# THESIS

AN INVESTIGATION OF
CONTACTS AND CONTACT
ENDURANCE

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# AN INVESTIGATION OF
# CONTACTS AND CONTACT ENDURANCE

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# CONTACTS AND CONTACT ENDURANCE

Connections are established in automatic telephony by means of the contacts on springs actuated by the armatures of relays and magnets. The contacts are either riveted or welded to springs of various materials and gauges and are then aligned in proper position on the spring assembly. Their position depends on the circuit duty, causing certain springs with their associated contacts to make or break when the relay is energized.

The duty to which any contact is subjected depends on its position in the circuit, that is, the operation of opening or closing the circuit may occur once in the establishment of a through connection as in the case of the ring cut off relay, or a number of times as in the case of the pulsing relay which responds to the impulses sent by the calling device at the subscriber's station. Again, the number of operations may be indefinite as given in the case of the rotary line switch which operates until it finds an idle trunk.

In order to insure definite electrical connection with the back or break contact, the armature springs are given a certain tension when in the normal or non-operate position of the relay. In every case the power of the relay when energized is more than sufficient to cause proper electrical contact of the armature spring contact with the front or make spring contact. These tensions are determined by the operating conditions togehter with the design and winding characteristics of the relay.

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Contact Materials:

Experiments over a large number of years have gradually reduced the kinds of material suitable for contacts in automatic telephony to three alloys of approximately the following compositions:

| | |
|---|---|
| Metal A | Platinum with less than 2% Iridium |
| Metal B | Silver 90%, Gold 10% |
| Metal C | Gold 70%, Silver 25%, Platinum 5% |

These metals will be referred to later as platinum, silver and gold, respectively.

The physical and chemical characteristics such as density, melting point, heat conductivity, hardness, mechanical wear, chemical corrosion and resistance to spark erosion largely determine the durability of a contact. Some of these characteristics in the case of the pure metals entering into contact materials are given below in Table 1.

Table 1.

| Material | Density | Melting Point | Resistance | Heat Conductivity. |
|---|---|---|---|---|
| Platinum | 21.37 | 1755 | 10.96 Microhms per cm3 | 0.173 |
| Gold | 19.1 | 1063 | 2.22 | 0.705 |
| Silver | 10.6 | 961 | 1.47 | 1.006 |
| Tungsten | 19.3 | 3200 | 6.2 | 0.476 |
| Nickel | 6.9 | 1452 | 6.93 | 0.142 |
| Copper | 8.89 | 1083 | 1.77 | 0.91 |

It may be noted that platinum has the highest melting point, the greatest specific resistance and a relatively low heat conductivity. Silver on the other hand has a low melting

point, a low specific resistance and a very high heat conductivity. Gold has characteristics between those of platinum and silver.

Mechanical Construction of Contacts:

Contact material is usually obtained in the form of wire of #14 and #18 B & S gauge. Figs. 1 and 2 illustrate the size of this material formed into rivets and the corresponding welded contacts. Riveted contacts are placed in a perforation of the contact spring and consequently insure a rigid mechanical structure. Contacts welded by automatic machines insure an equally good mechanical structure, but because of the reduced area of contact surface between the contact and the spring it would appear that the electrical and heat conductivity of the contact might be reduced from that obtained with riveted contacts.

Generally, large or #14 gauge contacts are attached to springs of heavy gauge and consequently are more readily riveted than welded. Fig. 2 shows such a large contact riveted in a heavy gauge spring.

Electrical Resistance of Junction between Contact and Spring:

Measurements made by the drop of potential method give resistances on the order of 45 to 150 microhms for the junction resistance between 18 gauge silver welded contacts and standard pulsing relay armature springs. These measurements were made according to the outline given in Fig.3. The resistance of the standard pulsing relay armature spring from terminal to contact is on the order of 5000 microhms.

Because the resistance between the contact and its

spring is so extremely small, in fact approximately on the same order as the spring material, this is not a point of increased resistance in the circuit; however, there may be a gain in thermal and electrical conductivity by riveting compared to welding, but this is difficult to determine.

Electrical Resistance between Contacts:

The electrical resistance between the point of contact where two different contact metals were used was measured by an accurate Wheastone Bridge. The contacts were assembled with their springs in the relay structure and the pressure was gradually increased and readings taken at various pressures. The results are shown graphically in Fig. 4. After arcing had occurred at the contacts by operation in the standard circuit the resistance was again determined in the case of the #14 gauge platinum contact and was found to be slightly lower for the greater pressures than when the contacts were new, although the difference is not very great. After these contacts were cleaned with a sand blasted steel contact file the resistances as shown in Fig. 5 increased materially and the results were somewhat erratic, caused probably by the irregular surfaces in contact.

The Problem Stated:

A number of years ago it was noted that certain relay contacts, particularly those of the pulsing or line relay showed signs of forming a crater on the negative or back contact with a corresponding building up on the positive or armature contact, resulting in sticking contacts as well as decreased life of operation (Fig.6). An investigation was started to determine the nature of this phenomenon and the results obtained to date are given below.

Possibility of Reverse Current:

Since in a carbon arc a crater forms on the positive electrode, and a corresponding point on the negative, it was supposed that a reversal of current, as a condenser discharge, might be responsible for this action. To test this theory an oscillogram was made of the current flow through the contacts, and through the condenser circuit of a standard connector as shown in Fig. 7. The oscillogram O-51 shows that the condenser charges and discharges a number of times at the beginning of the pulse, and once at the end, but in no case is the current reversed through the contacts. From study of the circuit, as will be shown later, it is apparent that the condenser can charge only through the relay and can discharge only through the back and armature contacts in a direction the same as the relay supply current. At no time does a tendency exist for any current to flow contrary to the direction of the relay supply current.

Metal Arc different from Carbon Arc:

To determine the formation of the crater in a metallic arc instead of carbon, two copper electrodes 1/4" diam. were used. With a current of 2 amperes the crater formed on the negative. The positive electrode operated at a higher temperature than the negative, resulting in a small globule of molten copper and copper oxide being formed. Because of surface tension, the globule assumed a spherical form causing the negative electrode to assume a crater since the arc always played between this spherical globule and the shortest point to the negative electrode.

TABLE 2.

| Electrode Negative | Combination Positive | Diam.of Electrodes | I Amps. | Duration of Arc | Cond.of Neg. | Cond.of Pos. | Remarks |
|---|---|---|---|---|---|---|---|
| Copper | Carbon | 0.25" | 1.5 | 30 min. | Crater | Pointed | Carbon consumed more rapidly than copper. |
| Carbon | Copper | 0.25" | 1.5 | 30 min. | Crater | Bead | Carbon electrode hotter than copper. |
| Copper | Copper | 0.125" | 2.0 | 50 min. | Crater | Bead | Negative consumed faster |
| Carbon | Copper | 0.25" | 3.0 | 30 min. | Crater | Bead | Carbon consumed faster than copper. |
| Carbon | Carbon | 0.25" | 3.0 | 30 min. | Pointed | Crater | Positive is hotter |
| Copper | Copper | 0.3125" | 2.0 | 2 Hr. 35 min. | Crater | Bead | Molten copper of positive formed into beads and dropped off. Crater formed by short arc deeper than that formed by a longer arc. |
| Copper | Copper | 0.125" | 2.0 | 4 hours | Crater | Bead | Electrodes graduated in centimeter divisions. After test noted that negative was shortened by 50% more than positive electrode. |
| Copper | Copper | 0.125" | 2.0 | 4 hours | Crater | Bead | Negative lost 8% in weight. Positive electrode with beads of copper and copper oxide that dropped from it, increased weight 3%. This leaves 5% of weight lost on neg. electrode as amount lost in vaporization. |
| Copper | Copper | 0.3125" | 2.5 | 6.5 hours | Approx. flat | Approx. flat | Positive electrode kept cool by a stream of cold water flowing thru electrode from point 5 mm away from arcing surface to other end of electrode. |

NOTE: All arcs took place in open air at a room temperature of $25^{\circ}$ centigrade. Voltage across arc varied from 28 to 50 volts with line voltage of 110 volts.

When the electrodes were kept at room temperature except for the actual point of the arc, by running cold water in at one end of the electrode and out near the point of arc, the two electrode surfaces remained parallel except for slight irregularities.

This indicated that the electrodes could burn without forming a noticeable crater when the electrodes were kept cool or if the thermal conductivity was relatively large. Tests made on smaller electrodes showed that the formation of the negative crater increased rapidly as the diameter of the electrodes was decreased. The significance of these tests and their verification with contacts are again referred to later.

In every case metal was transferred from the negative to the positive electrode. Beads of copper and copper oxide formed and dropped from the positive electrode from time to time during operation. Table 2 gives the results of material transference when metallic electrodes are used, together with the physical forms of the electrodes after an arc has been maintained.

These tests on metallic arcs gave indication that thermal conductivity and size of the electrodes may affect the formation of the crater.

<u>Pulsing through Resistances as Load:</u>

From the tests on metallic arcs it was but a step to equip a number of pulsing relays with #18 gauge platinum contacts and then let these contacts intermittently pass a current through a non-inductive resistance of low value to hasten the contact deterioration. After impulsing through 8.15Ω for 15000 times the positive contacts developed a long point and the negative con-

tacts a very deep crater (Springs 15,16,18,19). These contacts are almost identical with those obtained in practice which show a negative crater (Springs 25,26,34,35). The substitution of larger back contacts, that is #14 gauge platinum yielded a much less pronounced crater on the negative and a complete absence of black deposit around both contacts.

Spark Quenching:

The usual form of spark quencher consists of a condenser in series with a non-inductive resistance. This combination may be connected either across the contacts as shown in Fig. 8, or across the coil as shown in Fig. 9. On opening the circuit, the condenser absorbs the energy of the magnetic field about the coil which would manifest itself as a spark at the contacts without a condenser. The resistance in series with the condenser limits the momentary rush of discharge current of the condenser at the moment of make.

In either case the condenser charges in such a direction that the discharge across the contacts, if these be opened and closed with but a small intervening time interval, is in the same direction as the battery current. From Fig. 10, which gives the theoretical solution of the discharge of a condenser, it is seen that the current at the moment of make may be varied over a considerable range. The ideal case would be the one where the resistance in series with the condenser is very large at the moment of make, in order to let it discharge very slowly and at a low current value so as to prevent arcing and possibly welding at the contacts. On the other hand the same condenser should have no resistance in series at the moment of break in order that the condenser may act as an energy absorber as efficiently as possible.

In practice, a resistance is usually chosen so as to offer a satisfactory mean between these two extremes. From the curve, Fig. 10, it will be noted that a ten ohm resistance will allow the discharge current to reach a maximum value of 5 amperes, but this current persists for only an infinitesimally small time; in fact after less than 4/10000 of a second this current has been reduced practically to zero. In the case of a 100 ohm resistance with a 0.5 mfd. condenser the discharge current reaches a maximum value of 0.5 amperes and then reduces gradually to zero after 2/1000 of a second. When a 250 ohm resistance is used with a 2.0 mfd. condenser the discharge current reaches a value of 0.2 amperes which reduces to zero very slowly in comparison to the previous cases as may be seen by reference to the figure. A ten ohm resistance, therefore, because of the short duration of the discharge current ought not to cause undue erosion of the contacts. This point will be mentioned again later where it will be shown that the contact trouble previously referred to may be eliminated without changing the value of resistance which unless noted otherwise remained at ten ohms during all succeeding tests.

The action of the condenser in series with the resistance (Fig. 8) when placed across the contacts is somewhat different than when the combination is connected across the coil. In the first case the condenser, while in a discharged condition, acts as a shunt circuit to the contacts at the moment of break. At that instant the resistance of the circuit is only that offered by the series resistance. As the condenser charges the counter electro motive force increases, and that to all intents and purposes is the same as adding resistance. If the contacts are completely

separated before this apparent resistance of the condenser reaches an appreciable value, the condenser prevents arcing at the contacts. For a definite rate of break such as that of a relay, a minimum value of capacitance exists which will offer such a low apparent resistance during the separation of the contacts. A larger condenser may be used, but in that case the series resistance must be increased in order that the discharge current on make will be held within reasonable bounds. A 0.5 mfd. condenser was used as a spark quencher in all subsequent tests, since this value of condenser has apparently enough capacity to act as a sufficiently low resistance shunt across the contacts until these are completely separated to prevent arcing.

The action of the condenser across the coil, Fig. 9, may be analyzed in a different manner since in this case the capacitative reactance should be equal and opposite to the inductive reactance of the coil at that particular speed of current interruption. If the condenser breaks down, the battery is short circuited during operation and therefore this adaptation of the condenser and series resistance has not found application and will not be further considered.

Relay Chattering:

From the oscillogram O-51 and similar ones O-52 and O-53, it was noted that the relay armature chattered when de-energized, that is, the armature did not come to rest gradually on return, but caused the relay contacts to open and close several times. An oscillogram was made of the currents as in the previous O-51, but in addition a mirror was mounted on the residual screw of the armature of the relay. The results obtained as shown on O-83 indicate that the armature rebounds at least two times

between the armature stop and the armature spring, causing the current to be interrupted and resulting in sparking at the contacts.

The movement of the relay armature may also be checked visually by the aid of successive sparks from an induction coil. When the sparks occur separated by a time interval of slightly more than the interval of a cycle of operation of the relay, the operation of the relay appears to pass through its cycle of operation at a greatly reduced speed.

Since the rebound of the armature occurs between the armature stop and the armature spring oscillograms were made to determine the effect of increasing or diminishing this gap. In O-80 comparison is made between armature chattering with the armature stop in the normal position, and when entirely removed. There is no doubt that the armature stop is not the only contributing cause to the rebound. Subsequent investigations led to the belief that the residual magnetism of the relay core acted as a restraining force and rebound is established by means of this and the periodicity of the spring. Apparently the clearance of the armature stop does not affect the rebound. A check test shown in O-81 where the clearances on the same relay were 0.003" 0.010" and entirely removed verifies these conclusions.

<u>Elimination of Relay Chattering:</u>

From the above tests it became apparent that some means for holding the armature against the armature stop on release would eliminate the chattering and the resulting sparking at the contacts. Accordingly, tests were made with a "C" type spring acting from a point under the residual screw and terminating under a screw on the heel piece. With the proper adjustment of the

armature spring which now was influenced by the tension in the "C" spring, the arcing was materially reduced at the contacts. An oscillogram O-12 shows the effect in the vertical magnet circuit with and without the "C" or damper spring.

Numerous damper springs were made as for example one which lies against the armature spring as shown in Fig. 11, and others where the force is applied to the armature arm as shown in Figs. 12 and 13. One of the latter where the spring acts against the arm near the bushing has been found to be very satisfactory with regard to spark elimination. The adjustment for any such damper spring in order to be effective may vary between 10 and 20 grams back pressure, measured on the armature just back of the armature stop and just as the armature leaves the stop.

When two 18 gauge welded platinum contacts are operated on the armature and back springs of the pulsing relay of a standard connector the result as mentioned above consists of a deep crater on the negative or back spring and a corresponding building up of material on the positive or armature spring. A check test made at this point on a standard connector resulted in the verification of the above and is shown by the spring contacts 31 and 32. These contacts operated for 1,515,140 impulses after which time the switch became inoperative due to the contacts sticking.

The same connector on the identical impulsing circuit was then equipped with a similar pair of contacts, but the damper spring last mentioned was added to prevent chattering of the relay. Sparking at the contacts was practically eliminated and the switch operated 765,520 impulses with the contacts bright and clean with a slight indication of a crater in the positive. The wear on the contacts was insignificant (Springs 27 and 28; see also Fig.

armature spring which now was influenced by the tension in the "C" spring, the arcing was materially reduced at the contacts. An oscillogram O-82 shows the effect in the vertical magnet circuit with and without the "C" or damper spring.

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14). Because of the appearance of the indication of a slight positive crater a check test was made on the same connector, the contacts of which after 788,960 impulses yielded similar results (Springs 29 and 30).

These tests together with similar ones prove conclusively that the pitting of the negative platinum welded contact and the building up on the corresponding positive contact can be eliminated by the use of this damper spring resulting in a longer life for the contacts and freedom from contact troubles.

Effect of Larger Contacts - Thermal Conductivity:

From the experiments on the thermal conductivity of the metal arcs mentioned above and the fact that reduced sparking resulted from a non-chattering relay, it appeared that the 18 gauge platinum contacts were perhaps too small to carry the heat away quickly between impulses or groups of impulses.

Springs were made with large contacts of platinum, gold and silver and assembled in the standard connector. The results of these tests are given in Table 3. Of the various combinations tried, #18 gauge welded platinum as a positive on the armature spring when mated with #14 gauge riveted silver contact as a negative on the back spring formed a combination which after impulsing over three million times showed a pair of contacts perfectly flat with but little wear; bright and entirely free from any black deposit around the contacts (Springs 43 and 44).

These tests which were made without damper springs indicate that even though a relay chatters and causes additional arcs, this arcing does not cause the contacts to wear away, nor the pitting action to occur provided the negative contact be made sufficiently large. These results have been borne out in

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These tests which were made without damper springs indicate that even though a relay chatters and causes additional arcs, this arcing does not cause the contacts to wear away, nor the pitting action to occur provided the negative contact be made sufficiently large. These results have been borne out in practice over a number of years.

Tests were made with a relay equipped with such contacts and a damper spring in addition, and after operation for several days with no noticeable sparking, the contacts were examined and they showed absolutely no deterioration nor burning at the points. All the above tests were made on the circuit as given in Fig. 7, and with a spark quencher consisting of a 0.5 mfd. condenser with 10ω non-inductive resistance in series. It, therefore, appears that a pulsing relay when equipped with a #18 gauge platinum contact on the armature spring and a #14 gauge silver contact on the back spring and having in addition a properly tensioned damper spring will perform with only occasional sparking and with a resulting long life.

Check Tests. Results with various Contact Metals:

Using the impulsing device Fig. 15 and various contact metals and combinations on a standard connector Fig. 7 results were obtained which agree with the previous results obtained in the general way of contact performance. The back contact was large and riveted in every case while the armature contact was a #18 gauge platinum welded contact. No damper spring was used. The contacts were pulsed between two and a half and three and a half million times in each case. Tabulated data is given in Table 3.

TABLE 3.

| Spring No. | Contact | Pulses | Condition of Contact |
|---|---|---|---|
| (39 + | Pt. 18 ga. W | 2582500 | Very slightly pitted |
| (40 - | Ag. 14 ga. R | 2582500 | Flat, Edges rise slightly |
| (41 + | Pt.18 ga. W | 2636600 | Flat |
| (42 - | Ag.14 ga. R | 2636600 | Flat |

| | | | |
|---|---|---|---|
| (43+ | Pt. 18 ga. W. | 3028540 | Flat, Slightly irregular |
| (44 - | Ag. 14 ga. R | 3028540 | Flat, Slightly irregular |
| (45+ | Pt. 18 ga. W. | 3000060 | Flat |
| (46 - | Ag. 14 ga. R | 3000060 | Flat |
| (47+ | Pt. 18 ga. W | 2896960 | Flat, Black deposit |
| (48 - | Au.. 14 ga. R | 2896960 | Flat, Black deposit |
| (49 + | Pt. 18 ga. W | 2887800 | Flat, Black deposit |
| (50 - | Au. 14 ga. R | 2887800 | Flat, Black deposit |

The material lost on the positive springs 39 to 45 was slightly less than the amount lost with springs 47 and 49.

Test on Self-Interrupting Rotary Lineswitches:

Metal arcs at contacts and the resulting formation of negative craters, particularly those as shown in the previous Fig. 6, may depend on still other contributing causes than those outlined above. Concurrent with the above tests data was obtained on the performance of various combinations of the three contact metals, both riveted and welded, when operated in the lineswitch circuit Fig. 16.

Condenser charge and discharge oscillograms for one switch are given in the oscillogram O-174 to O-177 for one, one and two, one to four and one to six switches operating simultaneously off the same current supply. An interaction is indicated. Just as a number of these switches may operate simultaneously in practice so were a number of switches never less than six operated in obtaining the data listed in Table 4. It is very difficult to describe the condition of the contacts, and conclusion and comparisons can only be made by reference to the original samples.

Micro-photographs of some of these test specimens are attached. The relation of electrolytic action, thermal conductivity, etc. between the various contact metals on each other when operated in such a circuit can perhaps be better correlated after further tests which are now in progress are completed.

In a general way the results obtained in this self-interrupting circuit are similar to those obtained with the pulsing type relay. That is, a large contact on the negative and a smaller platinum contact on the positive spring result in a combination yielding long life, freedom from excessive sparking and very small wear.

It is to be noted, however, that such tests as the above because of the greater current, increased rapidity of operation and heavier duty cause the deterioration to proceed at a greater rate than in the pulsing relay where the operation through several million pulses requires from three to four weeks continuous operation.

Conclusions:

Metal arcs may produce a crater in either positive or negative electrodes or contacts. The intensity of the spark and the ensuing rise of temperature at the positive contact form a small bead of molten metal which gradually is enlarged into a long point causing a corresponding depression in the negative contact. Such a combination of contacts causes irregular action due to sticking of the contacts and a deviation from the normal adjustment of the springs and air gap.

By the elimination of relay chattering, the sparking is materially reduced, and in particular its effect since during

chattering the current is interrupted at a high rate which does not allow the contacts to cool between interruptions. Chattering in a relay may be prevented by the adaptation of a suitable damper spring. The use of a large negative contact further increases the life of the contact combination.

The best combination on the pulsing relay within the scope of contact metals tested consists of a #18 ga. platinum positive contact, either riveted or welded on the armature spring, operating with a #14 ga. silver negative contact riveted on the back spring. In addition the relay is equipped with a suitably tensioned damper spring.

P. G. ANDRES
Research Engineer

April 5, 1924.

# T A B L E 4

## Sheet 1.

### PLATINUM #18 Ga. WELDED

### POSITIVE

| + No. | - No. | - | #Impulses | + Contact Condition | - Contact Condition |
|---|---|---|---|---|---|
| 52 | 51 | #14 A.E. | 4087500 | Irregular Cone | Lost |
| 75 | 76 | #18 A.E. | 3166200 | + Came off | Test being repeated |
| 54 | 53 | #14 A.E. | 5296275 | Smooth Convex | Smooth Shallow Crater |
| 73 | 74 | #16 A.E. | 3582950 | Small Even Cone | Small Even Crater |
| 60 | 59 | #18 Pt. | 2616125 | Smooth Convex | Smooth Shallow Crater |
| 62 | 61 | #18 Pt. | 2444525 | Smooth Small Cone | Shallow Irregular Crater |
| 71 | 72 | #18 Pt. | 3304825 | Smooth Small Cone | Small Even Crater |

### PLATINUM #18 Ga. WELDED

### NEGATIVE

| - No. | + No. | + | #Impulse | - Contact Condition | + Contact Condition |
|---|---|---|---|---|---|
| 59 | 60 | #18 Pt. | 2616125 | Smooth Shallow Crater | Smooth Convex |
| 61 | 62 | #18 Pt. | 2444525 | Shallow Irregular Crater | Smooth Small Cone |
| 72 | 71 | #18 Pt. | 3304825 | Small Even Crater | Smooth Small Cone |
| 84 | 83 | #18 A.E. | 3605175 | Smooth Crater | Smooth Even Small Cone |
| 66 | 65 | #14 A.E. | 3508175 | Long Smooth Prong | Very Deep Crater |
| 78 | 77 | #18 A.E. | 3861000 | Deep Smooth Crater | Long Pointed Cone |

TABLE 4

Sheet 2

SILVER CONTACT METAL #18 WELDED

POSITIVE

| + No. | - No. | - | #Impulses | + Contact Condition | - Contact Condition |
|---|---|---|---|---|---|
| 77 | 78 | #18 Pt. | 3861000 | Long Pointed Cone | Deep, Smooth Crater |
| 79 | 80 | #18 A.E. | 3667250 | Deep Crater "V" Shaped | Wedge Shaped Point |
| 81 | 82 | #18 W.E. | 3757225 | Deep Round Crater | Large Round Cone |
| *56 | 55 | #14 A.E. | 2362125 | Rough Shallow Crater | Small Irregular Cone |
| *64 | 63 | #14 A.E. | 669900 | Small Rough Crater | Small Irregular Cone |
| *65 | 66 | #18 Pt. | 3508175 | Very Deep Crater | Long, Smooth Prong |
| *69 | 70 | #14 W.E. | 3362525 | Very Deep Crater | Lost |

SILVER CONTACT METAL WELDED #18 GA.

NEGATIVE

| - No. | + No. | + | #Impulses | - Contact Condition | + Contact Condition |
|---|---|---|---|---|---|
| 74 | 73 | #18 Pt. | 3582950 | Small Even Crater | Small Even Cone |
| 86 | 85 | #18 W.E. | 3725475 | Smooth-Flat, Edges Black | Smooth Flat Edges Blackened |
| 80 | 79 | #18 A.E. | 3667250 | Wedge Shaped Point | Deep V Shaped Crater |
| *53 | 54 | #18 Pt. | 5296275 | Smooth Shallow Crater | Smooth Convex |
| *68 | 67 | #14 W.E. | 3414375 | Flat Rough, Edges Black | Flat Rough Granular |
| *55 | 56 | #14 A.E. | 2362125 | Small Irregular Cone | Rough Shallow Crater |
| *63 | 64 | #14 A.E. | 669900 | Small Irregular Cone | Small Rough Crater |

*Indicates #14 Gauge Silver Contact Riveted

# TABLE #4

Sheet 3

GOLD CONTACT METAL #18 WELDED

POSITIVE

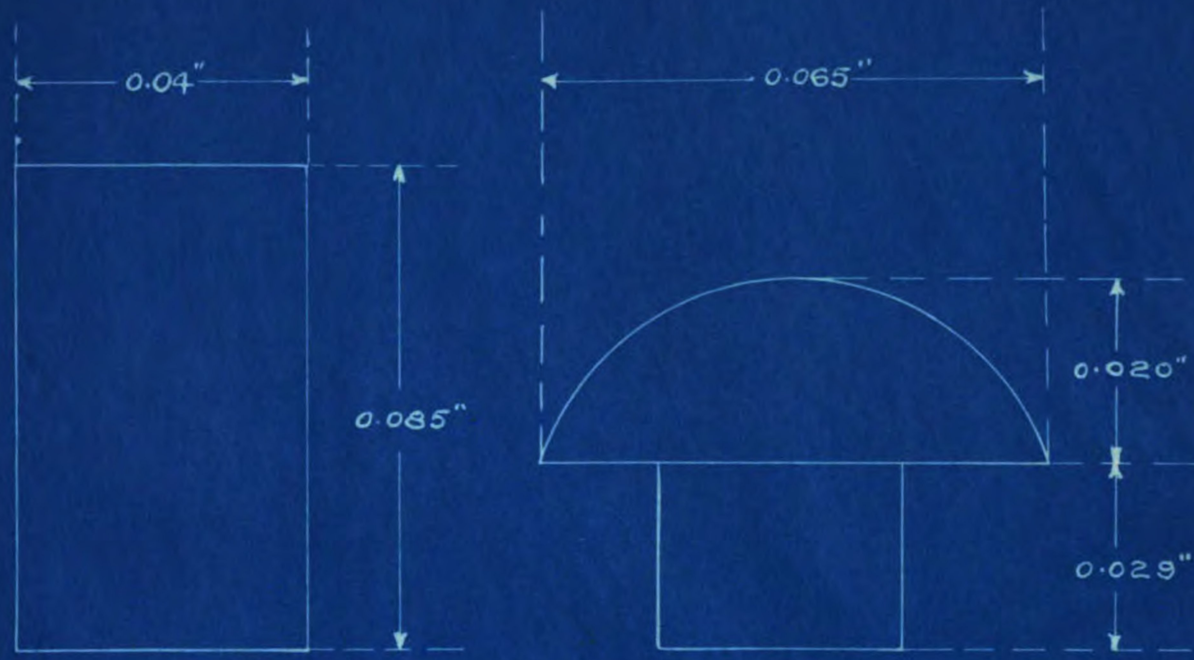
| + No. | - No. | - | #Impulses | + Contact Condition | - Contact Condition |
|---|---|---|---|---|---|
| 83 | 84 | #18 Pt. | 3605175 | Smooth Even Small Cone | Smooth Crater |
| 85 | 86 | #18 A.E. | 3725475 | Smooth - Flat Edge Bulckened | Smooth - Flat Edge Blackened |
| 87 | 88 | #14 W.E. | 3757225 | Rough-Wedged Shaped Edges Blackened | Rough V shaped Crater. Edges Blackened |
| *56 | 57 | #14 W.E. | 4466850 | Nearly Flat Slightly Convex | Very Shallow Crater, Nearly Flat |
| *67 | 68 | #14 A.E. | 3414375 | Flat-Rough-Granular | Flat-Rough Edges blackened |

GOLD CONTACT METAL #18 GA. WELDED

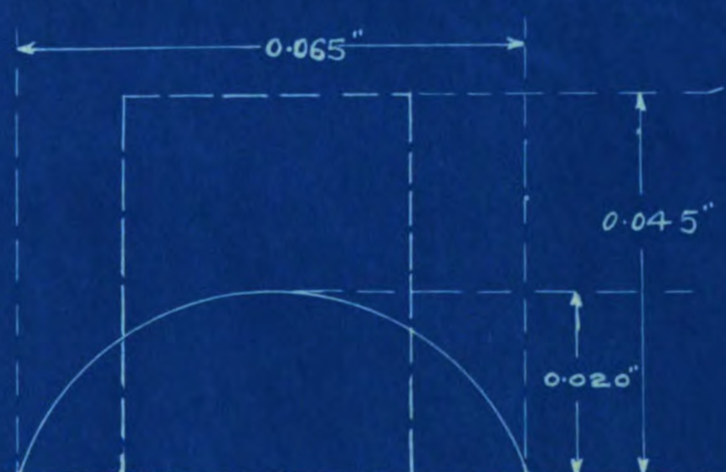
NEGATIVE

| - No. | + No. | + | #Impulses | - Contact Condition | + Contact Condition |
|---|---|---|---|---|---|
| 76 | 75 | #18 Pt. | 3166200 | + Came off. | Now trying again |
| 82 | 81 | #18 A.E. | 3757225 | Large Round Cone | Deep Round Crater |
| *51 | 52 | #18 Pt. | 4087500 | Lost | Irregular Cone |
| *57 | 58 | #14 W.E. | 4466850 | Shallow Crater Nearly Flat | Slightly Convex, Nearly Flat |
| *88 | 87 | #18 W.E. | 3757225 | Rough "V" shaped Crater Black edges | Rough Wedge shaped, Edge Blackened |
| *70 | 69 | #14 A.E. | 3362525 | Lost | Very deep crater |

*Indicates #14 Gauge Gold Contact Riveted




BLANK FOR RIVETED CONTACTS.




BLANK FOR WELDED CONTACTS.

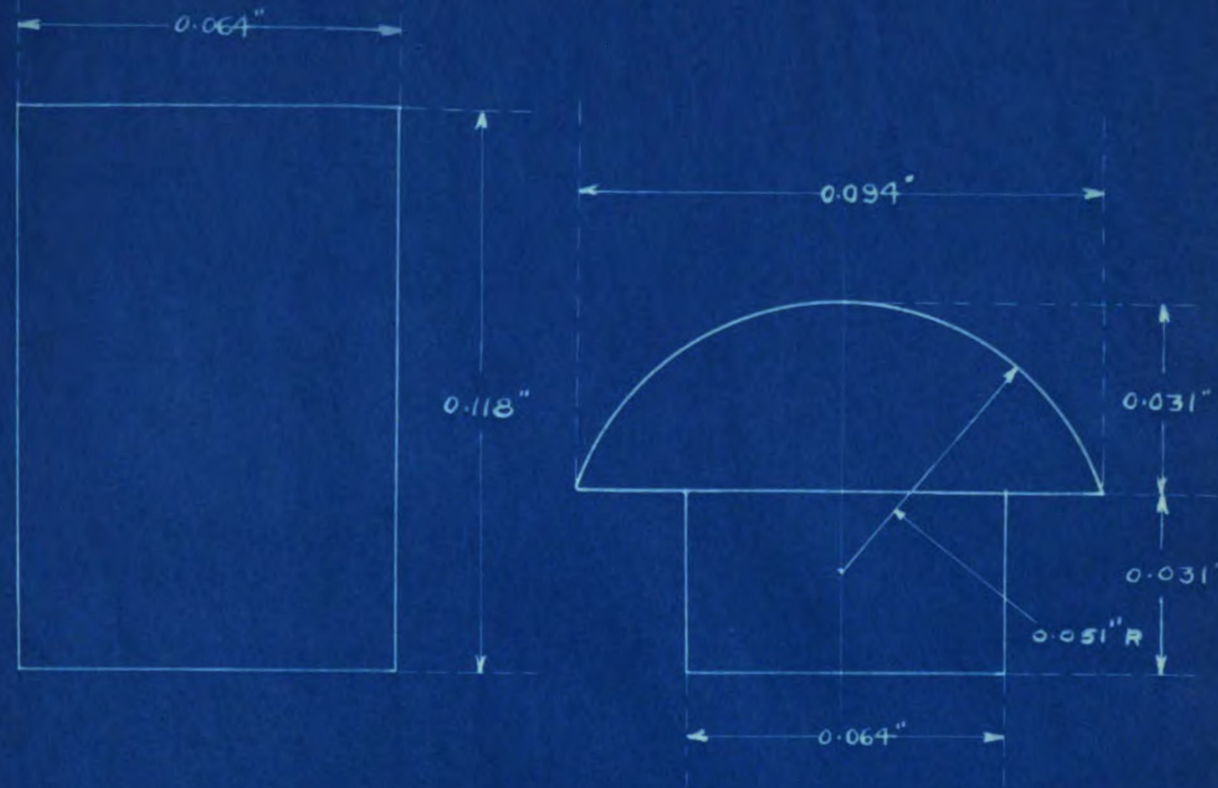
FIG. 1

NO. 18 B & S GAUGE CONTACTS.

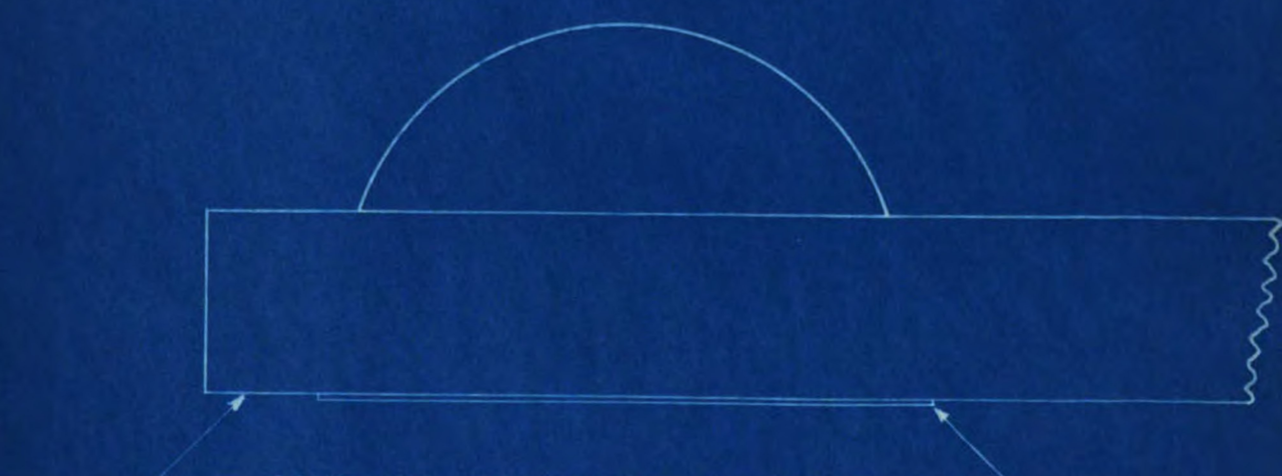
APPROVED

GHJ

CONTACTS AND CONTACT ENDURANCE. | ELS-537




BLANK FOR RIVETED CONTACTS.




CONTACT RIVETED IN SPRING.

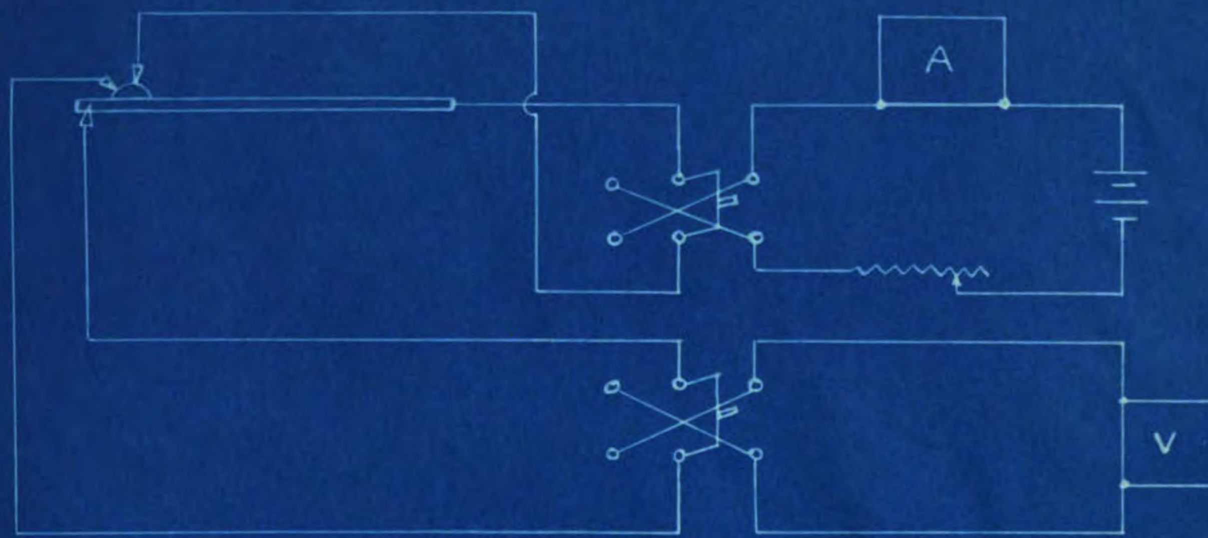
FIG. 2

NO. 14 B+S GAUGE CONTACTS.

APPROVED

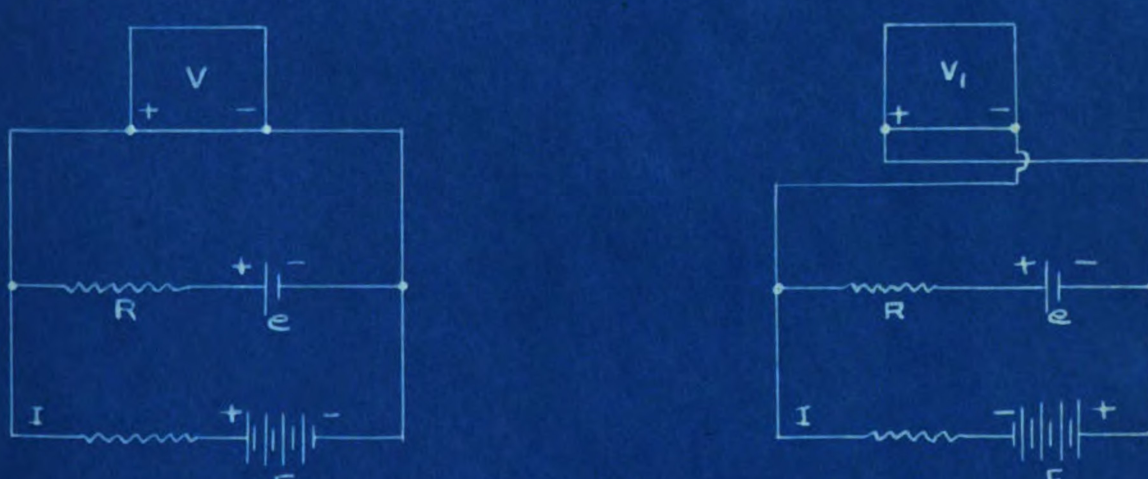
CONTACTS AND CONTACT ENDURANCE. | ELS-538

JUNCTION RES. BETWEEN CONTACT + SPRING.




A = 0 – 6 AMPS.

V = 0 TO 0.0025 VOLTS    RES. = 100 ω




$V = IR + e$

$V_1 = IR - e$

$V + V_1 = 2(IR)$

$\frac{V + V_1}{2} = IR$

$V_1 = IR - e$

FIG. 3

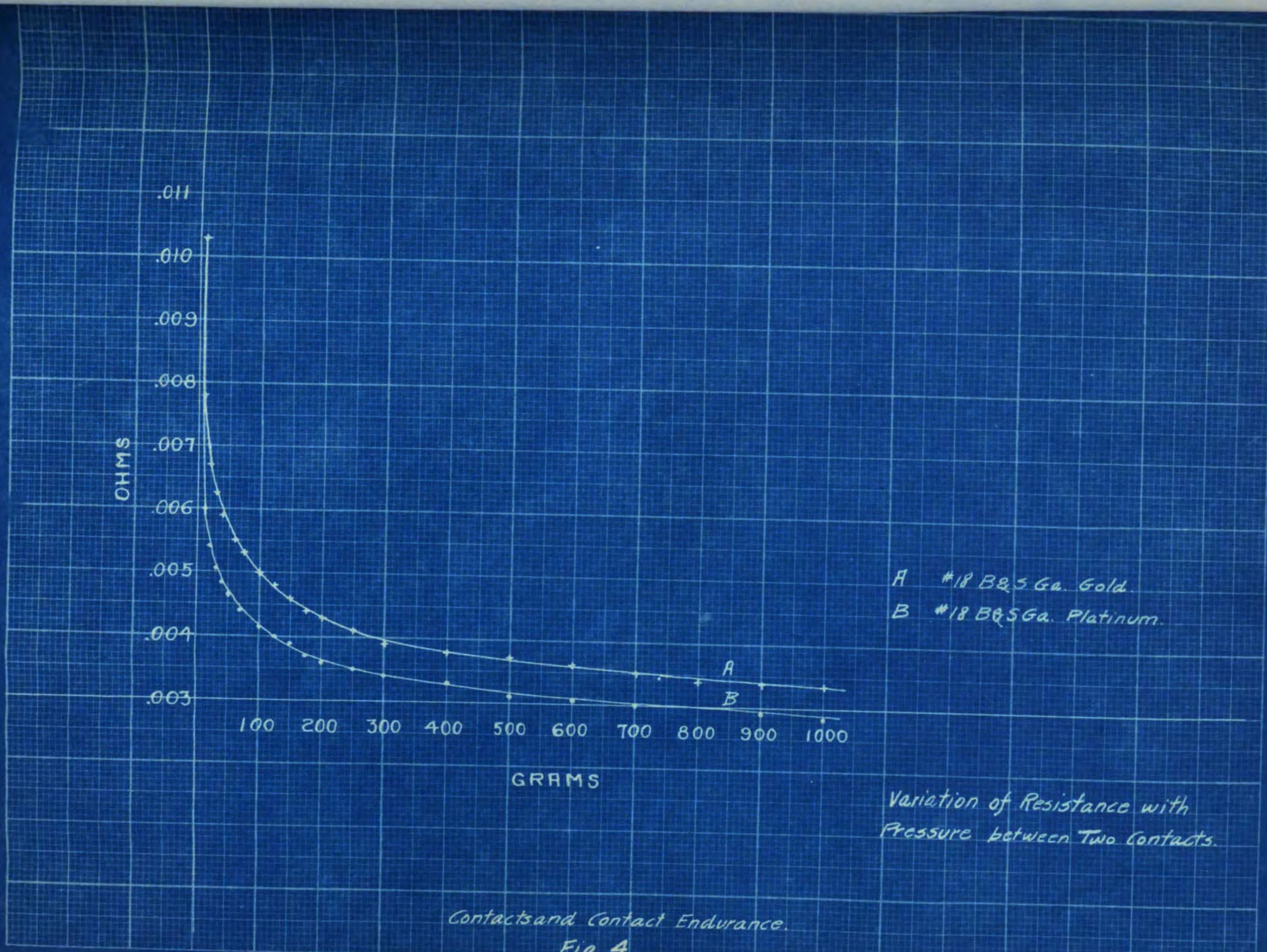
e = THERMAL E.M.F.

APPROVED

GH

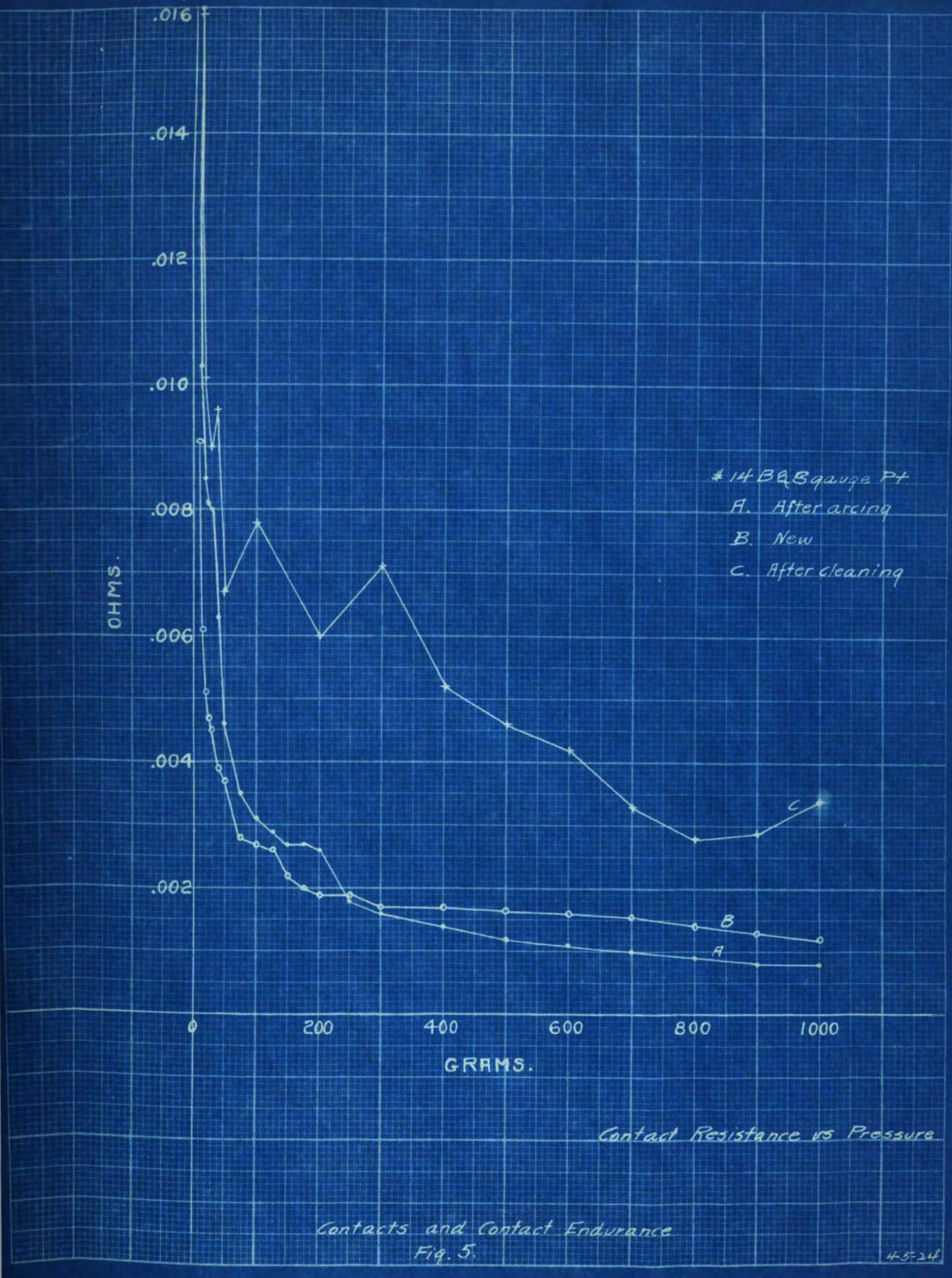
CONTACTS AND CONTACT ENDURANCE.

ELS-53

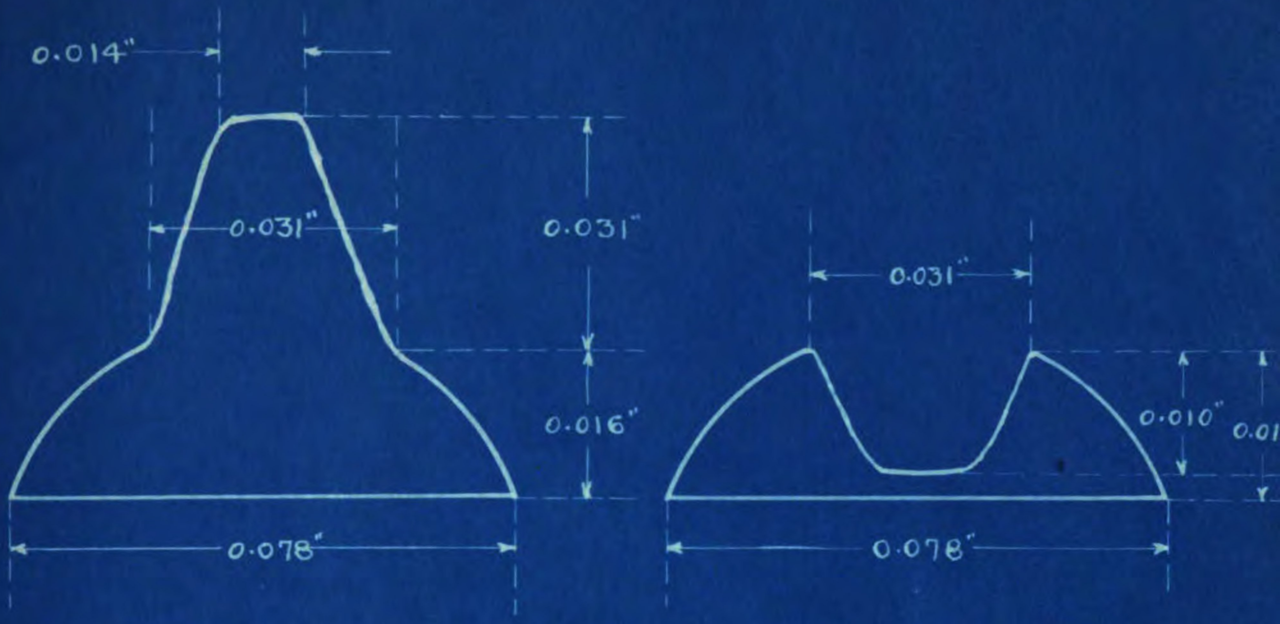



Contacts and Contact Endurance.
Fig. 4.

PGA 4-4-24.

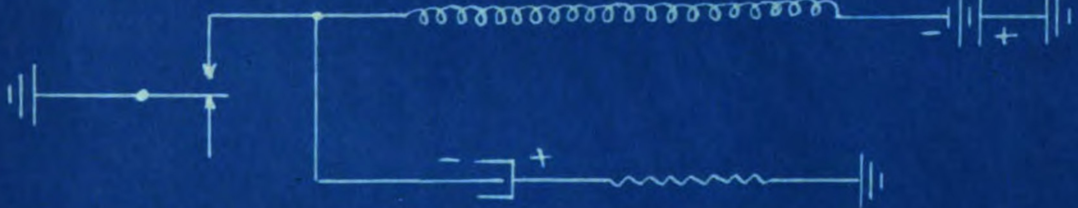



Contacts and Contact Endurance
Fig. 5.



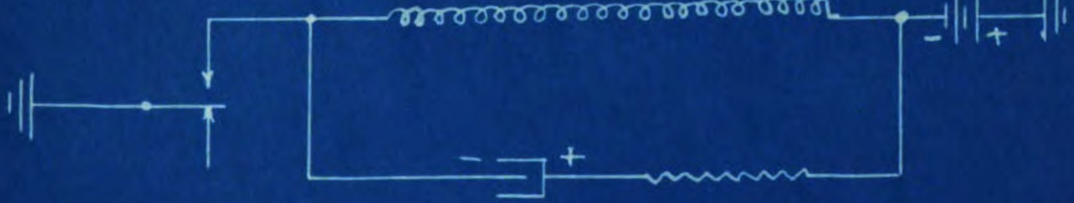

APPROX. SIZE OF NEGATIVE CRATER + POSITIVE POINT.

FIG. 6




SPARK QUENCHER ACROSS CONTACTS.

FIG. 8



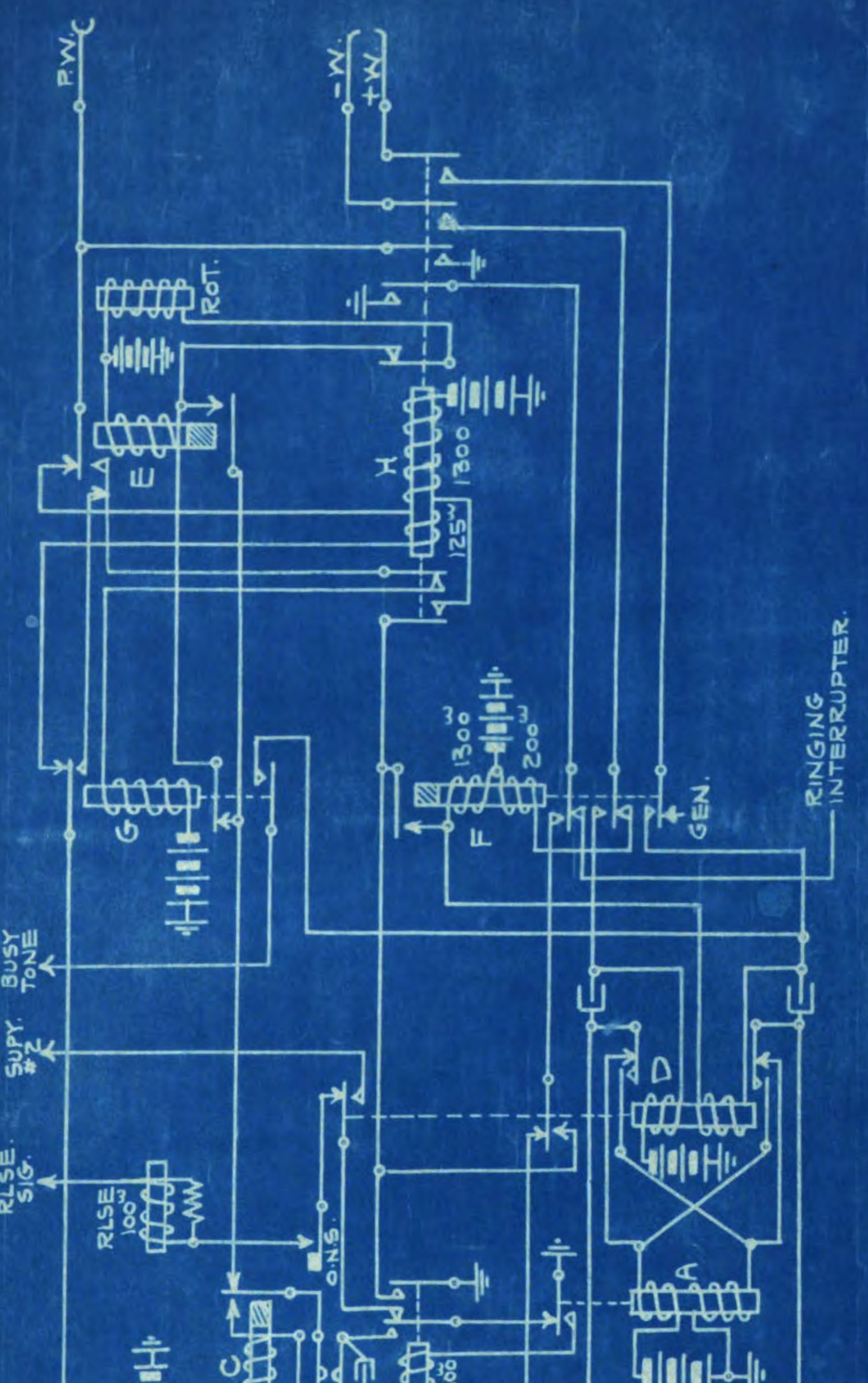

SPARK QUENCHER ACROSS COILS.

FIG. 9

GH.

CONTACTS AND CONTACT ENDURANCE. | ELS-54C

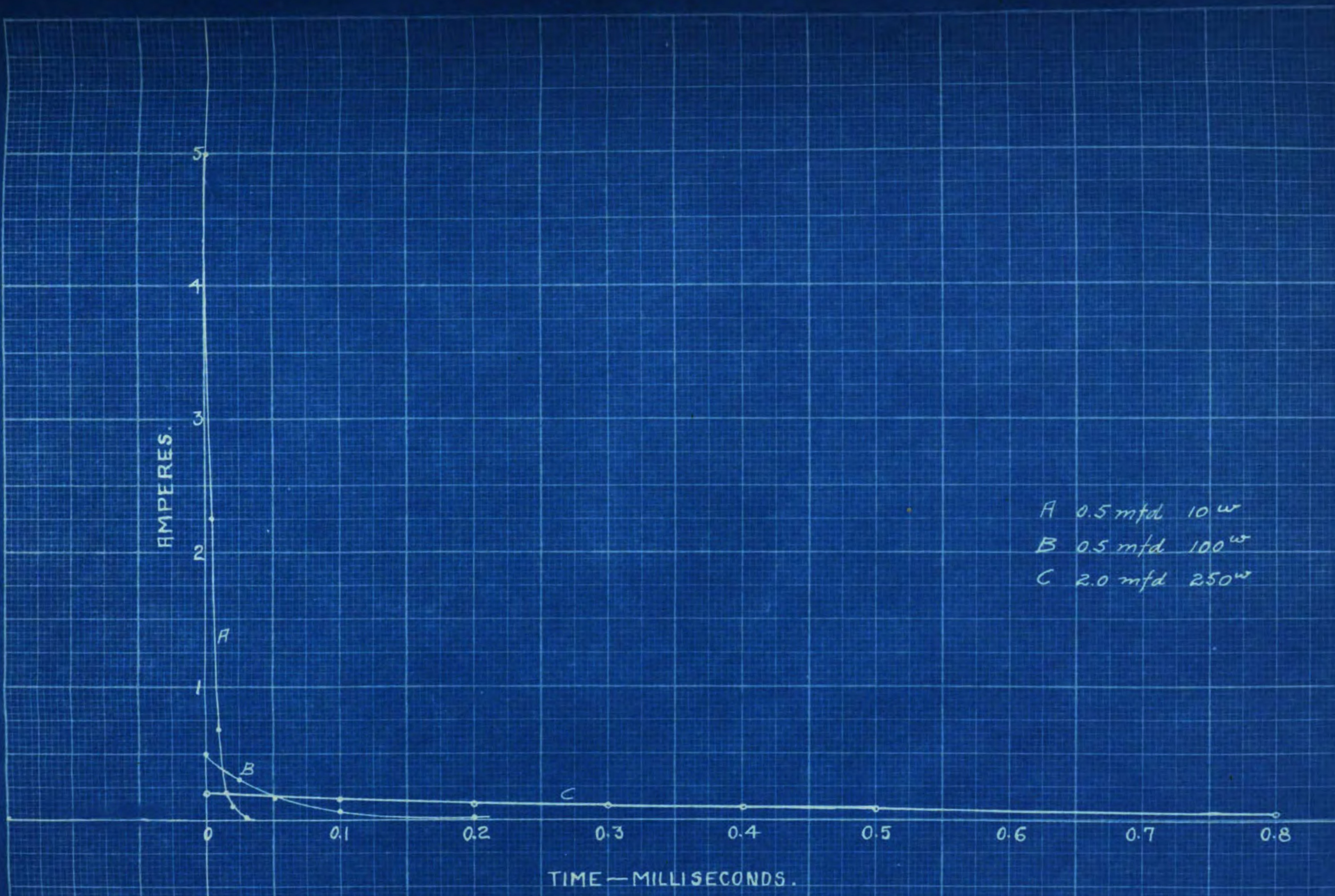
APPROVED




*Contacts and Contact Endurance.*
*Fig 7.*

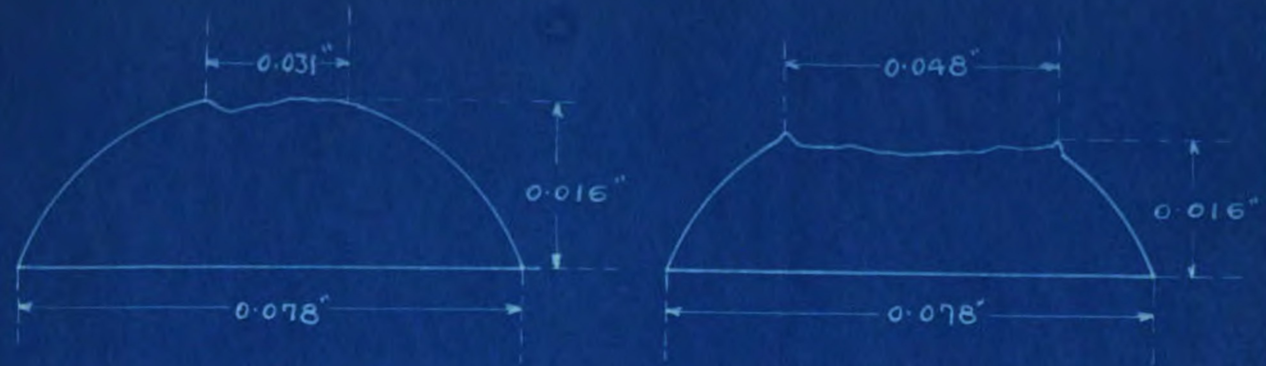
Connector, Sideswitchless, Cct. 18513-A. Simplified

TS-56



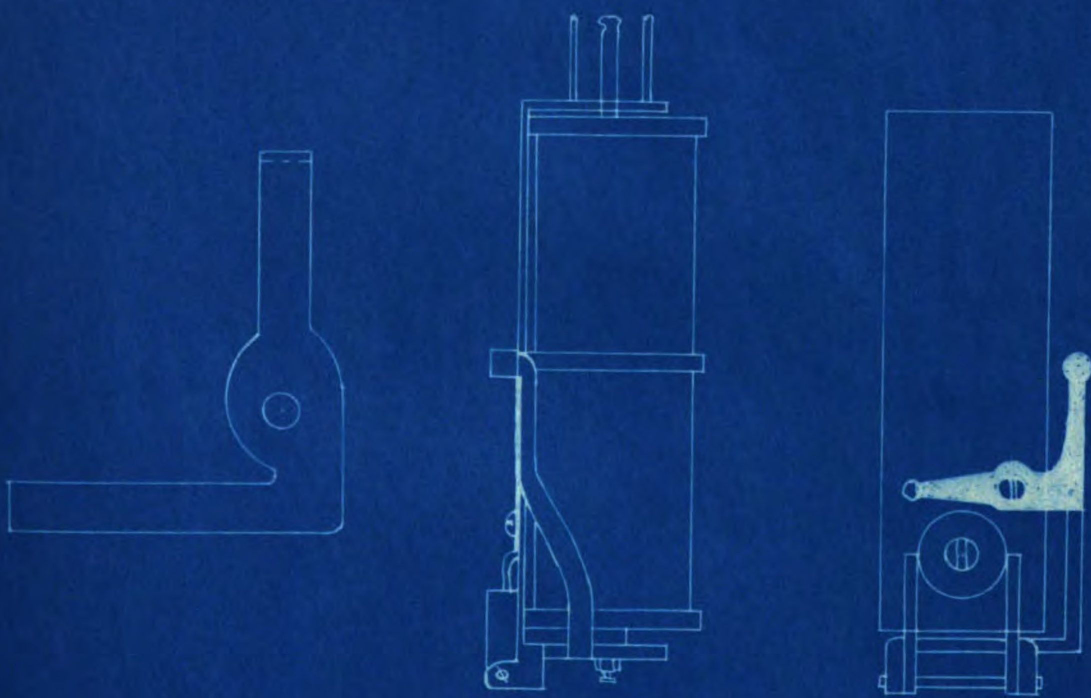

Current Time Decay.
Spark Quencher.

Contacts and Contact Endurance.
Fig. 10




APPROX. SIZE OF NEG. & POS. CONTACTS AFTER USE WITH DAMPER SPRING

FIG. 14.

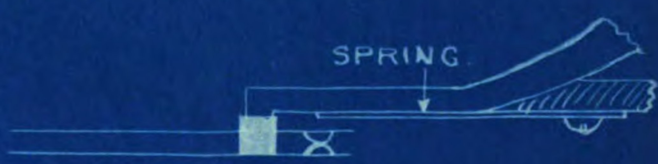


ADAPTATION OF DAMPER SPRING TO RELAY.

FIG. 13.


DAMPER SPRING AGAINST SPRING.

FIG. 11



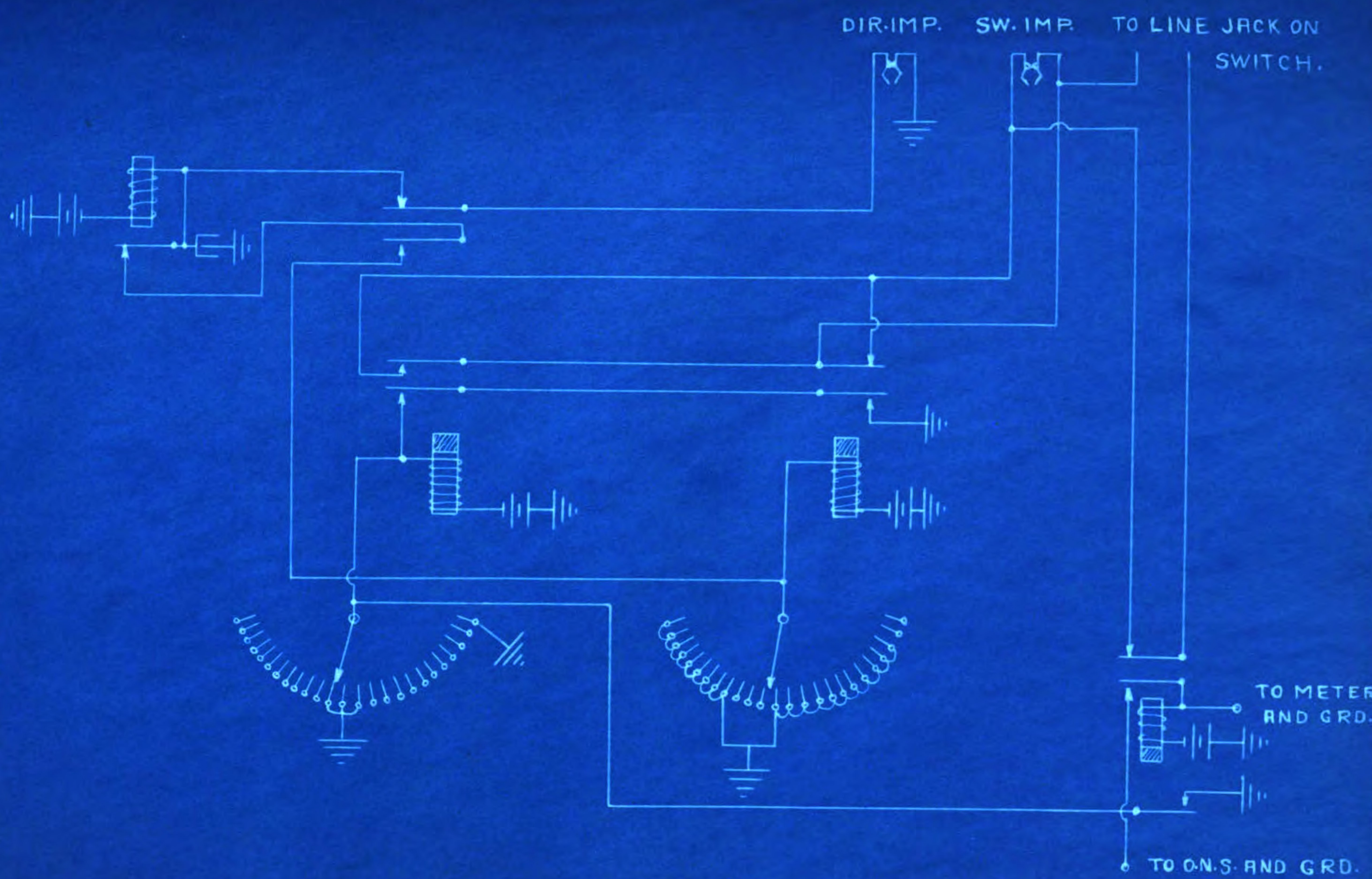

DAMPER SPRING AGAINST ARMATURE ARM.

FIG. 12.

GH.

CONTACTS AND CONTACT ENDURANCE | ELS-541

APPROVED [signature]



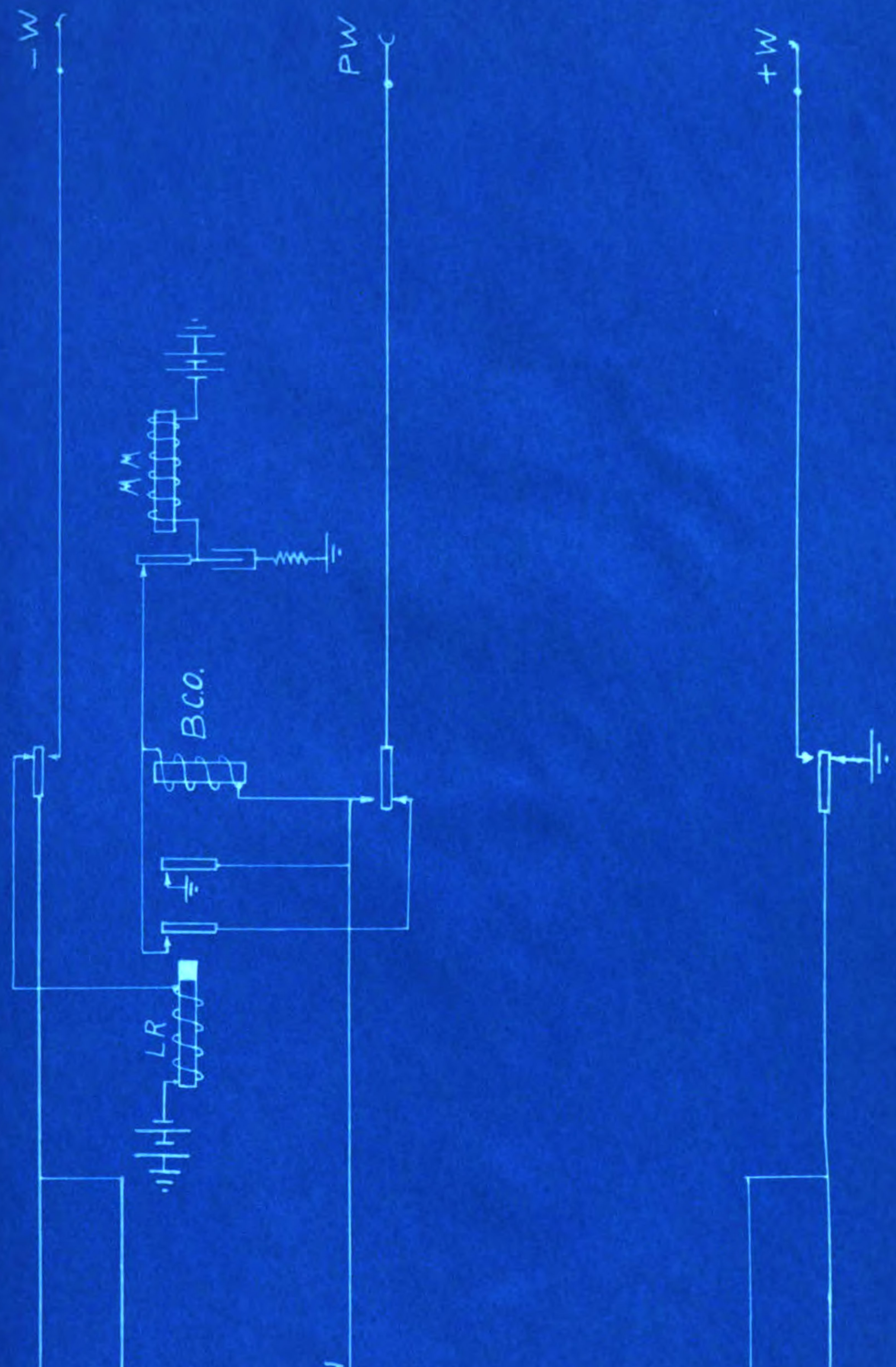

IMPULSE SENDER FOR CONTACT LIFE TEST.

Fig 15.

GH

CONTACTS AND CONTACT ENDURANCE.

ELS-542

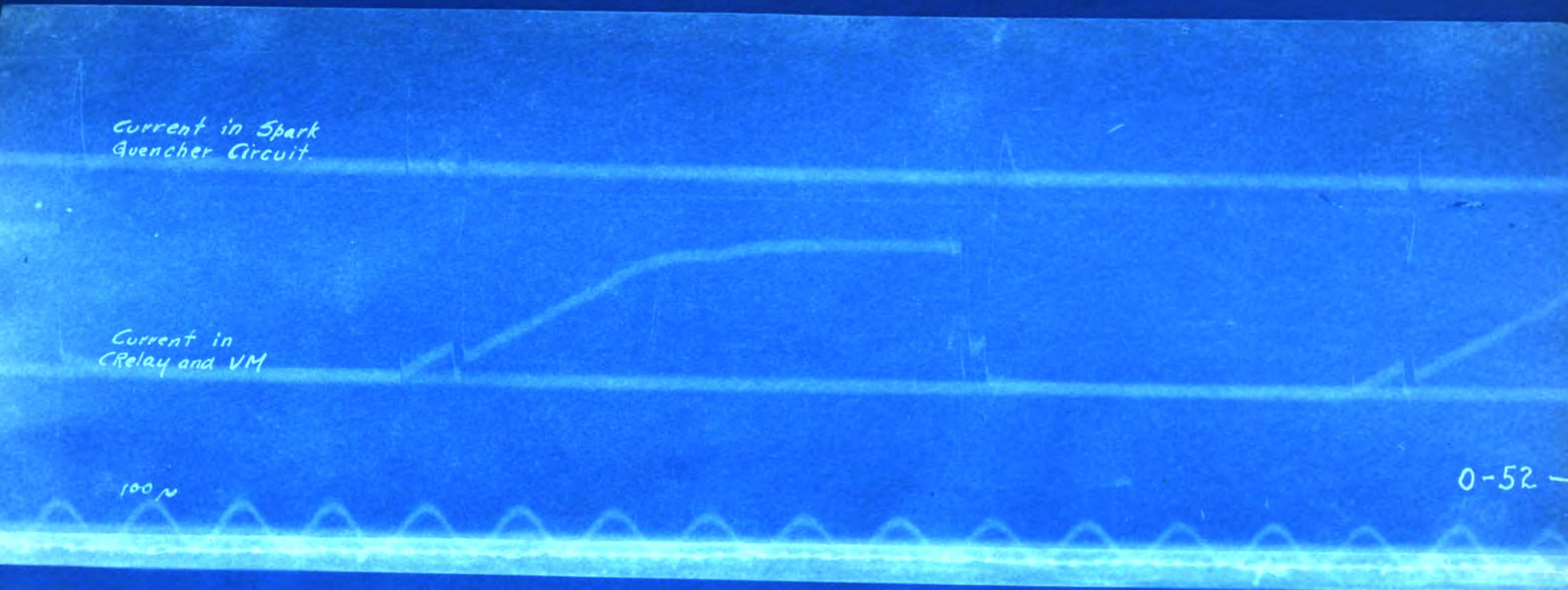



SIMPLIFIED ROTARY LINESWITCH
CIRCUIT DIAGRAM.
Fig 16.

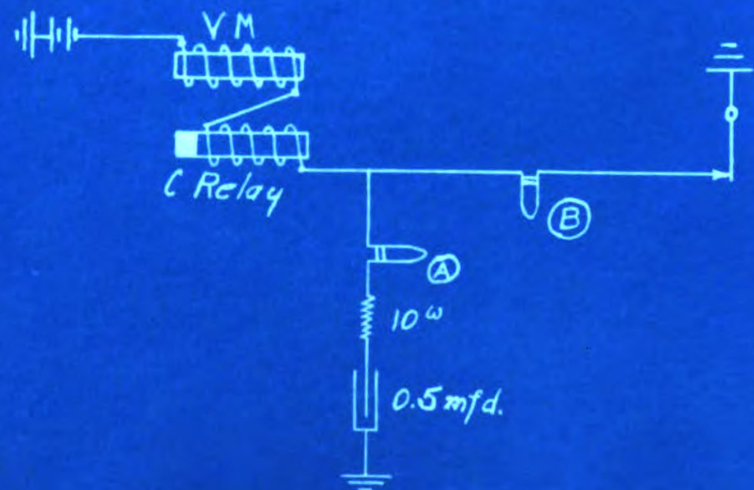
BPH

CONTACTS AND CONTACT ENDURANCE.

ELS-543.

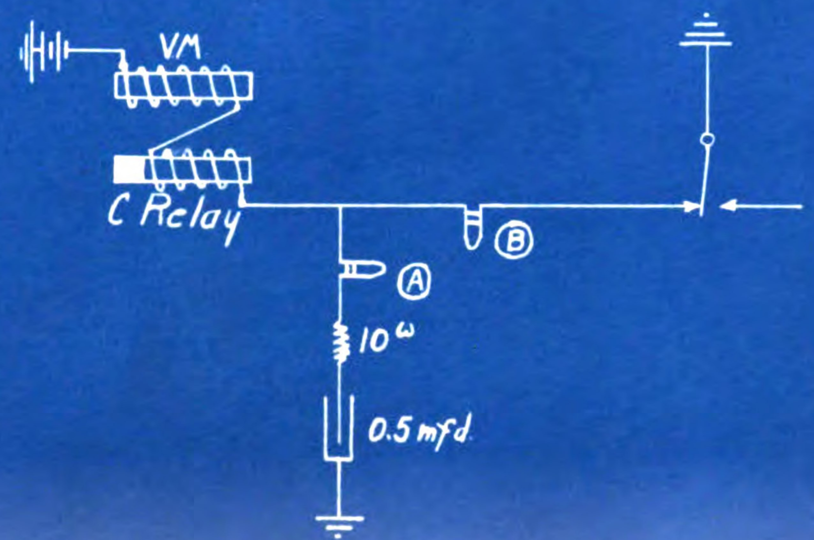


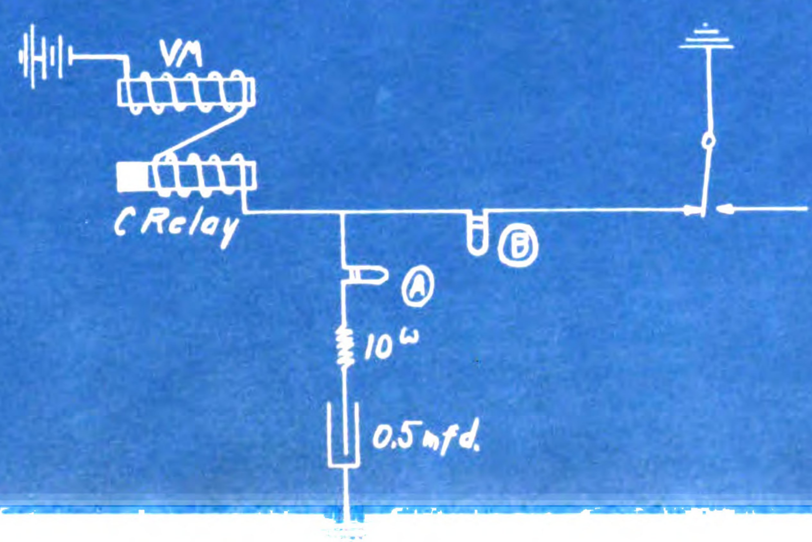
Current in Spark
Quencher Circuit.
Current in
C Relay and VM
100 ~
0-52

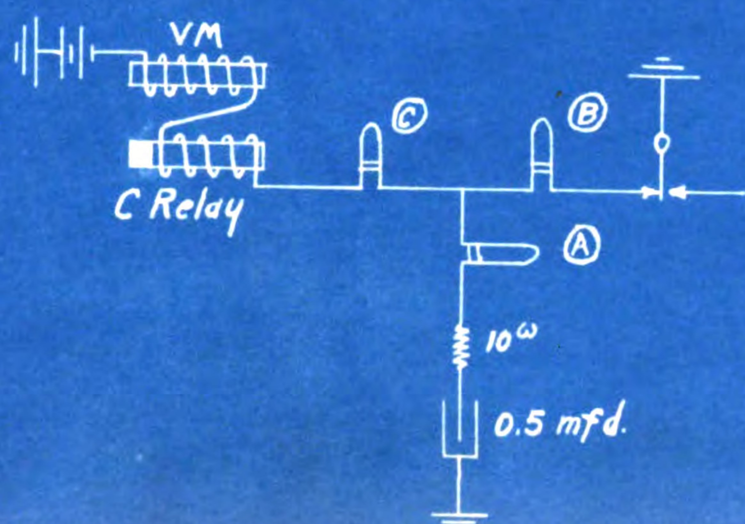



VM
C Relay
Ⓑ
Ⓐ
10 ω
0.5 mfd.

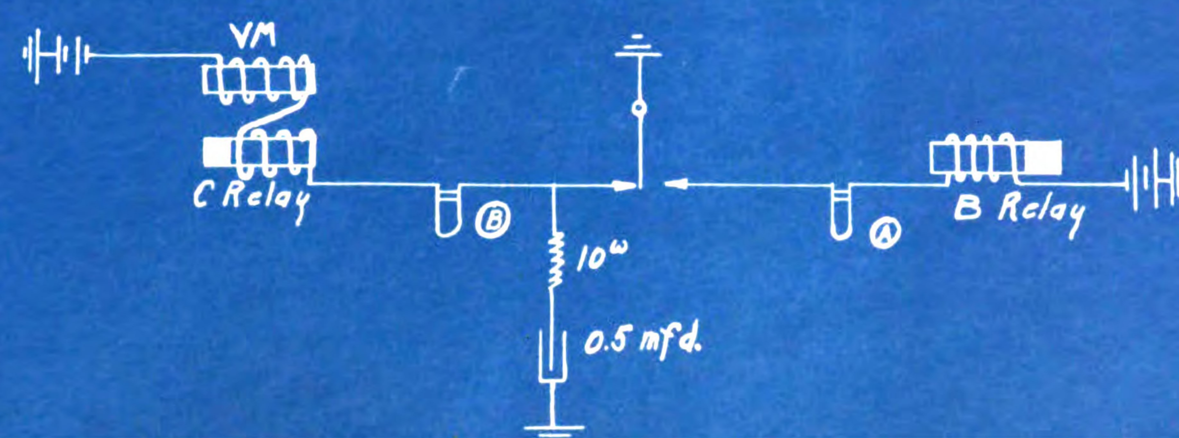

0-5

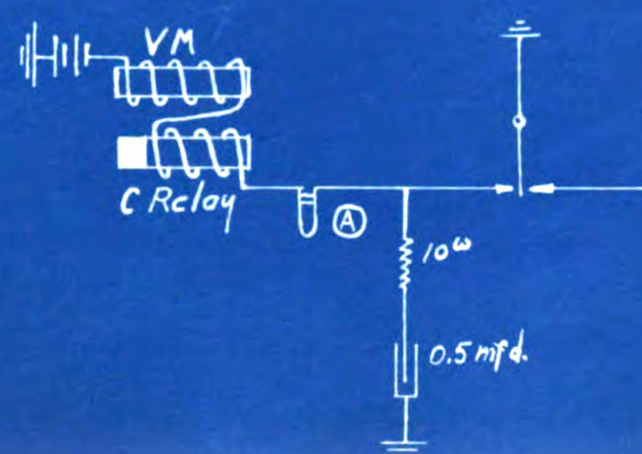

VM
C Relay
Ⓐ
Ⓑ
10ω
0.5 mfd


VM
C Relay
A
B
10ω
0.5 mfd.

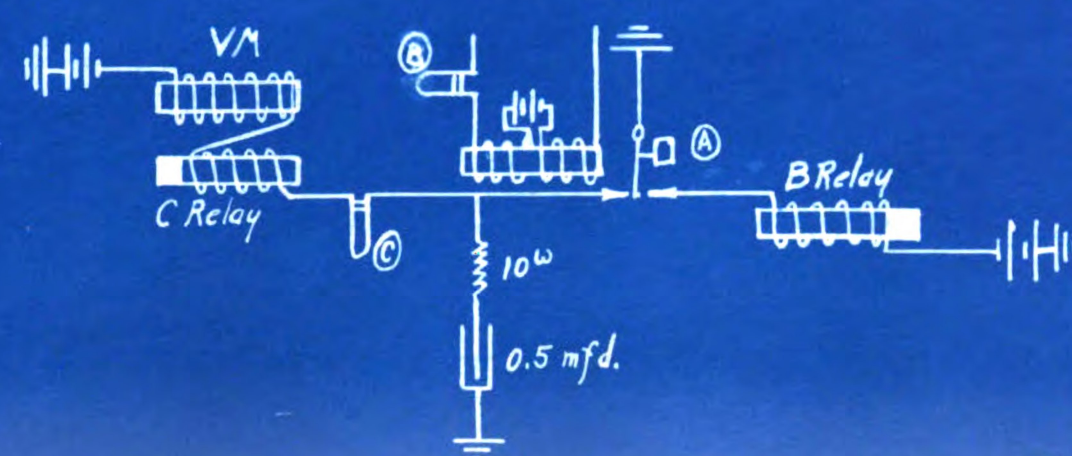



0-55

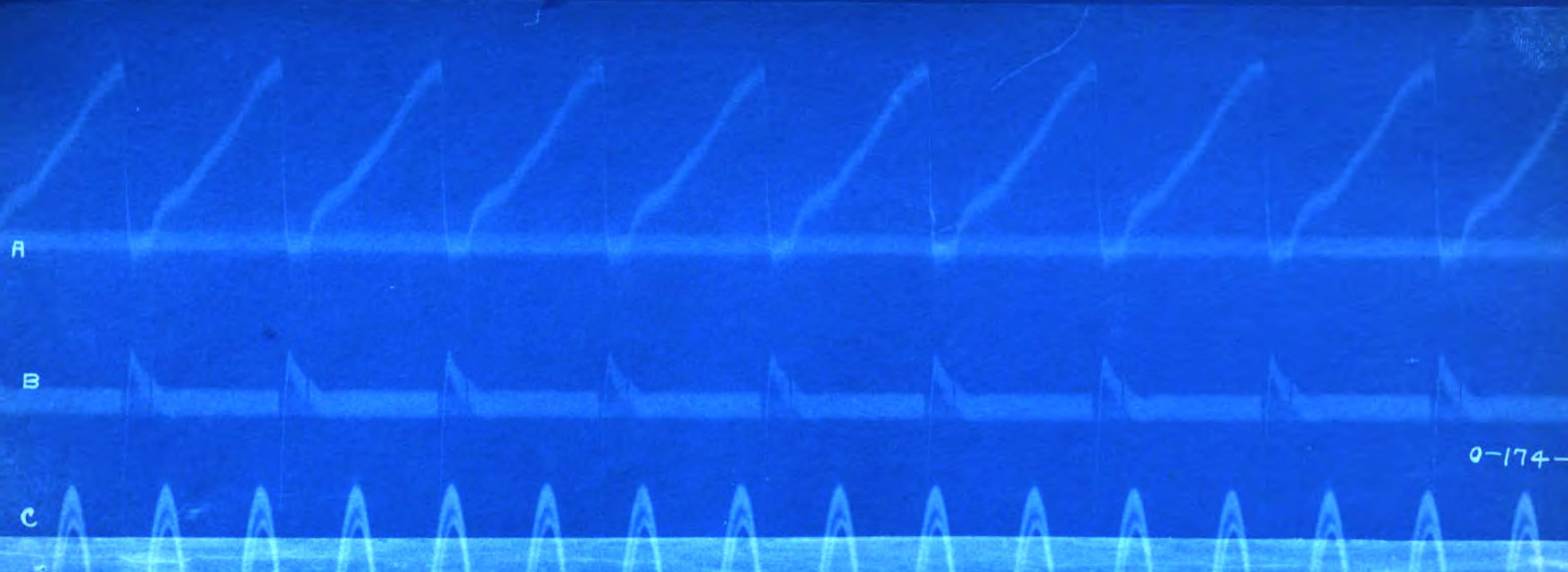

VM
C Relay
Ⓑ
10ω
0.5 mfd.
Ⓐ
B Relay

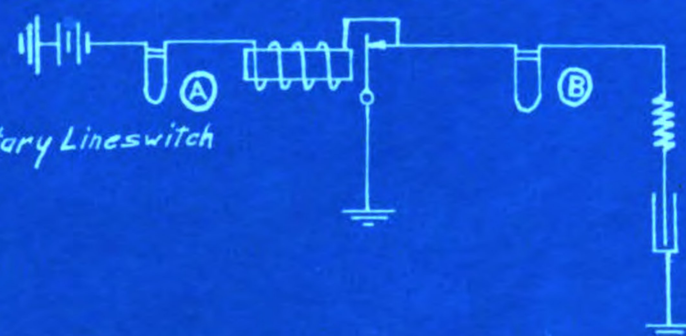



0-81



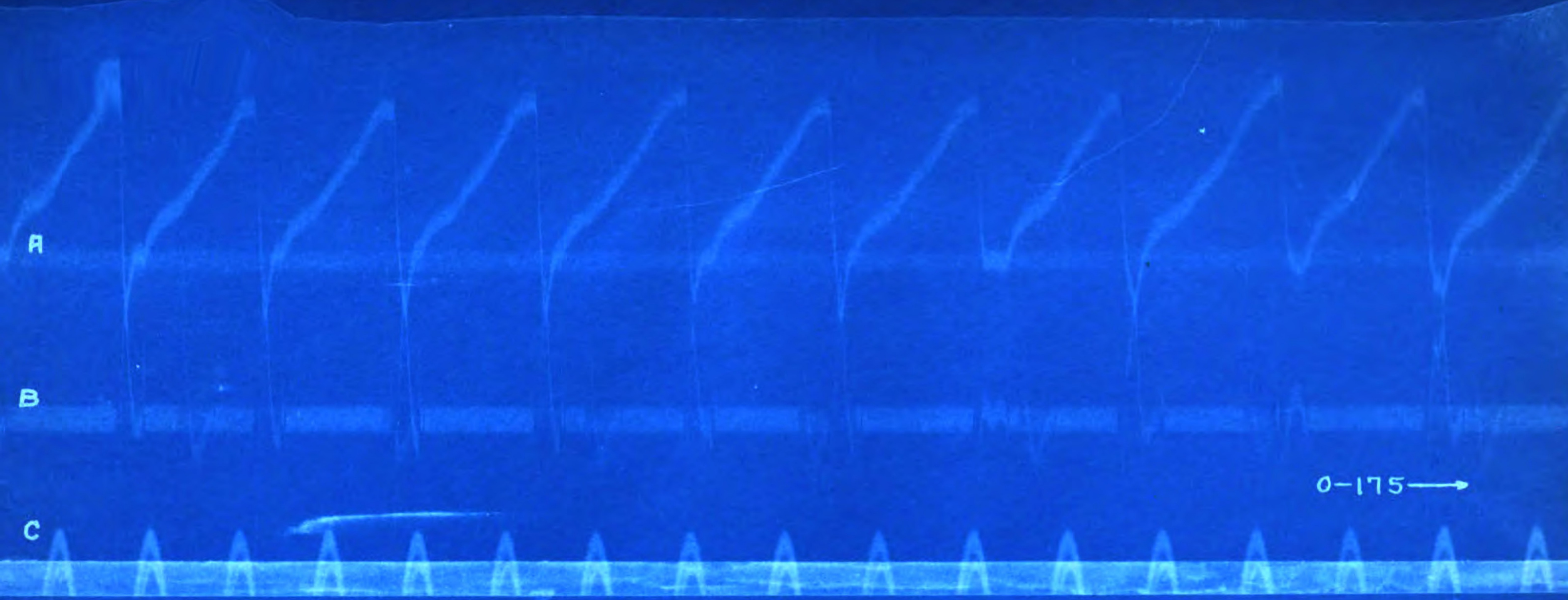

0-83



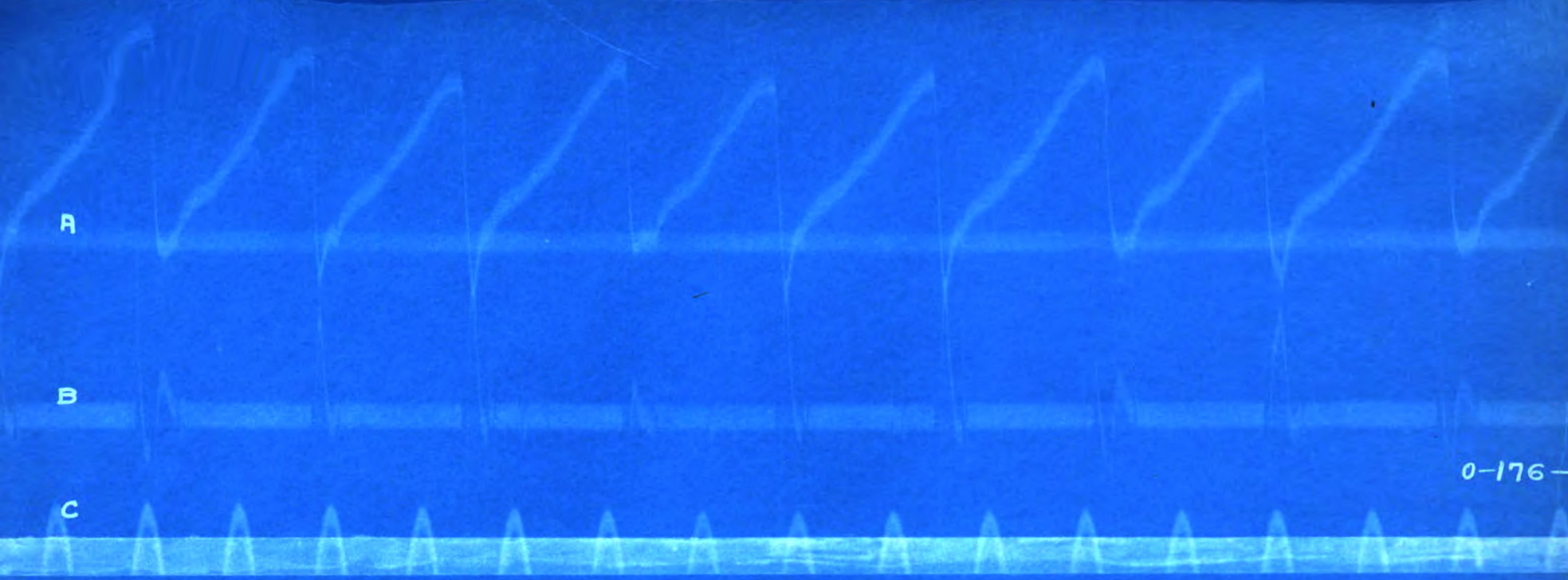




Rotary Lineswitch

0·174




SIMILAR TO NO. 174 EXCEPT 2 SWITCHES IN PARALLEL

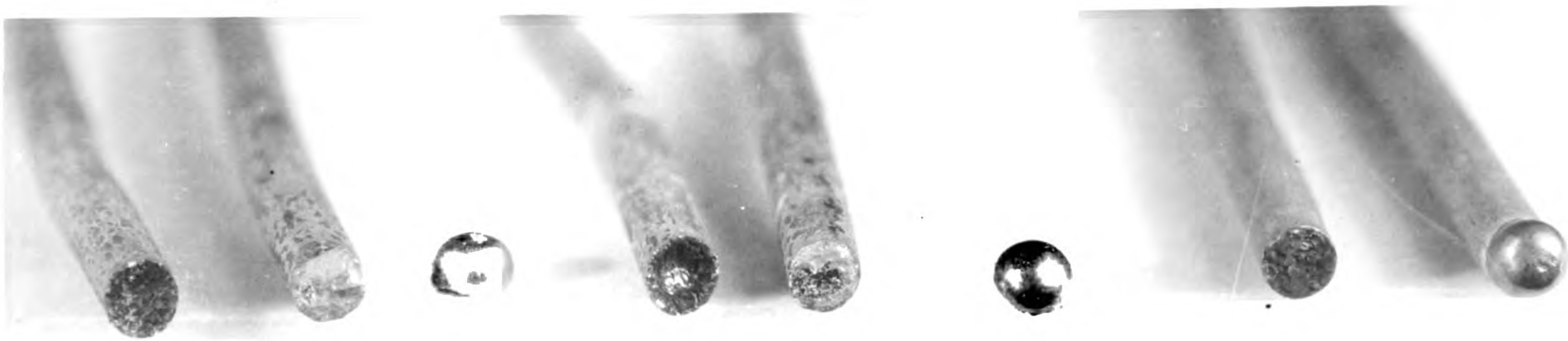



SIMILAR TO NO. 174 EXCEPT 4 SWITCHES
IN PARALLEL.

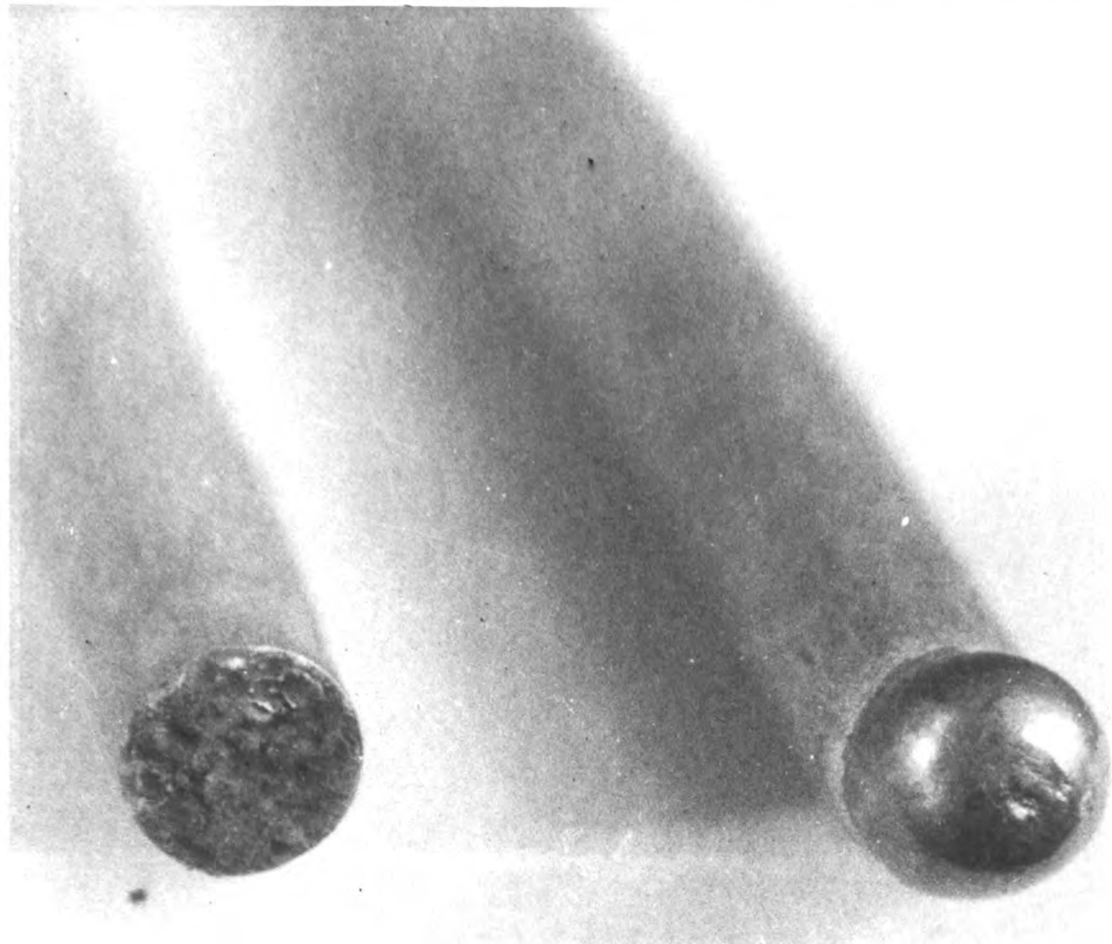
0-176


SIMILAR TO NO. 174 EXCEPT 6 SWITCHES IN PARALLEL.

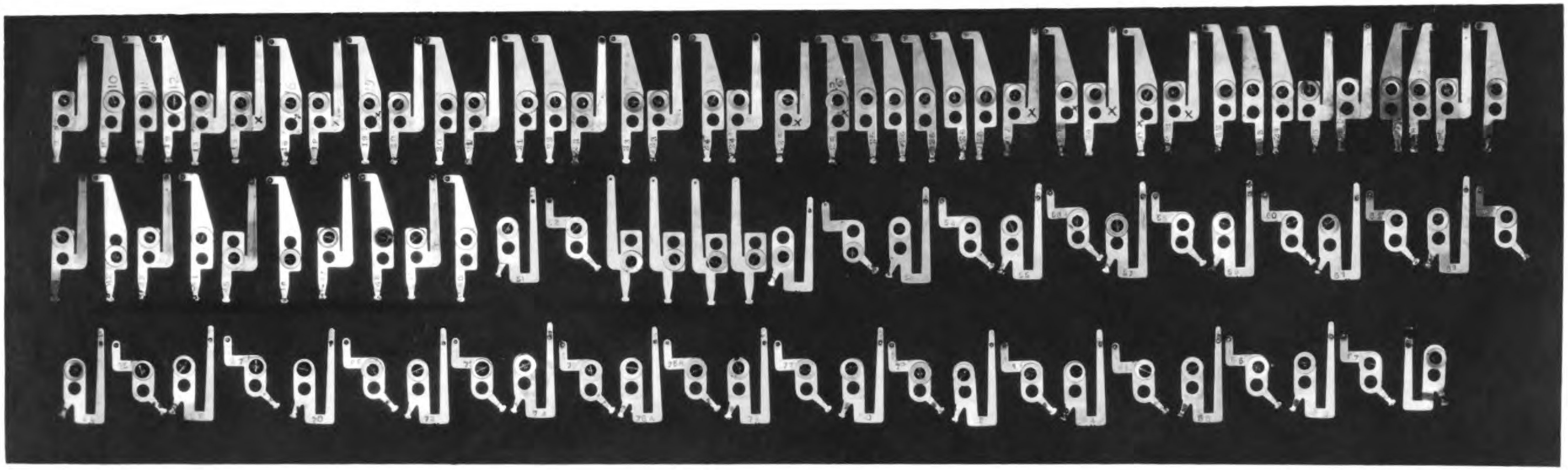
METALLIC AND CARBON ELECTRODES.



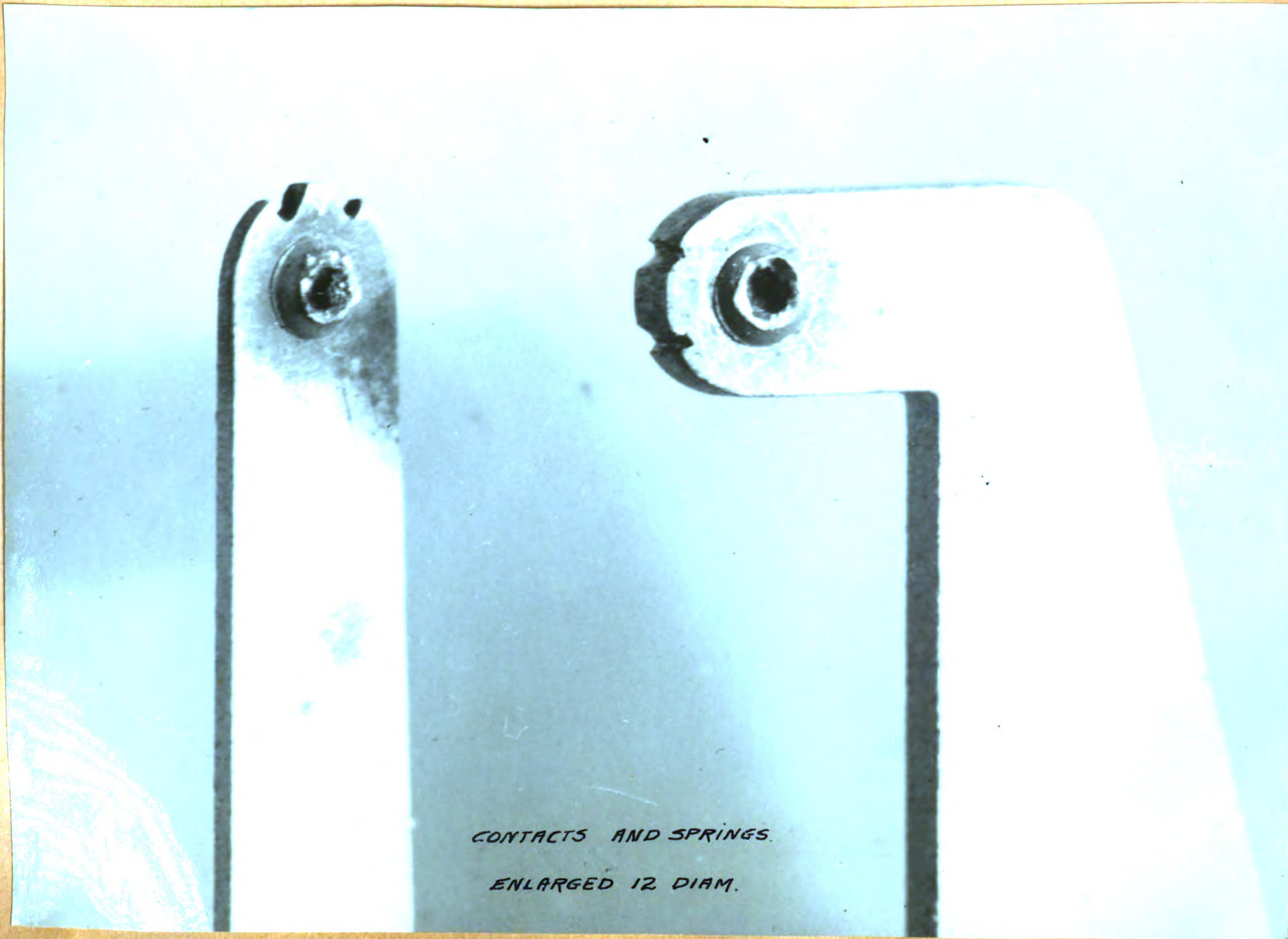
METAL ELECTRODES. – CRATER + BEADS.



ENLARGED NEG. CRATER. POS. BEAD.

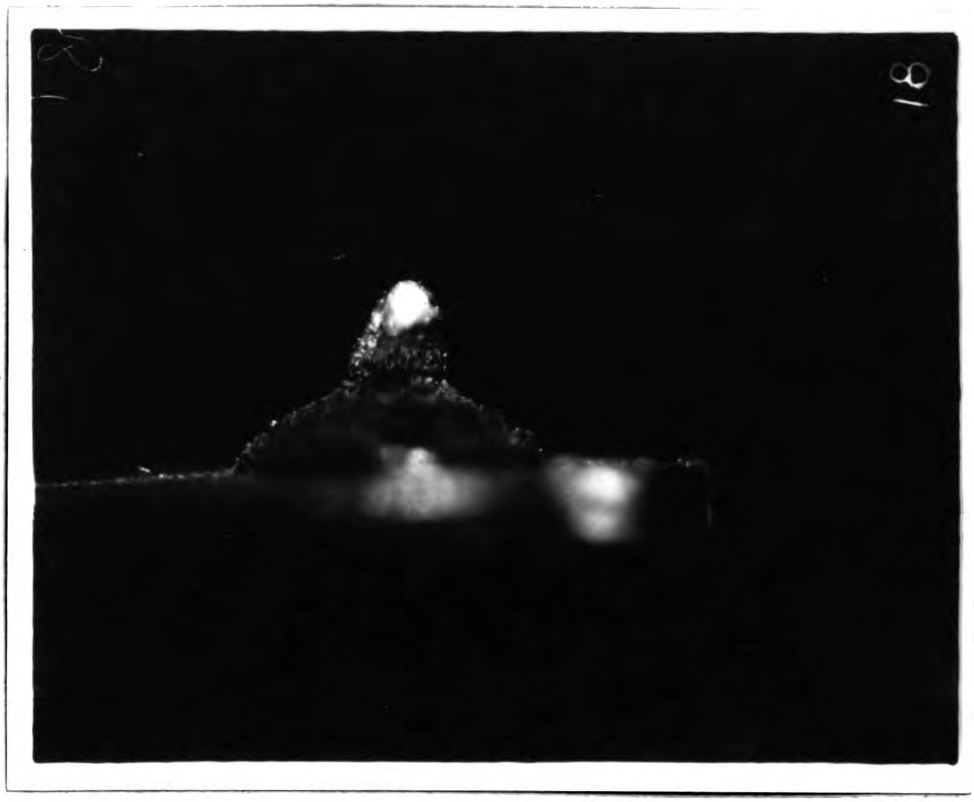


CONTACTS AND CONTACT SPRINGS.


CONTACTS AND SPRINGS.
ENLARGED 12 DIAM.

C15. Pt. #18 ga. 15000 impulses. Pos.

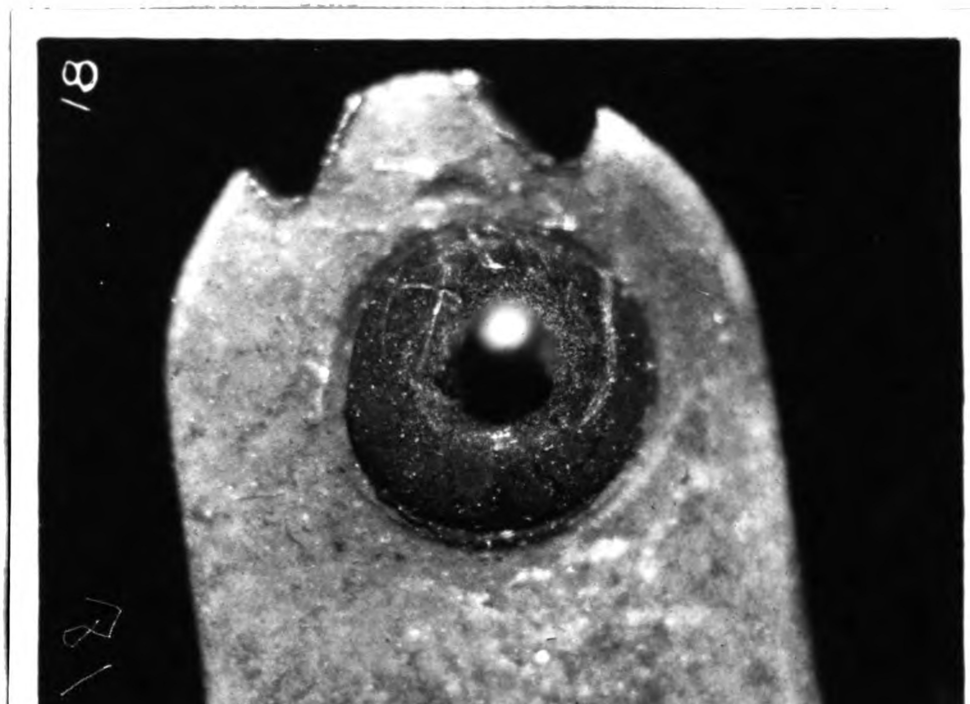
C16. Pt. #18 ga. 15000 impulses. Neg.



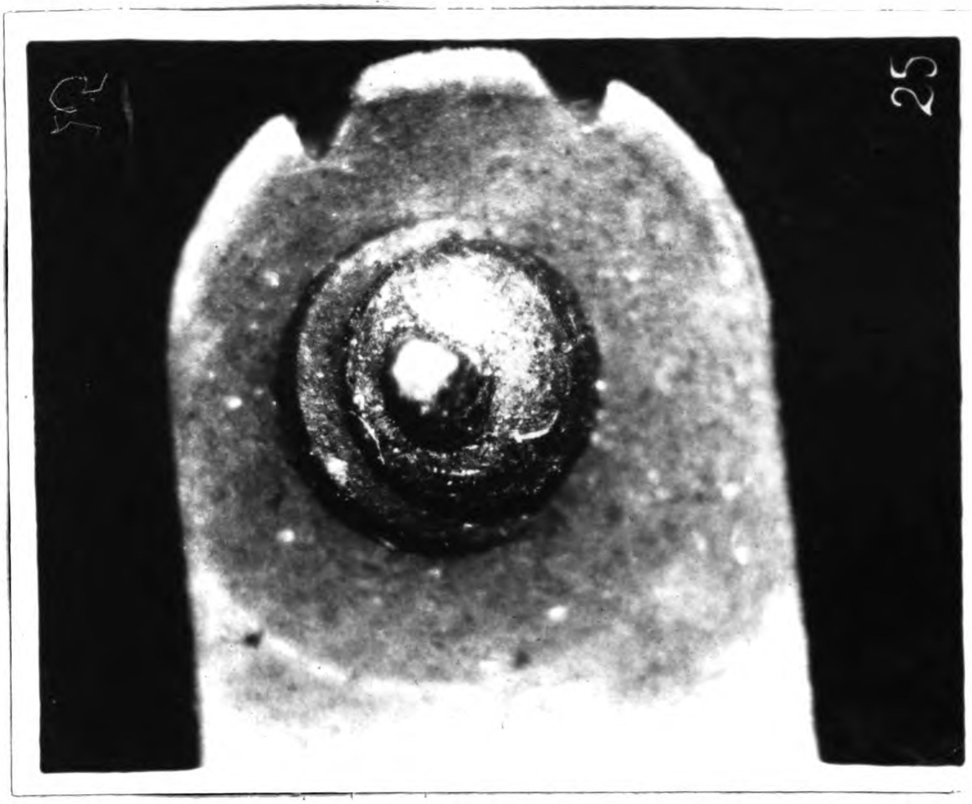
C18. Pt. #18qa. 15000 impulses. Pos.

Side View.

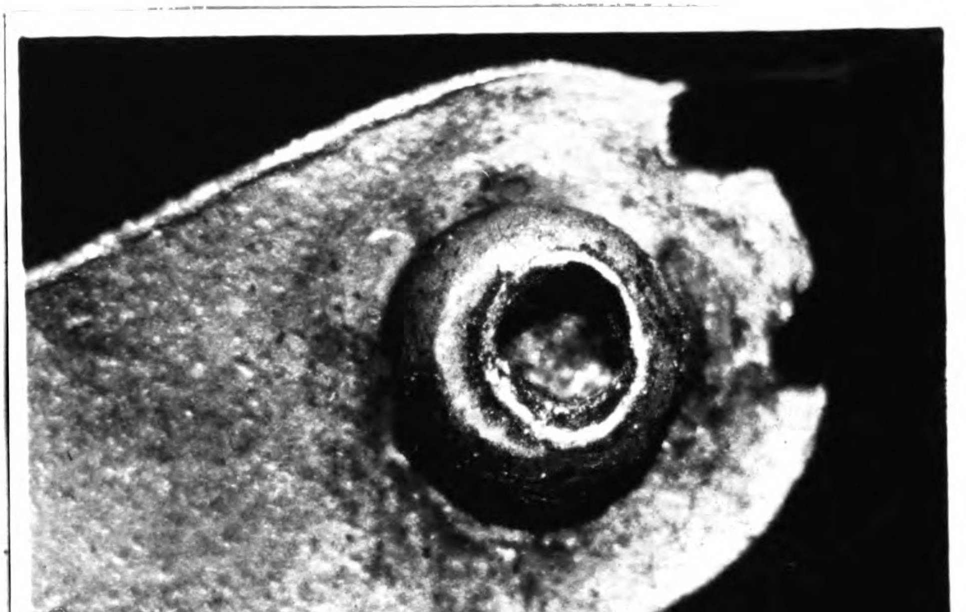
C19. Pt. #18ga. 15000 impulses. Neg.



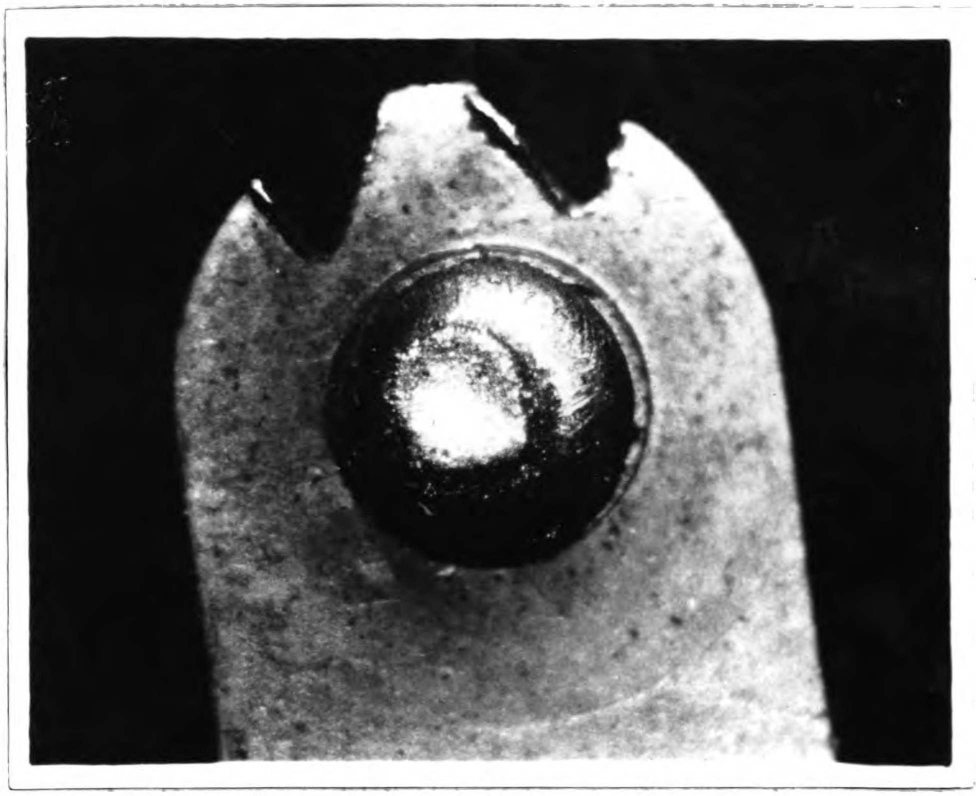

C18 Pt. #18ga. 15000 impulses. Pos.



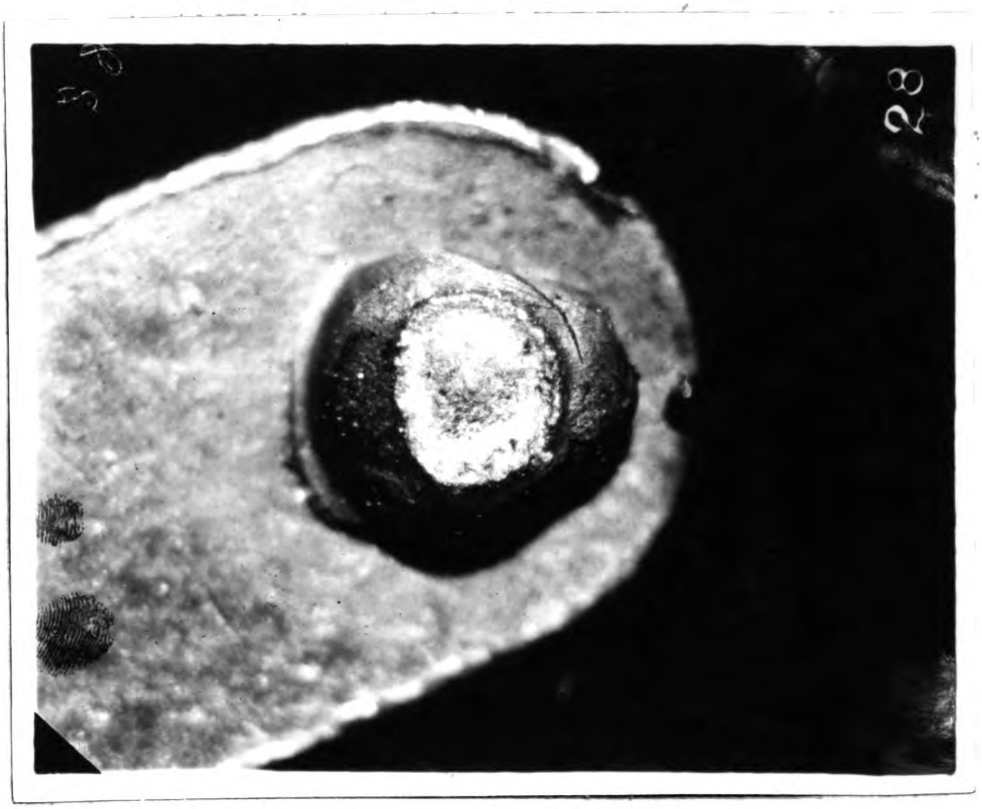
C25. Pt. #18ga. 1yr. Service. Pos. Los Angeles, Cal.



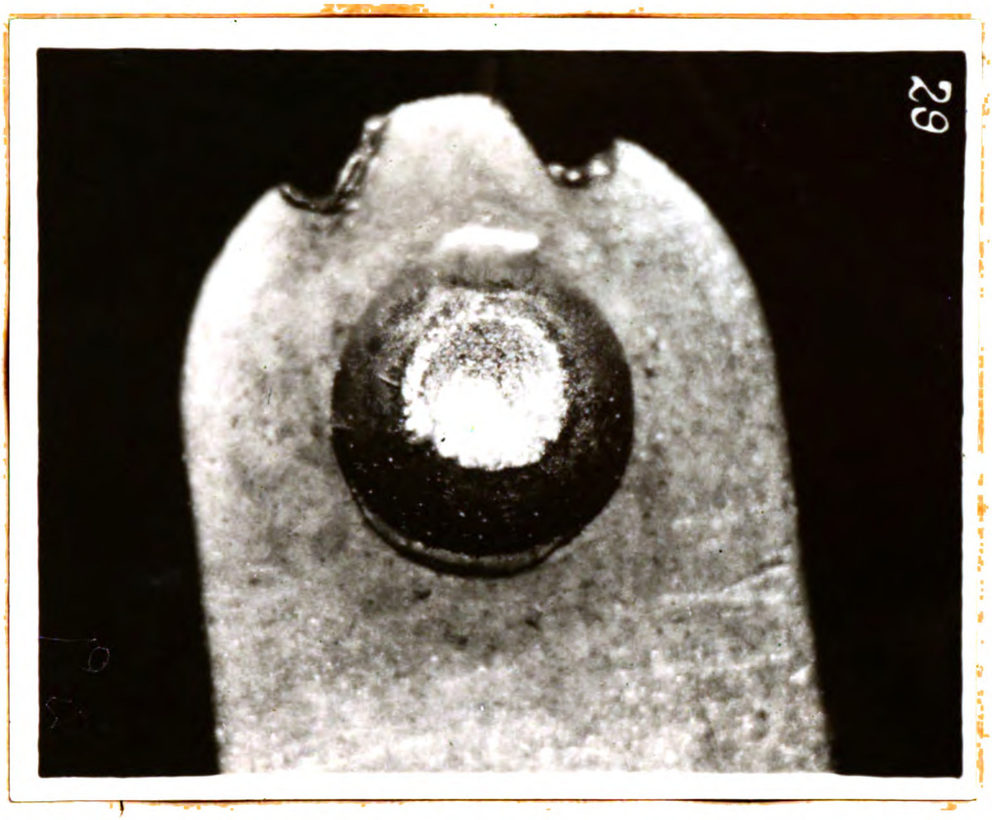
C26. Pt. #18ga. Neg. Honolulu, Hawaii, H.T.



C27. Pt. #18ga. 765520 impulses. Pos. Damper Spring.



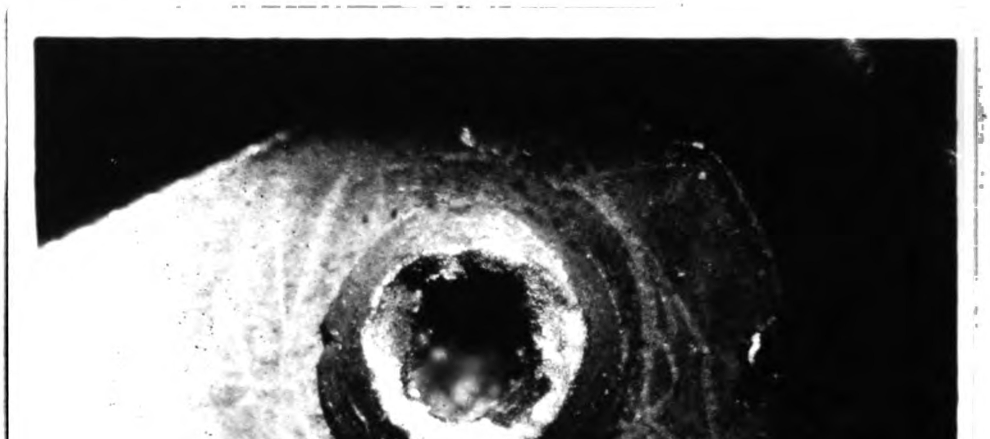
C28. Pt. #18ga. 765520 impulses. Neg. Damper Spring.



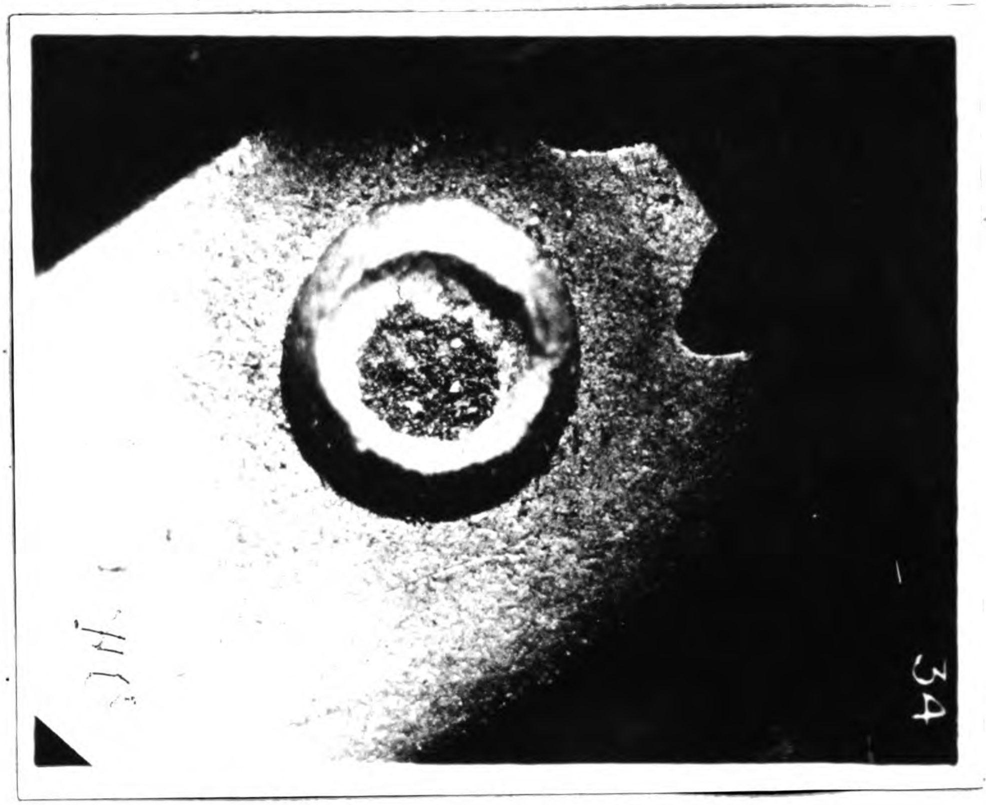
C29. Pt. #18ga. 788960 impulses. Pos. Damper Spring.

C30. Pt. #18ga. 788960 impulses. Neg. Damper Spring.

C31. Pt. #18ga. 1515140 impulses. Pos.



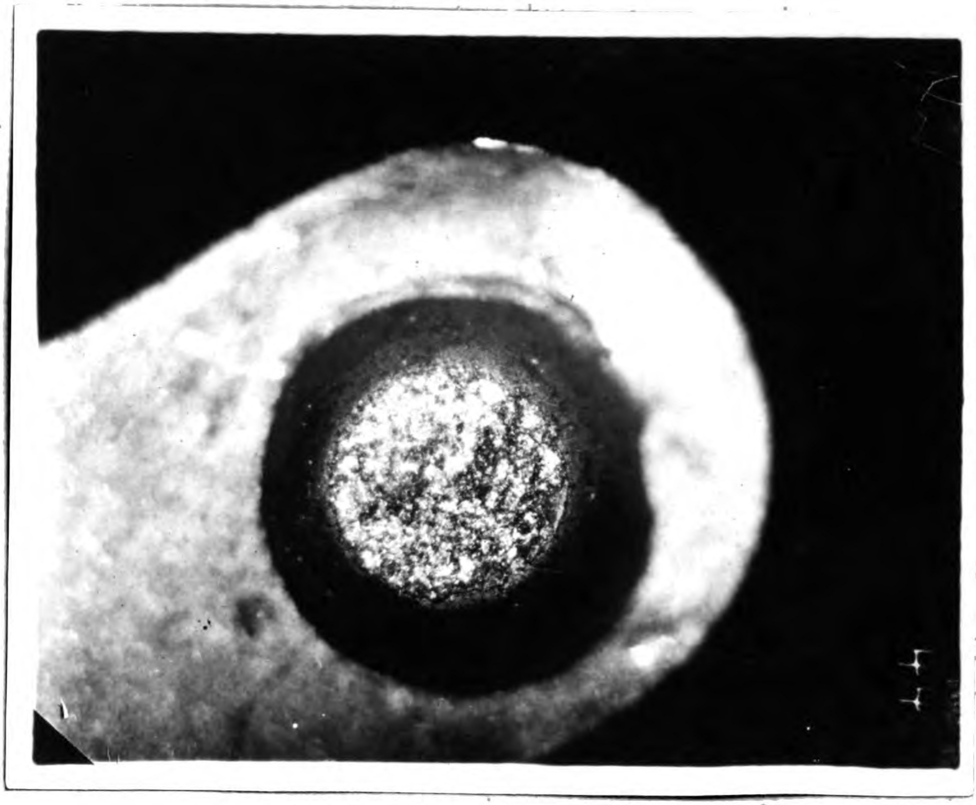
C32. Pt. #18ga 1515140 impulses. Neg.



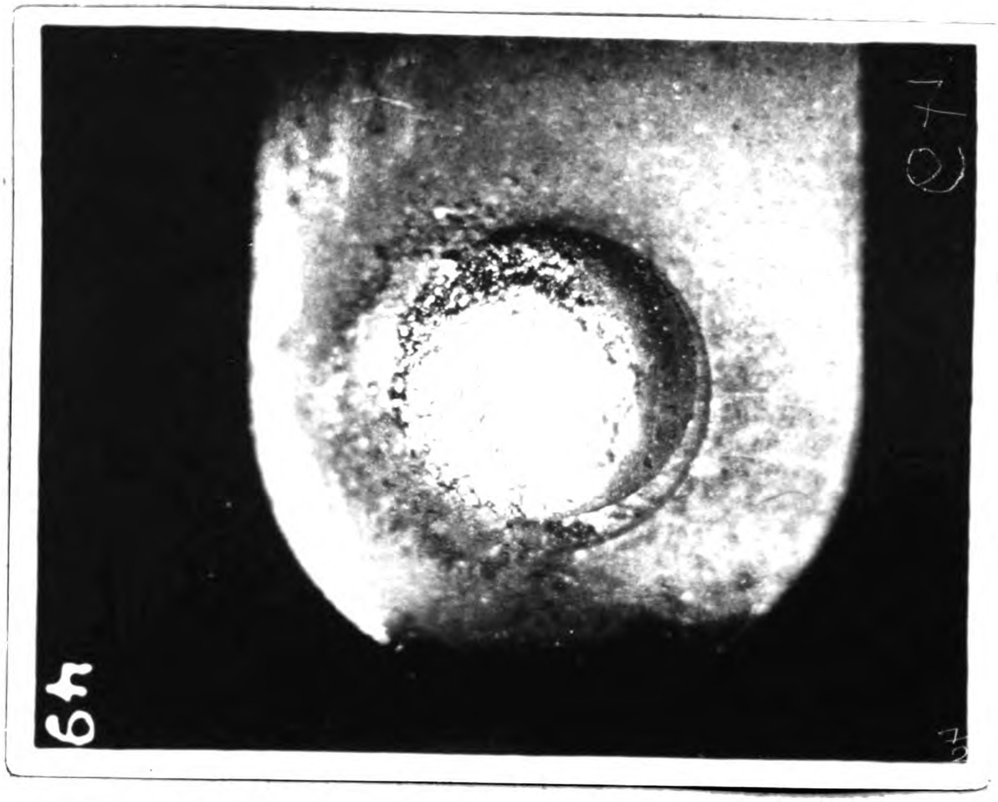
C34. Pt. #18ga. 5 years. Honolulu Hawaii H.T. Neg.

C35. Pt. #18ga. 5 years. Honolulu, Hawaii. H.T. Pos.

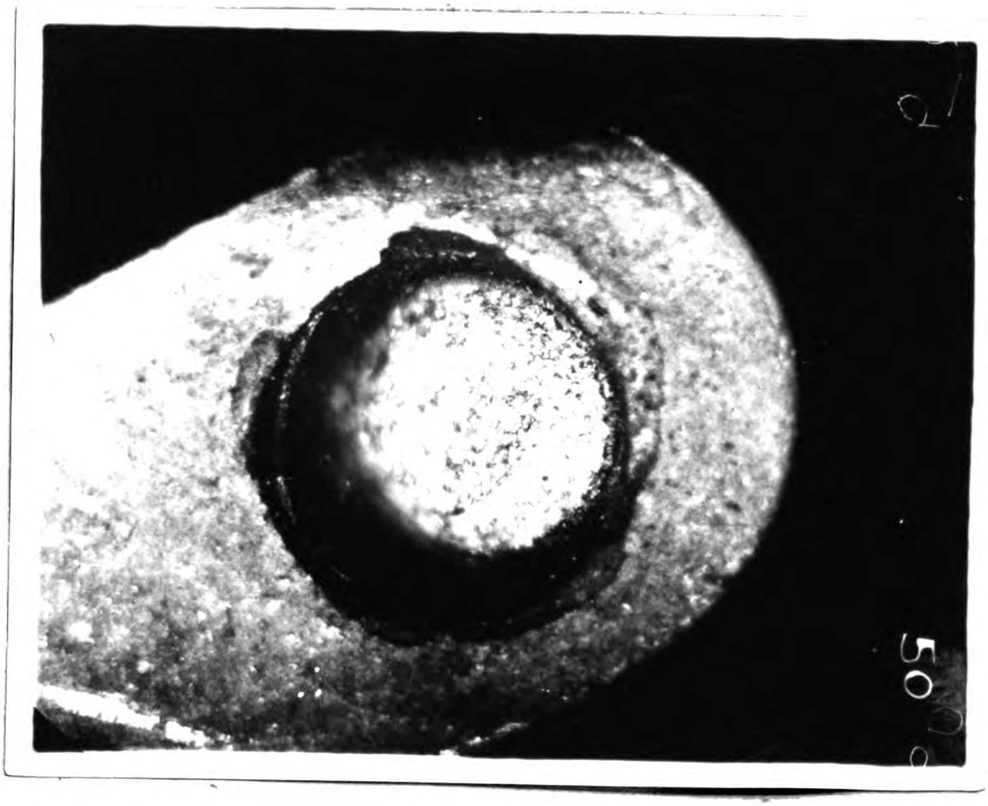
C43. Pt. #18ga. 3028540 impulses. Pos.



C44. Ag. #14ga. 3028540 impulses. Neg.

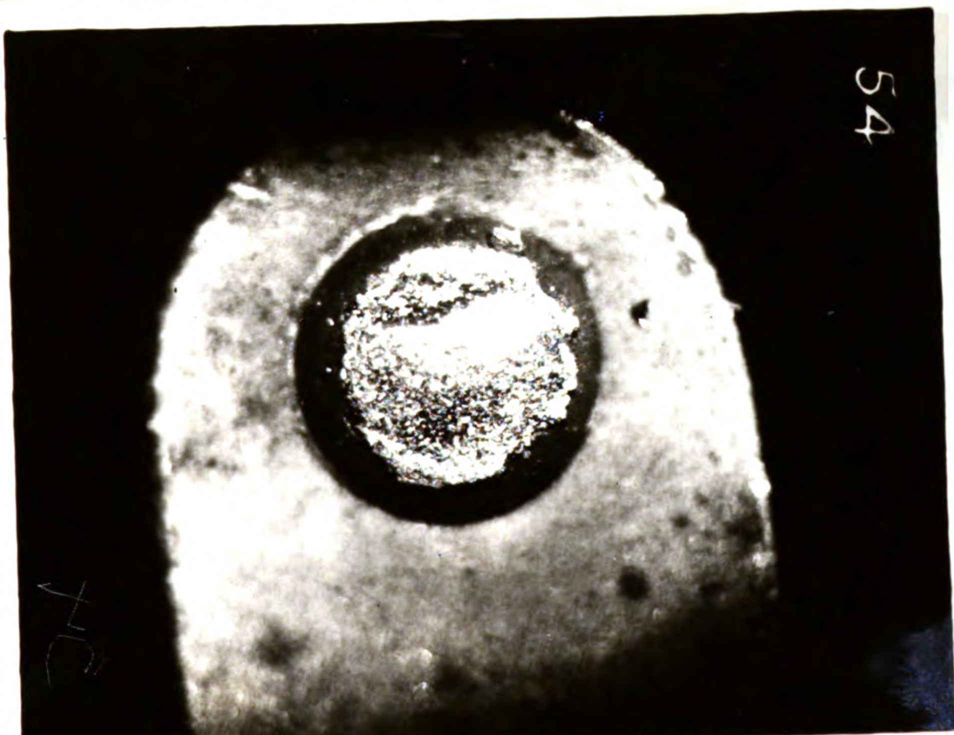


C49. Pt. #18 ga. 2887800 impulses. Pos.

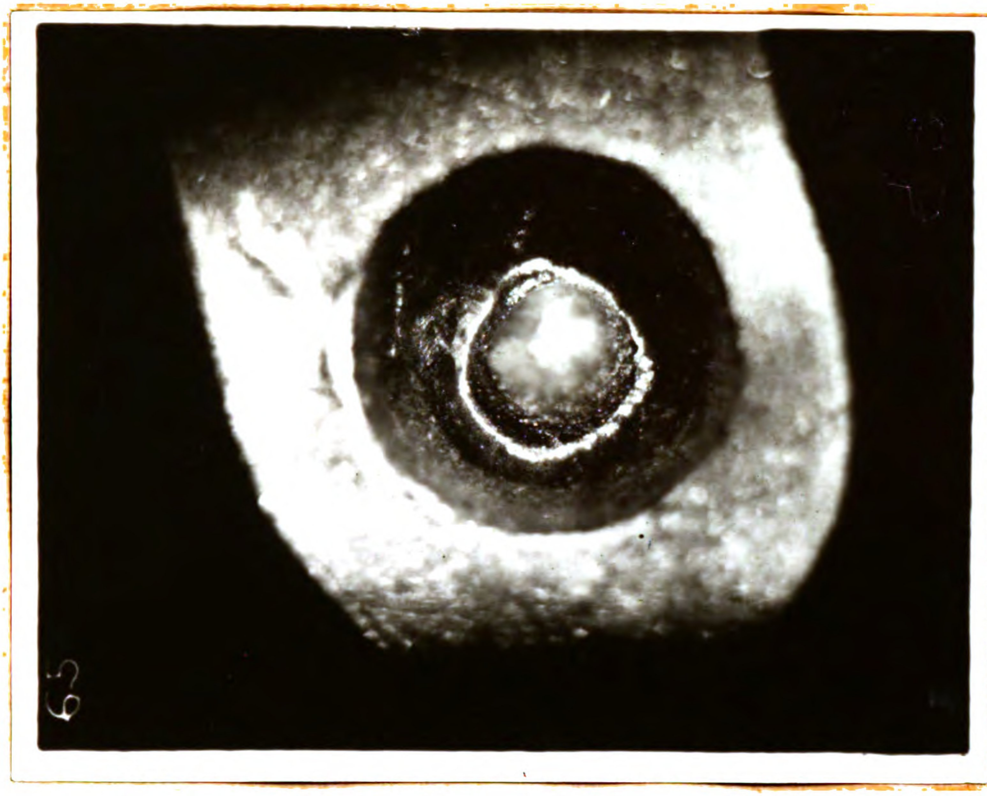


C50. Au. #14 ga. 2887800 impulses. Neg.

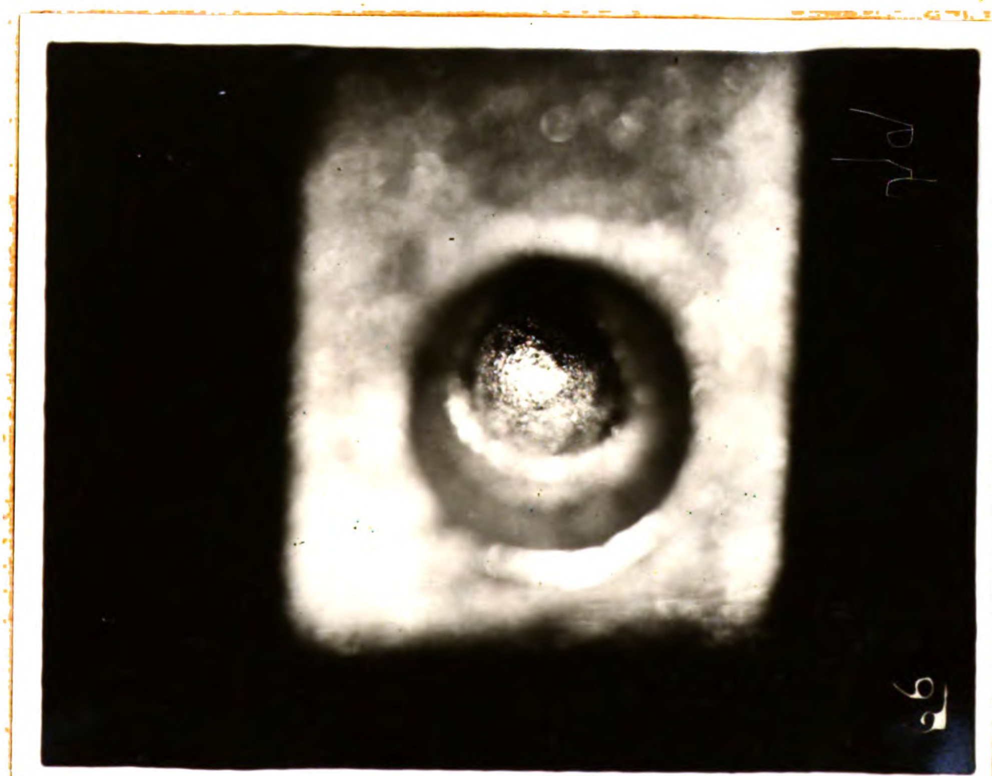
R 53. Ag. #149a 5296275 impulses. Neg.



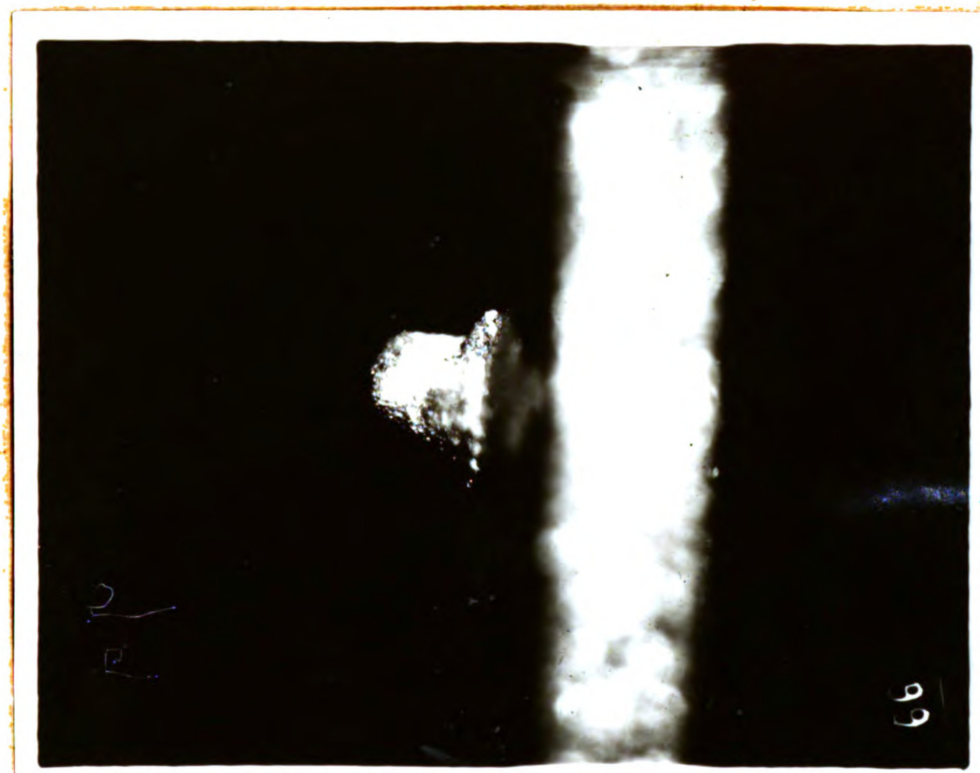
R 54. Pt #189a. 5296275 impulses. Pos.



R65 Aq. #14qa. 3508175 impulses. Pos.



R66. Pt. #18qa. 3508175 impulses. Neg.



R66. Pt. #189a. 3508175 impulses. Neg.

Side View.

ROOM USE ONLY