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# DIELECTRIC PROPERTIES

# OF

# SOME COMMON HIGH EXPLOSIVES

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# DIELECTRIC PROPERTIES OF SOME COMMON HIGH EXPLOSIVES

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DIELECTRIC PROPERTIES OF SOME COMMON HIGH EXPLOSIVES

In connection with projects involving nuclear irradiation of explosives and studies of the feasibility of using dielectric heating for determining induction times and related experiments, it was required that various electrical properties of certain high explosives be known, such as resistivity, dielectric constant at both high and low frequencies, dissipation factor, and dielectric strength. Explosives to be measured included PBX, TNT, Composition B (Comp. B), Baratol, Octol, and PBX-9404 ~~(see Figure 8)~~.

Resistivity:

Resistivity measurements were performed and were of a fairly simple nature. Cylinders of each explosive were machined to a length of 3/4 inch and a diameter of 3/4 inch, and were placed in a desiccator (using silica gel as a desiccant) for several days, after being coated on both ends with conducting silver paint. The purpose of this coating was to insure that all parts of the surfaces of the cylinder ends would make intimate electrical contact with the electrode surfaces of a fixture designed to hold the cylinders. Resistance measurements were then made on a Terra-ohmmeter. Values of resistivity $\rho$ , as calculated from $\rho = \frac{AR}{d}$, are given in the following table, Figure 1:

Figure 1

| Material | Resistance, ohms | Resistivity, ohm-centimeters |
|---|---|---|
| PBX | $\infty$ | $\infty$ |
| TNT | $6 \times 10^{10}$ | $8.97 \times 10^{10}$ |
| Comp. B | $2.4 \times 10^{10}$ | $3.59 \times 10^{10}$ |
| Baratol | $1.2 \times 10^{11}$ | $1.79 \times 10^{11}$ |
| Octol | $2 \times 10^{10}$ | $2.99 \times 10^{10}$ |
| PBX-9404 | $2.8 \times 10^{10}$ | $4.19 \times 10^{10}$ |

These measurements were made at both 100 and 400 volts on the Terra-ohmmeter, and the samples appeared to have no significant voltage coefficient over this range.

Dielectric Constant:

The dielectric constant (k) can be determined by measuring the capacitance of a fixture having typically parallel plates with the dielectric material completely occupying the volume between the plates, then removing the dielectric and measuring the air-spaced plates' capacitance. The ratio of the capacitances thus measured is a good approximation of the dielectric constant.

Two methods were apparent for the measurement of these values. Most obvious was by the use of a capacitance bridge which may be driven by a wide range of frequencies. The other was by the measurement of time constants of the loaded vs. the unloaded fixture. The second method was chosen for the Comp. B measurements requiring long time constants.

The maximum time constant is limited by the dielectric itself in the isolated capacitor fixture, assuming no other leakage in the fixture. For parallel plates the capacitance $C = \frac{\epsilon_0 k A}{d}$ and the resistance $R = \frac{\rho d}{A} 10^2$, where $\rho$ = ohm-centimeters, all other quantities MKS units. It can be seen that RC is given by the expression $T = \epsilon_0 k \rho 10^2$ and that there are no optimum proportions that will produce a maximum time constant.

Wafers of the six types of explosive were machined to a thickness of .039", $\pm$ .0015" and to a diameter of 2.5" + .002". Aluminum alloy discs were machined to a diameter of 5" and a thickness of .5". These were ground and polished to a flatness exceeding that of the wafers. This fixture, Figure 2, was used for both time constant and capacitance bridge methods. Glass blocks are used for weighting the upper electrode for consistent spacing to the wafer's thickness.

The purpose of making the plates of four times the area of the wafers was to simplify calculations for fringe capacitance. With the dielectric wafer in place, the fixture can be considered as essentially two capacitors in parallel, e.g., the capacitance of the area covered by the explosive wafer comprising one, and the remaining plate area separated by air, plus the edge, or fringe capacitance plus interlead and fixture-to-ground capacitance comprising the other. With this arrangement, these parasitic capacitances are essentially constant in both the loaded and the unloaded fixture.

These plates were connected to the measuring equipment by means of two copper strips 3/8" wide and .010" thick for low inductance, 4" long for good separation of the upper plate from the grounded panels of measuring equipment, and placed edgewise and well-separated, for low interlead capacitance. Figure 3 shows the fixture in use with the bridge arrangement. The plates have been separated for illustrative purposes, and a PBX wafer is in place. Measurement of capacitance of the fixture with the explosive removed was made by separating the plates exactly .039" by means of sections of a PBX wafer .039" thick, of such small size that less than .1% capacitance change would have been caused.

When measured on a General Radio Model 716C capacitance bridge, the capacitance was found to be 122.2 picofarads, as compared with the calculated value of 112.0 picofarads, using the equation $C_{pf} = .0885\ k\ \frac{A_{cm^2}}{t_{cm}}$.
The difference is caused by stray capacitance, consisting of the fringe capacitance plus interlead and fixture-to-ground capacitance.

The expression for k as a function of C is obtained by considering the system as consisting of two capacitors in parallel, then the total capacitance, C is $C_1 + C_a$, where $C_1$ is capacitance from the explosive area, (i.e., .25A) and $C_a$ is that resulting from the remaining area, including stray capacitance. Therefore $C = \frac{\epsilon_0}{d}(.25Ak + A_a)$ and A is the physical plate area. The ratio of measured to calculated capacitance is 1.08 so that the effective area is $1.08A = .25A + A_a$. Using $A_a = f A$ yields f = .83 therefore

$$\frac{\epsilon_0 A}{d}(.25k + .83) = C$$

for d = .039" and A the area of a 5" circle with MKS units, 113.2 (.25k + .83) $= C_{pf}$.

For a plate separation of t the coefficient changes by the ratio of $\frac{.039}{t}$, t now in inches*. This gives $11.2\,\frac{(0.39)}{t}(.25k + .83) = C_{pf}$.

Solving for k,

$$k = .907\, C_{pf}{}^{t} - 3.322$$

Values for k were obtained by substituting measured values for $C_{pf}$ and t in the above equations.

By using the capacitance for air, the equation degenerates properly.

In making time constant measurements, an external load resistance of 26 megohms was arrived at by a method of successive approximations such that RC products were roughly equal to the quarter period of a 50-cycle signal. This is smaller than the $\epsilon_0 k \cdot \rho\, 10^2$ limit. The load is roughly one-tenth the internal resistance of a Comp. B wafer.

To avoid disturbing the system, it is important that the measuring instrument have an input impedance large compared to the 26 megohm load. A typical oscilloscope will not meet this requirement, even with a 10X probe. Therefore, a circuit possessing this characteristic is necessary, along with a low output impedance to drive an oscilloscope.

The Kiethley Model 210 Electrometer and DC Amplifier appeared to fill these requirements. Input impedance is $10^{14}$ ohms and the output impedance $4.3 \times 10^3$ ohms. No correction was made for non-linearity in the Kiethley instrument, e.g.,

$$\left(\frac{E_o}{E_i}\right)_{60\text{ V. in.}} = .93\left(\frac{E_o}{E_i}\right)_{30\text{ V. in.}}$$

Figure 4 shows an oscillogram taken on a Tektronix Model 513D oscilloscope, with .1 millisecond time markers located as a fiducial at the 37% point of the vertical scale. From this record it can be seen that the charged fixture (charged to 60 volts), air-separated to .039" reached the 37% point in .00345 second. Applying the equation $C_{mf} = \frac{T_{sec}}{R_{meg}}$ = 132.9 picofarads, approximately 8% higher than the value of $122.2_{pf}$ measured on the G. R. 716C bridge.

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* $\frac{.039-t}{.039} < .02$ in all these measurements

Repeating the test, with the fixture loaded with a Comp. B wafer .0405" thick, and calculated with the equations used for solving for k showed a dielectric constant of 4.014, for a discharge time of 5.3 milliseconds across 26 megohms. This approximates a period of 50 cycles, if one considers 5.3 milliseconds as equivalent to one quarter of the period of oscillation. Later tests with a 716C bridge driven by 50 cycles yielded a dielectric constant of 3.67. Further tests of the other materials gave values approximately 8% higher than those measured by the bridge method. This is what would be expected not correcting for the nonlinearity observed in the Kiethley instrument.

All other measurements for k were made on a General Radio Model 716C capacitance bridge, using a General Radio Model 1302A RC oscillator as a driving source for frequencies under one kilocycle, and a Hewlett Packard Model 650A Test Oscillator plus a Hewlett Packard Model 460A decade amplifier for the higher frequencies, for higher driving voltage and hence sharper nulls than the G, R. oscillator alone was capable of. The low frequency cut-off of the 460A amplifier is just below one kilocycle, or it could have been used at the lower frequencies also with the G. R. oscillator.

Figure 5 shows the capacitances, thicknesses and dissipation factors of the six explosives tested. All measurements were made at a room temperature of 75°F. and all wafers had been desiccated for several weeks. Figure 6 shows the dielectric constants computed from the values shown in Figure 5.

Dissipation Factor

Dissipation factors are shown also in Figure 5. The dissipation factor is defined as the ratio of the energy dissipation to the energy stored in the dielectric per cycle, or as the tangent of the loss angle. For dissipation factors less than 0.1, the dissipation factor may be considered equal to the power factor of the dielectric.

Dielectric Strength

Dielectric strength measurements were made with the same desiccated explosives as were used in the dielectric constant measurements. Aluminum electrodes were fabricated, 3/4" long and 3/4" in diameter, were polished, and the edges rounded to about 1/16" radius and mounted on Lucite plates. These were connected across a .1 microfarad 40 kilovolt capacitor which was charged through a 20 megohm resistor by a continuously variable 0-40 kilovolt power supply. The wafers were placed between these electrodes and voltage was applied at the rate of rise of one kilovolt per two seconds and the voltage noted at which breakdown occurred, as listed in the following table, Figure 7. Two or more tests were performed on each type of explosive.

Figure 5

DISSIPATION FACTOR AND CAPACITANCES vs FREQUENCY OF HIGH EXPLOSIVES

| Explosive and Sample Number | Thickness | 25 cps | | 50 cps | | 100 cps | | 1 kc | | 10 kc | | 100 kc | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | D | $C_{pf}$ | D | $C_{pf}$ | D | $C_{pf}$ | D | $C_{pf}$ | D | $C_{pf}$ | D | $C_{pf}$ |
| PBX-2 | .0385" | | | | | 0.000 | 167.4 | .00005 | 167.3 | .0001 | 167.3 | .0000 | 167.2 |
| TNT-1 | .040" | .5 | 270.2 | .204 | 254. | .16 | 234.0 | .062 | 195.6 | .036 | 177.2 | .015 | 170. |
| Baratol-3 | .0385" | | | | | .0042 | 200.0 | .0011 | 199.3 | .00065 | 198.6 | .0011 | 198.2 |
| Baratol-2 | .0380" | | | | | .005 | 199.2 | .0011 | 197.7 | .0003 | 197.4 | .0005 | 197.1 |
| Comp. B-2 | .0405" | .045 | 194.0 | .03 | 190.4 | .023 | 187.4 | .012 | 183.1 | .0042 | 181.7 | .0019 | 180.2 |
| Octol-2 | .040" | | | | | .006 | 177.6 | .002 | 176.2 | .0012 | 175.4 | .0012 | 174.6 |
| PBX 9404-1 | .0385" | | | | | .05 | 200.5 | .01 | 196.0 | .0037 | 194.6 | .0056 | 192.9 |
| PBX 9494-1 | .0395" | | | | | .041 | 197.2 | .0035 | 193.3 | .0027 | 191.7 | .0058 | 190.2 |

Figure 6

COMPUTED DIELECTRIC CONSTANTS OF HIGH EXPLOSIVES

| Explosive and Sample Number | Thickness | 25 c | 50 c | 100 c | 1 kc | 10 kc | 100 kc |
|---|---|---|---|---|---|---|---|
| PBX-2 | .0385" | | | k = 2.523 | 2.520 | 2.520 | 2.517 |
| TNT-1 | .040" | k = 6.481 | 5.893 | 5.167 | 3.774 | 3.107 | 2.849 |
| Baratol-1 | .0385" | | | k = 3.662 | 3.637 | 3.613 | 3.599 |
| Baratol-2 | .038" | | | k = 3.543 | 3.492 | 3.481 | 3.471 |
| Comp. B-2 | .0405" | k = 3.804 | 3.672 | 3.562 | 3.404 | 3.353 | 3.297 |
| Octol-2 | .040" | | | k = 3.121 | 3.070 | 3.042 | 3.013 |
| 9404-1 (PBX) | .0385" | | | k = 3.679 | 3.522 | 3.473 | 3.414 |
| 9404-3 (PBX) | .0395" | | | k = 3.742 | 3.603 | 3.545 | 3.492 |

Figure 7

Dielectric Strength of High Explosives

| Explosive | Sample No. | Thick-ness in. | Breakdown Voltage KV | Volts/ mill | Remarks |
|---|---|---|---|---|---|
| PBX-9404 | 1 | .0385" | 21 | 548 | Loud report; shattered |
| PBX-9404 | 3 | .0395" | 22 | 571 | Loud report; shattered |
| TNT | 1 | .040" | 4 | 100 | Shattered |
| TNT | 2 | .040" | 3.5 | 87.5 | Shattered |
| Baratol | 2 | .038" | 5.5 | 144.7 | Punctured and broke |
| Baratol | 2 | .038" | 5.5 | 144.7 | Other half of sample used |
| Comp. B | 2 | .0405" | 8 | 197.5 | Broke; used half for next test |
| Comp. B | 2 | .0405" | 4 | 98.8 | May have been cracked by first test |
| Comp. B | 3 | .125" | 22 | 176 | Undesiccated, punctured |
| Comp. B | 4 | .125" | 23.5 | 188 | Desiccated 2½ days; punctured; silicone grease bead on edges |
| Octol | 3 | .040" | 6 | 150 | Punctured and broke |
| Octol | 4 | .039" | 5 | 128.2 | " " " |
| PBX | 2 | .0385" | 29 | 753.2 | No puncture; may have arced around edge |
| PBX | 2 | .0385" | 35 | 909.1 | Punctured; edge rimmed with silicone grease |

Tests were performed on two different thicknesses of Comp. B, as it was felt that the wide differences (two-to-one) in breakdown voltages noted between the first test on a whole wafer and the second performed on a salvaged piece of this wafer, left some question as to the validity of these figures. As no more thin wafers were available, two discs 1½" in diameter and .125" thick were used. The first was tested immediately and the second after placing in a desiccator for two and one-half days.

Breakdown in the second thick wafer test occurred at a voltage almost proportional to the thickness of the two wafers being compared. This was not as expected, as dielectric strength varies inversely with the square root of thickness, approximately. A possible explanation lies in the fact that when viewing the thinner wafer against strong light, there appeared to be areas of lesser density almost comparable to the thickness of the wafer, whereas similar areas of lesser density in the thicker wafers were unlikely to be found aligned with each other. All of the other explosives except octol appeared to be much more homogeneous, hence might be expected to more closely follow the dielectric strength vs. square root dependence.

Although the probability of detonation is small with these dimensions, these tests were conducted behind a barricade.

The explosives tested were characteristic of those normally supplied and were in accordance with the following specifications, Figure 8:

Figure 8

Specifications for Explosives

| Explosives | Specification No. | Fabrication Method | Composition |
|---|---|---|---|
| PBX | PA-PD-711 | Pressed | 91/8.5/1.5 RDX/dioctylphthalate/ polystyrene |
| TNT | JAN-T-248 | Cast | 100/TNT |
| Comp. B | MIL-E-401B | Cast | 59.5/39.5/1-RDX/TNT/ wax |
| Baratol | None | Cast | ~76/ ~24/.06/.1 barium nitrate/TNT/ stearoxyacetic acid/ cellulose nitrate |
| Octol | X-PA-PD-896 | Cast | 75/25 - HMX/TNT |
| PBX-9404 | Mil-P-45446 (Ord) | Pressed | Classified |

It would be expected that small deviations in these mixtures could cause some small changes in observed dielectric measurements.

These explosives were chosen because of their common use and easy availability, and because they were believed to be of interest in the explosives research field. The methods described may be applied not only to other explosives of low conductivity, but to other dielectric materials as well.

A literature search has indicated that little work of this nature has been done in evaluating explosives; it is therefore recommended that any future compilations of the properties of explosives include electrical as well as physical characteristics. Further, these electrical measurements can be seen as supplementary criteria for evaluating the purity, homogeneity and reproducibility of batches of explosives and, with the exception of the dielectric strength determination, as possible tests in a non-destructive testing program. Fundamental studies in the explosive field require a knowledge of intrinsic explosive properties. It is hoped that the measurements described herein will be useful to other investigators.

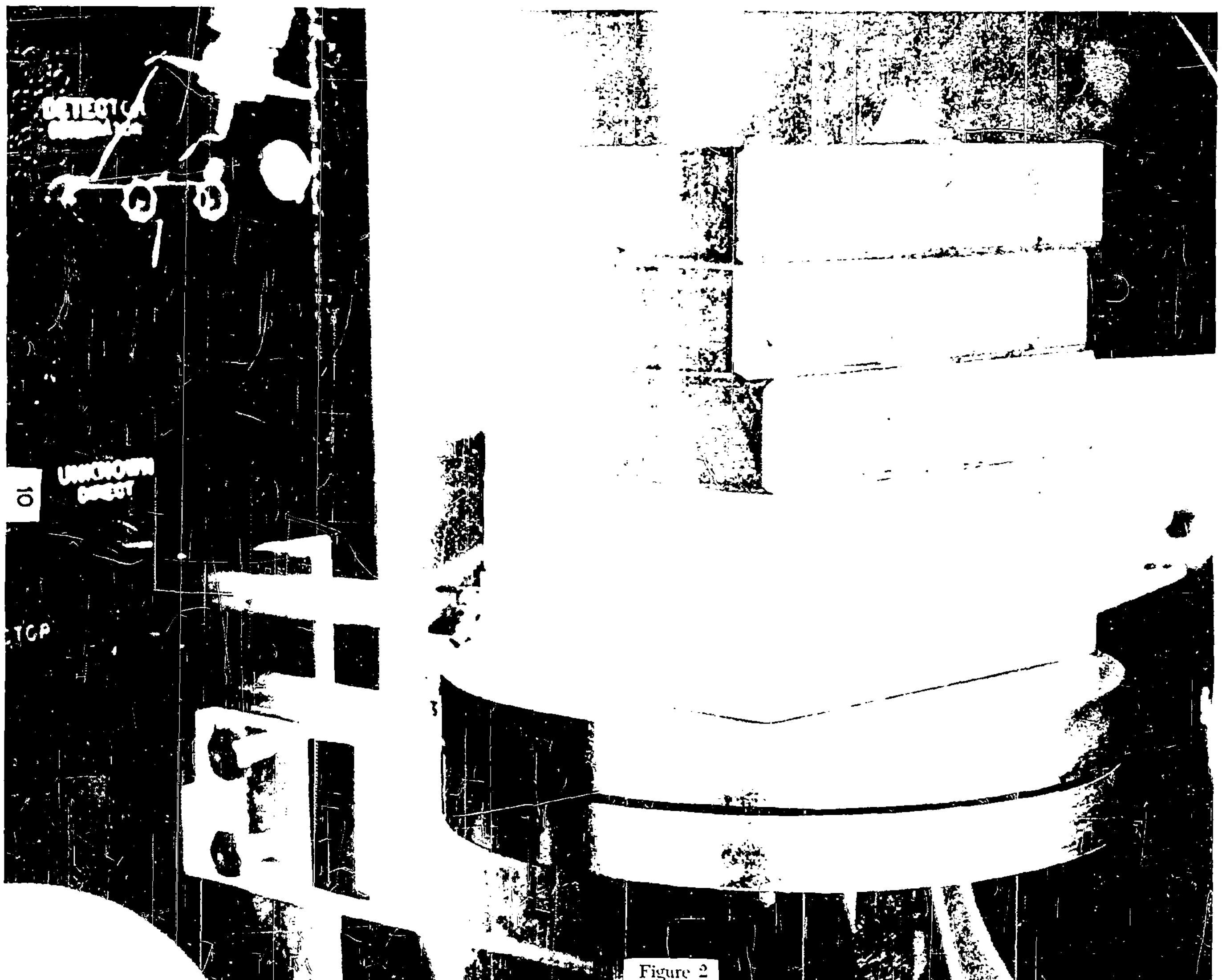


Figure 2

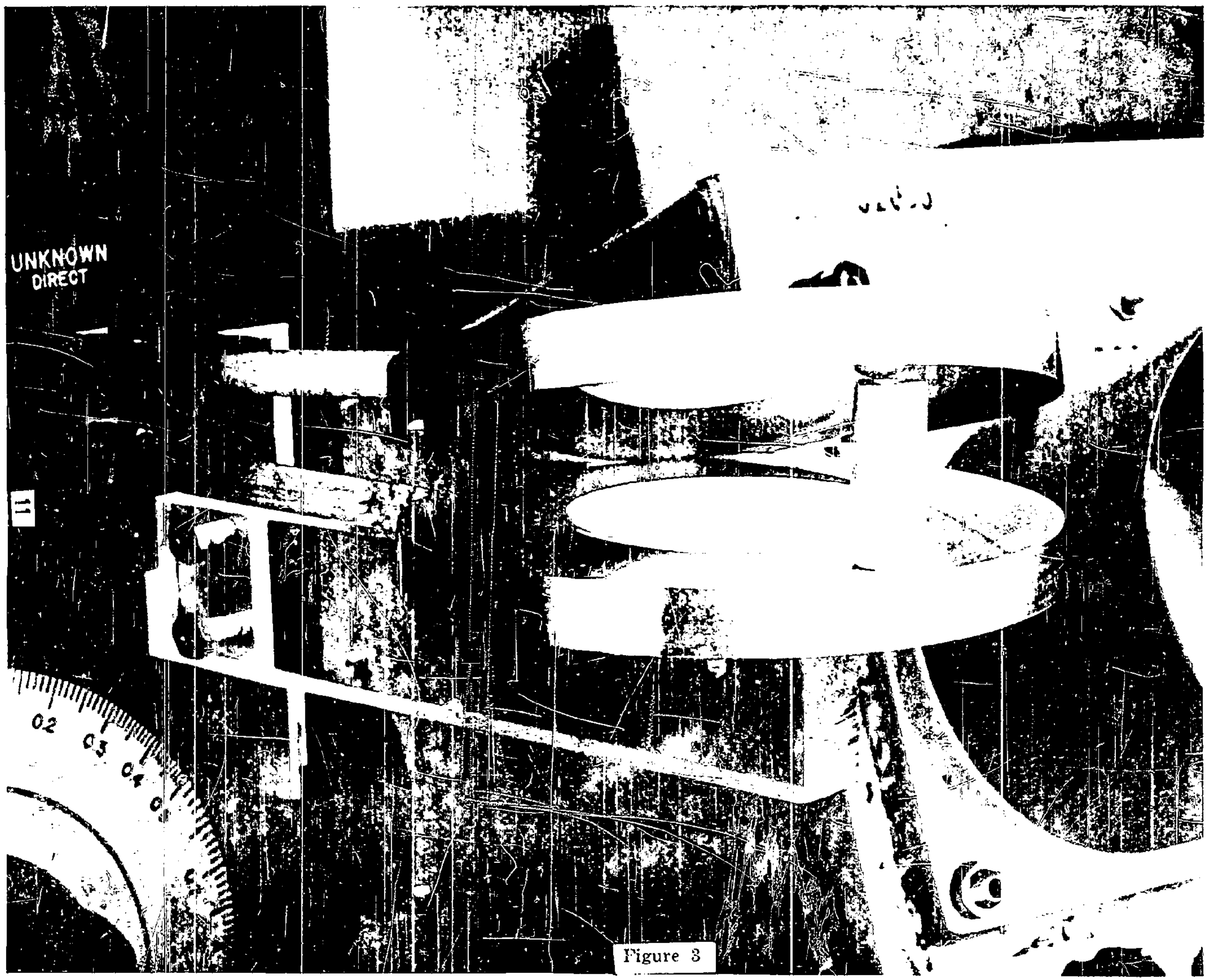


Figure 3

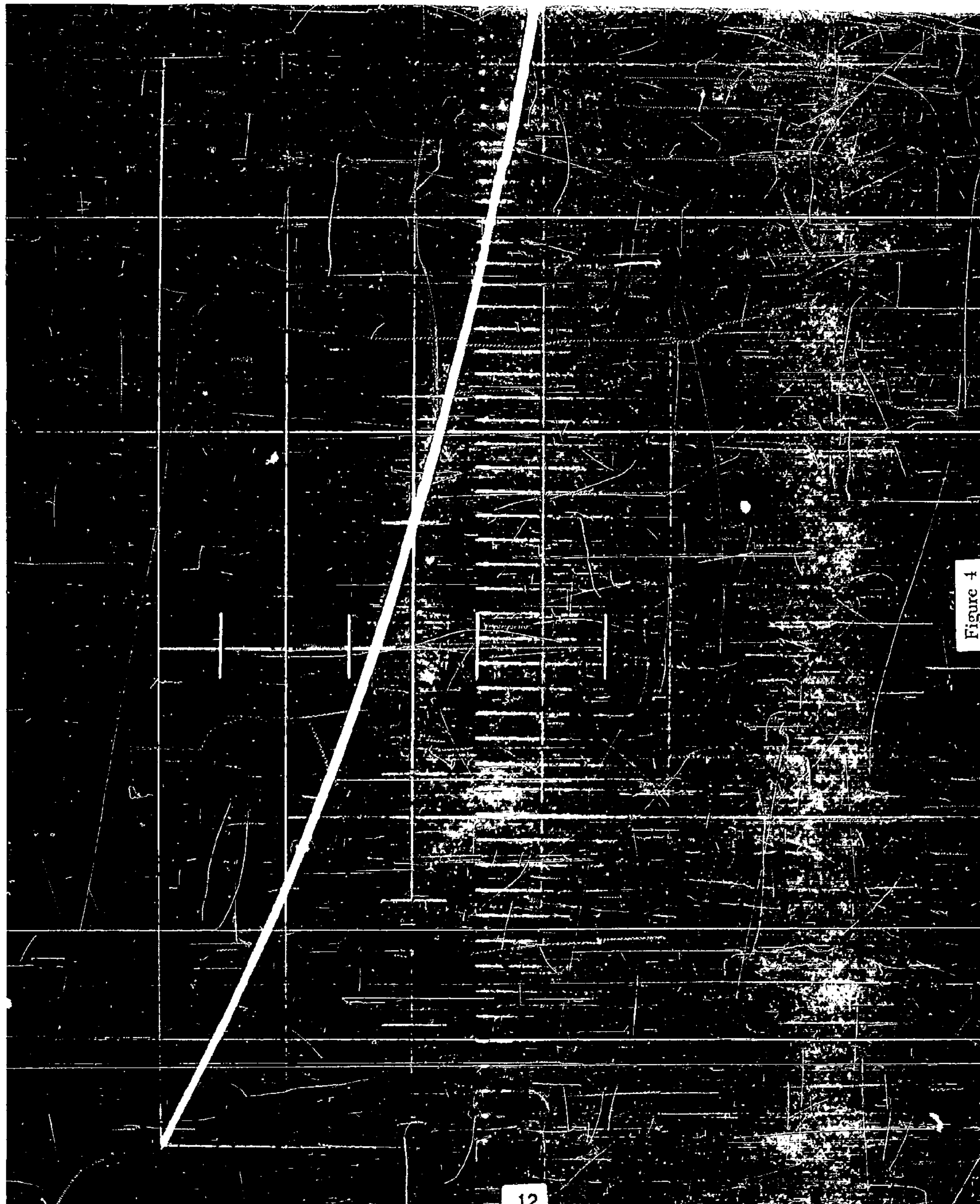

Figure 4

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