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NAVY DEPARTMENT  
BUREAU OF ENGINEERING

Report on

ELECTRICAL PERFORMANCE OF MULTI-ELECTRODE MERCURY VAPOR  
RECTIFIER TUBE IN DOUBLE THREE PHASE CIRCUIT  
TYPE W-224.

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## AUTHORIZATION FOR TEST

1. The subject tests were authorized by reference (a) under Title V of "Test Special Type Vacuum Tubes".

Reference: (a) Bu.Eng.Ltr. NPL4/N8(2-6-W8) of 7 Feb. 1934.

## OBJECT OF TEST

2. The object of this investigation was to study the electrical performance of a multi-anode mercury vapor rectifier tube design, recently developed by the Raytheon Production Corporation of Newton, Mass., for comparison with rectifier tube designs already existing and in present day use, to determine its superiority or inferiority with respect to these.

## ABSTRACT OF TEST

3. The electrical performance of the multi-anode mercury vapor rectifier tube operating in a three phase half wave double "Wye" circuit was observed. The ambient temperature surrounding the tube was varied, and the starting time found under full load conditions. Voltage regulation with load was determined, and a value of percent ripple voltage given.

## CONCLUSIONS

### Superiority of Subject Tube Performance

The superiority of the subject tube in its electrical performance over its predecessors is in its following capabilities:

- (a) To withstand large overloads without damage.
- (b) Self renewing cathode, with much longer life than found in mercury vapor rectifier tubes of the coated cathode type.
- (c) An outstanding design feature making possible the satisfactory operation at temperatures as low as minus 30° Centigrade is the separation of the vaporizing and condensation zones in the tube.
- (d) Successful operation of multi-anode type of rectifier tube.
- (e) Diminished radio frequency interference from tube of multi-anode type.
- (f) Both plate and filament potentials can be applied simultaneously, thus eliminating some interlocking electrical devices, to the number of three relays, in present rectifier equipments.
- (g) The subject tube is not adversely affected by low cathode potentials, and therefore will obviate the necessity for two more relays and an alarm bell.
- (h) The subject tube design provides for currents of 10 amperes or more at 120 volts, these values being considerably larger than those now available from any rectifier control circuit of present design.
- (i) Elimination of pre-conditioning period of from 15 to 30 minutes. When a tube replacement is made, all tube potentials may be immediately applied.

## RECOMMENDATIONS

(a) Based on the superiority of electrical performance of the subject rectifier tube over its predecessors, and the great possibilities present in its development, not only in power rectification, but in future application to ship control equipment and other uses, it is strongly recommended that the Raytheon Production Corporation be given an opportunity through contract to design and construct a high voltage rectifier unit suitable for shipboard radio transmitter power supply use along similar lines followed on the subject multi-anode rectifier tube. Such equipment, when obtained, should be sent to this Laboratory, for thorough investigation and electrical performance determination, and then placed on shipboard for a three month trial period under actual service conditions.

## DESCRIPTION OF APPARATUS UNDER TEST

### Description of tube.

4. The gaseous discharge device shown in Plate 1 is a mercury vapor rectifier of the multi-anode-pool type. It consists of a glass envelope with 8 wires passing through the upper end of the glass structure, 6 leads for carrying current to the 6 individual anodes, and a pair of heater wires for the cathode. At the bottom of the globe-shaped vessel is a protuberance which forms a well into which is deposited mercury, with barium in solution. Projecting downward into the mercury pool is a cylindrically shaped metal structure which acts as a high pressure arc chamber. In this chamber a tantalum heater is located at a position approximately 1/4-inch above the mercury pool.

5. When the heater is energized, thermal energy is radiated to the mercury pool below. Upon heating, some of the mercury and barium is vaporized, with an accompanying increase in the vapor pressure in this chamber. The vapor rises, some of it coming through the six "arc discharge ports", one of which is shown in Plate 1. The vapor continues to move outward past the anodes, until it impinges on the relatively cold inner surface of the glass envelope, where it condenses, and thereby returning by gravity to the pool below. The heated vapor in the arc chamber is readily ionized upon being subjected to an electric field, and thus acts in a manner similar to any mercury vapor rectifier tube. A distinctive feature of this tube giving superiority over its predecessors is this high pressure arc chamber which permits lower ambient operating temperatures.

### Photograph of Tube and Circuit.

6. Plate 2 shows the multi-anode rectifier tube and the 6 phase circuit to which it is connected. The circuit is supplied from a 220 volt, 3 phase, 60 cycle power supply. The secondary circuit which is connected to the tube consists of a three phase half wave double "Wye" system with an interphase transformer to cause proper load division. The output from the rectifier is filtered to diminish the value of the output ripple.

### Diagram of Connections.

7. Plate 3 shows the diagram of connections of the circuit used with the multi-anode rectifier tube.

## METHOD OF TEST

8. In Plate 2 is shown the apparatus used for the subject tests, and Plate 3 gives the circuit diagram of connections used during the tests herein reported. The method used to obtain the "arc starting time" at various ambient temperatures, was to place the multi-anode rectifier tube in a refrigerator compartment, whose internal temperature was varied to suit the test requirements. When the voltage regulation curve was obtained, the ambient temperature was that of the room, or 18° Centigrade.

## DATA RECORDED DURING TESTS

9. The data recorded during tests are shown in tables 1 and 2,

plate 4, and under "Results of Test", and were taken with the object of obtaining information on the following rectifier characteristics:

- (a) Electrical Circuit Characteristics.
- (b) Operation Tests; load, temperature, and starting time.
- (c) Method of Arc Ignition at Low Temperatures.
- (d) Voltage Regulation.
- (e) Value of Ripple.
- (f) Mechanical Design.

#### PROBABLE ERROR IN RESULTS

10. The meter readings are accurate to  $1/2$  of 1%; the thermometer readings to  $\pm 0.1$  degree; the starting time in Table 1 to  $\pm 10$  seconds; and the starting time to  $\pm 3$  seconds in Table 2. The rectifier voltage regulation with load shown in Plate 4 is accurate to 2% despite the fact that the load voltage and current were measured to  $1/2$  of 1%. This is by reason of the fact that the line supply voltage may have fluctuated  $\pm 1\%$ , during the period while measurements were being taken.

#### RESULTS OF TESTS

##### Electrical Circuit Characteristics

11. The circuit is supplied from a 220 volt, 3 phase, 60 cycle power supply. The full load continuous output rating is 120 volts d.c., at 5 amperes, with 50% of time intermittent rating of 10 amperes. The heater voltage applied to the multi-anode rectifier is 3.2 volts on the high tap, and 2.8 volts on the low tap, the higher voltage being recommended if and when the tube is difficult to ignite. The secondary volts per phase from the center tap to the anode is 117 volts, R.M.S. The remaining alternating voltages between phases are:

Between phase 1 and 2 =	117 v. R.M.S.
Between phase 1 and 3 =	209 v. "
Between phase 1 and 4 =	229 v. "
Between phase 1 and 5 =	208 v. "
Between phase 1 and 6 =	116 v. "

##### Operation Tests; load, temperature, and starting time.

12. The first group of operation tests was made on May 6th with full load at ambient temperatures in the tube compartment as shown in Table 1. The tube was operated on the low filament voltage tap of 2.8 volts. The starting time was measured as the moment of application of potentials to the moment when the arc was ignited. The results are given in Table 1. The interval between tests amounted to or exceeded 30 minutes.

TABLE 1

<u>Test Number in Sequence</u>	<u>Tube Compartment Temp. Degrees Centigrade</u>	<u>Starting time - minutes.</u>
1	+20	3
2	+10	3
3	0.0	3
4	-8	4
5	-14	4
6	+18	1

13. The second group of operation tests was made on May 7th, with the filament voltage supplied through the higher tap, making its value 3.2 volts. This was made necessary by the fact that the tube would not ignite with potentials applied when the tube ambient temperature was below that of the room.

TABLE 2

<u>Test Number in Sequence</u>	<u>Tube Compartment Temp. Degrees Centigrade</u>	<u>Starting time - minutes and seconds</u>
7	-9	2 min. 20 sec.
8	-13	3 min. 37 sec.
9	-29.5	0 min. 48 sec. with intermittent igniter circuit in operation
10	+30	1 min. 2 sec.
11	+38	0 min. 27 sec.
12	+50	0 min. 27 sec.

Method of Arc Ignition at Low Temperatures.

14. With the rectifier tube and circuit as shown in Plate 1, it was found necessary to use an auxiliary means to start the arc discharge when the temperature of the air surrounding the multi-anode rectifier was reduced below room temperature to minus 29.5° Centigrade. The method used to ignite the tube was to temporarily raise the anode-cathode voltage on a single pair of electrodes. Once ignited, the arc persists as soon as potentials are applied and a load is applied to the output of the rectifier circuit.

15. The necessity of auxiliary means for igniting this tube at low temperature can be obviated by the proper cathode heater and arc chamber design.

#### Voltage Regulation

16. The voltage regulation of this rectifier equipment is shown in Plate 4 for output load current values from 0.5 ampere to 25 amperes, the latter value being 500% of full load. The voltage regulation is caused mostly by the transformer impedance, as this is much higher than the tube impedance. The arc drop in this multi-anode rectifier averages about 5 to 6 volts, and does not vary greatly from this value for various anode currents.

17. If it were necessary, the output load voltage could be made constant over the normal range of load currents, or the rectifier could be designed so as to give a rising output voltage with load by compounding the interphase transformer.

#### Value of Ripple

18. The value of ripple voltage has been diminished to approximately 1/4 of 1% by the filter included in the output load circuit.

#### Mechanical Design

19. The design of the tube should include a means of electrical connection to the anodes and heater circuit more satisfactory than the present scheme shown in the photographs of Plate 2. The mercury pool at the bottom of the tube should be heat insulated to diminish radiation, especially at low temperatures.

### CONCLUSIONS

#### Superiority of Subject Tube Performance

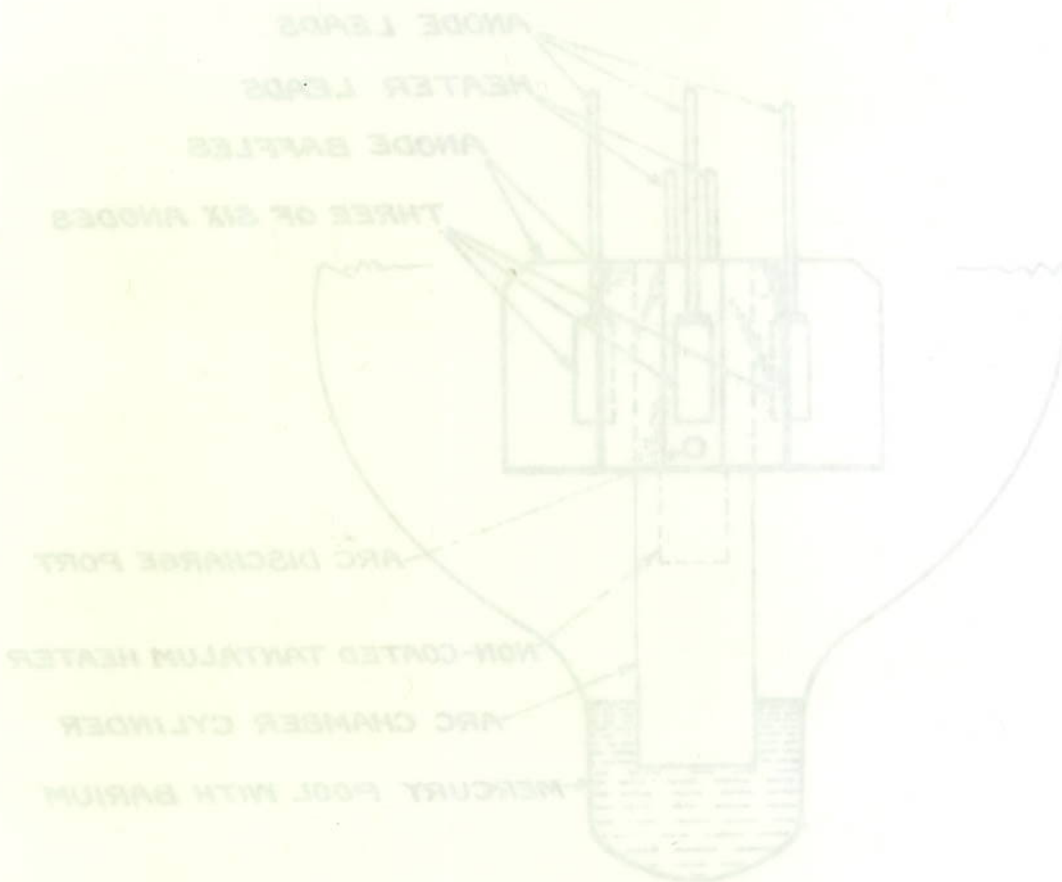
20. The superiority of the subject tube in its electrical performance over its predecessors is in its following capabilities:

- (a) To withstand large overloads without damage.
- (b) Self renewing cathode, with much longer life than found in mercury vapor rectifier tubes of the coated cathode type.
- (c) An outstanding design feature making possible the satisfactory operation at temperatures as low as minus 30° Centigrade is the separation of the vaporizing and condensation zones in the tube.
- (d) Successful operation of multi-anode type of rectifier tube.
- (e) Diminished radio frequency interference from tube of multi-anode type.
- (f) Both plate and filament potentials can be applied simultaneously, thus eliminating some interlocking electrical devices. to the number of three relays, in present rectifier equipments.

(g) The subject tube is not adversely affected by low cathode potentials, and therefore will obviate the necessity for two more relays and an alarm bell.

(h) The subject tube design provides for currents of 10 amperes or more at 120 volts, these values being considerably larger than those now available from any rectifier control circuit of present design.

(i) Elimination of pre-conditioning period of from 15 to 30 minutes. When a tube replacement is made, all tube potentials may be immediately applied.



(c) The subject tube is not adversely affected by ion cathode  
 potentials, and therefore will obviate the necessity for two more relays  
 and an extra bell.

(d) The subject tube design provides for currents of 10 amperes or  
 more at 150 volts, these values being considerably larger than those now  
 available from any rectifier control circuit of present design.

(e) Elimination of pre-conditioning period of five to 30 minutes  
 when a tube replacement is made, all tube potentials may be immediately  
 applied.

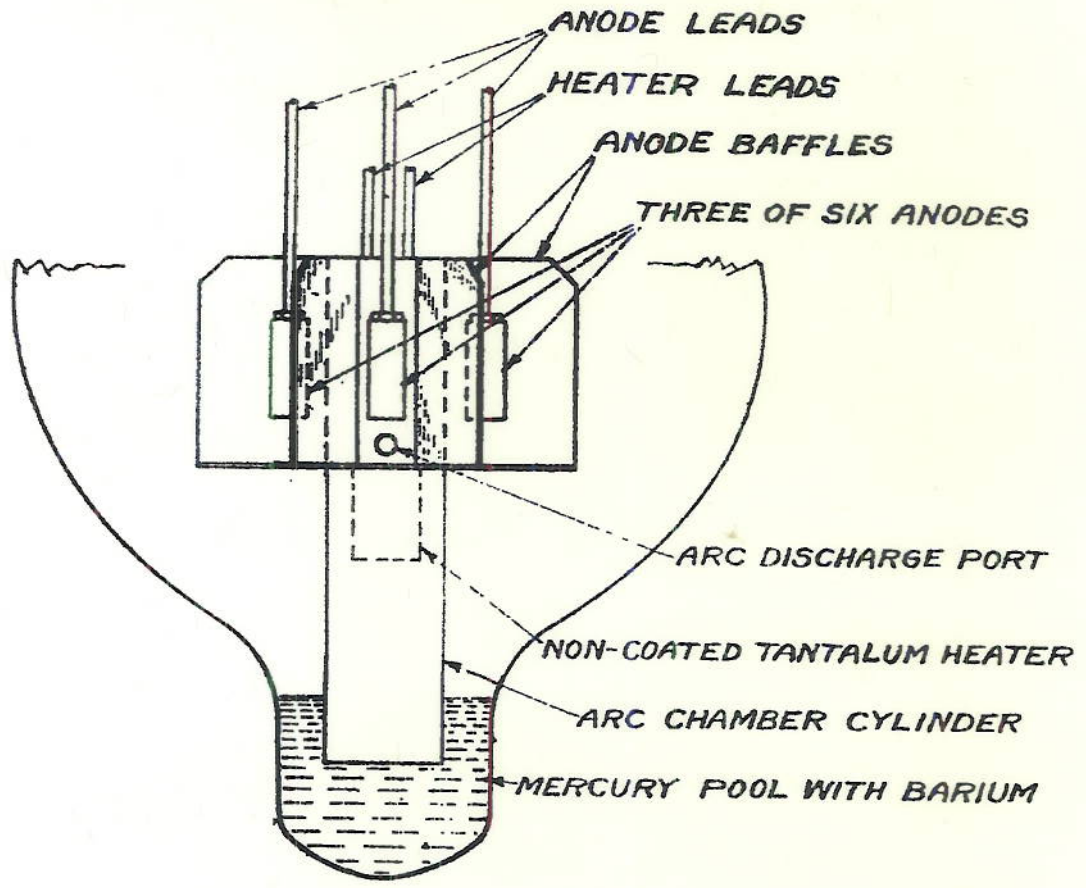


PLATE 3

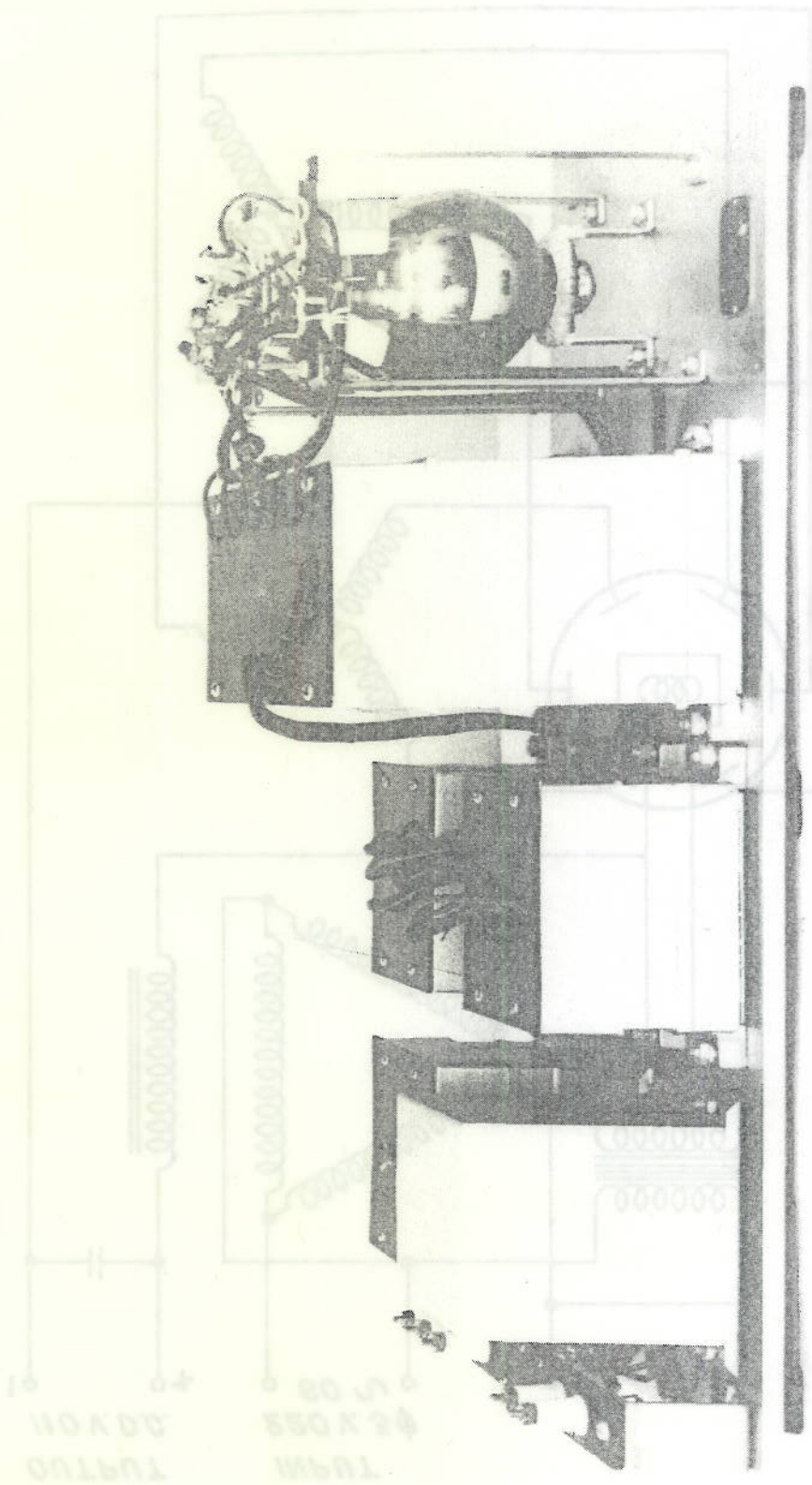


PLATE 2

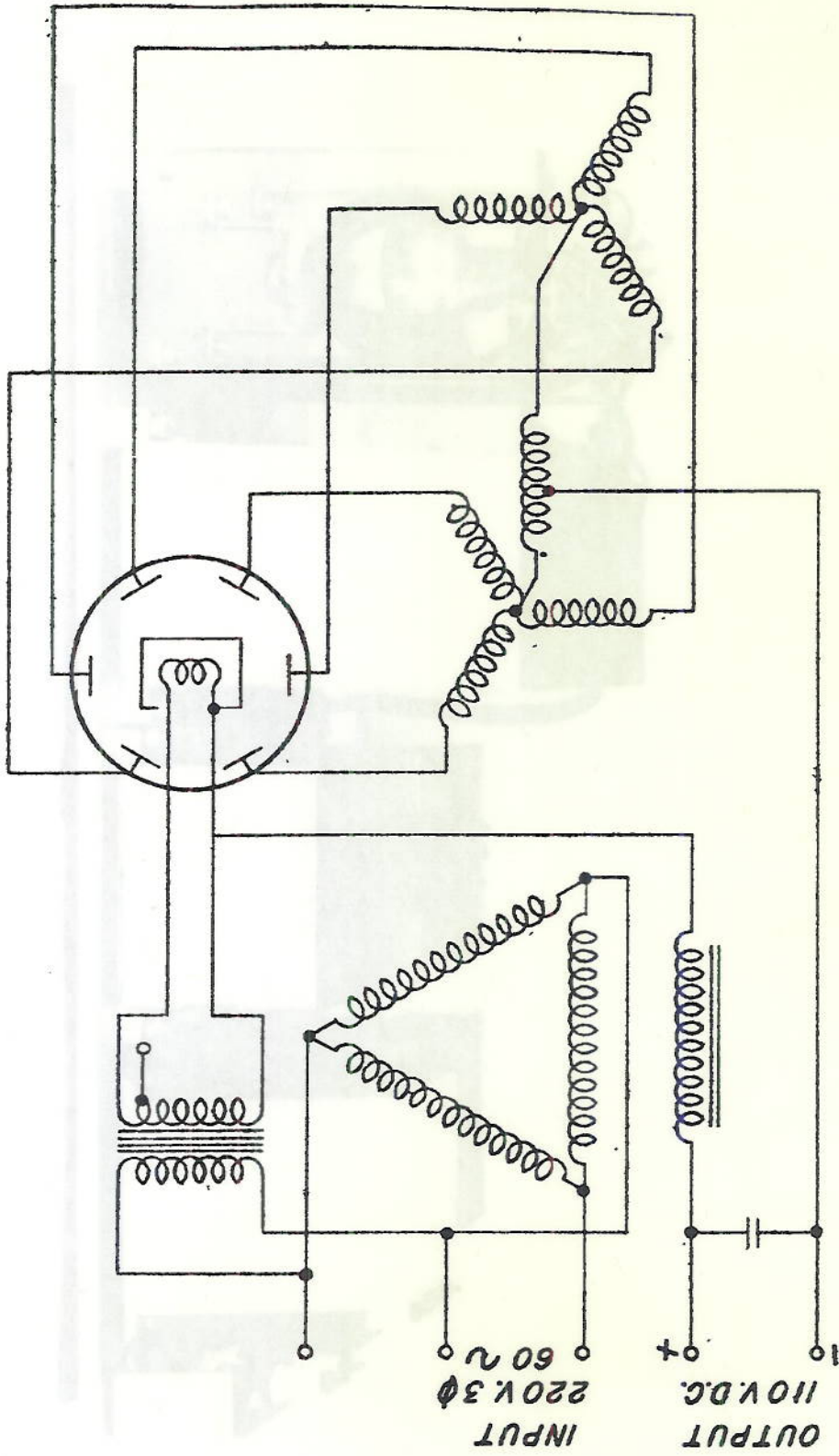
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МАДОЮ ОУИИИ  
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WIRING DIAGRAM  
OF

RAYTHEON TYPE W-224 6 PHASE  
MULTI-ELECTRODE MERCURY VAPOR  
RECTIFIER TUBE AND CIRCUIT



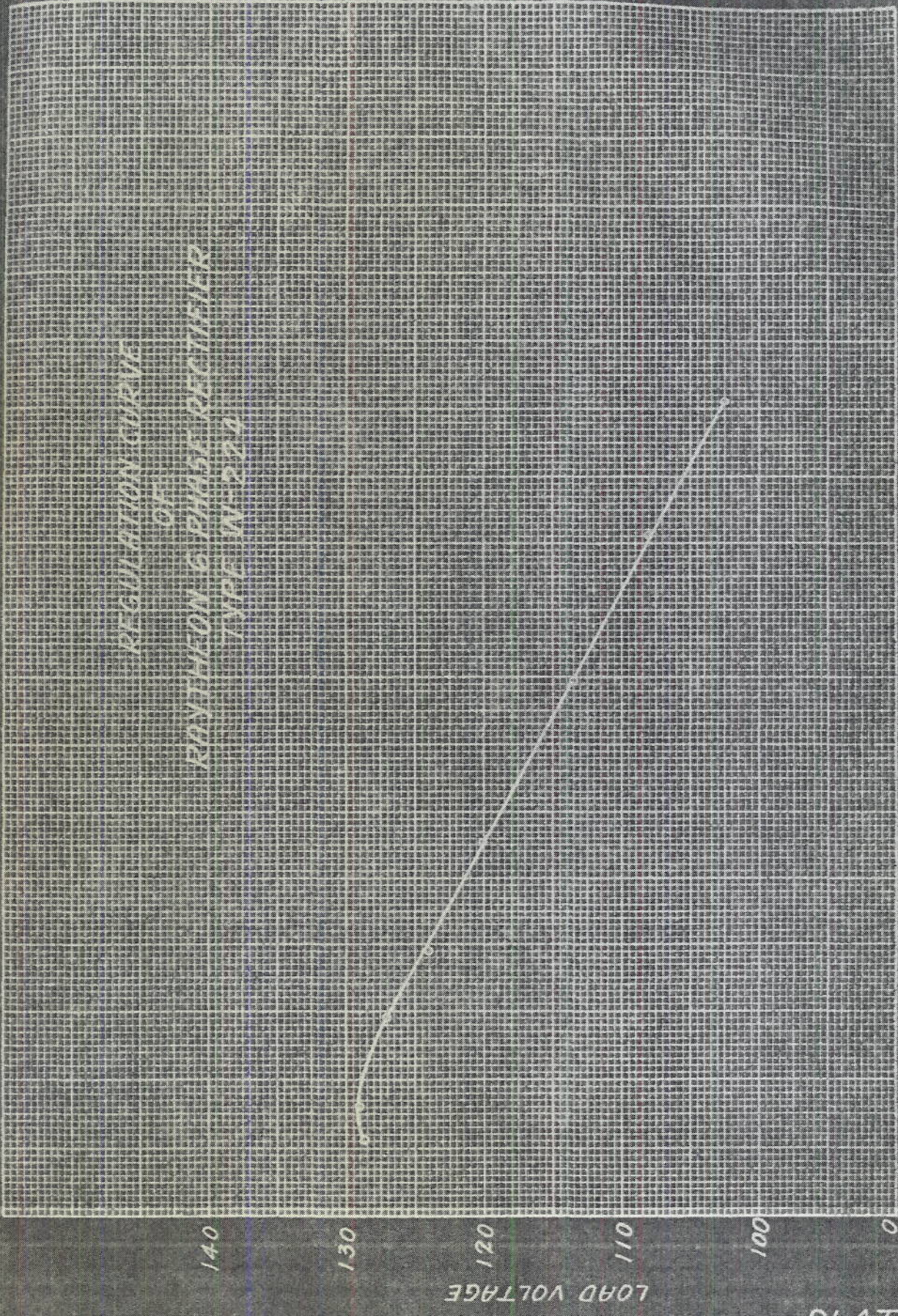


PLATE 4

AMPERES LOAD CURRENT

LOAD VOLTAGE

PLATE 4

