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ELECTRICAL RESISTANCE METHOD OF MEASURING THE VELOCITY IMPARTED TO METALS BY HIGH EXPLOSIVES

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ABSTRACT

An electrical resistance method of measuring velocities imparted to metals by high explosive (H.E.), requiring much the same equipment as the electrical contact method described by Froman in LA 182 has been developed. The method consists essentially of driving the metal into a helical coil made of nichrome wire a few thousands of an inch in diameter, wound with the pitch sufficiently small to keep the shock wave in the wire from moving faster in the direction of motion of the metal than the metal itself moves. The assumption is made that the nichrome penetrates into the metal surface and does not pile up above it. The good agreement obtained between this method and the electrical contact method indicates that this assumption, at least in the case of the metals studied (i. e., copper and steel), is justified. Photographs of these spirals indicate the probability of a metallic splash when the plates move into them; this raises some question as to the reliability of the method.

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ELECTRICAL RESISTANCE METHOD OF MEASURING THE VELOCITY IMPARTED TO METALS BY HIGH EXPLOSIVES

The three electrical methods originally proposed to measure the velocity imparted to metals by high explosives (H. E.) are the pin-contact method, the condenser microphone method, and the electrical resistance method. The electrical contact method, described by Froman in LA 182, has proved to be by far the most useful of these methods. The condenser microphone technique has been described by D. Marshall in LA 259.

Not because any immediate use was visualized for the electrical resistance method, but because it was considered desirable to develop the technique and have it available in case a use were found, the research reported in this paper was undertaken. The advantages of such a method are: (1) a continuous record is obtained, and (2) the velocity of a very small area of the metallic surface can be measured.

Two techniques have been developed for this method: (1) the variable-current technique, and (2) the steady-current technique.

I. The Variable-Current Technique.

A typical shot setup and the pre-amplifier for the variable-current technique are illustrated in Fig. 1.

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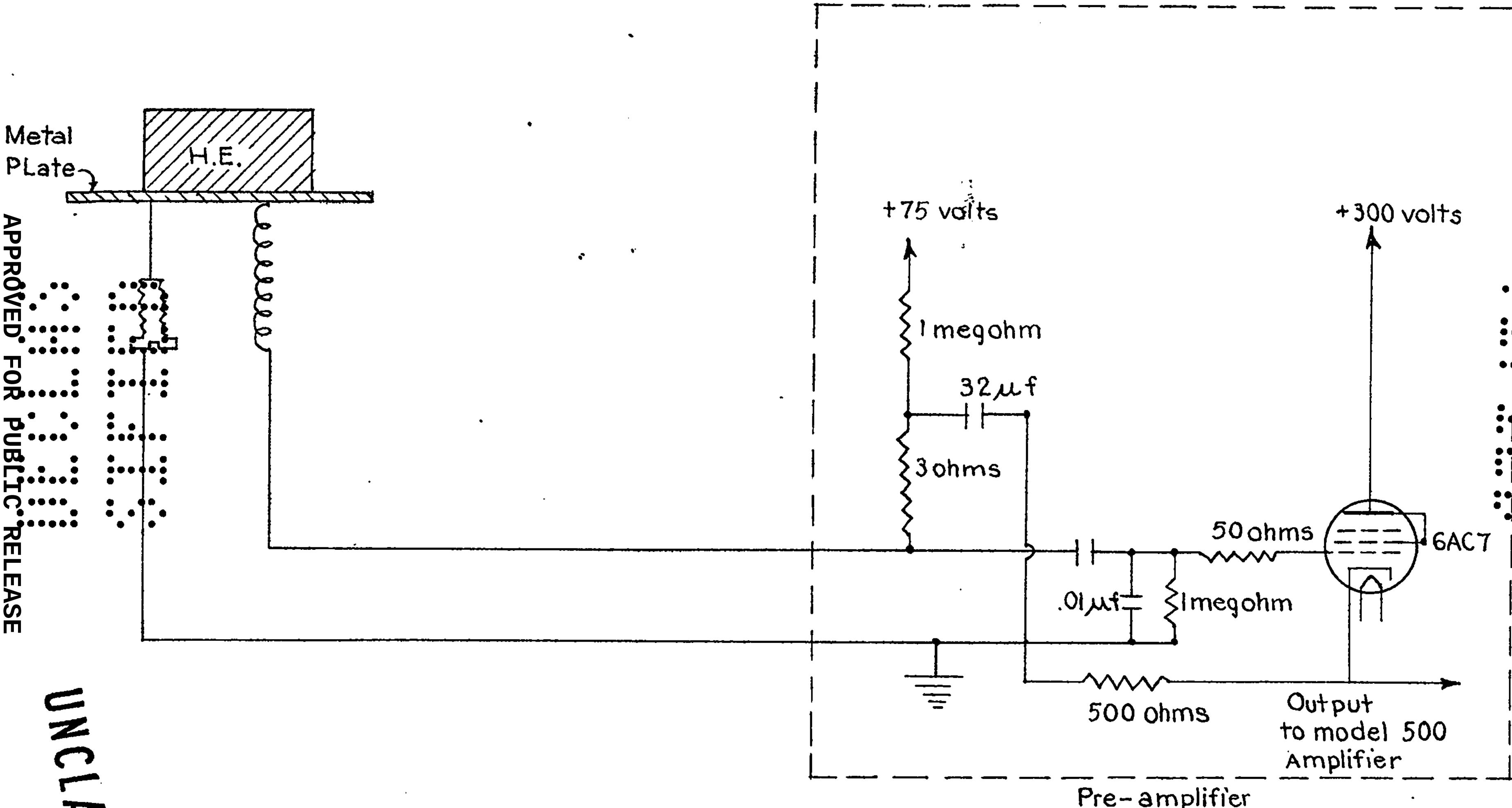
Metal
PLate
H.E.
+75 volts
1 megohm
32 μf
3 ohms
.01 μf
1 megohm
50 ohms
+300 volts
6AC7
500 ohms
Output
to model 500
Amplifier
Pre-amplifier

FIG. 1

...g and 2 1/2" diameter and copper plates about ... were used to develop this technique. The nichrome coils were made of 0.003" or 0.005" wire, wound to a pitch of about 1.5 mm, and a diameter of 2.4 mm. The length of the coils varied from 1 to 2 cm. At least two ground pins were used. The coils was placed as close as possible to the plate without making electrical contact. A 6AC7 was used as a cathode follower to drive the signal line between the firing pit and the amplifier in the control hut.

It will be observed that the helical coil and the point A (Fig. 1) from which the signal is fed through the 100 $\mu\mu f$ condenser into the cathode follower are originally at a potential of 75 volts. If A is shorted to the plate, a current starts flowing from the 32 μf condenser (consisting of a bank of Tobe-Filtermite condensers) through the 3 ohm resistor and the helix, and the potential of A changes to the IR drop across the helix. When the plate reaches the end of the helix the potential at A reaches that of ground.

A typical record obtained on the oscilloscope when the copper plate is driven into the nichrome helix is illustrated in Fig. 2.

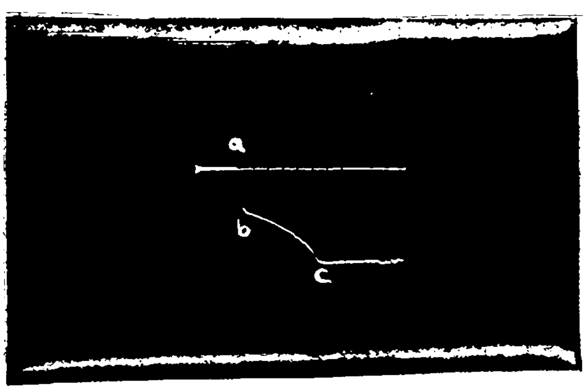

Fig. 2

The horizontal trace is a timing sweep put on the film before the shot is fired; the breaks in the line are 1 microsecond apart. The solid trace is the record of the shot

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itself. When point a is reached, the copper plate makes contact with the coil. The potential of point A (Fig. 1) suddenly drops from 75 volts to the I R drop across the coil. If R_o is the initial value of the resistance of the coil, the current $I_o = 75/(R_o + 3)$, and $V = I_oR_o = 75\,R_o/(R_o + 3)$. About 5 microseconds later, when point c is reached, A is at ground potential, since the plate has reached the end of the coil. The velocity of the plate must be obtained from the analysis of the record between b and c. If one knows the length of the helix, the time between b and c itself gives the average velocity.

To determine the time-distance curve, first determine the vertical distance of various points along bc from the base-line. The horizontal distance of each point from a gives the time.

Let V, I, and R be the instantaneous values of the voltage current, and resistance associated with the spiral at time t. Then

$$V = I\,R.$$

Since both I and R are changing with time

$$\frac{dV}{dt} = I\,\frac{dR}{dt} + R\,\frac{dI}{dt}$$

But $I = 75/(R + 3)$ (The voltage across the condensers is essentially constant during the time the plate is driven into the spiral).

$$\therefore\ I = -\frac{75}{(R + 3)^2}\,\frac{dR}{dt},$$

and

$$\frac{dV}{dt} = \left(\frac{75}{R+3} - \frac{75\,R}{(R+3)^2}\right)\frac{dR}{dt}$$

Let $R = R_o - \rho\,y$, where R_o is the initial value of R, ρ is the resistance per unit length of the solenoid, and y is the distance the plate has moved.

Also let $3 + R_o = R_1$. Then

$$\frac{dV}{dt} = 75\,\rho\left[\frac{R - R_1}{(R_1 - \rho\,y)^2}\right]\frac{dy}{dt}$$ [redacted]

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Integrating this equation gives the result

$$V - V_0 = 75\left(\frac{R_0 - R_1}{R_1} - \frac{R_0 - R_1}{R_1 - \rho y}\right),$$

where V_0 is the I R drop across the spiral at t = 0, or when y equals the initial length of the helix. Since V is proportional to the vertical displacement of the record from the base line, it can be determined from the record and from knowing V_0. Since everything on the right-hand side of the equation is constant except y, y can be calculated from this equation. A plot of y as a function of t gives the distance - time curve desired. Fig. 5 gives the distance - time curve obtained from the record shown in Fig. 2. On the same graph, data from one shot fired with the pin-contact method are included.

II. The Steady-Current Technique.

In order to reduce the possibility of inductive effects, to improve the chances of measuring the velocity at two or more separate points, and to simplify the analysis of the record obtained, a steady current technique was developed.

A typical shot set up and the pre-amplifier are shown in Fig. 3.

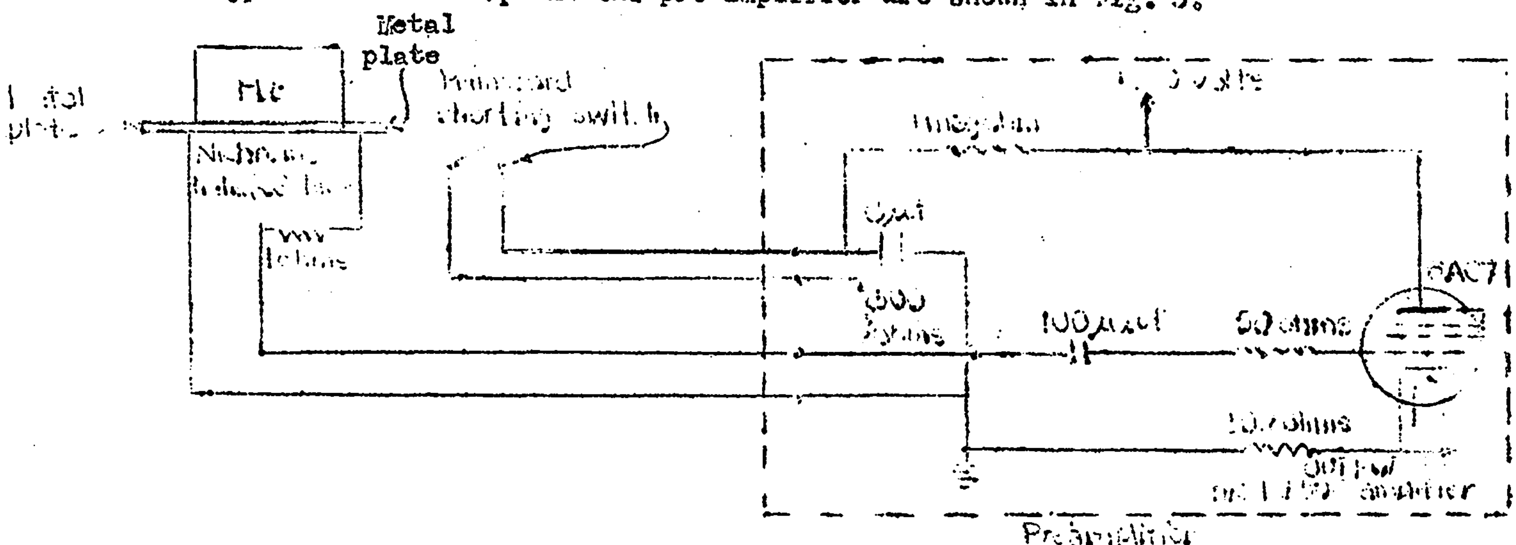

Fig. 3

The nichrome coil is initially in contact with the metal plate, so that point A, the variation in potential of which is to be measured, is at ground potential. About 20

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microseconds before the metal plate starts to move, the shorting switch is closed. This shorting switch consists of two brass tubes, one inside the other, separated by cellulos acetate. The brass tubes are put inside a steel tube. Inside the inner brass tube fits snugly a piece of primacord, which is arranged to detonate at one end of the switch about 20 microseconds before the metal plate starts to move. While the primacord detonates through the switch the inner and outer brass tubes are shorted together. This type of switch was developed by Leon Fisher.

As soon as the switch closes a current (about 0.6 amps) starts flowing through the nichrome coil. This raises the potential of point A to about 4.2 volts, giving a positive pulse which occurs before the beginning of the sweep.

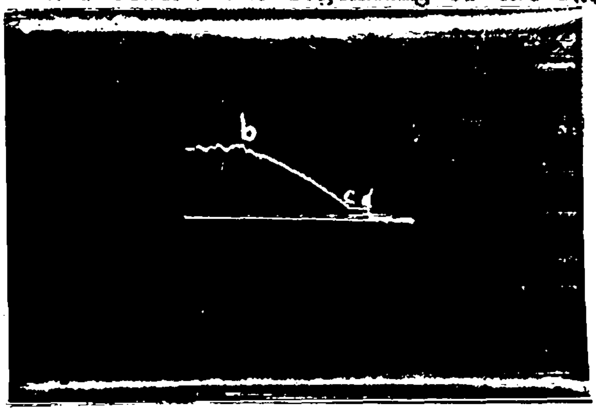

Fig. 4

The record remains parallel to the base line until the metal starts to move into the coil. This happens when point b is reached. There is often a sudden drop of a millimeter or so in the record, because the contact resistance is suddenly reduced. Then the record slopes down toward the base line until the end of the coil is reached. When the 1-ohm resistor is shortened out by the pin P in Fig. 3, the trace suddenly drops to the base line, since A is again at ground potential.

Since the resistance of the nichrome coil is small relative to that of the 500 ohms in series with it, the current is nearly constant during the time the metal moves into the coil. Therefore

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$$\frac{dV}{dt} = I \frac{dR}{dt} = I \rho \frac{dy}{dt}$$

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where ρ is the resistance per unit length of the coil, and $\frac{dy}{dt}$ is the velocity of the metal moving into the coil. Since both I and ρ are constants,

$$\frac{dy}{dt} = \frac{1}{I\rho}\,\frac{dV}{dt}$$

The distance the plate has moved is therefore given by

$$y_0 - y = -(V_0 - V)/I\rho$$

where y_0 is the initial length of the coil, and V_0 is the voltage across it when the contact resistance has been effectively dropped to zero. Since V is proportional to the height of the record above the base line, $y_0 - y$ can be readily calculated. A typical time-distance curve obtained from a record such as shown in Fig. 4 is plotted in Fig. 6. A curve obtained by using the same amount of explosive and the same type of metal plate using the pin-contact method is shown on the same graph.

It often seems to be the case that the shorting primacord switch did not close as early as it should. A peculiar delay as great as 20 microseconds has been observed. For this reason it was the practice to adjust the primacord lengths so that the detonation wave arrived at the switch at least 20 microseconds before the metal started to move into the coil.

The velocity of two different parts of a metal plate have been successfully measured in the same shot by putting two nichrome coils under it, and by using two separate electronic units but the same shorting switch. No interaction between the separate units was observed on the records.

III. <u>General Discussion of the Method</u>.

The steady-current technique should be superior to the variable-current technique for a number of reasons: (1) there are fewer variables, so that the record is both more reliable and easier to interpret; (2) the current surge is much smaller, so that there is much less chance of introducing inductive effects; (3) since the current through the coil is steady during the entire velocity record, the chance of interaction of separate units to measure simultaneously the velocity at different points on the

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metallic surface should be much less. The last two points were not experimentally verified, since no effects attributable to inductance could be detected in either technique, and no attempt was made to use two or more units simulatneously in the variable current technique. However, difficulties encountered in the use of shorting switches decreased the chance of getting a good record in the steady current case. If important applications are found for the method further research in the use of shorting switches for this purpose should be carried out.

Two attempts were made to measure velocities in 1/3-scale hemispherical implosions. Data were obtained in only one case, and some small oscillations appeared on this record. The velocity data agreed quite well with similar data obtained by the pin-contact method. In the second attempt, there was so much hash on the record that no information could be obtained. In both attempts the steady-current technique was used.

In all shots in which the electrical-resistance method was used, unshielded wires about six feet long connected the shot assembly to the preamplifier. The method would undoubtedly be better for large shots if the preamplifier were placed very close to the shot assembly and blown up each time.

Attempts to measure the velocity imparted to metallic plates were made by using straight nichrome wires placed parallel to the direction of motion of the plates. Peculiar results were observed. The shape of the oscilloscope record indicated an increase in the resistance of the wire during the first micro-second of the motion of the plate. This is undoubtedly caused by the mechanical and temperature effects resulting from the shock wave in the nichrome wire moving ahead of the metal. This makes it impossible to use a straight wire unless it is inclined at such an angle that the normal component of the shock velocity is less than the velocity of the metal, or unless the velocity of the metallic surface is greater than the shock velocity in nichrome.

A scheme to measure the temperature in a shock wave passing through a slab of canvass-base bakelite 3/8" thick was tested. A nickel wire, 0.002" in diameter, was placed against the bakelite on the side opposite the charge so that the shock wave would reach

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the whole length of the wire at nearly the same time. The nickel wire was connected into the steady-current-technique circuit in place of the nichrome coil. It was hoped that the resistance of the heated wire, and thus its temperature, could be recorded on the oscilloscope trace before the wire broke. Three good records were obtained, and these indicated that the wire was heated to a temperature of the order of 600°C before it broke, provided the effects of the mechanical deformation of the wire can be neglected. Pentolite cylinders of 2 1/2" diameter and 3" high were used. A technique based on these experiments might be worked out to measure both the temperature and the velocity simultaneously on the same shot to see if there is a correlation between them. The temperature should be a function of the pressure in the shock wave, so that if a correlation could be obtained between the variations of temperature and velocity, one might be able to conclude that large variations in the observed velocity are produced by irreproducability of the high explosives or to some other real cause rather than to errors in the measuring technique.

No doubt much valuable information could be obtained by the electrical resistance method. Additional development work should be done if it is believed that information can be obtained by it and not by other methods. Thus far no important information can be obtained by the electrical resistance method that can not be obtained by the electrical contact method. The indication of a metallic splash occuring as the metal drives into the helical coil, as revealed in photographs taken by W. Koski's group should also be farther investigated; the agood agreement obtained between pin-contact and resistance data indicate, however, that the nature of this splash is such that it probably produces no disturbing effects.

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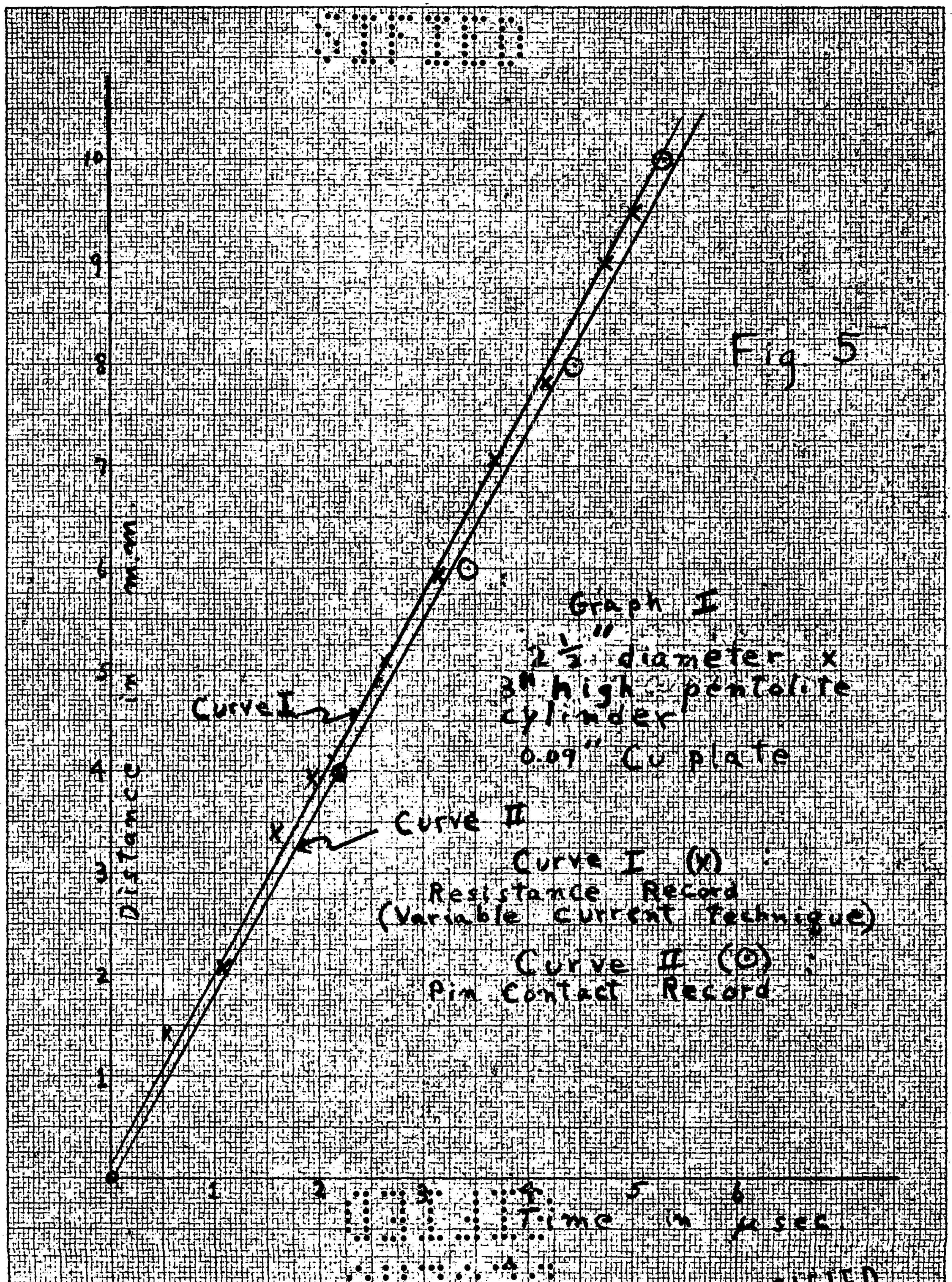
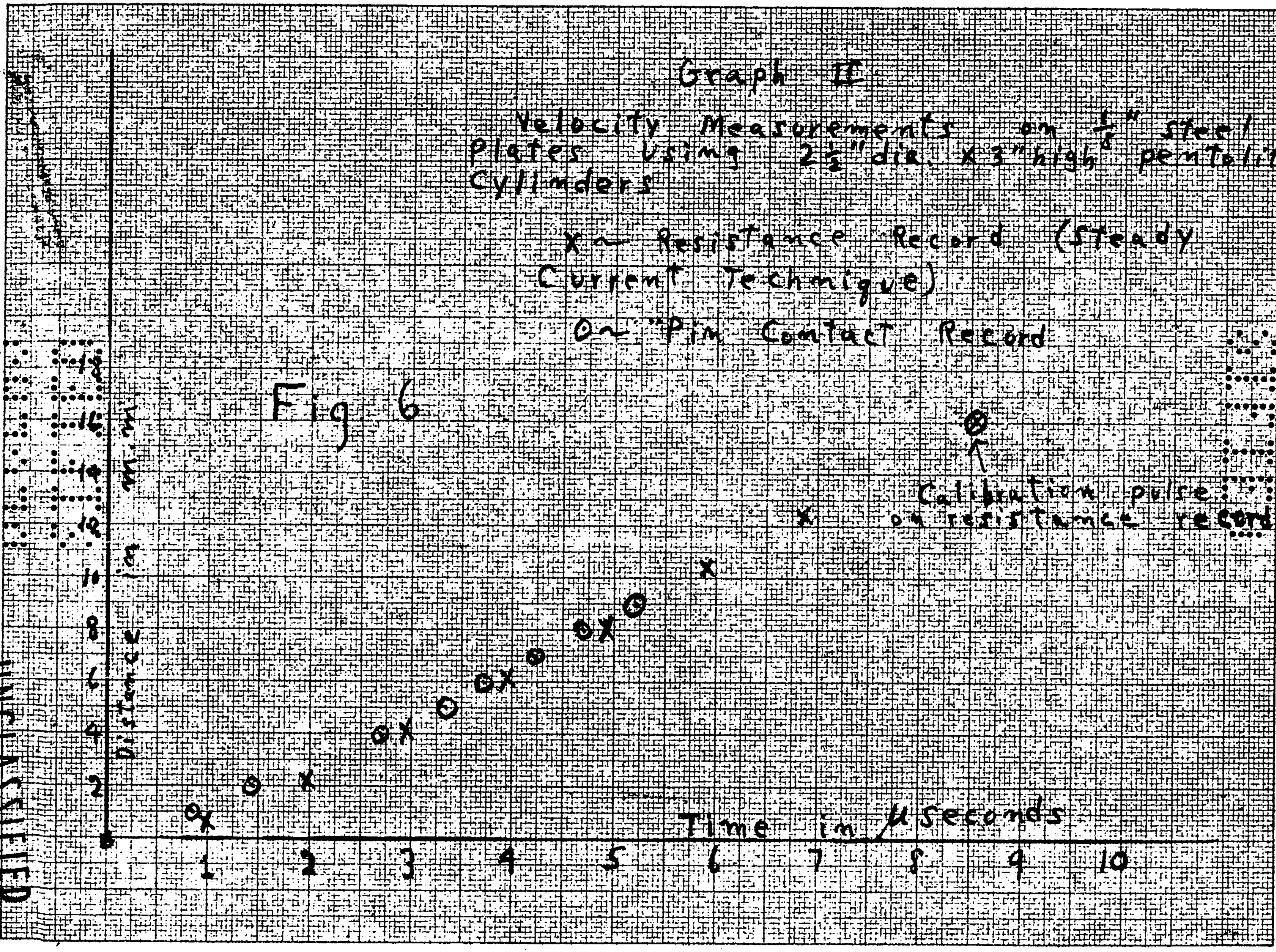


Fig 5
Graph I
2 1/2" diameter x
3" high pentolite
cylinder
0.09" Cu plate
Curve I
Curve II
Curve I (X)
Resistance Record
(Variable Current Technique)
Curve II (⊙)
Pin Contact Record
Distance m.m.
Time in μsec
1
2
3
4
5
6
7
8
9
10


Graph II
Velocity Measurements on 1/8" steel Plates Using 2½" dia. x 3" high pentolite Cylinders
x ~ Resistance Record (Steady Current Technique)
O ~ "Pin Contact" Record
Fig 6
Calibration pulse on resistance record
Distance in mm
Time in μseconds
1
2
3
4
5
6
7
8
9
10
2
4
6
8
10
12
14
16
18

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