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Report No. R-1269

Electrical Characteristics, Performance and Suitability of General Electric Type FP-163, Time Delay, Electronic Relay.

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SUBJECT

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BY

NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

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AUTHORIZATION

1. Tests authorized by reference (a) form the subject matter of this report which specifically treats of an electronic device manufactured by the General Electric Company and designated by them as Kenotron type FP-163 "Time Delay Electronic Relay". References (b), (c) and (d) are informative on matters relevant to the origin of the present problem.

Reference: (a) BuEng.ltr.NOs-35693 (11-25-W8) of 11 Sept.1935.
(b) BuEng.ltr.NOs-35693 (11-25-W8) of 10 Dec. 1934 to INM., Schenectady, N.Y.
(c) INM., Schenectady, N.Y.,ltr. C-35693(223), C-36484(132) of 23 Nov. 1934 to BuEng.
(d) General Electric Co's. ltr. of Nov.13, 1934 to INM, Schenectady, N.Y., on contracts NOs-35693 and NOs-36484.

OBJECT OF TEST

2. The object of this investigation is to study the operation of the General Electric type FP-163 vacuum tube time delay relay with its associated circuit, to ascertain its electrical performance in this circuit, to obtain its mechanical and electrical characteristics, and to determine its suitability for use in Naval Service equipment.

ABSTRACT OF TESTS

3. One group of four samples of the subject type tube submitted by the General Electric Company for suitability tests was employed to obtain the data presented in this report.

4. The time delay characteristics of the four samples were obtained at ambient temperatures of 0°C, 25°C and 50°C before vibration and at 25°C after vibration.

5. The volt-ampere characteristics of the four samples, employing direct voltages, were determined for an ambient temperature of 25°C.

6. The subject tube is normally used in series with a suitable copper oxide rectifier. The tube's performance with and without the oxide rectifier and its tendency to "arc-back" were experimentally determined. The volt-ampere characteristic of the copper oxide rectifier and its forward resistance at normal current were obtained at ambient temperatures of 0°C, 25°C and 50°C.

7. The heater voltages used were those determined by the manufacturer and displayed on the base of the tubes. The samples were subjected to vibration for one minute and the resulting effect on the tube's performance determined.

be found useful in two important respects: (1) It tends to eliminate the possibility of arc-back due to the comparatively high inverse resistance of the oxide rectifier. (2) It tends to increase the rectification efficiency of the rectifier tube proper.

(j) The forward and inverse resistances of the copper-oxide rectifier were found to be functions of the temperature, decreasing with increasing temperature. The inverse resistance of the oxide rectifier was found to be very high, approaching infinity, at 0°C, 46,000 ohms at 25°C and 5,800 ohms at 48.5°C.

(k) The identification of the subject tube, including the heater voltage and serial number designations, as displayed on the base, is subject to erasure and fading and is therefore unsatisfactory.

(l) It will be noted in some graphs of the time delay characteristics, that after the initial time delay the current at $t = 0$ has an instantaneous value with a 90 degree slope, then in the next 3 to 4 seconds it decreases to a minimum value, and thereafter it begins to rise exponentially in a characteristically normal fashion. The explanation of this break in the characteristic is due to the fundamental design of the subject tube. Although the heater current commences its flow at the instant of closing the supply switch the oxide coating fails to receive any part of this heat energy until 3 to 4 seconds have elapsed.

(m) The space current for the period of 2.5 to 3.5 minutes of initial heating is zero for the initial time delay of the subject tube. Referring to NRL Report No. R-1233 it will be noted that the space current for the type FP-164 tube, which is also designed to have a time delay characteristic, is greater than zero for the same interval of time. This result arises from the fact that in the case of the type FP-163 tube, the barium oxide coating is heated almost entirely by conduction from the cathode, whereas in the case of the type FP-164 tube, the barium oxide coating is heated partly by direct radiation from the heater and partly by metallic conduction from the cathode mass proper. Consequently, in the FP-164, the coating receives almost immediately a quantity of heat energy by direct radiation from the heater sufficient to raise the temperature of the coating to a degree that permits a small amount of emission thus providing the means whereby some space current flows as shown by the graphs.

(n) The repeatability of the time delay of the subject tube under the same conditions of test before vibration was found to be generally satisfactory.

RECOMMENDATIONS

(a) It is recommended that the subject tube be re-designed mechanically in order that: (1) The axis of the helical heater remain at all times coincident with the axis of the cylindrical cathode. (2) The plate be more rigidly supported so that vibration does not change its relative position with respect to the cathode. Such an undesirable condition tends to diminish the time delay period to an appreciable extent becoming detrimental to the tube and destroying the purpose for which it was designed.

(b) The identification of the subject tube, including the heater voltage and serial number designations, should be stamped in a legible and permanent manner with no possibility of erasure.

DESCRIPTION OF MATERIAL AND APPARATUS UNDER TEST

8. Description of Tube. The subject tube is a high vacuum tube designed for a low internal drop. It is fundamentally a diode or half-wave rectifier, its basic elements consisting of a plate and a cathode, the latter being heated partly by radiation and partly by conduction from a concentric helical heater. The tube is primarily designed to provide a delayed time function of current. The time delay property of this tube is a result of the unique construction of its cathode which consists of a solid mass of nickel metal in the form of a hollow right circular cylinder enclosing the helical heater, as may be seen in Plates 1 and 2. Attached to and surrounding the cathode mass is a thin metallic sheet forming a concentric cylinder. On the lower end of this sheet, on the outward surface, is a layer of barium oxide coating of 1/4 inch width. Surrounding this coating and spaced a small distance from it is a thin metallic sheet in the form of a circular band of the same width as the coating and concentric with the cathode mass. This band serves as the anode. The upper end of the heater is welded to the cathode mass, as may be seen by reference to Plates 1 and 2.

9. Principle of Operation. The manner in which the subject tube produces its time delay is as follows: The cathode mass is heated, indirectly in large part by radiation, and directly in small part by conduction from the heater. The oxide coating which is the main source of electrons is heated directly by conduction from the cathode mass. The size of the mass, and the available heat energy, as determined by the heater voltage and impressed direct plate potential, provide a gradual heating of the coating and, hence, a gradual increase in the emission of electrons from the coating.

10. Plate 1 is a photograph showing the assembled tube and its individual parts. Plate 2 shows a vertical cross-section of the essential inner structural arrangement of the elements of the subject tube.

11. Description of Apparatus. Plate 3 is a photograph of the experimental set-up of the apparatus for conducting the various tests. The essential items consist of the following:

- (a) A 110-6.5 volt, single-phase, 60 cycle per second, 500 watt transformer, for supplying power to the tube.
- (b) A suitable variable resistor. An initial value of 750 ohms is recommended by the manufacturer.
- (c) A control relay, manufacturer's type CR2810-1265H-143. This relay is so adjusted as to be energized by the rectified direct current when it reaches its normal value of 40 milliamperes.
- (d) A copper oxide rectifier, manufacturer's type 6RC3E164, 125 volt input, 39 volt, 65 milliamperes output. This oxide rectifier is used in series with the subject tube, the negative potential end of the rectifier being connected to the anode of the tube. The purpose of the rectifier is, presumably, to protect the subject tube from any tendency it may have to arc back. Another equally important circuit function is to increase the rectification efficiency of the

subject tube when needed.

- (e) A variable filament rheostat capable of carrying the normal heater current of 3.5 amperes.

12. Diagram of Connections. Plate 4 shows the electrical circuit connections employed in obtaining the time delay characteristics.

METHOD OF TEST

13. The procedure employed in obtaining the desired data was as follows: With the tube cold at room temperature the primary supply voltage was adjusted to exactly 110.0 volts, the heater voltage to that marked on the base of the tube, and the rise of the rectified current against time noted. The time was determined by means of a stop watch, indicating minutes and seconds, from the instant of closing the supply switch.

14. The time delay characteristics at ambient temperatures of 0°C and 50°C were obtained by placing the apparatus inside an automatic temperature controlled compartment.

15. The tendency of the subject tube to arc-back was determined by operating the tube without the copper oxide rectifier in the circuit.

16. The subject tube was given a vibration test for one minute with no voltages applied. The effect of the vibration on the operating performance of the tube was determined by obtaining its time delay characteristic immediately after the vibration.

17. The volt-ampere characteristic of the tube was obtained by applying direct potentials.

18. Inasmuch as the copper oxide rectifier is required for the normal operation of the subject tube, the determination of the characteristic properties of the former are evidently desirable. The volt-ampere characteristic of the oxide rectifier was obtained using direct voltages and its forward resistance at 40 milliamperes was determined from its characteristic at ambient temperatures of 0°C, 25°C and 50°C. The inverse rectifier resistance was also determined at these temperatures for voltages corresponding to the normal circuit current of 40 milliamperes. The volt-ampere characteristic for 0°C and 50°C was obtained with the rectifier enclosed within the temperature controlled compartment.

DATA RECORDED DURING TESTS

19. The data obtained during the tests are plotted and shown as graphs on Plates 5 to 27 inclusive.

20. The data for the initial time delay and the time delay after two minutes off, with the values of external resistances used and the varying conditions of ambient temperature under which the tests were conducted are given in Table 1.

21. Plates 12 to 27 inclusive show the time delay characteristics of the subject tube under the conditions indicated on the plates.

22. Plates 8 to 11 inclusive show the volt-ampere characteristics of the tubes at ordinary room temperature.

23. Plates 5 to 7 inclusive show the volt-ampere characteristics of the copper oxide rectifier at three different temperatures.

PROBABLE ERROR IN RESULTS

24. The accuracy of the data obtained throughout the tests is well within 1%.

RESULTS OF TEST

25. The results of the tests are given in Table 1, and the graphs are shown on Plates 5 to 27 inclusive.

26.(a) Tube No. 108, heater voltage 4.45 volts, and employing an external resistance of 250 ohms, had initial time delay, before vibration, of 9 minutes and 50 seconds, 9 minutes and 43 seconds, and 10 minutes and 43 seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After the vibration the initial time delay at 25°C was 9 minutes and 32 seconds. The specification requirement is that the initial delay period fall within the range of from 9 to 13 minutes.

(b) The time delays after a 2 minute off period were, before vibration, 5 minutes and 30 seconds, 5 minutes and 30 seconds, and 6 minutes and 25 seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After vibration the time delay at 25°C was 5 minutes and 45 seconds. The specification requirement is that this delay period fall within the time range of from 4 to 7 minutes.

27.(a) Tube No. 109, heater voltage 4.65 volts, and employing an external resistance of 450 ohms, had initial time delays, before vibration, of 10 minutes and zero seconds, 6 minutes and 30 seconds, and 8 minutes and zero seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After vibration the initial time delay at 25°C was 11 minutes and 30 seconds.

(b) The time delays after a 2 minute off period were, before vibration, 6 minutes and zero seconds, 3 minutes and 21 seconds, and 4 minutes and 15 seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After vibration the time delay at 25°C was 4 minutes and 20 seconds.

28.(a) Tube No. 110, heater voltage 4.10 volts, and employing an external resistance of 150 ohms, had initial time delays, before vibration of 7 minutes and zero seconds, 12 minutes and 20 seconds, and 14 minutes and 25 seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After vibration the time delay at 25°C was 7 minutes and 7 seconds.

(b) The time delays after a 2 minute off period were, before vibration, 3 minutes and 8 seconds, 7 minutes and 19 seconds, and 7 minutes and 32 seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After vibration the time delay at 25°C was 3 minutes and 9 seconds.

29.(a) Tube No. 111, heater voltage 4.35 volts, and employing an external resistance of 250 ohms, had initial time delays, before vibration, of 9 minutes and 47 seconds, 8 minutes and 36 seconds, and 9 minutes and zero

seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After vibration the time delay at 25°C was 4 minutes and 52 seconds.

(b) The time delays after a 2 minute off period were, before vibration, 4 minutes and 35 seconds, 4 minutes and 54 seconds, and 4 minutes and 24 seconds for ambient temperatures of 25°C, 0°C and 50°C respectively. After vibration the time delay at 25°C was 1 minute and 23 seconds.

30. Tubes Nos. 108, 110 and 111 show a definite break in the smoothness of the volt-ampere characteristic, a rather abrupt change in slope, occurring at exactly 10.0 volts in each case. Tube No. 109 apparently is an exception. See Plates 8 to 11 inclusive.

31. Tests on the subject tube have shown that employing 750 ohms for the external resistance and increasing the heater voltage proportionally no substantial control of the initial time delay period is obtained. The delay is apparently largely controlled by the magnitude of the applied direct plate potential which in turn depends on the drop in the external resistance employed.

32. The shape of the rectified current wave, with and without the copper oxide rectifier, was found to be satisfactory, one alternation being completely suppressed, as viewed on the screen of an oscillograph.

33. With the oxide rectifier removed from the circuit, no arc-back occurred in any of the tubes.

34. The forward and inverse resistances of the copper oxide rectifier were found to be functions of the temperature and decreasing with increasing temperatures. The inverse resistance was found to be very high, approaching infinity, at 0°C, 46,000 ohms at 25°C, and 5,800 ohms at 48.5°C.

CONCLUSIONS

35. The subject tube holds promise of material possibilities for Navy use but at its present stage of development it is not entirely satisfactory, particularly from a mechanical design standpoint.

36. The tests of four samples indicate that the time delay period is primarily a function of the effective direct voltage impressed on the plate of the tube and, to a lesser extent, a function of the heating of the cathode.

37. The external resistance required in order that the time delay period fall within a predetermined range of time is considerably different for each sample submitted. This resistance was found to be considerably smaller than the value recommended by the manufacturer.

38. The method of suspension of the helical heater at its upper end is not such as to insure a reasonably satisfactory coincidence of the axes of the heater and the cylindrical cathode mass as may be seen in plate 2. The fact that the heaters for all of the samples had their central portions displaced to such an extent as to almost touch the inner wall of the cathode gave rise to the following undesirable effect: A few seconds after power is applied to the tube from the "cold" condition, and regardless of the ambient temperature, the temperature expansion of the heater

47. The space current for the period of 2.5 to 3.5 minutes of initial heating is zero for the initial time delay of the subject tube. Referring to NRL Report No. R-1233 it will be noted that the space current for the type FP-164 tube, which is also designed to have a time delay characteristic, is greater than zero for the same interval of time. This result arises from the fact that in the case of the type FP-163 tube, the barium oxide ~~coating~~ is heated almost entirely by conduction from the cathode, whereas in the case of the type FP-164 tube, the barium oxide coating is heated partly by direct radiation from the heater and partly by metallic conduction from the cathode mass proper. Consequently, in the FP-164, the coating receives almost immediately a quantity of heat energy by direct radiation from the heater sufficient to raise the temperature of the coating to a degree that permits a small amount of emission thus providing the means whereby some space current flows as shown by the graphs.

48. The repeatability of the time delay of the subject tube under the same conditions of test before vibration was found to be generally satisfactory.

TABLE 1

General Electric, Time Delay, Electronic Relay, Vacuum Tube Device, Type FP-163. Partial summary of characteristics versus temperature, before and after vibration tests on tubes. Time given in minutes and seconds required to actuate control relay, General Electric type CR 3810-1265H, at its rated current of 40 milliamperes, d.c.

Conditions: - Temperature, 25° Centigrade, before vibration.

Tube Ser. No.	Heater Voltage (Volts)	External Resistance (Ohms)	Initial Time Delay	Time Delay after two minutes off.
108	4.45	250	9-50	5-30
109	4.65	450	10-0	6-0
110	4.10	150	7-0	3-08
111	4.35	250	9-47	4-35

Conditions: Temperature, 0° Centigrade, before vibration.

108	4.45	250	9-43	5-30
109	4.65	450	6-30	3-21
110	4.10	150	12-20	7-19
111	4.35	250	8-36	4-54

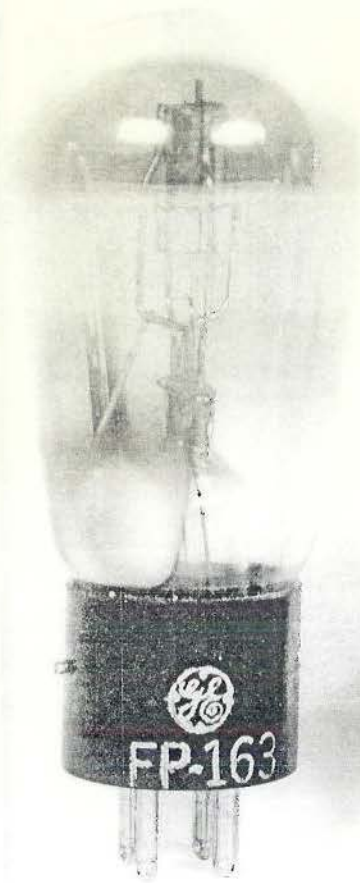
Conditions: Temperature, 50° Centigrade, before vibration.

108	4.45	250	10-43	6-25
109	4.65	450	8-0	4-15
110	4.10	150	14-25	7-32
111	4.35	250	9-0	4-24

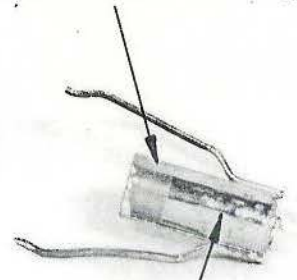
Conditions: Temperature, 25° Centigrade, after vibration.

108	4.45	250	9-32	5-45
109	4.65	450	11-30	4-20
110	4.10	150	7-07	3-09
111	4.35	250	4-52	1-23

51-4-10



Barium Oxide Coating



Cathode Mass (Nickel)

"Getter" Pan

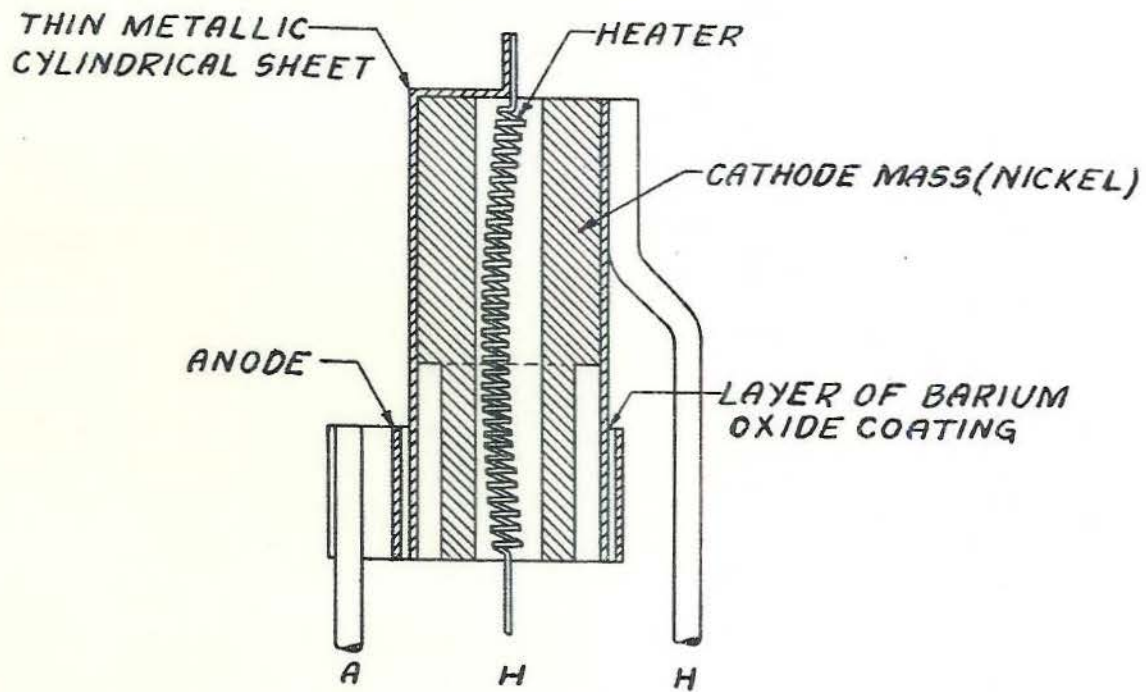


Anode



Heater

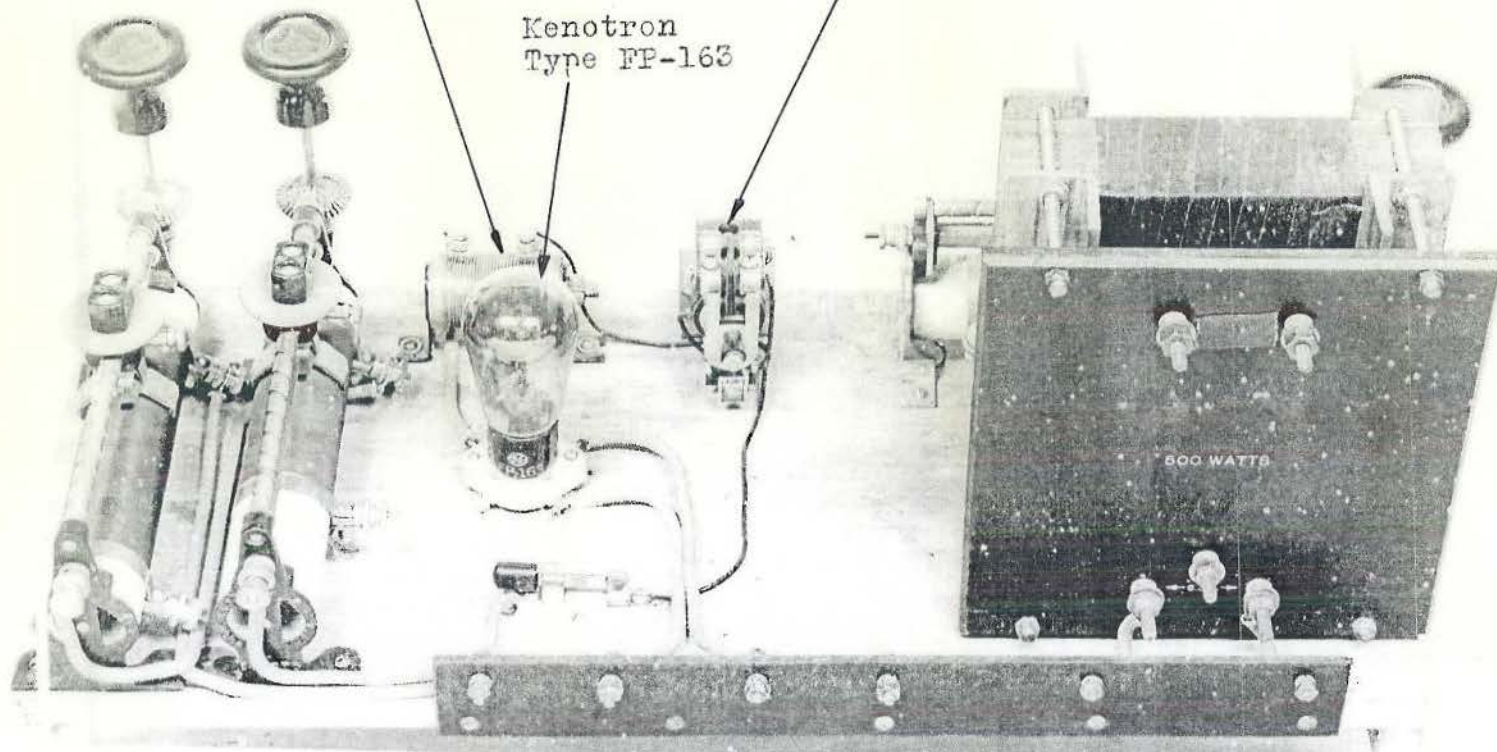
1652



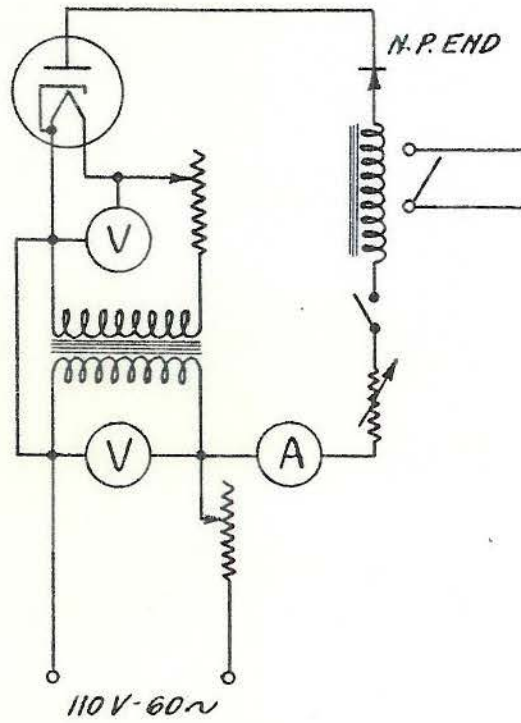
Copper Oxide Rectifier
Type 6RC3B164

Control Relay
Type CR2810-1265H-143

Kenotron
Type FP-163

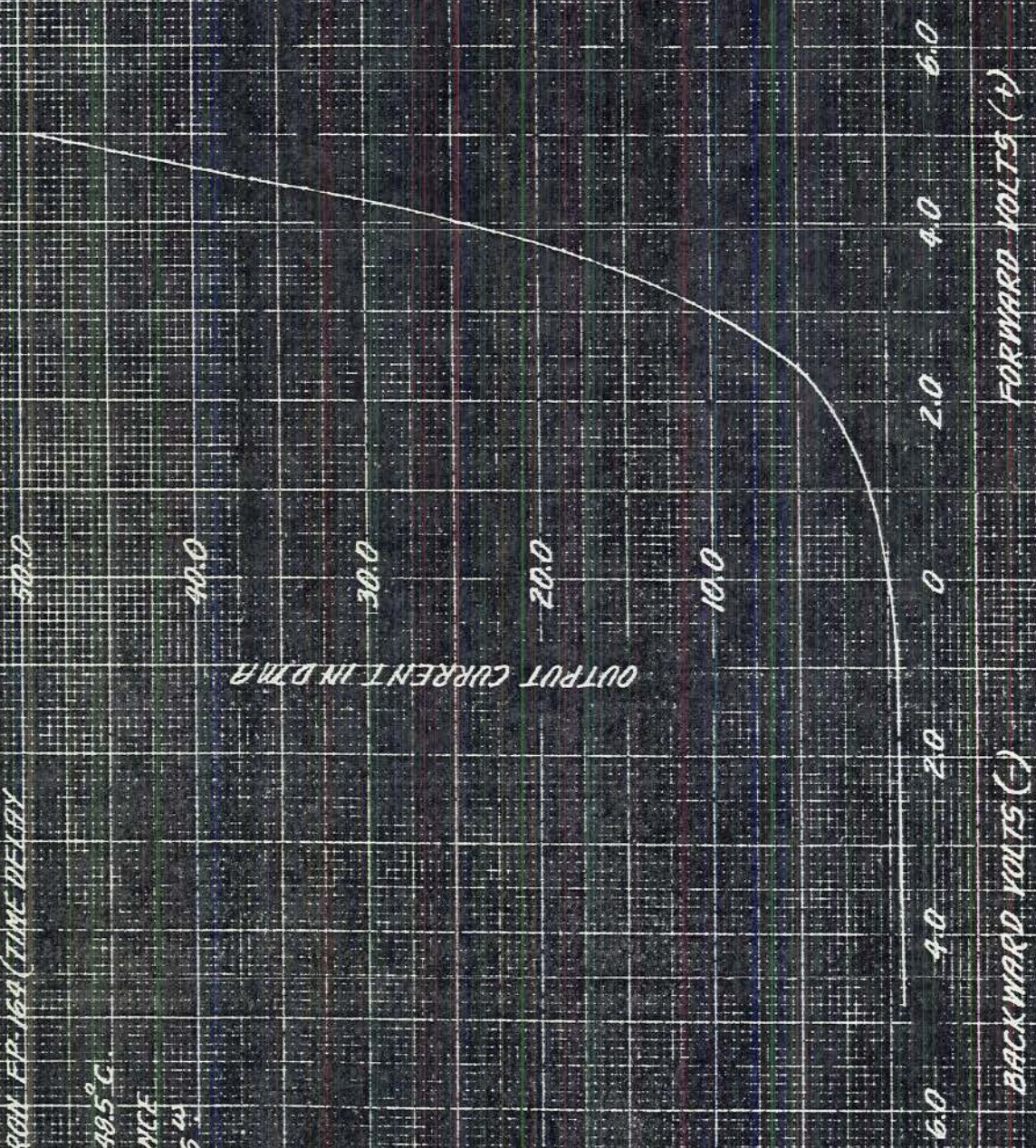


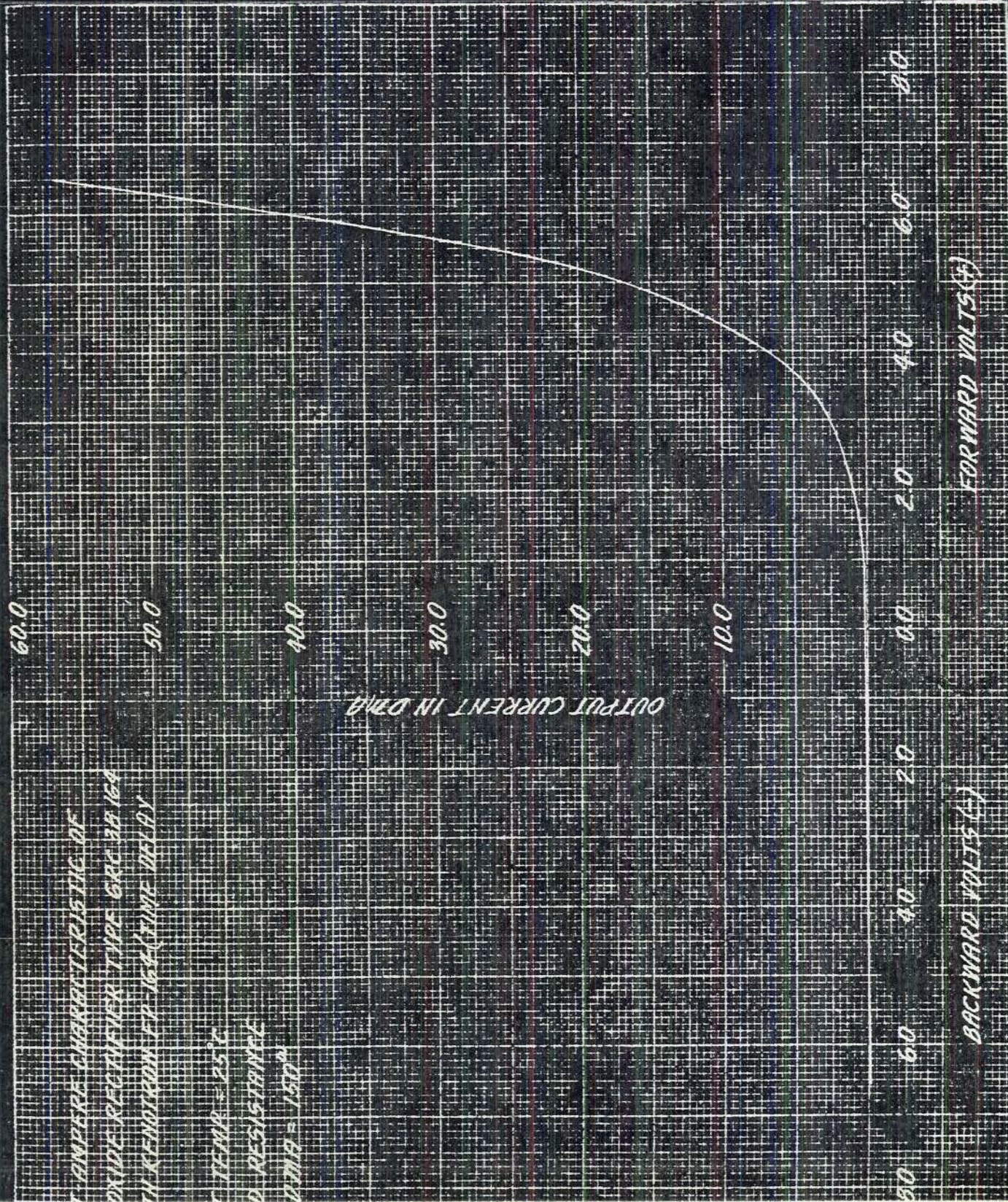
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THE VOLT-AMPERE CHARACTERISTIC OF
COPPER OXIDE RECTIFIER TYPE 6 RC 3B 164
USED WITH KENOTRON FR-164 (TIME DELAY
TUBE)
AMBIENT TEMP 49.5°C
FORWARD RESISTANCE
AT 400 DMA = 116 Ω

OUTPUT CURRENT IN DMA





THE VOLT-AMPERE CHARACTERISTIC OF
COPPER OXIDE RECTIFIER TYPE GAC 30 164
USED WITH KENNEDY 77 164 (TIME DELAY
TUBE)
AMBIENT TEMP = 25°C
FORWARD RESISTANCE
AT 40.0 V DMA = 150 Ω

OUTPUT CURRENT IN DMA

FORWARD VOLTS (V)

BACKWARD VOLTS (V)