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TECHNICAL REPORT

MATERIAL LABORATORY

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9ND-NYNS-900-P-1A

DRY CIRCUIT PHENOMENA
and
VARIABLE CONTACT RESISTANCE
of
PRESSURE TYPE ELECTRICAL CONNECTIONS

Fundamental Study Project No. 30
Final Report

20 December 1962

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SUMMARY

The signal levels in modern electronic equipment are often of a very low level and with present trends toward transistorized and miniaturized gear signals of lower levels will be common. Environmental conditions for these equipments are also becoming more severe in shipboard and missile applications. This project concerns the development of methods and instrumentation for a more complete and precise evaluation of pressure type electrical connections in communication circuit sizes.

This work resulted in the development of effective methods for detecting:

a. Dry circuits at a signal level of 0.1 microvolt or more.

b. Contact resistance changes with varying load.

c. Transient and average resistance changes of connections, during mechanical disturbance, of 10 milliohms or more.

Recommendations were made to the Bureau of Ships during the course of this work to include methods (a) and (b), above, in an applicable specification. Both methods have been incorporated in specification MIL-C-22857 of 20 February 1962.

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ADMINISTRATIVE INFORMATION

1. This investigation was authorized under Fundamental Study Program of MATLAB SR 011-01-01 - September 1959, under the general job title "Military Sciences". Six semi-annual status reports were prepared on this study for Laboratory distribution.

ACKNOWLEDGMENT

2. This investigation was accomplished by the Cable Section of the Material Laboratory under the supervision of Mr. George J. Thompson, Section Head.

BACKGROUND

3. Signals encountered in electronic circuitry are often of a very low magnitude and pressure type electrical connections transmitting them require careful design and installation techniques. Electrical connections that would operate satisfactorily at potentials of a few volts to several hundred volts may appear as an open circuit (dry circuit) in the microvolt or millivolt signal level region. Pressure type connections may also be a source of electrical noise in electronic gear. The generation of this noise is often of sufficient magnitude to mask out the signal voltage and render the equipment inoperative. Although various studies have been made concerning electric contact theory (See Bibliography), firm methods and instrumentation for evaluating dry circuitry at low signal levels, contact resistance change versus loading and transient contact resistance conditions during mechanical shock or vibration have not been established. This investigation covers a study of pressure type electrical connections as applied to Navy equipment and the development of methods and instrumentation for their evaluation.

OBJECT

4. The object of this investigation was to conduct a study of electric contact behavior under dry circuit, current loading, and mechanical disturbance conditions and develop methods and instrumentation to evaluate the quality of pressure type electrical connections.

PROCEDURE

5. A comprehensive study was made of electric contact theories which included a review of previous work (See Bibliography) and conferences with representatives of manufacturers of electronic gear. The information obtained was analyzed and a plan of attack was decided upon for the evaluation of pressure type electrical connections as applicable to Navy equipment. The overall project was divided into three parts under the following general subjects:

a. Dry Circuits - Investigation of pressure type connections at signal levels as low as 0.1 microvolt.

b. Resistance Change vs Load Current - Investigate changes in contact resistance from a low level current to full load.

c. Resistance Transients - Investigate resistance change magnitude and duration in pressure type connections when subjected to mechanical disturbances.

RESULTS

6. Dry Circuits - Instrumentation was developed to detect dry circuit electrical connections at signal levels as low as 0.1 microvolt. The basic circuit used is shown under Figure 1 and consists of a battery, polarity reversing switch, rheostat, ammeter and calibrated shunt. The shunt consists of a copper bar 3" x 1/2" x 14" with ten indexed points located so as to provide 0.1 microvolt increments when the current in the bar was 0.2 ampere. Higher voltage levels were obtained by increasing the current in decades which resulted in proportional voltage drops in the bar. Although these low level voltages can be obtained by voltage divider systems, the method described herein was chosen both for simplicity and because of its low resistance voltage source that provides stability regardless of external circuit resistance changes. The portion of the circuit used to detect a dry circuit consisted merely of an electronic microammeter (KINTEL Model 204A) with a sensitivity of 2×10^{-11} ampere per division and an input impedance of 10^4 ohms in series with the electrical connection being investigated. With an applied potential of 10^{-7} volts and a test sample connection of negligible resistance, the detecting current is 10^{-11} ampere or 1/2 division on the microammeter at maximum sensitivity. Although this amount of instrument deflection is sufficient to detect connection continuity or a dry circuit, ambient electrical noise was usually of a magnitude that caused instrument pointer drift and masked out the signal being detected. Stability of the equipment was improved by carefully shielding all leads and supplying 110 volt, 60 cycle power to the microammeter from an isolated source (Small motor-generator). Further improvement of the visual detection system was accomplished by connecting a low range millivoltmeter to the output of the vacuum tube microammeter amplifier and observing the greater pointer deflections obtainable on the millivoltmeter. Vacuum tube microammeters with higher sensitivities are available, such as the Kiethley model 150A with a sensitivity of 10^{-10} ampere full scale, but this instrument has an input resistance of 10^6 ohms. This high resistance in series with a test connection resistance in the order of 10^5 ohms would barely be detectable. Although calibration of the lower impedance microammeter that was used with the auxiliary millivoltmeter was not attempted because of noise interference, contact resistances in the order of a few thousand ohms were detectable at 10^{-7} volts and dry circuits were determined on a "go" and "no go" basis.

7. An investigation was conducted on randomly selected pressure type electrical connectors most of which had been conditioned by vibration, salt spray and overload. Although these connectors were investigated primarily to test the operation of the aforementioned equipment, several dry circuit connections were detected and the range of voltage required to obtain electrical continuity was from 0.2 microvolts to 50 volts. The maximum rate of contact failures (dry circuits) found was approximately 1 in 20 for any particular connector type investigated. During the evaluation of these connections it was found that after the voltage had been increased to a level that caused electrical continuity in a dry circuit, reducing the voltage to the lowest level (0.1 microvolt) did not interrupt the circuit.

8. Contact Resistance versus Current - The resistance of the connectors was determined after the dry circuit measurements by the ammeter-voltmeter method.

The low level measurement was made by applying an open circuit potential of 20 millivolts and limiting the connector current to a maximum of 50 milliamperes. This was followed by a resistance measurement at full connector load. Both measurements were made as rapidly as possible to minimize heating effects.

9. Transient Changes in Contact Resistance - Methods and instrumentation to determine the transient changes of connector resistance when subjected to mechanical disturbance were developed. The procedure used to produce mechanical disturbance was the shock test described under Method 202A in MIL-STD-202B of 14 March 1960. A wiring diagram showing the circuit devised to detect transient resistance changes with magnitudes in the order of 10 milliohms or greater, and the provisions for oscilloscope calibration is shown under Figure 2. A photograph of the assembled equipment is shown under Figure 3. Referring to Figure 2, switch S_1 is first closed and rheostat R_1 is adjusted until the millivoltmeter indicates 20 millivolts. Switch S_2 is then closed and with decade resistor R_3 at zero, resistor R_2 and the oscilloscope controls are adjusted to internally trigger the oscilloscope when the decade resistor R_2 is increased one step (10 milliohms). The oscilloscope beam should be "zeroed" vertically at the center of the graticule and the beam deflection calibrated by increasing R_2 and R_3. After calibration has been completed resistor R_3 should be returned to zero and R_2 to its original position that will cause the oscilloscope to trigger when R_2 is increased 10 milliohms. Because of the exceptionally low signal level produced across the 0.1 ohm resistor for the oscillograph circuit, a D.C. amplifier (Kiethley, Model 150A) was used to increase the signal to the input of the oscilloscope. Although the output of this amplifier produces a wave shape with typical chopper characteristics as shown under curve "A" of Figure 4, examination of wave forms generated by connections subjected to impact indicates that transient resistance magnitudes can be measured with an accuracy of approximately $\pm$ 5 percent which is considered adaquate for this type of measurement. Curve "B" on Figure 4 shows a typical oscilloscope calibration of from zero to 200 milliohms by the resistance substitution method previously described. Curve "C" of Figure 4 shows transient resistance changes of ten pin and socket type connectors in series when subjected to impact. Curve "D" of Figure 4 shows a transient resistance change followed by a wire break after approximately 15 milliseconds at a crimped connection on a pin and socket type connector.

10. Measurements were taken on one "As Received" and seven aged multi-contact connector specimens, using the equipment and procedure described in paragraph 9, above. The connector specimens had gold plated contacts and the aged specimens had been subjected to 500 insertion and withdrawal cycles, followed by the salt spray test in accordance with paragraph 4.3.7 of MIL-E-16366C(Ships). The connectors were subjected to five 50 G impact drops followed by five 100 G impact drops. The contacts showed change of resistance due to impact as follows:

Specimen	Condition	Number of Contacts Used	Change of Resistance, Milliohms									
			50 G Impact					100 G Impact				
			1	2	3	4	5	1	2	3	4	5
1	"As Received"	10	*	*	*	*	*	*	*	*	*	*
2	Aged	10	10+	10+	*	10+	10+	10+	*	+90, -30	10+	*
3	Aged	6	1100+	10+	10+	+20, -80	10+	+50, -300	-1100+	10+	Similar to 1	Similar to 1
4	Aged	5, 4	*	+60, -30	*	+20	+260	1 Contact opened	1100+	+20	+200	+20
5	Aged	10	*	*	10+	10+	*	+40, -20	+100, -50	*	*	*
6	Aged	10	*	*	*	10+	*	+30, -20	+60, -30	1100,+ -10	-640	+100, -60
7	Aged	10	*	*	*	*	*	*	+10, -20	Similar to 2	Similar to 2	Similar to 2
8	Aged	10	*	+20, -10	+20, -10	+180	+60, -50	+90, -80	Similar to 1	+240 -20	Similar to 1	+100, -50

* Less than 10 milliohms

Oscilloscope traces showing change of resistance due to impact are shown in Figure 5, as follows:

Curve	
A	Specimen 3, first 50 G impact
B	Specimen 8, first 100 G impact
C	Specimen 4, first 100 G impact
D	Specimen 4, second 100 G impact

11. Contact Resistance Change During Vibration - The method for determining contact resistance changes as described under paragraph 9 of this report is applicable when transient resistance changes with durations in the order of microseconds or milliseconds occur, such as when an electrical connection is subjected to a single impact. A method and instrumentation was also developed to record connector resistance changes over longer periods of time as may occur when a connector is subjected to continuous vibration. A simple series circuit consisting of a two volt battery, milliammeter, rheostat, decade calibrating resistors (0.01 and 0.1 ohm steps) and test specimen was used and the voltage drop across the test specimen was applied to the input of a Model 851321 continuous balance Brown recorder operated at maximum gain and sensitivity. The circuit current was adjusted for one milliampere and the recorder was calibrated by increasing the decade resistors from zero in ten milliohm steps. The resultant calibration curve is shown on the left side of Figure 6. The recorder calibration was found to be approximately linear on both sides of the zero center and the sensitivity was 3.6 milliohms per scale division. A pin and socket type connector that had been conditioned by current overload and salt spray was subjected to random vibration to demonstrate the operation of the equipment and the resultant curve is shown on the right side of Figure 6. The recorder chart speed was one revolution in ten minutes and the stylus slewing speed was 20 seconds for full scale travel. The curve shown on the right side of Figure 6 represents either the actual resistance change or what may be termed a "long time average" of contact resistance variation. The relative slow response of the recorder as compared to that of the oscilloscope would exclude detection of a single transient resistance change with a duration of a few milliseconds but would tend to "average" a series of closely spaced transients.

CONCLUSIONS

12. The methods and instrumentation developed and described in this report will detect a "dry circuit" connection at a signal level of 0.1 microvolt or more, determine differences in connector resistance at 20 millivolts and at rated full load, detect transient resistance changes of 10 milliohms or more and record connector resistance variation during continuous vibration.

13. Conditions have been found under which pressure type connections used in Navy equipment have exhibited "dry circuits", resistance change dependent on applied voltage, and resistance change with mechanical disturbance.

RECOMMENDATIONS

14. Recommendations made during the course of this work have been accepted by the Bureau of Ships as follows:

a. The "Dry Circuit" test developed by the Laboratory has been included in Specification MIL-C-22857(SHIPS) of 20 February 1962 (Par. 4.8.13(a)).

b. The Resistance vs Load test developed by the Laboratory has been included in Specification MIL-C-22857(SHIPS) of 20 February 1962 (Par. 4.8.13(b)).

15. It is further recommended that the methods and instrumentation developed herein for determining transient and average contact resistance changes during mechanical disturbance be included in Specification MIL-C-22857(SHIPS).

16. The aforementioned methods should be applied to the development of optimum materials and platings for connectors in sizes normally used for communication circuits.

Samuel H. Behr
SAMUEL H. BEHR
Principal Investigator

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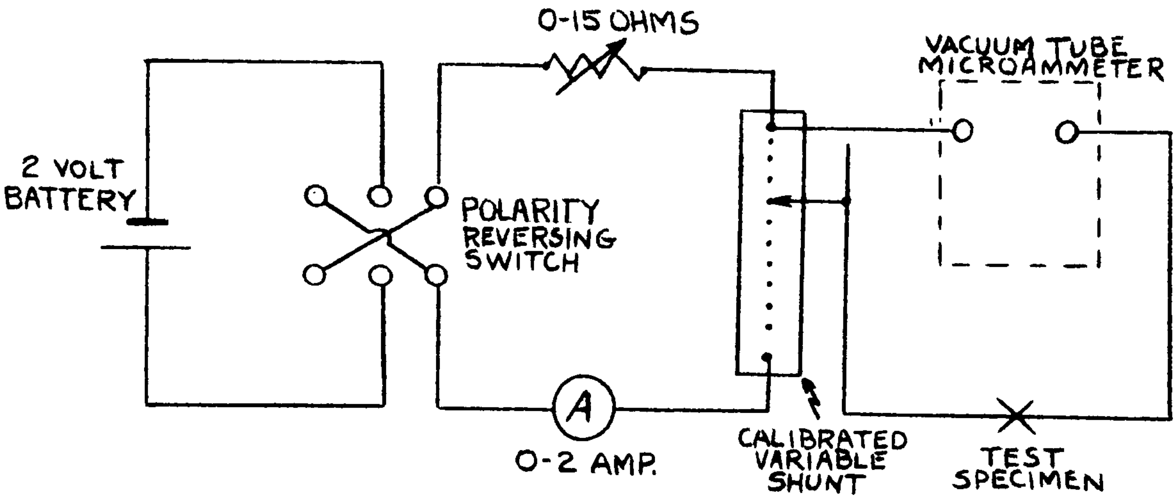
FIGURE 1

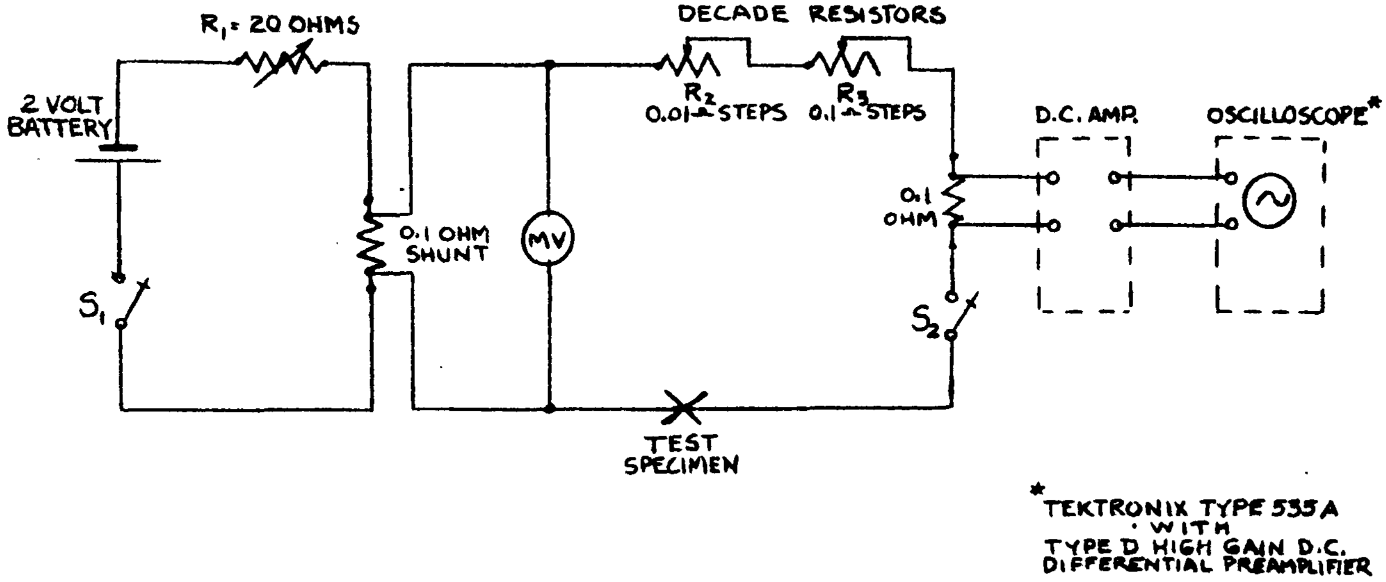
CIRCUIT FOR DRY CIRCUIT MEASUREMENT



NOTE: See text (Par. 6) for detailed description of equipment.

FIGURE 2

CIRCUIT FOR TRANSIENT RESISTANCE CHANGE MEASUREMENT



NOTE: See text (Par. 9) for detailed description of equipment.

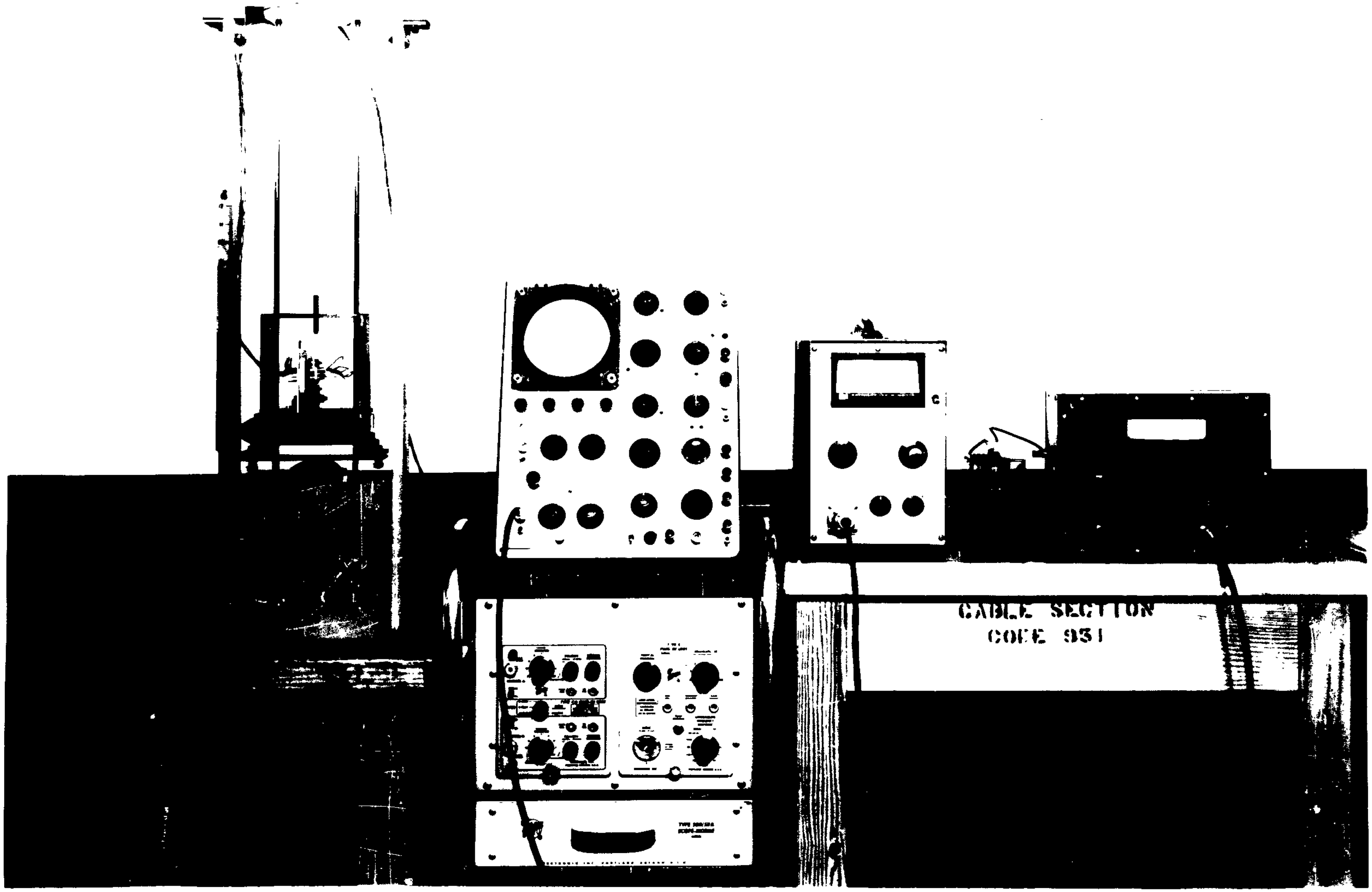


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Figure 3 - Equipment for Transient Resistance Change Measurements.

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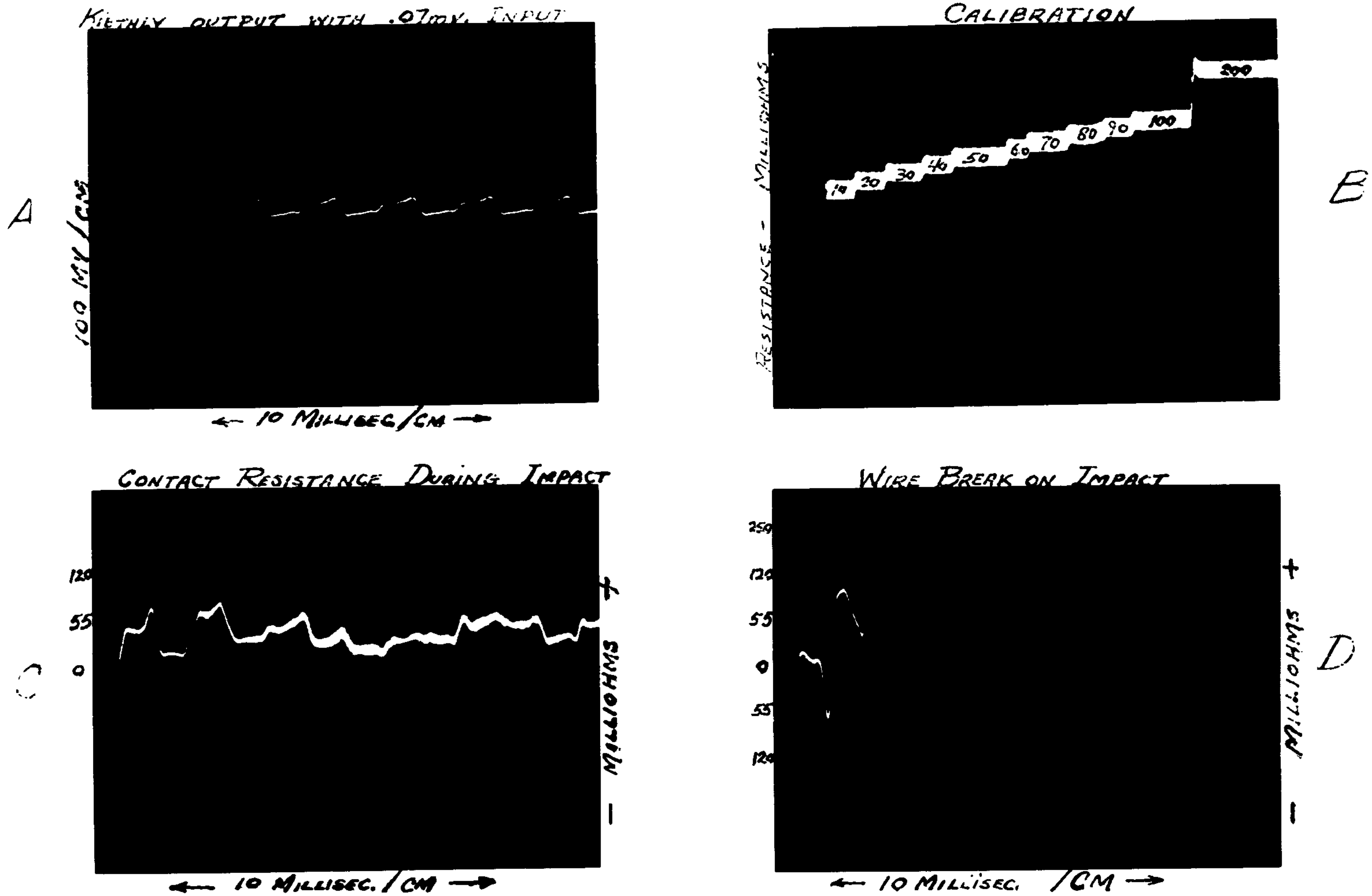

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Figure 4 - Oscilloscope Traces

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FIGURE 5

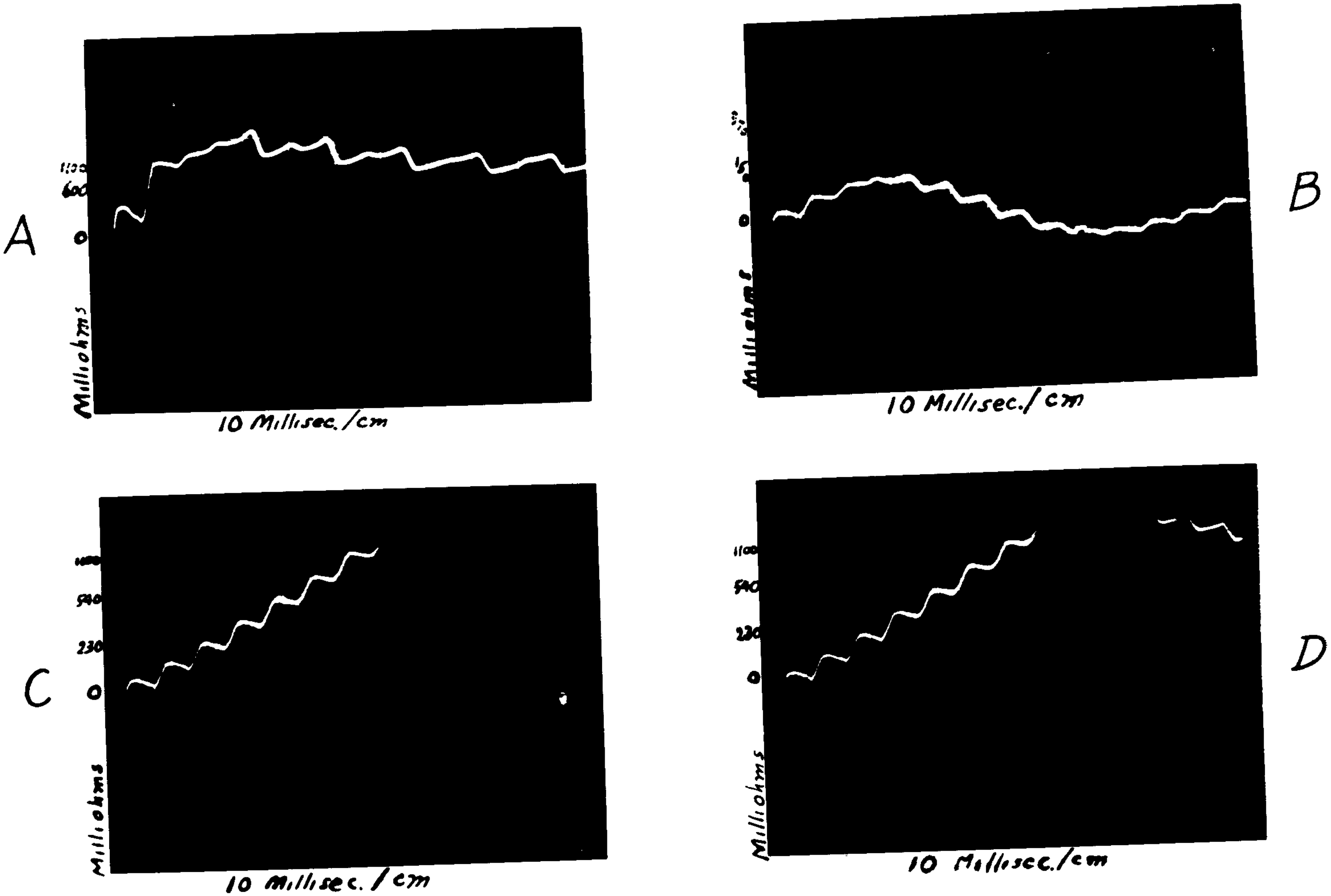

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Figure 5 - Oscilloscope Traces Showing Change of Contact Resistance Due to Impact

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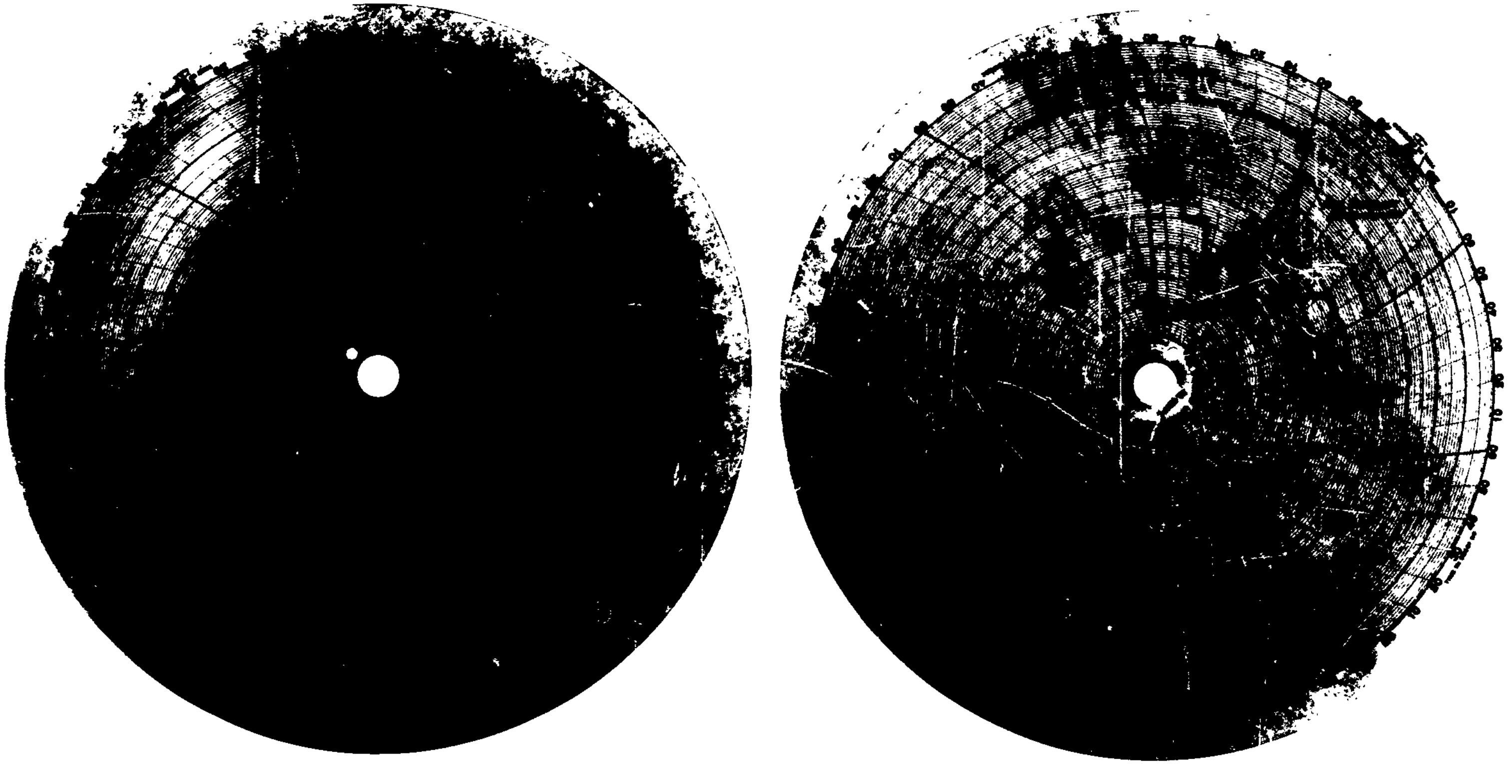

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Figure 6 - Calibration Curve and Resistance Change of Connection Subjected to Random Vibration

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