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AIRCRAFT ELECTRICAL RESEARCH DIVISION
ENGINEERING AND EVALUATION SECTION

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PROCEDURE FOR CONDUCTING CONTACT RESISTANCE (MILLIVOLT DROP) TESTS ON AN CONNECTORS

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Report E-2816

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NRL Problem No. 31E83

ABSTRACT

Two problems dealing with AN electrical connectors were investigated in accordance with Project Directive TED No. NRL 31E83. These were: (1) determination of the most suitable method of measuring millivolt drop across the contacts, and (2) to establish whether the values of millivolt drop now stated in Specification AN-W-C-591b, reference (a), should be changed. The following methods of measuring millivolt drop were investigated: (a) by holding the contacts in parallel V's or on knife edges, (b) by the use of sharp pointed probes built in the form of dividers, and (c) by means of pigtail leads soldered to the contact terminals together with the main conductor cable.

As a result of tests described herein and based on experience of previous qualifying tests, the conclusion has been reached that when measuring millivolt drop in qualifying laboratory tests where the contact is necessarily assembled in the connector, pigtails should be used. However, if millivolt drop is to be measured at the place of manufacture where the contact is unassembled, then the most suitable method is the use of paralleled knife-edged V's.

With respect to the specified millivolt requirements and as a result of tests and analysis of values obtained from other reports, it is concluded that while the present specifications are not out of line with the progress of the art, acceptance tests are based on average values which allow a few contacts with extremely high drops to be accepted. For the purpose of eliminating these contacts with high drops either a method of inspection and test should be devised which will eliminate all contacts having abnormally high millivolt drops, or the contact should be redesigned in such a way as to reduce the wide variation of millivolt drop, taking into account the manufacturing tolerances which must be allowed for in the production of large numbers of contacts.

Both of these aspects of the problem are outside the scope of the present investigation.

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AUTHORIZATION

1. The investigation reported herein was requested by the Bureau of Aeronautics in reference (a).

INTRODUCTION

2. This project was undertaken because of the need to review the present millivolt drop specification (reference (c)), combined with a request from the Cannon Electrical Development Company (reference (b)), for a change in specification requirements. The Cannon Electric Development Company also suggested a new method of determining millivolt drop consisting of parallel V's or knife edges. Accordingly, this method was investigated and compared with the present method used as well as with a third method devised by this Laboratory. The importance of a millivolt drop specification lies in the fact that the measurement of this drop and its change after environmental and endurance tests furnishes a valuable indication of the quality of the contact with respect to design, quality of the material, ability to maintain contact pressure, resistance to corrosion, and quality of the silver plating. In reviewing the millivolt drop specifications, several factors are involved. The magnitude of the voltage drop across a contact, as well as in any other piece of electrical equipment, is important because it is related to the following factors:

(a) system voltage regulation
(b) temperature rise
(c) power loss.

That each of these factors should be as small as possible, consistent with size and weight, needs no argument. In this investigation, the second factor (temperature) is particularly examined to determine whether the present specified millivolt drops give dangerous temperatures or give temperatures exceeding those of the associated cables.

3. Millivolt drop measurements have, in the past, been made on contacts assembled in the connector. This has been done because of the necessity to make other tests on the assembled connector, and because the millivolt drop measurements are repeated during and after the environmental and endurance tests. The procedure of this Laboratory as requested by the Bureau of Aeronautics has been to average all millivolt drop measurements for any particular size and manufacturer; and, on the basis of a comparison of this average with the specified value, to recommend acceptance or rejection of the product. An analysis of the qualification tests made by this Laboratory indicates a very wide variation of these millivolt drops from the average. Also, the contacts having abnormally high millivolt drops are those which cause most of the trouble in the field, and are those which should be eliminated.

There is included in this report a consideration of the necessity of closer inspection control of the product by the manufacturer, and a sounder statistical approach to the evaluation of millivolt drop.

4. The examination of millivolt drop specifications is accordingly divided into two parts. The first is a discussion of the tests made particularly for the purpose of this investigation and of the results obtained. The second part is a general discussion and analysis of millivolt drop measurements previously made by this Laboratory and contained in qualification test reports as indicated in the bibliography (reference (d) to (f)).

DISCUSSION OF PROCEDURE AND RESULTS

5. The majority of the tests to study means of measuring the millivolt drop were made on a number of different connectors manufactured by the American Phenolic Corporation, the Cannon Electric Development Company and the Monowatt Electric Corporation. Tests on individual contacts were made on all sizes from No. 0 to No. 20 from these same companies. The data for the analysis of millivolt drop values is taken from previous laboratory reports as indicated in references (d) to (f).

6. Millivolt drop across a contact generally refers to the drop across the entire length which may be as much as 2 1/2 inches. In order to determine what part of the drop is in the material of the contact and how much occurs at the actual contact surfaces, measurements were made by placing pointed probes attached to voltmeter leads on either side of the junction point of the male and female contacts and as close to this point as possible. The results are given in Table I and, except for a number of wide variations, indicate that the drop at the point of contact constitutes from 30 to 40 per cent of the total millivolt drop. Inasmuch as all of the specified qualification tests are made on the assembled connector and since the contact junction point is then inaccessible, the points at which the millivolt drop measurements are made is important as over 60 per cent of the total drop is in the contact material itself. In the following proposed methods which are described, this subject is, therefore, discussed and is made one of the criteria of the value of the method.

7. Methods of Measuring Millivolt Drop. In the following discussion the measurement of millivolt drop is considered from two points of view, (1) measurement of the drop across a single isolated contact, and (2) measurement of the drop across a contact when assembled in a connector.

8. The method proposed by the Cannon Electric Development Company (reference (b)) consists of the use of two small V-shaped knife edges mounted on a structure giving them rigidity and spaced

1 5/8 inches apart. When measuring millivolt drop the contact is pressed down in the V making contact on the knife-edged sides. Suitable leads are connected from the V's to a millivoltmeter.

9. This method is satisfactory for use with single unassembled contacts. It cannot, however, be used on contacts assembled in a connector as is done in qualifying tests in the laboratory because of interference with other contacts and with the back shell of the connector. In specifying the spacing of the V's no fixed arbitrary distance should be stated for all size contacts, but rather this distance should have some definite relation to the length of the particular size contact being tested.

10. The use of straight knife edges is similar to that of the V's, but the latter method has two advantages: (1) it furnishes two points of contact instead of one, and, (2) it assures having the contact rigidly fixed while being tested.

11. Dividers (see figure 1) were designed and constructed as an alternative method of measuring contact drop. In application they are held in the hand and applied to the extreme ends of the contacts. With clean contacts very little pressure is necessary, and even after the contacts have been subjected to corrosion testing, it is not difficult to penetrate any corrosive coating and obtain a good reading. This method is very easy and rapid to apply. Its principal disadvantage is that it can only be used when the shell does not extend beyond the back sockets of the contacts. This is not the case with most connectors now available, but a number of new designs have been considered having a non-removable back shell which would preclude the use of dividers.

12. The present method of measuring contact drop is by the use of pigtails (figure 2) which are soldered to the contact sockets together with the main conductor wires. The chief disadvantage of this method is the length of time required to solder these additional pigtail wires. Other disadvantages are the possibility of getting a poorly soldered joint which would give erroneous readings and the possibility of having the pigtails short with adjacent ones and also give erroneous readings. This latter, however, could be overcome by using insulated pigtails. The principal advantage of this method is that it is equally applicable to all designs of connectors both present and future.

13. Temperature Investigation. High operating temperatures have injurious effects on connectors as follows:

(a) The rate of oxidation approximately doubles for every 15°C rise in temperature and the corrosion itself reduces insulation resistances, increases contact resistance and increases the difficulty of mating the connectors.

(b) Electrolysis is also accelerated with an increase in temperature.

(c) Breakdown strength of the insert material and of the surrounding air are both reduced somewhat. However, this change is small up to 100°C which is the maximum operating temperature of the connector.

14. In view of the foregoing, tests were made to determine the temperature rise with varying contact drop and also to compare the temperature of the contact with that of cable of the same size. In making any comparison of temperature in a cable-connector system, a great many variables may be present which will affect the results. These variables are listed below:

(a) Rated current in a cable depends on whether the cable is single or in conduit and either rating is different from the rating of the same size contact.

(b) The temperature is in part dependent on the number of contacts in a connector.

(c) In a multiple contact connector the millivolt drop of all contacts will not be the same even though they are the same size.

15. For purposes of comparison of the temperature of the contact and cable and in order to reduce the amount of work involved, all the tests which follow were made with a single bare mated contact and aircraft type cable of the same size with both carrying the rated current of the contact.

16. Table II lists the millivolt drops which give equal temperatures at the contact and in the cable. These values are derived from the curves of figures 3 and 4. Figure 3 shows the change of contact temperature with millivolt drop at rated current. The millivolt drop was varied by marring the surface of the plug contact with a cold chisel and file. The curves of figure 4 are cable temperature versus current for each size cable. The use of these curves to obtain the figures of Table II can best be explained by example. From figure 4 the temperature of the No. 8 cable at rated current (of the contact) is seen to be 50°C. On figure 3 the No. 8 contact at the same temperature has a millivolt drop of 8.7 MV. As stated above these values will theoretically give an equal temperature in the contact and in the cable, and if they are exceeded there will be a flow of heat from the contact to the cable.

17. The test data in figure 3 is the average of measurements made on each of three manufacturer's products. There is a considerable variation among contacts of different makes and

in figure 5 are shown the temperature-millivolt drop curves of No. 4 contact made by Amphenol and Cannon. The Amphenol contact is larger than the Cannon (about 25 per cent by weight) and, therefore, has greater radiating surface and greater conductivity.

18. It will be noted, Table II, that on the basis of temperature the allowable millivolt drop on contact sizes Nos. 12, 16, and 20 are considerably higher than the present specification requirements. On contact sizes Nos. 0, 4 and 8, the millivolt drops giving the same temperature as the cable are somewhat lower than required by the specifications. At the specified values this means there will be a flow of heat from the contact to the cable. The difference for sizes Nos. 4 and 8 is negligible but for No. 0 the difference is 3 out of 8 millivolts or 37 1/2 per cent.

19. Table II also gives the millivolt drops based on the recommendations of the Cannon Electric Development Company. These are arrived at by calculation of the drop in 3 1/4 inches of cable of the corresponding size. This is a purely arbitrary figure and is twice the proposed V spacing of 1 5/8 inches. It is interesting to note, however, that these values very roughly approximate those based on temperature, particularly, that for size No. 0 the drop is again less than now specified.

GENERAL DISCUSSION

20. An analysis was made of all available millivolt drop measurements taken by this Laboratory. The results are shown in the curves of figures 6 to 11. These curves represent the combined data on contacts of all manufacturers. In order to make up these curves, all millivolt drop measurements on a particular size contact were arranged in ascending order of magnitude. For any assigned maximum value, the average value of all those below this figure was calculated and a curve plotted showing the average millivolt drop of a group of contacts having a preassigned maximum value. In each case the curve of maximum values rises at a uniform rate until, as it approaches the maximum number of contacts, a sharp rise is noted. It is these contacts with abnormally high millivolt drops which it would be desirable to eliminate and if all contacts having drops above a given maximum value were rejected, the average millivolt drop of those remaining would be fairly close to the present specification requirements as can be seen on the curves.

21. The above discussion has dealt with millivolt drops measured before the contact has been subjected to the environmental and endurance tests. After such tests the millivolt drop will be substantially greater than before the tests as indicated on the same curves. This increase in drop after the environmental

and endurance tests must be considered in assigning a maximum drop which will be accepted on a new contact because there must be some assurance that if a particular group of contacts is accepted on the basis of initial tests neither the maximum nor the average drop will be unduly high after environmental and endurance cycles.

22. Table III includes data taken from the curves of figures 6 to 11. The figures chosen were an attempt to keep the maximum millivolt drop within reason, and yet to prevent the rejection of too many contacts. Column II represents a suggested maximum above which any contacts will be rejected at the factory. If this is effected it can be reasonably expected that the maximum drop after environmental and endurance cycles will be as shown in column IV. Column III will give the corresponding average drop for this maximum. Column V represents the percentage of contacts of all manufacturers which will pass the specifications.

23. In order to eliminate those contacts having exceptionally high millivolt drops, consideration has been given to a production test whereby every mated contact pair would be tested for millivolt drop and only those having a drop at or below a certain specified value would be accepted. The weakness of this method arises from the fact that certain tolerances of the outside diameter of the plug contact and the inside diameter of the socket contacts are necessarily allowed. A particular pair may test satisfactorily but when the pair are separated and the two halves later used with other mating parts, the tolerances may be such as would give an abnormally high millivolt drop. Misalignment due to faulty insert material when later assembled in the connector may also cause a high millivolt drop,

24. A second possible method of eliminating those contacts having exceptionally high drops would be the design of an entirely new contact so that over the range of allowable manufacturing tolerances there would be less variation in the millivolt drop.

25. Investigations dealing with these two factors were felt to be beyond the scope of this report.

CONCLUSIONS

26. The use of V's represents the most practicable method of measuring the initial millivolt drop of unassembled contacts which may become an established practice at the place of production.

27. For measuring the millivolt drop of contacts assembled in connectors as in the Naval Research Laboratory qualification tests, pigtail leads soldered or crimped to the contact together with the current carrying conductors should be used.

28. While it was found important to keep millivolt drop at a minimum in order to keep temperature, system voltage drop and power loss at a minimum, it is of greater importance to eliminate the few contacts having abnormally high millivolt drops which are causing trouble in the field.

29. In order to accomplish this, further investigation should be undertaken to establish a method, preferably at the point of manufacture, whereby all contacts having high millivolt drops are eliminated, or to design a contact whose millivolt drop varies within comparatively narrow limits regardless of the allowable manufacturing tolerances.

RECOMMENDATIONS

30. If contacts are measured for millivolt drop in an unassembled condition, V-shaped knife edges should be used.

31. For measuring millivolt drop of contacts assembled in connectors, as in qualification tests, pigtail leads soldered or crimped to the contact together with the current carrying conductor should be used.

32. The Bureau of Aeronautics should undertake action to determine a means of initially testing contacts at the factory in order to eliminate effectively all contacts having abnormally high millivolt drops.

33. The initial millivolt drop to be used as a maximum acceptable value in factory testing involves engineering judgment. It can be based on the curves and data included in this report. A set of suggested values are shown in column II of Table III.

REFERENCES

34.
(a) BuAer ltr E-3122-MEH, F36-2(7), dated 25 August 1945.
(b) Cannon Electric Development Company letter dated 30 July 1945.
(c) AN Aeronautical Specifications AN-W-C-591b, Amendment 1, 18 April 1945.
(d) NRL Report F36-2(7)(760-1), 760-25/45(lb), dated 14 February 1946, Qualification Test on AN Electrical Connectors of Cannon Electrical Development Company.
(e) NRL Report F36-2(7)(760-1), 760-24/45(tj), dated 11 January 1946, Qualification Test on AN Electrical Connectors of American Phenolic Corporation.
(f) NRL Report F36-2(7)(760-1), 760-16/45(lb), dated 3 December 1945, Qualification Test on AN Electrical Connectors of Monowatt Electrical Corporation.

TABLE I

CONTACT DROP AS A PERCENTAGE OF TOTAL DROP

SIZE	MANUFACTURER	OVERALL DROP MV	CONTACT DROP MV	PER CENT
1/0	Cannon	10.0	5.9	59.0
	Amphenol	7.0	1.3	18.6
4	Cannon	5.9	1.7	28.8
	Amphenol	9.8	6.1	62.3
8	Cannon	6.2	2.4	38.7
	"	9.9	5.8	58.6
	"	4.2	1.6	38.1
	"	4.1	1.3	31.7
	"	3.8	1.2	31.6
	Amphenol	9.7	3.5	36.1
	Monowatt	5.5	1.6	29.1
	"	6.5	3.0	46.1
	"	7.1	2.7	38.0
	"	23.0	16.0	69.5
	"	6.8	2.7	39.7
12	Amphenol	13.2	4.5	34.1
	"	18.9	7.3	38.6
	Monowatt	13.9	3.0	21.6
	Cannon	22.3	6.0	26.9
16	Bendix	8.0	1.5	18.7
	"	6.0	1.8	30.0
	"	11.4	0.7	6.1
	Breeze	18.1	7.6	42.0
20	Elcon	3.6	1.2	33.3
	"	11.8	5.5	46.5
		Average		35.6

TABLE II

MILLIVOLT DROP VALUES OBTAINED BY VARIOUS CONSIDERATIONS

CONTACT SIZE	0	4	8	12	16	20
Current Rating of Contact	200.0	110.0	60.0	35.0	20.0	10.0
Millivolt Drop Giving Equal Temperature in Cable and Contact	5.0	7.5	8.7	22.0	27.0	27.5
Millivolt Drop Recommended by Cannon	6.0	8.0	11.0	16.0	22.0	28.0
Present Specifications	8.0	8.0	9.0	11.0	15.0	12.0

I

SPECIFICATION DATA BASED ON ELIMINATION
OF EXCEPTIONALLY HIGH MILLIVOLT DROP CONTACTS.

I	II	III	IV	V	VI	VII	VIII
AN SIZE	INITIAL MAXIMUM AT FACTORY	AT THE LABORATORY AFTER ENVIRONMENT & ENDURANCE CYCLES		PERCENTAGE OF PRESENT CONTACTS THAT PASS	UNASSEMBLED AVERAGE TEMP. °C.	UNASSEMBLED MAXIMUM TEMP. °C.	BASED ON AVERAGES PRESENT SPECIFICATION
		AVERAGE	MAXIMUM				
0	12	12.4	24.0	95	60	69.5	8
4	12	10.4	15.7	80	60	65.0	8
8	13	10.7	22.4	74	52	58.5	9
12	19	13.0	33.0	85	53	66.0	11
16	27	16.7	30.0	90	53	62.0	15
20	15*	10.0	35.0	90	40	53.5	12

* Size 20 contact is essentially the same physical size as the size 16, but the current rating is one-half; hence, the drop is approximately one-half that of size 16.

MILLIVOLT DROP BY DIVIDER METHOD

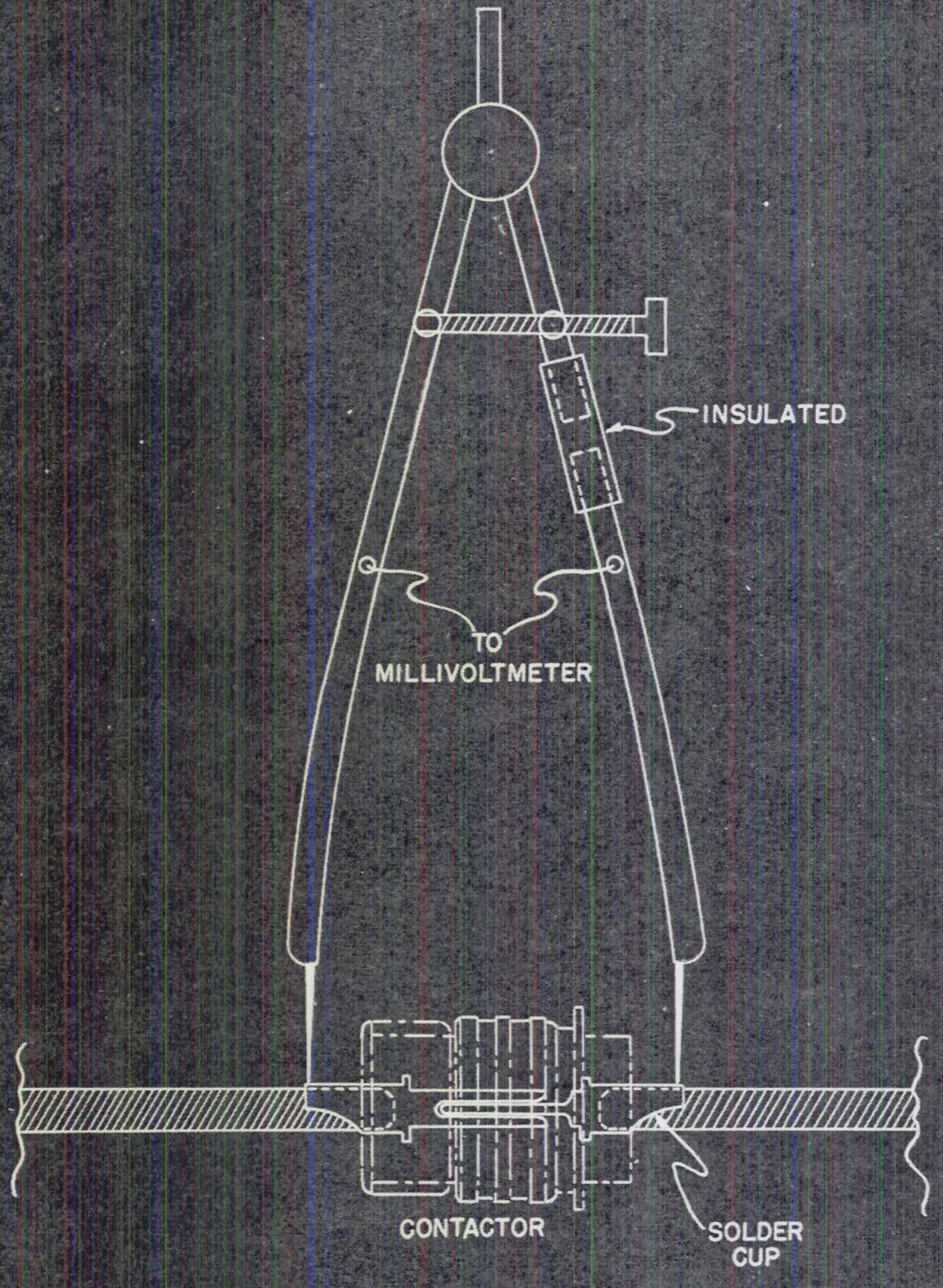

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FIG. 1

MILLIVOLT DROP BY PIGTAIL METHOD

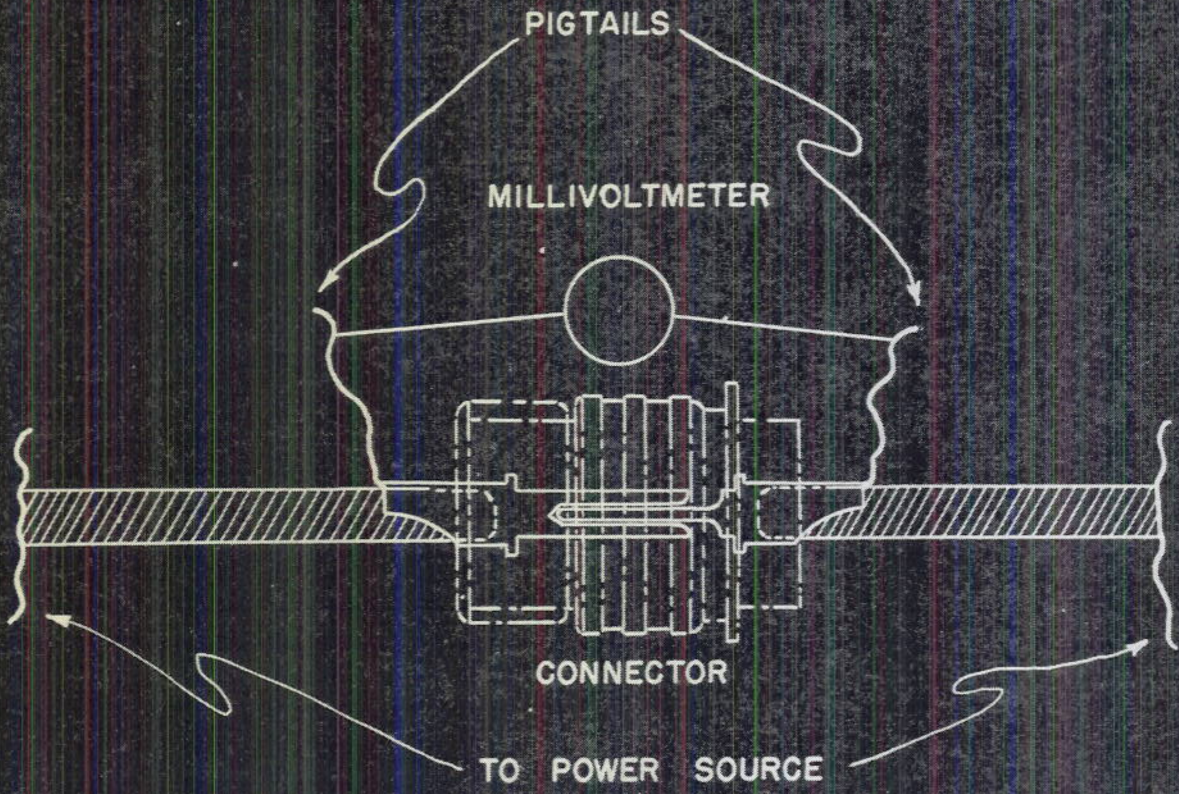

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FIG. 2

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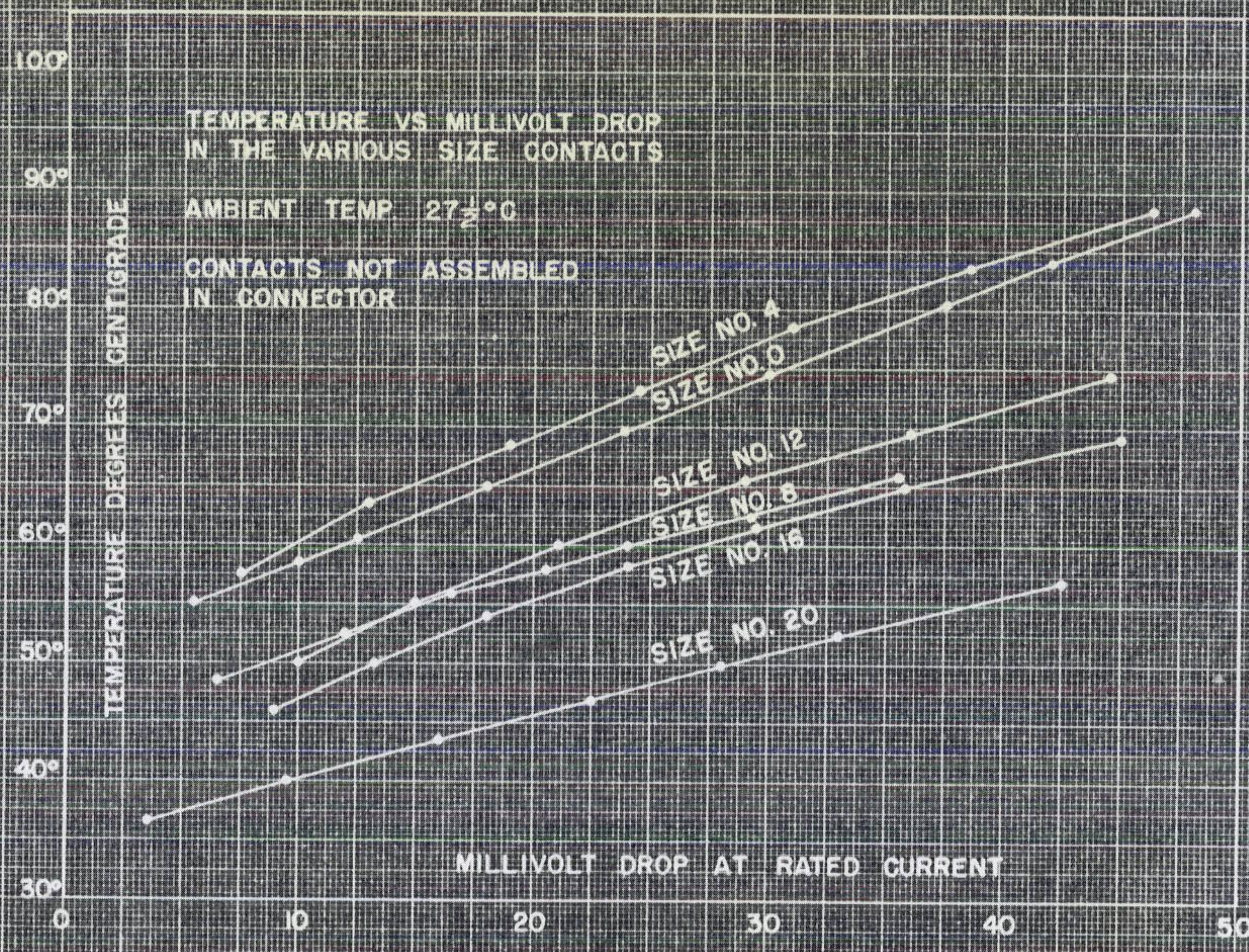

TEMPERATURE VS MILLIVOLT DROP
IN THE VARIOUS SIZE CONTACTS
AMBIENT TEMP 27½°C
CONTACTS NOT ASSEMBLED
IN CONNECTOR
TEMPERATURE DEGREES CENTIGRADE
MILLIVOLT DROP AT RATED CURRENT
SIZE NO. 4
SIZE NO. 0
SIZE NO. 12
SIZE NO. 8
SIZE NO. 16
SIZE NO. 20
100°
90°
80°
70°
60°
50°
40°
30°
0
10
20
30
40
50

FIG. 3

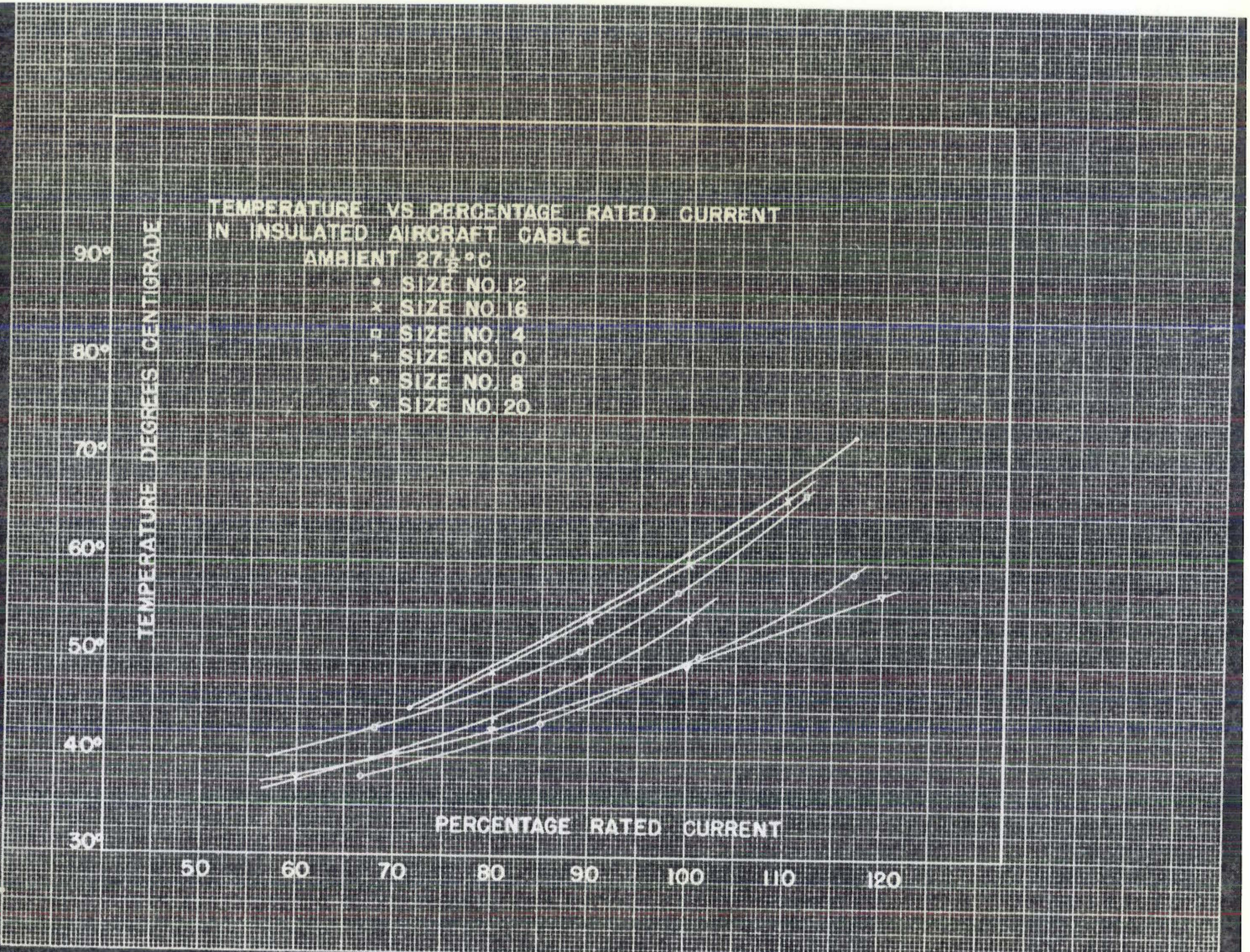
TEMPERATURE VS PERCENTAGE RATED CURRENT
IN INSULATED AIRCRAFT CABLE
AMBIENT 27½°C
• SIZE NO. 12
× SIZE NO. 16
□ SIZE NO. 4
+ SIZE NO. 0
○ SIZE NO. 8
▽ SIZE NO. 20
TEMPERATURE DEGREES CENTIGRADE
90°
80°
70°
60°
50°
40°
30°
PERCENTAGE RATED CURRENT
50
60
70
80
90
100
110
120

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FIG. 4

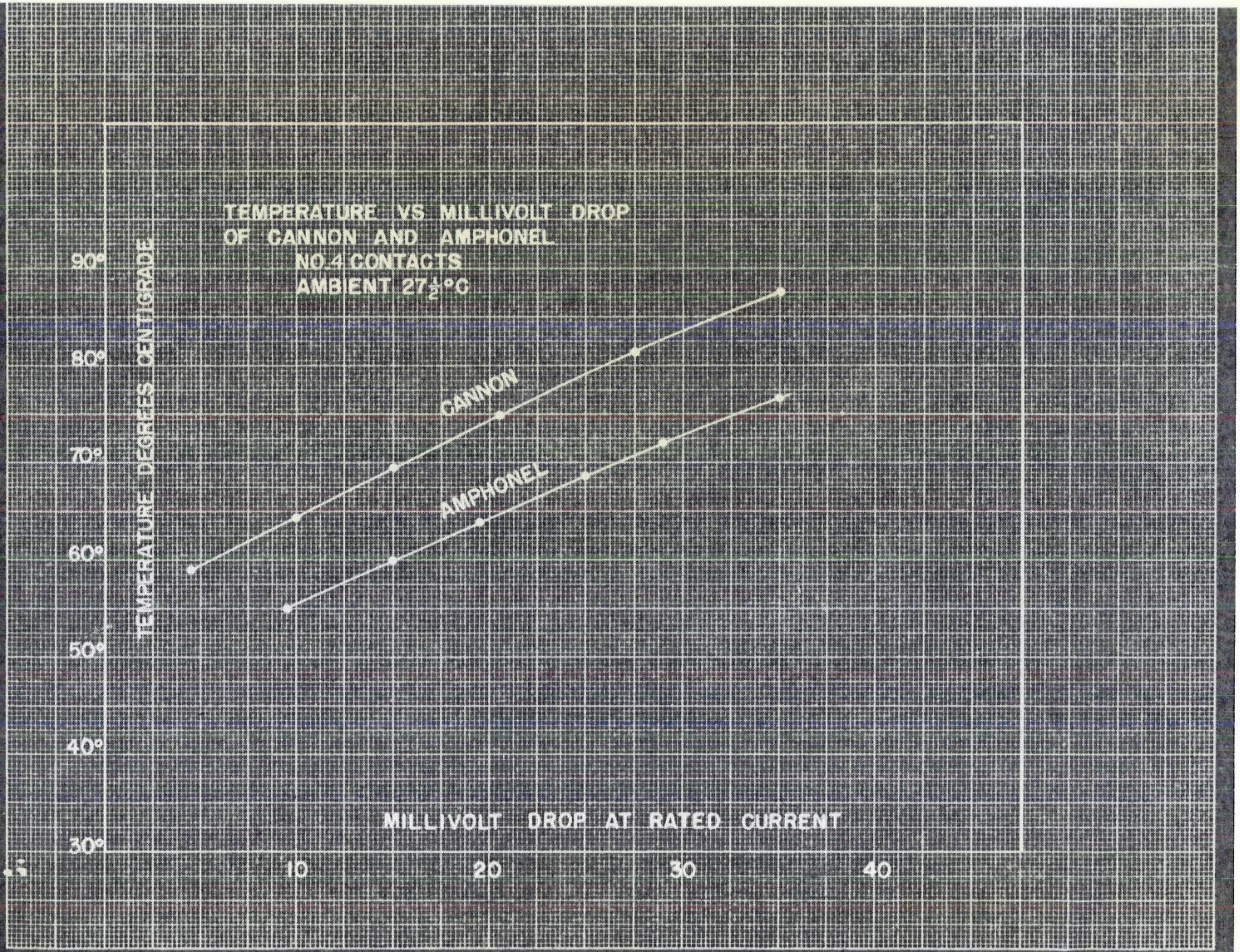
TEMPERATURE VS MILLIVOLT DROP
OF CANNON AND AMPHONEL
NO.4 CONTACTS
AMBIENT 27½°C
CANNON
AMPHONEL
TEMPERATURE DEGREES CENTIGRADE
90°
80°
70°
60°
50°
40°
30°
10
20
30
40
MILLIVOLT DROP AT RATED CURRENT

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FIG. 5

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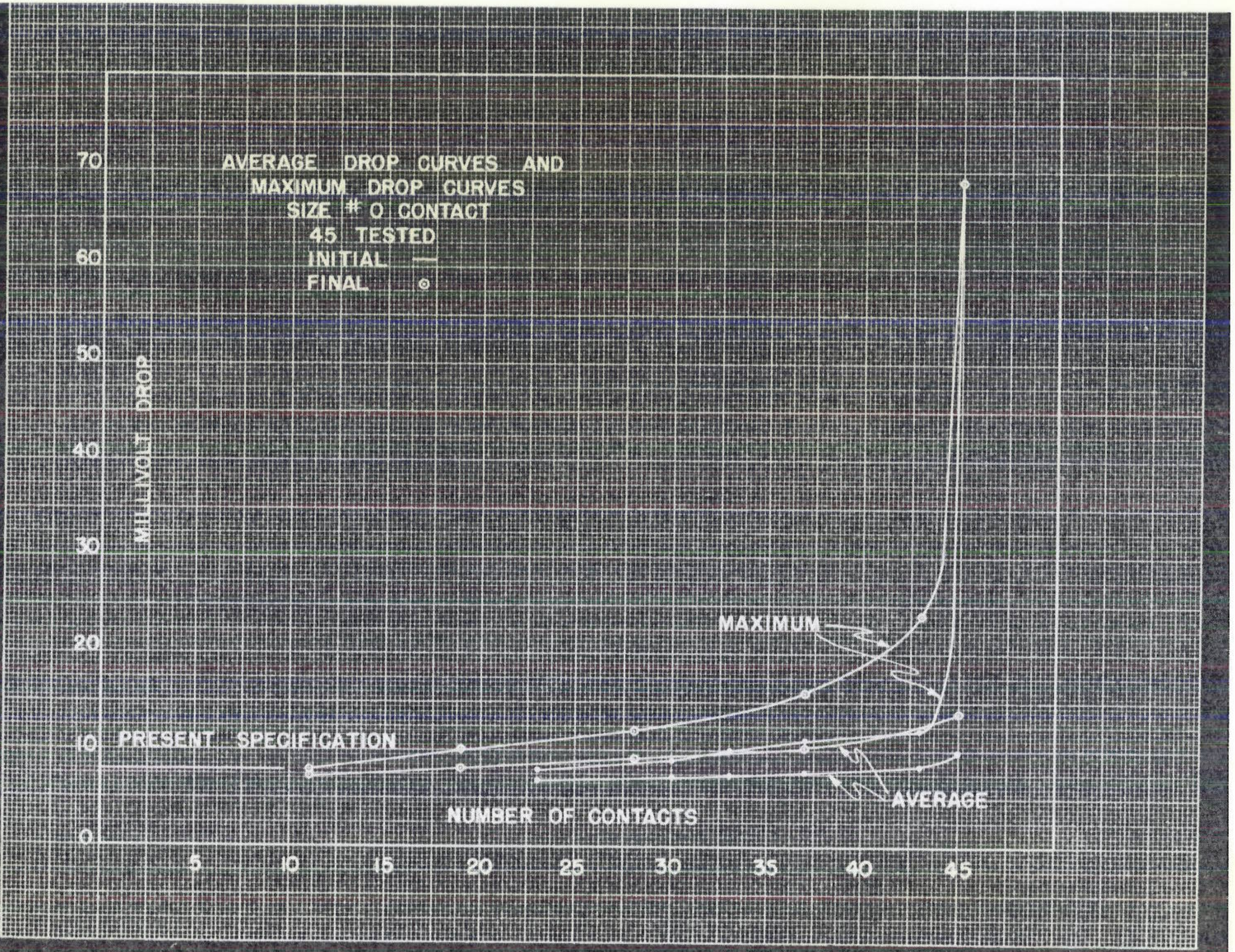
AVERAGE DROP CURVES AND
MAXIMUM DROP CURVES
SIZE # 0 CONTACT
45 TESTED
INITIAL —
FINAL ⊙
MILLIVOLT DROP
70
60
50
40
30
20
10
0
PRESENT SPECIFICATION
MAXIMUM
AVERAGE
NUMBER OF CONTACTS
5
10
15
20
25
30
35
40
45

FIG. 6

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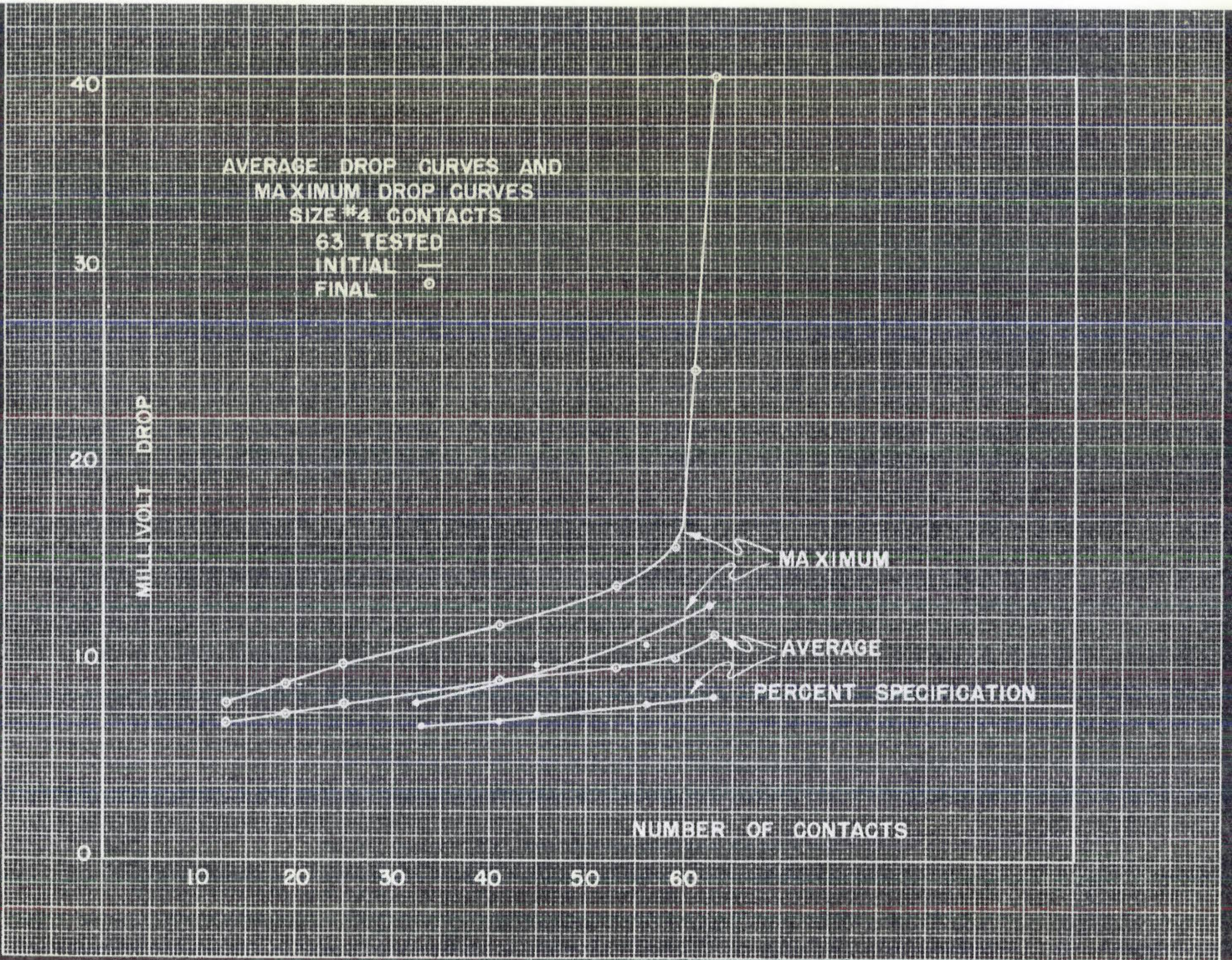
AVERAGE DROP CURVES AND
MAXIMUM DROP CURVES
SIZE #4 CONTACTS
63 TESTED
INITIAL —
FINAL ⊙
MILLIVOLT DROP
40
30
20
10
0
10
20
30
40
50
60
NUMBER OF CONTACTS
MAXIMUM
AVERAGE
PERCENT SPECIFICATION

FIG. 7

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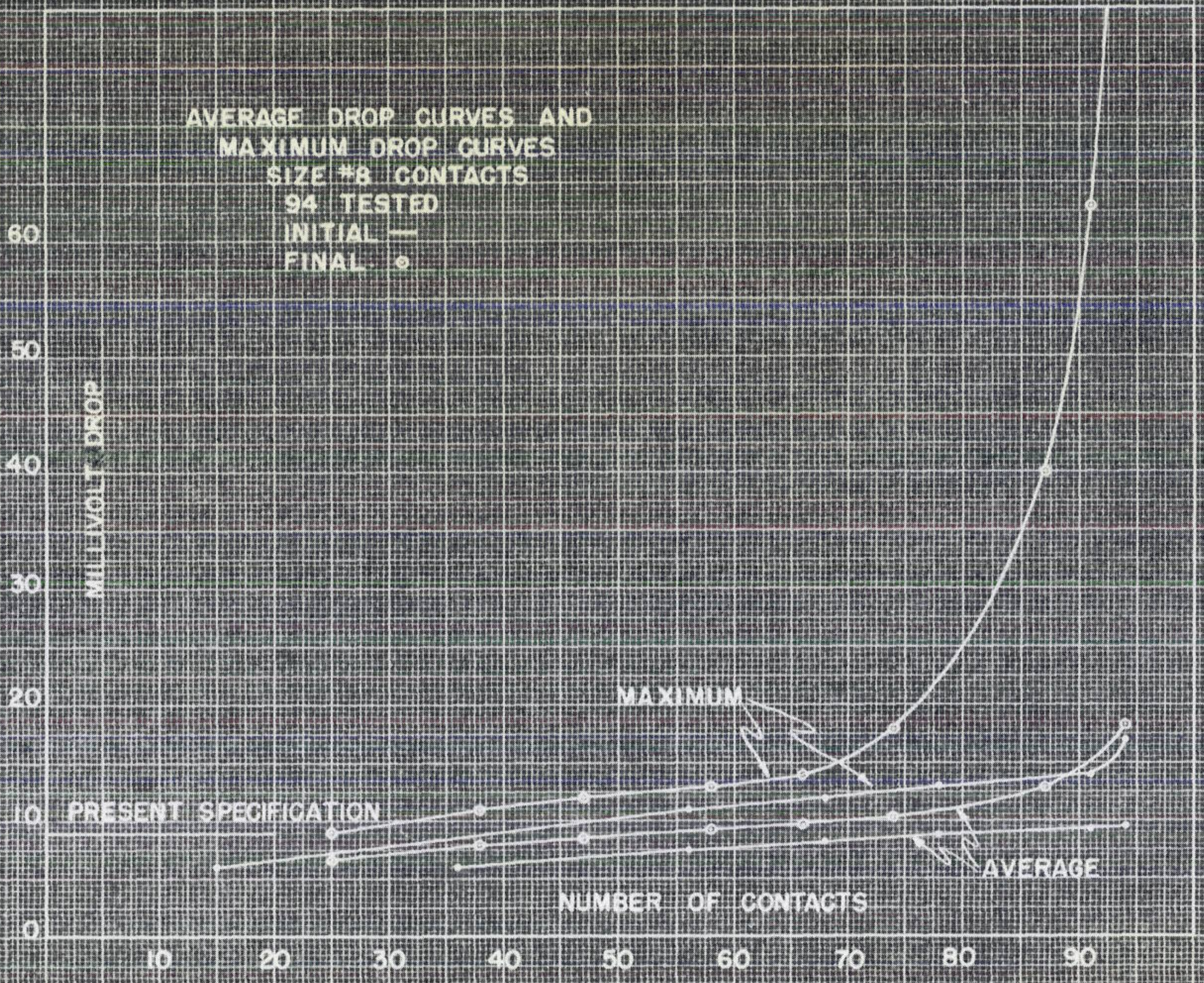
AVERAGE DROP CURVES AND
MAXIMUM DROP CURVES
SIZE #8 CONTACTS
94 TESTED
INITIAL —
FINAL ⊙
MILLIVOLT DROP
0
10
20
30
40
50
60
PRESENT SPECIFICATION
MAXIMUM
AVERAGE
NUMBER OF CONTACTS
10
20
30
40
50
60
70
80
90

FIG. 8

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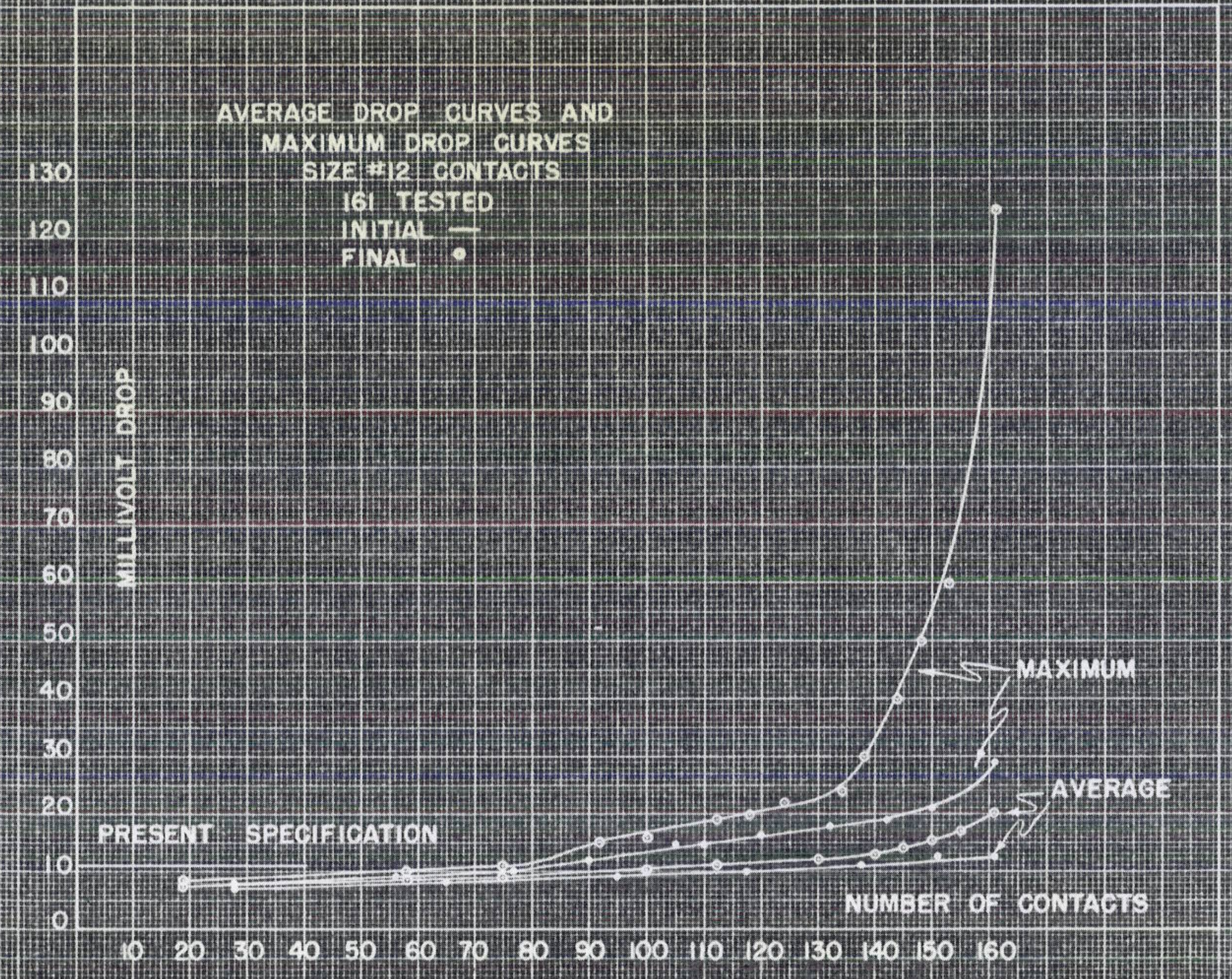
AVERAGE DROP CURVES AND
MAXIMUM DROP CURVES
SIZE #12 CONTACTS
161 TESTED
INITIAL —
FINAL ⊙
MILLIVOLT DROP
130
120
110
100
90
80
70
60
50
40
30
20
10
0
PRESENT SPECIFICATION
MAXIMUM
AVERAGE
NUMBER OF CONTACTS
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160

FIG.9

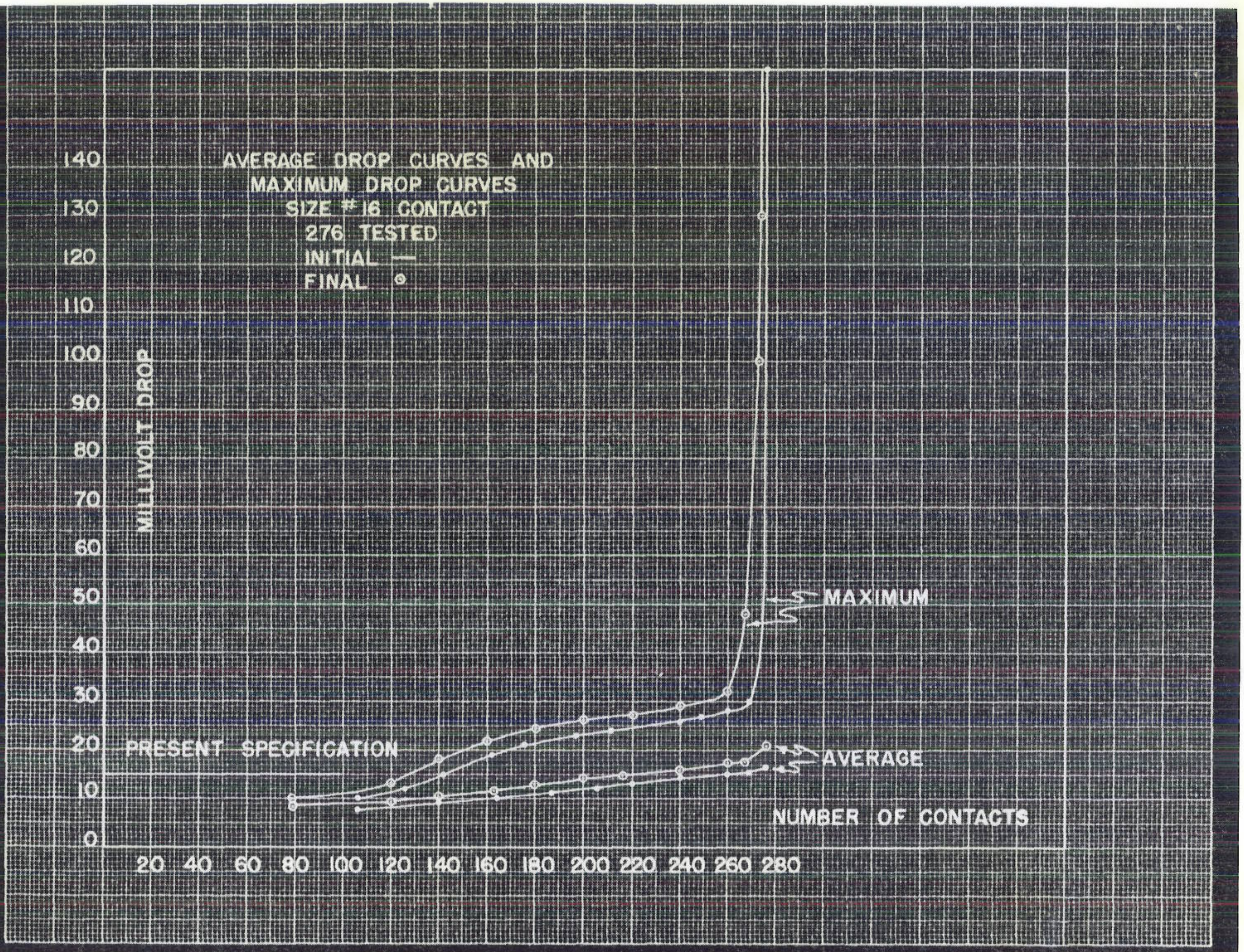
AVERAGE DROP CURVES AND
MAXIMUM DROP CURVES
SIZE #16 CONTACT
276 TESTED
INITIAL —
FINAL ⊙
MILLIVOLT DROP
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
PRESENT SPECIFICATION
MAXIMUM
AVERAGE
NUMBER OF CONTACTS
20 40 60 80 100 120 140 160 180 200 220 240 260 280

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FIG. 10