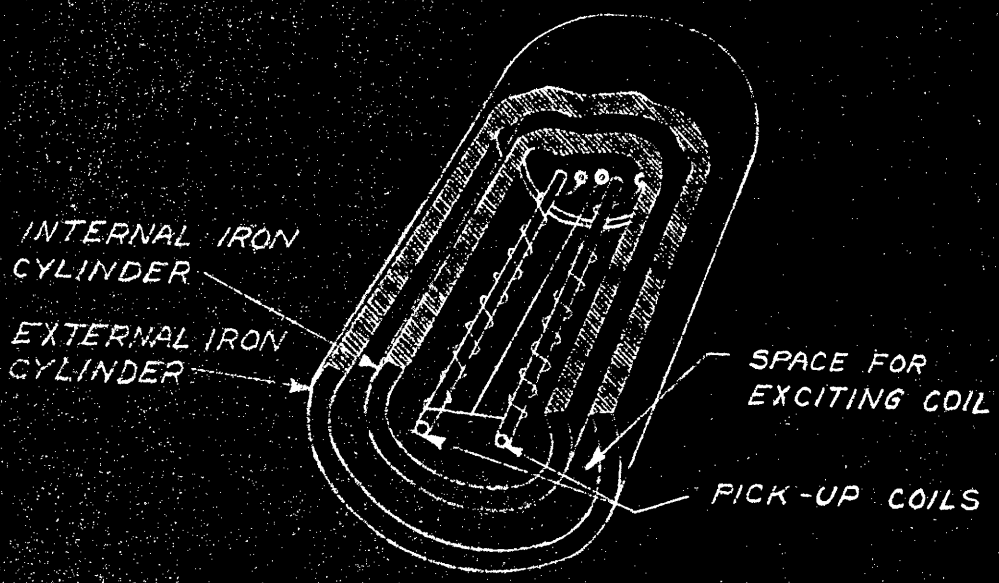
16. The characteristic deflection of the microammeter as a flaw is traversed is given by Plate 8 b. The center of the pickup unit is directly over the flaw when the meter goes through the zero point. Approximately 6 seconds are required for this deflection as a flaw is crossed by the motor driver scanner. Thus, a deflection due to a flaw can easily be distinguished from random background movements.

17. It is suggested that full sensitivity be used in scanning a blade. If a flaw is encountered which deflects the microammeter off scale, the operator can immediately turn the sensitivity down so this deflection remains on scale. Plate 8 gives an estimate of the deflection to be expected for various surface and subsurface flaws. One typical surface fatigue crack in a propeller blade was found to give a full scale deflection at a sensitivity of 2.

18. It may be necessary occasionally to reset the zero of the microammeter as the pickup unit moves to thicker or thinner portions of the blade.

Remarks

A varying line voltage of the power line will cause instability of the microammeter, therefore, a steady line voltage is necessary. If a voltage regulator is used it is essential that it be of such a type that it will give a good sine wave form as a poor wave form greatly reduces the sensitivity and stability of the apparatus.



PICK-UP UNIT

PLATE I

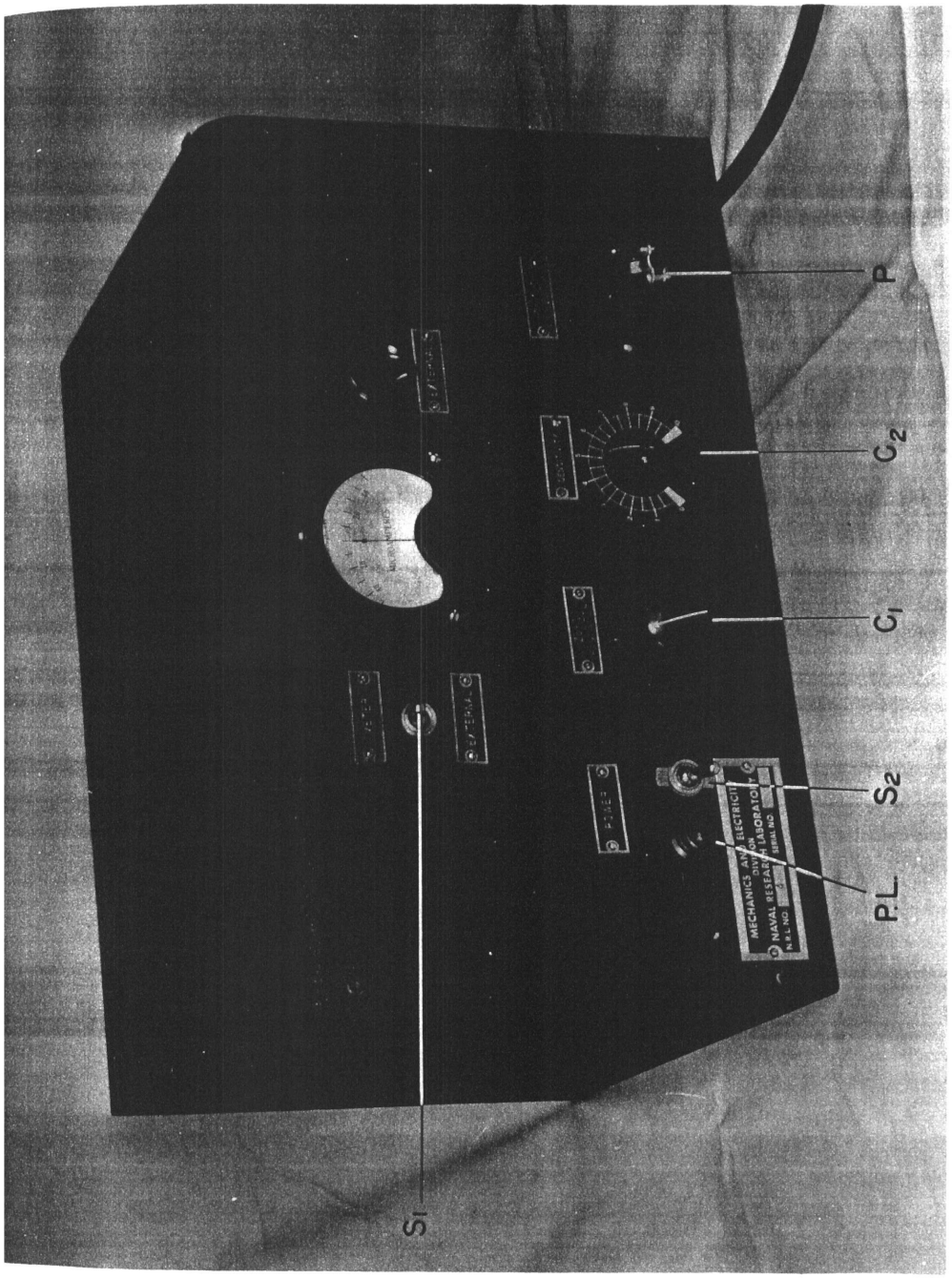

P
C_2
C_1
S_2
P.L.
S_1
MECHANICS AND ELECTRICITY
DIVISION
NAVAL RESEARCH LABORATORY
N.R.L. NO.
SERIAL NO.
POWER
EXTERNAL

PLATE 2

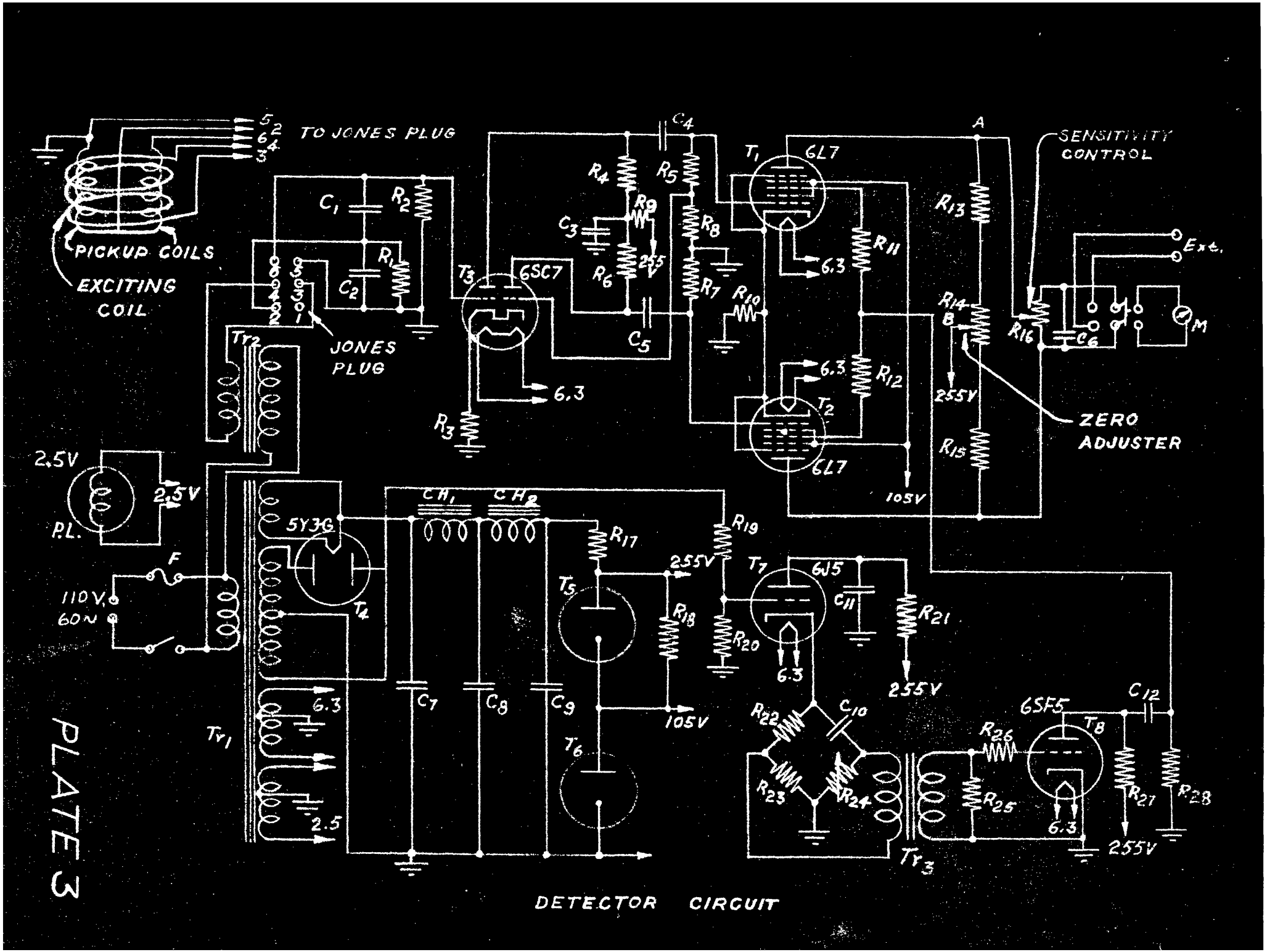


PLATE 3

DETECTOR CIRCUIT

M = Megohm
K = Thousand Ohms

R_1 - Depends on pickup unit
R_2, R_4, R_6 - 0.1 M
R_{11}, R_{12}, R_{19}, R_{25}, R_{28} - 1.0 M
R_5, R_7 - 0.27 M
R_8, R_{21} - 8.2 K
R_{10} - 120 ohms
R_{13}, R_{15}, R_{18} - 10K
R_{14} - 25 K W.W. Pot.
R_3, R_{17} - 1 K
R_{16} - 1 K W.W. Pot.
R_{20} - 25 K
R_{22}, R_{23} - 470 ohms
R_{24} - 10 K W.W. Pot.
R_{26} - 2M
R_9, R_{27} - 47 K
C_1, C_2 - Depends on pickup unit
C_4, C_5 - .025 mfd.
C_6 - 40 mfd.
C_7, C_8, C_9 - 10 mfd, 450 V electrolytic
C_3, C_{11} - 8 mfd, 450 V electrolytic
C_{10} - .5 mfd.
C_{12} - .01 mfd.
Tr_1 - Thordarson T-70R21
Tr_2 - Thordarson T-13R19
Tr_3 - RCA 9632
CH_1 - Thordarson T-13C28
CH_2 - Kenyon T-157
T_1, T_2 - 6L7
T_3 - 6SC7
T_4 - 5Y3G
T_5 - VR150/30
T_6 - VR105/30
T_7 - 6J5
T_8 - 6SF5
F - 2 ampere fuse
P.L. 2.5 volt pilot light

Circuit Constants for Detector Circuit

Plate 4

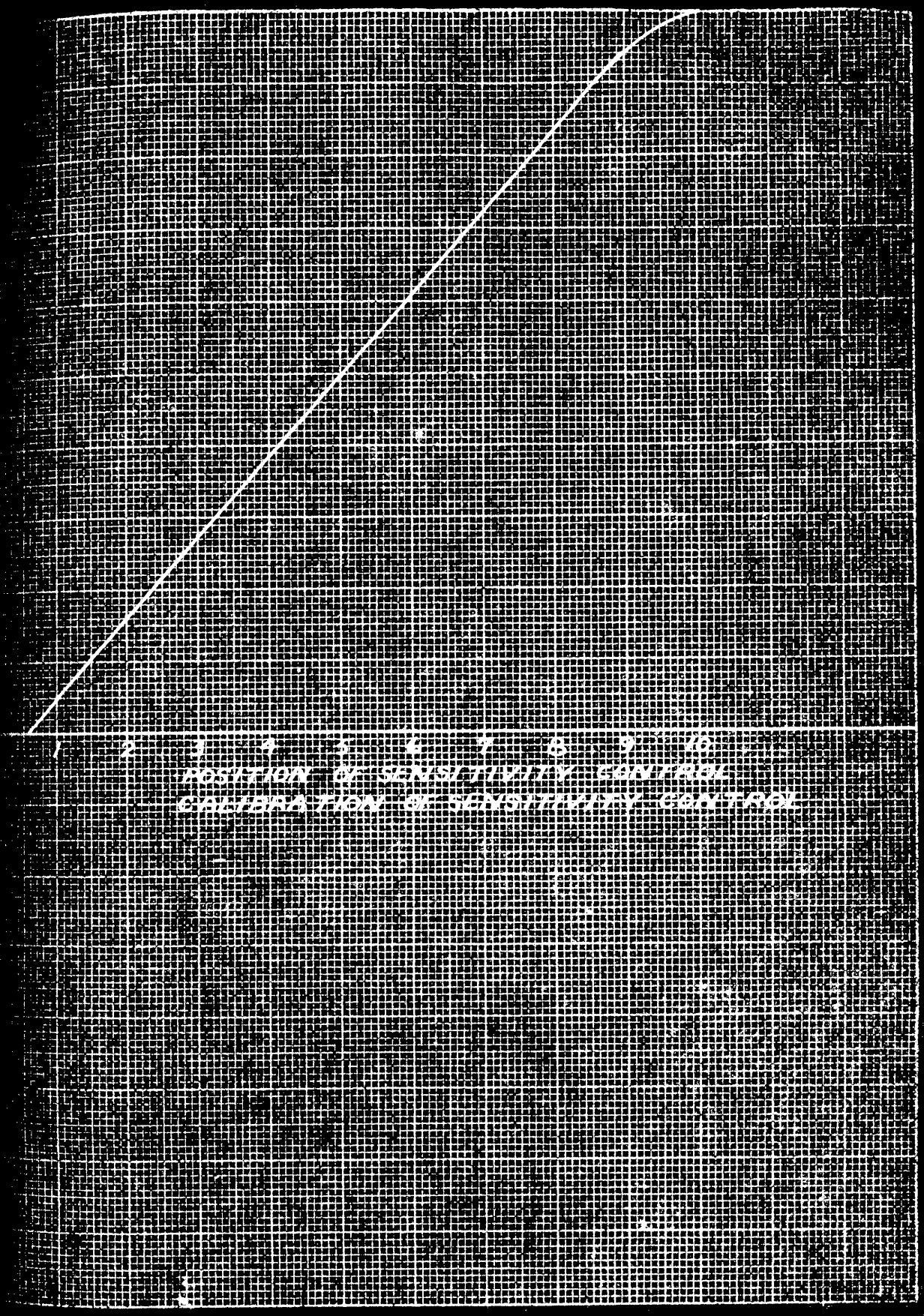
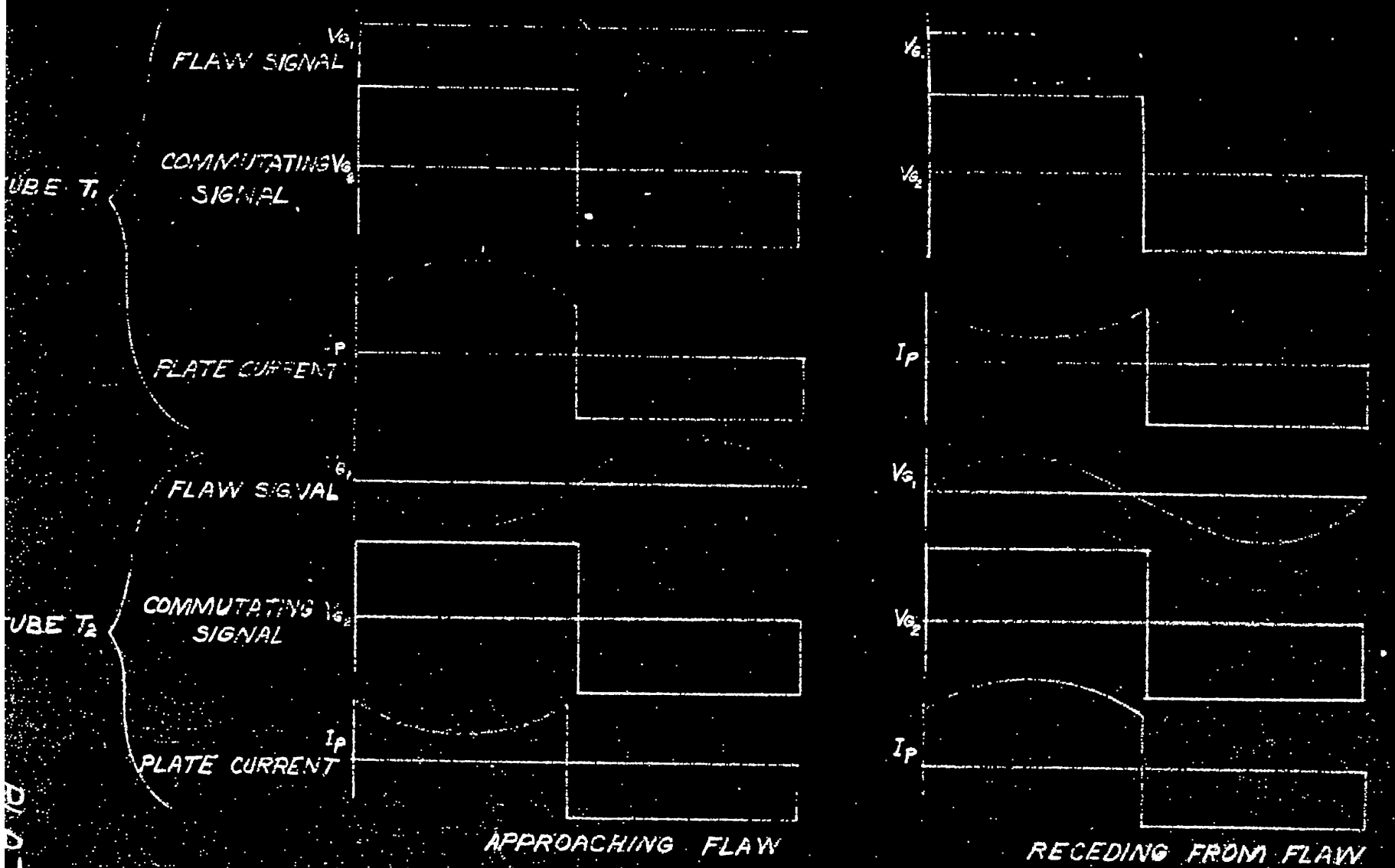
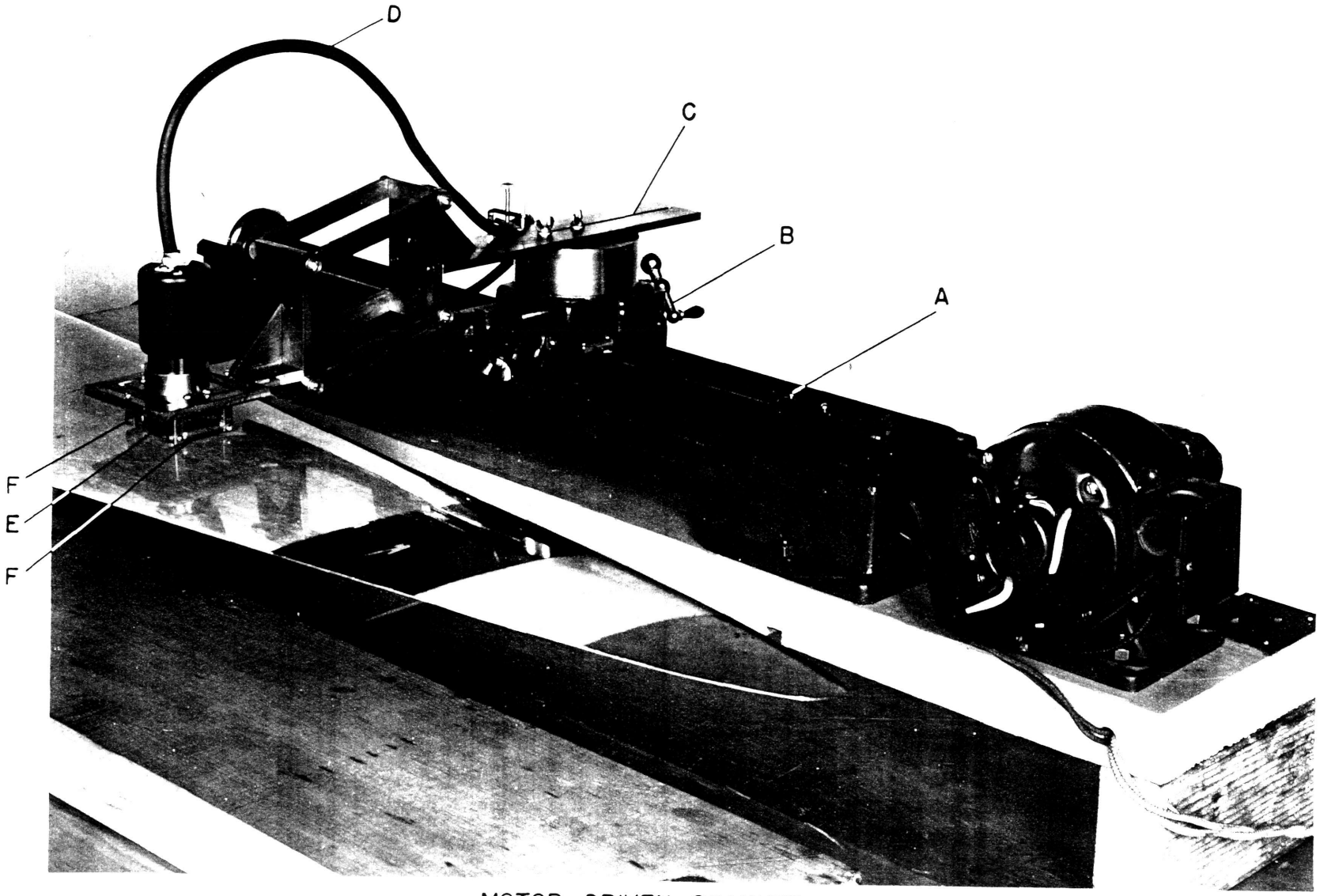

POSITION OF SENSITIVITY CONTROL
CALIBRATION OF SENSITIVITY CONTROL

PLATE 5

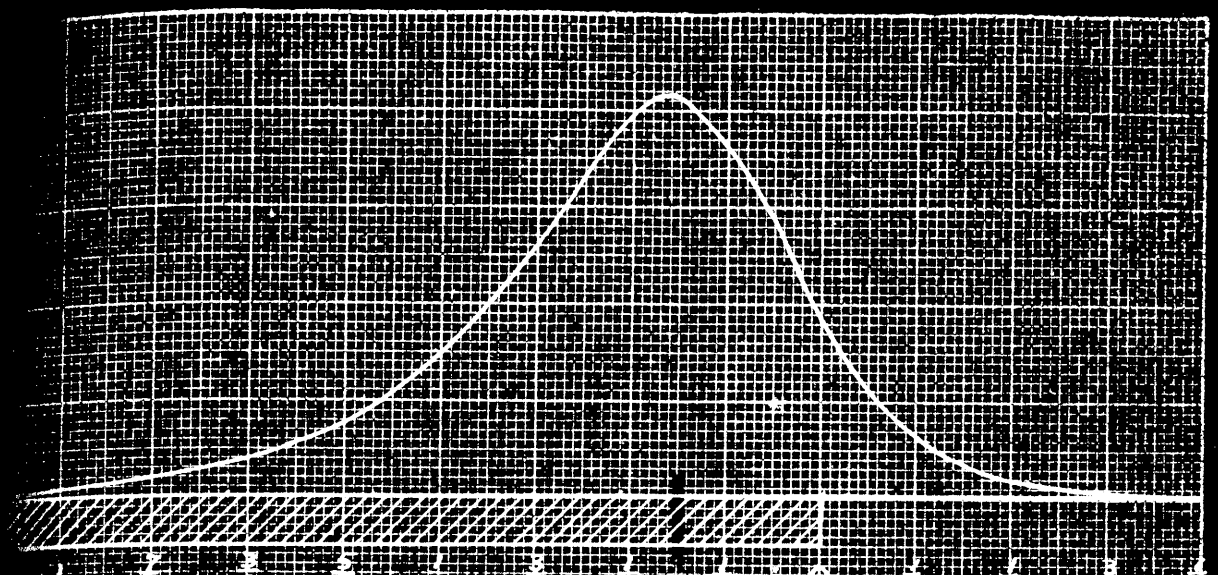


CORRESPONDING FLAW SIGNAL, SQUARE WAVE COMMUTATING SIGNAL AND RESULTING PLATE CURRENT FOR TUBES T_1 AND T_2 AS PICK-UP UNIT APPROACHES AND RECEDES FROM FLAW.

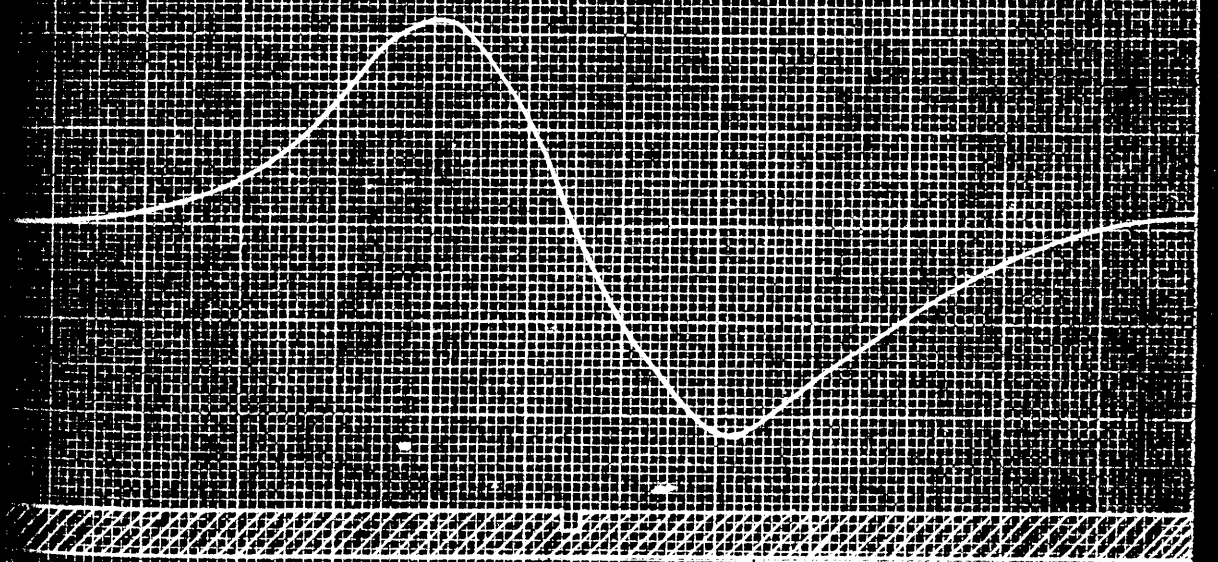


MOTOR DRIVEN SCANNER

PLATE 7



DISTANCE IN INCHES FROM EDGE OF PLATE TO CENTER OF PICK-UP UNIT



DISTANCE IN INCHES FROM FLAW TO CENTER OF PICK-UP UNIT

DEFLECTION OF MICROAMMETER AS FUNCTION OF THE DISTANCE OF CENTER OF PICK-UP UNIT FROM EDGE

MICROAMMETER DEFLECTION AS A FUNCTION OF CENTER OF PICK-UP UNIT FROM A FLAW

PLATE 8

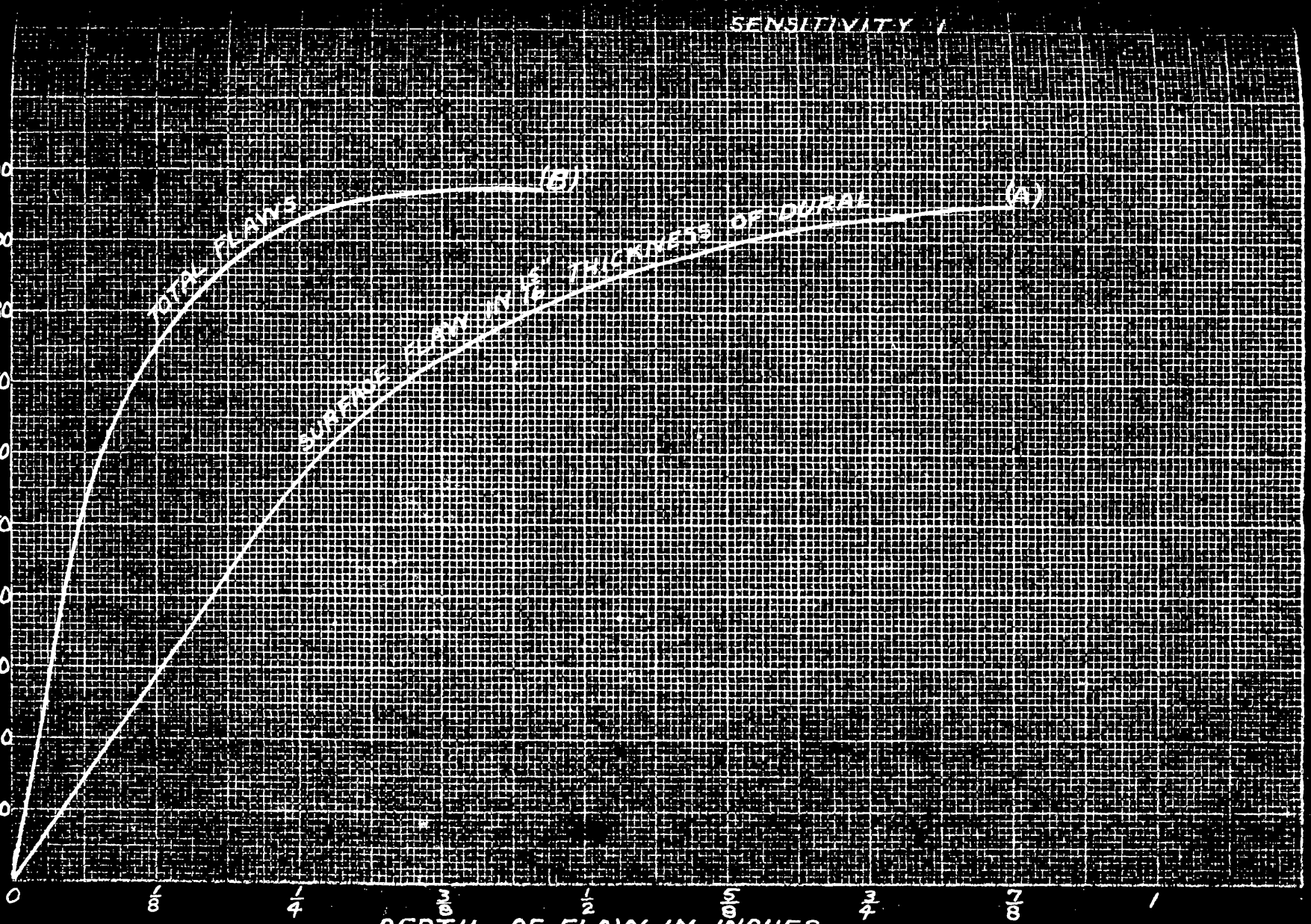
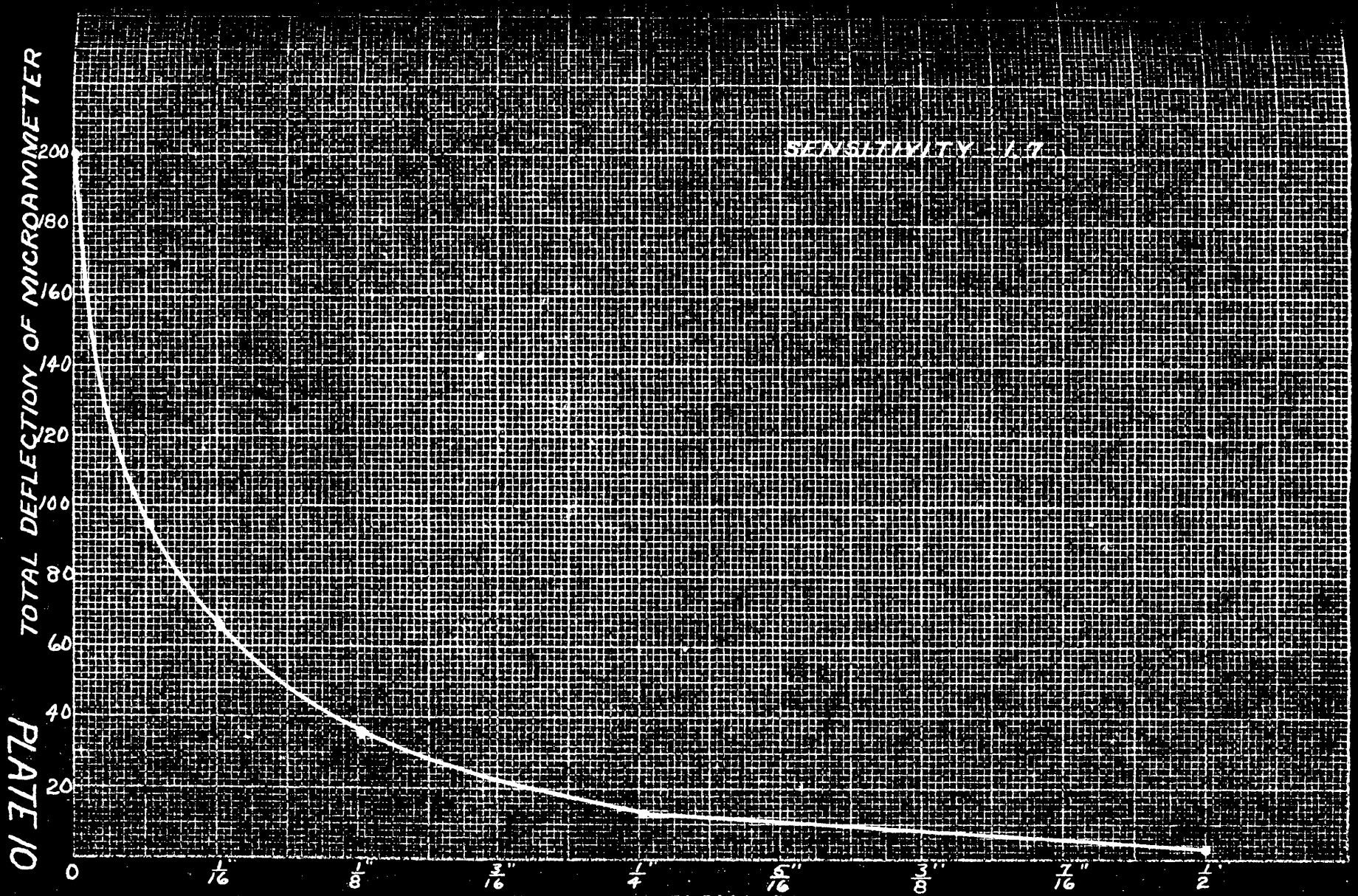

SENSITIVITY 1
TOTAL DEFLECTION IN MICROAMPERES
100
90
80
70
60
50
40
30
20
10
0
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
TOTAL FLAWS
(B)
SURFACE FLAW IN 1/16" THICKNESS OF DURAL
(A)
DEPTH OF FLAW IN INCHES
RESPONSE TO FLAWS IN 24 S-T DURAL

PLATE 9



RESPONSE TO SUBSURFACE FLAW IN 24 S-T DURAL

PLATE 10