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TOPICAL REPORT

LIFE TEST ON FOUR ELECTRICALLY-HEATED
THERMIONIC DIODES
WITH FLUORIDE VAPOR-DEPOSITED
TUNGSTEN EMITTERS

MASTER

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I. LIFE TESTS OF FOUR CYLINDRICAL DIODES WITH VARIOUS TYPES OF TUNGSTEN EMITTERS

A. INTRODUCTION

In the past year, Thermo Electron has built and life-tested four cylindrical diodes with tungsten emitters under AEC Contract No. AT(30-1)-3874. The emitters are 0.500-inch outer diameter by 1.500 inches in length (15 cm^2). The diode interelectrode spacing is a nominal 10 mils. The collectors are niobium. All emitters are fabricated from fluoride vapor-deposited tungsten. The emitter surfaces consist of an as-deposited surface, an etched as-deposited surface, an as-ground surface, and an etched as-ground surface. Comparative performance data, in light of the vacuum work function and x-ray diffraction pole figures of the various emitters, are presented, as well as life test data.

B. DIODE DESCRIPTION

The diode was designed as a life-test vehicle. As shown in Figure 1, the emitter is 0.500 inch in diameter by 1.500 inches in length (15 cm^2), supported by a 0.030-inch thick tungsten sleeve which is attached to the electron-bombardment (EB) heater support, which is in turn supported by the niobium-ceramic leadthrough assembly. The lower end of the emitter is centered by a tungsten pin riding in an alumina bushing. The EB heater support also serves as the emitter current lead. The EB heater and emitter thermocouples are exposed to test chamber vacuum within the center of the emitter and are accessible for maintenance.

The collector is niobium. Tantalum-sheathed, MgO-insulated tantalum heaters are brazed onto the outside of the collector to allow collector temperature control. The collector is attached to the water-cooled heat exchanger by niobium heat choke fins, which provide the thermal resistance from collector temperature to water temperature.

C. EMITTER PREPARATION

The emitters were fabricated by San Fernando Laboratories using tungsten fluoride vapor-deposition techniques. The emitter and sleeve are formed in one piece in this manner. After deposition, two emitters (WFG1 and 3) were ground to final dimensions and the thermocouple holes were electrical-discharge machined. The other two emitters (WAF1 and 2) were ground undersize to allow another thickness of tungsten to be deposited to the final emitter dimension, and then completed as WFG1 and 3. The four emitters were heat-treated at 2000°C for 30 minutes prior to obtaining x-ray diffraction pole figures. The partial pole figures for the 100 planes are shown in Figure 2. These pole figures were taken prior to etching emitters WAF2 and WFG1, as previous experiments have shown that etching does not affect the pole figure.

D. VACUUM WORK FUNCTION

The work functions of the emitters were taken in the measuring device shown in Figure 3. The device is a dynamically-pumped cylindrical vacuum diode of 12.15 cm² guarded emitter area with five pyrometer sight holes through the collector. The work functions were taken at a pressure below 1×10^{-6} torr and at emitter temperatures from 1700°K to 2200°K, opposite a niobium collector at 900°C.

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Figure 1. Cylindrical Diode.

Figure 2. Partial Pole Figures of the 100 Plane for Various Tungsten Emitters.

8902

Figure 3. Emitter Work Function Measuring Device.

An average emitter work function was obtained for each emitter in the following manner. A Schottky plot was obtained at four different power inputs. Using the current density and the five observed emitter temperatures at each power input and the Richardson equation ($A = 120$), twenty work functions were calculated. From these twenty work functions, the average work functions and standard deviations were obtained. The work functions are shown in Table I. WAF2 was etched and heat-treated twice and WFG1 was etched and heat-treated once prior to insertion into a diode.

E. INITIAL TESTING

Initial testing at Thermo Electron was conducted by varying the output current for a fixed input power and optimizing the cesium and collector temperatures for maximum output voltage at each output current. The output currents selected were 30, 60, 90, 120, 150, and 180 amperes, which are current densities of 2, 4, 6, 8, 10, and 12 amperes per square centimeter of emitter area. Maximum output current was limited to 200 amperes by instrumentation and the minimum output current was limited by maintaining an emitter temperature of 1800°C or less. The output voltage was measured between the emitter and collector lead terminals. The resistance of the emitter sleeve is 3.5×10^{-4} ohms. Input powers of 600, 750, and 900 watts were used. The input power in every case is the sum of the electron-bombardment power and the EB filament I^2R heater power. The output power is the output current times the output voltage as measured at the emitter and collector lead terminals. The efficiencies reported below are device efficiencies calculated as:

$$\text{Device Efficiency} = \frac{\text{Terminal Output Power}}{\text{Total Input Power}} \times 100$$

TABLE I
WORK FUNCTION OF TUNGSTEN EMITTERS

Serial Number	As-Deposited		As-Ground	
	WAF-1	WAF-2	WFG-1	WFG-3
Initial	$4.88 \pm .04$	$4.73 \pm .05$	$4.44 \pm .08$	$4.58 \pm .04$
Etched	—	$4.57 \pm .06$	$4.75 \pm .05$	—
Etched	—	$4.55 \pm .05$	—	—

F. PERFORMANCE COMPARISON

Comparison of the four diodes is shown in Figure 4, where the output power versus output voltage is plotted for each diode at power inputs of 600, 750, and 900 watts. Table II summarizes the performance of the four diodes at the maximum power output for each power input. Table III compares the performance in light of the work function and crystal orientation.

Two of the diodes, WAF1 (4.88) and WFG3 (4.58), were dynamically tested under the following conditions: emitter temperature at 1650 and 1800°C, collector temperature at 700 and 800°C, and variable cesium temperatures. These curves are shown in Figures 5 through 12.

The following observations were made from Figures 5 through 12. WAF1 (4.88) performed better at a higher collector temperature (800°C) and a lower cesium reservoir temperature (300 - 350°C), while WFG3 (4.58) performed better at a lower collector temperature (700°C) and a higher cesium reservoir temperature (335 - 400°C). At constant emitter temperatures and optimized conditions, WFG3 generally performed better than WAF1, as was seen in static testing at a constant power input. However, at identical conditions of low cesium reservoir temperatures or high collector temperatures at constant emitter temperatures, WAF1 performed better than WFG3.

Diodes WAF1 (4.88) and WFG1 (4.75) were tested at cesium temperatures of -10°C, -5°C, +5°C, +10°C, and +15°C from optimum cesium temperatures at each data point. The performance of -10°C was, in most cases, equivalent to that of +15°C, and the percentage

Figure 4. Optimum Test Data for Diodes.

TABLE II
CYLINDRICAL DIODES WITH TUNGSTEN EMITTERS

Serial Number	WAF-1	WAF-2	WFG-1	WFG-3
Work Function	4.88	4.55	4.75	4.58
<u>600 Watts Input</u>				
Max. device eff. - %	7.7	9.3	9.0	7.8
Max. output in w/cm ²	3.1	3.8	3.6	3.1
<u>750 Watts Input</u>				
Max. device eff. - %	8.9	10.2	9.7	9.3
Max. output in w/cm ²	4.5	5.1	4.9	4.6
<u>900 Watts Input</u>				
Max. device eff. - %	9.8	11.0	10.2	10.1
Max. output in w/cm ²	5.8	6.6	6.2	6.1

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TABLE III

COMPARATIVE RESULTS OF PERFORMANCE, WORK FUNCTION,
AND CRYSTAL ORIENTATION

Serial Number	WAF-1	WAF-2	WFG-1	WFG-3
Vacuum Work Function	4.88	4.55	4.75	4.58
100 Orientation	1st	2nd	3rd	4th
Performance	4th	1st	2nd	3rd

I-11

Figure 5. Dynamic I-V Curves for Diode WAF1 at $T_f = 1650^\circ\text{C}$, $T_c = 700^\circ\text{C}$, and $T_R = \text{variable}$.

Figure 6. Dynamic I-V Curves for Diode WAF1 at $T_f = 1650^\circ\text{C}$, $T_c = 800^\circ\text{C}$, and $T_R = \text{variable}$.

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Figure 7. Dynamic I-V Curves for Diode WAF1 at $T_E = 1800^\circ\text{C}$, $T_C = 700^\circ\text{C}$, and $T_R = \text{variable}$.

8889

Figure 8. Dynamic I-V Curves for Diode WAF1 at $T_E = 1800^\circ\text{C}$, $T_C = 800^\circ\text{C}$, and $T_R = \text{variable}$.

8890

Figure 9. Dynamic I-V Curves for Diode WFG3 at $T_f = 1650^\circ\text{C}$, $T_c = 700^\circ\text{C}$, and $T_R = \text{variable}$.

Figure 10. Dynamic I-V Curves for Diode WFG3 at $T_f = 1650^\circ\text{C}$, $T_c = 800^\circ\text{C}$, and $T_R = \text{variable}$.

8886

Figure 11. Dynamic I-V Curves for Diode WFG3 at $T_f = 1800^\circ\text{C}$, $T_c = 700^\circ\text{C}$, and $T_R = \text{variable}$.

Figure 12. Dynamic I-V Curves for Diode WFG3 at $T_f = 1800^\circ\text{C}$, $T_c = 800^\circ\text{C}$, and $T_r = \text{variable}$.

of variation at a given output current and power input was constant for the two diodes, independent of the relative performance of the diodes. The data for WAF1 and WFG1 at 15°C off optimum cesium temperature are shown in Figures 13 and 14, respectively. Diodes WAF2 (4.58) and WFG3 (4.55) were tested at a few off-optimum temperatures and were found to follow the same variation pattern as WAF1 and WFG1.

G. LIFE TEST RESULTS

The diodes were life tested at a constant power input of 750 ± 15 watts (50 watts/cm^2) and at a constant current output of 120 amperes (8 amps/cm^2). The cesium reservoir temperature was maintained at the optimum and the collector temperature was in the flat optimum range.

A plot of the electrode power density and cesium reservoir temperature versus time for the four diodes is presented in Figure 15. The apparent differences in the performance of each diode with time are discussed below. In all cases, the emitter performance is believed to be essentially stable with variations accounted for by filament changes, instrumentation changes, and diode reassembly.

1. WAF1

The emitter consisted of a 5-mil layer of as-deposited fluoride tungsten which was heat-treated at 2000°C for 30 minutes. The diode was tested for 6550 hours and a plot of electrode power density and cesium reservoir temperature versus time is shown in Figure 15. The diode was thermally cycled 20 times.

Figure 13. Off-Optimum Cesium Test Data for WAF-1 Diode.

Figure 14. Off-Optimum Cesium Test Data for WFG-1 Diode.

Figure 15. Plot of Voltage versus Time for the Four Diodes.

The average electrode power density was $4.68 \pm .08$ watt/cm² throughout the entire test period. During the first 1300 hours, the cesium reservoir temperature was 334°C to 335°C until the method of recording the data was changed from a potentiometer to a compensated Honeywell controller, at which time the cesium reservoir temperature was recorded at 331°C. Between 1825 hours and 2475 hours, the filament shorted to the emitter and was replaced several times. During this time, the cesium reservoir temperature was recorded at 321 - 322°C. From 2475 hours to 6550 hours the cesium reservoir temperature was recorded at 339°C, even though the filament was replaced again at 3550 hours.

Although the cesium reservoir temperature varied from 321°C to 339°C for a constant input and output, this variation is not attributed to changes in the emitter, since the cesium reservoir temperature was stable within 1°C during any particular time period where the filament and instrumentation were unchanging.

2. WAF2

The emitter consisted of a 5-mil layer of as-deposited fluoride tungsten which was first etched for three minutes in 5% NaOH at 180 mA/cm^2 (2.5 v), and then etched in alkaline ferrocyanide for eight minutes; it was then heat-treated at 2000°C for 30 minutes. The diode was tested for 6225 hours. A plot of electrode power density and cesium reservoir temperature versus time is shown in Figure 15. The diode was thermally cycled eight times.

The average electrode power density was $5.08 \pm .08 \text{ watt/cm}^2$ throughout the test period. During the first 2450 hours, the cesium reservoir temperature was 348 to 351°C, except during the last 500 hours, when the filament began to fail; the cesium reservoir temperature fell to 346 - 348°C and the electrode power density dropped to $4.90 \pm .02 \text{ watt/cm}^2$. After the filament was replaced at 2450 hours, the electrode power density returned to the average level of 5.08 watts/cm^2 and the cesium reservoir temperature slowly rose to 365 - 367°C. The changing cesium reservoir temperature may be attributed to a change in emitter temperature distribution resulting from a changing filament and input power density distribution, or a change in diode characteristics.

3. WFG1

The emitter consisted of a fluoride-deposited tungsten surface which was ground and then etched in 5% NaOH for three minutes at 180 mA/cm^2 and then heat-treated at 2000°C for 30 minutes. The diode was tested for 5250 hours. A plot of the electrode power density and cesium reservoir temperature versus time is shown in Figure 15. The diode was thermally cycled eight times.

The average power density was $4.94 \pm .02 \text{ watt/cm}^2$ for the first 1075 hours, at which time the metal-to-ceramic leadthrough was replaced and the diode was rebuilt and reprocessed using the same emitter-collector pair. After the 1075-hour point, the average electrode power density was $4.32 \pm .12 \text{ watt/cm}^2$. This difference in electrode power density, although not fully understood, is attributed to the reassembly of the diode.

During the first 1075 hours, the cesium reservoir temperature was 354 - 355°C. After 1075 hours, the cesium reservoir temperature was 363 - 365°C until filament was replaced at 2850 hours. After this time the cesium reservoir temperature was 370 to 372°C. These step changes in cesium reservoir temperature are attributed to the rebuilding of the diode at 1075 hours and the replacement of the filament after 2850 hours.

4. WFG3

The emitter was a fluoride-deposited tungsten surface which was ground and heat-treated at 2000°C for 30 minutes. The diode was tested for 5850 hours. A plot of electrode power density and cesium reservoir temperature versus time is shown in Figure 15. The diode was thermally cycled five times.

The overall average electrode power density was $4.48 \pm .20 \text{ watt/cm}^2$. During the first 725 hours, the average electrode power density was $4.62 \pm .02 \text{ watt/cm}^2$ and the cesium reservoir temperature was 360°C. After an instrumentation change, the average electrode power density was $4.64 \pm .04 \text{ watt/cm}^2$ and the cesium reservoir temperature was 363 - 364°C.

At 2300 hours, the filament was changed and the average electrode power density was $4.36 \pm .16 \text{ watt/cm}^2$. The cesium reservoir temperature was 365 - 367°C for the remainder of the test.

5. Conclusions

The performances of the four diodes with time indicate that the four emitter surfaces tested are stable for at least 6000 hours. Eliminating what are believed to be the effects of instrumentation and

filament changes, the maximum variation in electrode power density for the four diodes was 3.7%, which occurred in WFG3($4.36 \pm .16$ watt/cm²). Emitter stability is demonstrated by the fact that during the time periods when the filaments and instrumentation were unchanging (with the possible exception of WAF2), the maximum change in the observed cesium reservoir temperature was 3°C.

II. EQUIPMENT

A. INTRODUCTION

1. General

These life test stations provide the necessary power supplies, regulators, and monitoring equipment to operate and test a cesium thermionic converter for long periods of time and under a wide range of conditions. Numerous protecting circuits are included to reduce the likelihood of permanent damage to the converter under abnormal conditions. Total operating time is registered on a special meter to furnish a record of diode life. Strip chart recorder connections make it possible to record device temperatures and power during testing.

2. Console Equipment

The components of the console may be conveniently divided into four groups: heating power supplies, loading circuits, recording equipment, and protective devices.

a. Heater Supplies

Temperatures in the test cell are controlled and regulated by resistance heaters on the collector and the cesium reservoir and by electron bombardment of the emitter. In a typical diode, three collector heaters, two cesium reservoir heaters, and one emitter heater are used. The three collector heaters are interwound to achieve maximum heat transfer and have a common electrical connection with the two cesium reservoir heaters, which are similarly constructed. The resistance heater power is obtained from autotransformer-regulated,

low-voltage, transformer-isolated supplies. The console includes three such supplies. Panel HS 2550 provides up to 50 volts at 25 amps maximum and is manually controlled to drive two of the three collector heaters connected in series. Panel HS2525 provides 0 to 25 volts at up to 25 amps to the third collector heater through an indicating on-off controller which responds to a thermocouple installed near the collector, thereby directly controlling its temperature. Likewise, panel HS1515A controls cesium reservoir temperatures by a thermocouple and a triac proportional indicating controller. The two cesium reservoir heaters are normally connected in series and up to 15 volts at 10 amps is available for their operation. This more complicated arrangement is necessary in order to provide a stepless control and a better resolution of the cesium reservoir temperature.

The electron bombardment emitter heater uses a high-temperature auxiliary filament as an electron source and a high-voltage dc supply for the bombarding energy (panels EB104RC and HV41000, respectively). The source filament is operated under emission-limited conditions so that bombarding power may be controlled by varying the filament power. A servo-loop senses bombardment current and regulates the filament voltage to maintain constant emitter temperature.

b. Loading Circuits

Power output from the converter is absorbed in a transistor-regulated water-cooled load panel. This panel (LP200) maintains a constant current by varying the effective resistance of a bank of four parallel transistors connected in series with the converter. Front

panel meters continuously indicate converter output voltage and current. A separate low-voltage power supply provides the drive signal for the load transistors and offsets the losses in the connecting leads, thereby allowing the panel meters to indicate the actual converter output. For special tests, jacks on the panel allow direct access to the converter electrodes, providing both current and voltage connections.

c. Recording Equipment

Temperatures of the elements of the cell are monitored by thermocouples. These thermocouples are brought out through the baseplate to the console and connected through three Amphenol connectors in the rear panel to a multipoint strip-chart recorder to furnish a permanent record of the test program. Output current and voltage (after suitable attenuation) are simultaneously recorded in the same manner as temperature. Variations in power and temperature may be correlated from the record.

A running time meter registers the total operating time of the bombardment power.

d. Protection

The console protection devices function to shut down the system under the following conditions:

1. Water flow failure.
2. Power failure.
3. High seal temperature.
4. Vacuum leak.

Any other condition, such as heater failure, which leads to reduced output current and, hence, decreased electron cooling on the emitter, will activate a protection circuit to reduce the bombardment power, thereby protecting the emitter from excessive temperatures. A red pilot light in the upper right corner of the console indicates that the protection and bombardment circuits are functioning.

B. INSTALLATION

1. General Instructions

- a. Adjust all panel meters for mechanical zero.
- b. Locate the console on firm level floor, at least 2 feet away from rear obstructions.

2. Input Requirements

a. Console Power

208 volts, 60 cps, three-phase, 5-wire, 30 amps with ground. Three independent 30-amp circuit breakers installed into flexaplug. Green wire is equipment ground.

b. Water

0.2 gpm, rear right bottom panel. Input, 1/4" flare fitting, left; drain, 1/4" flare fitting, right.

c. Ground

1" inner diameter braid not over 12 feet long to connect console frame to cold water pipe.

3. Internal Connections: Console Panels and Power

The panels, shown individually in Figures 16 - 21, are installed into the cabinet as shown in Figure 22 and obtain power from a plug box inside the cabinet, accessible by opening the right rear door. The on/off override switch and the start pushbutton are also located on this plug box. See Figure 23 for location and wiring.

4. Special Wiring and Tubulation

a. Cesium and Collector Heater Connections (Panels HS2525 and HS1515A)

A thermocouple jack on the back of each controller connects to numbered thermocouple pins in the baseplate. Output wires connect to the screw terminal strip under the controller chassis. Use No. 10 wire for the output leads.

b. Collector Heater Connections (Panel HS2550)

As above, only no thermocouple jack.

c. Electron-Bombardment Filament Connections

To baseplate, use No. 10 wire, insulated for 3 Kv.

d. Vac-ion Pump Power Supply Connections

Plug the ac power cord into the plug box. Connect one end of the special shielded wire to the rear receptacle of the power supply and the other end to the pump. Connect the control power plugs into the rear receptacle of the power supply.

e. Power Panel LP200 (Upper)

Plug the No. 4-0 cables to the baseplate, the ac supply to the plug box, and the black and white twisted pair to the voltage taps.

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Figure 16. Electron Bombardment Power Supply (EB104RC).

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Figure 17. Cesium Heater Power Supply (HS1515A) and Collector Heater Power Supply (HS2525).

8877

Figure 18. Ion Pump Power Unit.

8881

Figure 19. Upper Load Panel (LP200) and Lower Load Panel.

8879

Figure 20. Collector Heater Power Supply (HS2550).

8882

Figure 21. High-Voltage Power Supply (HV41000).

8880

Figure 22. Panels Installed in Console.

Figure 23. A. C. Power and Interlock Connections.

A.C. POWER & INTERLOCK
CONNECTIONS

f. Power Panel SL220R (Lower)

Connect the water lines through the insulated couplings to the bell jar. The electrical connections are shown in Figure 24. Also, plug the two pigtails provided into the appropriate output jacks (see paragraph 7b).

C. OPERATING INSTRUCTIONS

1. Startup

a. Vac-Ion Pump

All power for the control and protection circuits is taken from the vac-ion pump and controlled by its circuit breaker. Accordingly, in order to start the console, the bell jar should first be evacuated by conventional means, such as a piston or an adsorption pump; then the vac-ion should be started, as described in detail in the ULTEK Manual No. C-1342. The pump-out valve of the bell jar is on the right side of the base plate and can be reached by removing the top cover of the console. When the indication on the vac-ion gauge reaches 1×10^{-5} torr, the vacuum in the bell jar will be hard enough to permit starting the collector and cesium reservoir heater supplies.

b. Power Switch

The power switch shown in Figure 23 has three positions: on (handle up), off (center), and override (handle down). In the "on" position, all protective circuits are operative and must be correctly set for continued operation. On "override," the waterflow and temperature interlocks are bypassed, allowing the system to be tested. To place in operation, the water flow is started, the recorder turned on and checked, and the power switch set to the "on" position. All panels should be turned off initially. Pressing the red "start" button located above the power switch will energize the power solenoid, which will lock on under the control of the power switch.

Figure 24. Internal Electrical Connections.

c. Electron Bombardment (EB) Heater

The EB 104RC panel should be set as follows: circuit breaker off, coarse and fine filament controls at zero, EB power off, selector switch low, protection switch off. The circuit breaker is then turned on, allowing the adjacent red pilot to light up. The coarse filament control is then advanced very slowly until a suitable heater current is shown in the ammeter (typically 25 amps).

d. Collector Heater HS 2550

The heater supply output control should be initially set at zero, and then the on-off switch should be turned on, activating the red pilot light. The output control is then advanced slowly until a suitable amount of power is delivered to the heaters (typically 10 amps at 30 volts). Caution should be exercised to avoid excessive outgassing of the heaters and consequent tripping of the circuit breaker of the vac-ion pump.

e. Collector Heater HS 2525

After turning the heater supply output control, shown in Figure 17, to zero, the switch is turned on and the controller allowed to warm up for about 30 seconds. At this time, the set knob should be adjusted to near the desired collector temperature. The scale will now be green, showing that more heat is called for. The control knob may now be advanced slowly to supply heater power. During initial heating, the bell jar pressure should be watched to avoid outgassing from the heater.

f. Cesium Heater

The reservoir temperature may now be increased in the manner described for the collector heater under section e, again using caution with regard to outgassing.

g. Electron Bombardment Supply EB104RC and HV41000

When the torr indicator at the Ultek vac-ion supply has stabilized for at least 10 minutes below 1×10^{-5} torr, the electron bombardment heating can be started. Initially, the voltage control on HV41000 should be set to zero and the circuit breaker of panel HV41000 turned on. Then the "on" button (black) on panel EB104RC is depressed, locking the power contactor on HV41000 on and turning on the red pilot light on EB104RC. The 10-turn current set point control is set to the desired current, the protection switch is set on automatic, and the voltage control is advanced slowly until the dc voltmeter on EB104 registers approximately 600 volts. At this time, some bombardment current should show in the dc ammeter, assuming that there is enough bombardment filament power available. If not, increase filament current until it does. Finally, the voltage control is advanced to near its desired setting. *

The power must be increased carefully to control outgassing, as discussed above. When the bombardment current becomes greater than approximately 80 milliamps, the elapsed time meter on panel HV41000 will start registering operating time and the protection light above the power panel will light, indicating that the protective circuits are functioning. The current should be set to produce the desired emitter temperature. This is best done by holding the

*The maximum allowable EB current is set by adjusting the current limit control after the proper range has been selected. (High, 0-4 A; low, 0-.8A.) See Figure 16 for location of these controls.

protection switch on "set" position, advancing the filament controls slowly, and observing the "null" indicator (see paragraph D 3b. The protection switch is then returned to the "auto" position.

At this point the servo-loop of the protection circuit will be active, causing the fine filament control to oscillate occasionally as the servo tries to stabilize emitter temperature. The coarse filament control should be adjusted so that the fine filament control normally sits at midrange.

h. Load Panels (Upper and Lower)

The upper load panel LP 200, shown in Figure 19, will indicate the diode output as heating takes place. Initially, the load power switch is turned on, illuminating the red pilot. Then the current control in the upper load panel and the voltage control in the lower load panel are both set at zero and the circuit breaker in the lower load panel is turned on (red pilot) to open-circuit the converter. The meter switch is turned on. As the emitter is heated, the voltmeter will indicate open-circuit voltage. When the output is greater than one volt, the voltage control is advanced slightly beyond the point where the converter output voltage starts dropping, due to the loading effect.* Adjustment of the current control will now vary the output voltage as the load current is changed.

i. Emitter Protection Relay

This relay continuously senses the output current and protects the emitter if the load current should decrease for any reason. The

* Maximum input voltage to the series transistors will not damage the panel, but will cause unnecessary heating of the transistor and rectifier heat sink.

current at which the relay operates is approximately 175 amperes, and release occurs at about 80 amperes. Before attempting continued operation, this relay should be set in the energized position by increasing the load current control to over 175 amperes and manually raising the emitter temperature to a maximum of 1700°C with the bombardment supply. With the protection switch "on", the dimming of the null light indicates that the relay has operated. The set point control must be close to the bombardment current for this action to take place. Once the relay has energized, the automatic controller on the EB is turned on and the diode load current and bombardment current are adjusted together, using care to avoid overheating the emitter. If the desired load current is below 80 amperes, the relay will release, causing the controller to decrease the emitter heating power. In this range, the protection switch should be turned off. As the temperature rises, the output power will increase and the desired operating conditions can be established.

2. Test Operation

a. Static Tests

During operation, conditions in the test cell are monitored by the millivolt and temperature recorder. The collector, emitter, and cesium temperatures should be set to the desired values and the load control adjusted to the proper operating point on the I-V characteristics. During this procedure, emitter temperature and bombardment power must be watched carefully to avoid overheating of the emitter due to reduced electron cooling at low load currents. Between approximately 80 and 170 amperes load current, the protection relay will

operate, causing the bombardment controller to increase the emitter power by about 30%. This relay should, therefore, be energized early in testing procedure, as described above. The device may now be operated continuously, with the protective circuits monitoring for abnormal conditions. The cesium and collector supplies will cycle to maintain the required temperatures. To trace out the I-V characteristics of the diode, the current setting on the load panel may be varied and the current and voltage readings of the meters noted. The converter can also be visually inspected and its temperature measured by optical means by lifting the nickel flap obscuring the observation window in the bell jar, using an external magnet.

b. Other Tests

For tests such as dynamic curve plotting, work function measurements, or very low-voltage, high-current operation, the pigtails interconnecting the load panel are removed, the meter switch is turned off (disconnecting the emitter protection relay), and a suitable external test panel is plugged into the collector and emitter test jacks. The voltage tab terminals will provide direct connection to the diode terminals for electrode voltage measurements.

3. Continuous Operation

The unit will operate as described above, and, after output current is obtained from the diode, the emitter protection may be turned on by following the procedure detailed in the console manual in Section C11 (Emitter Protection Relay). With this feature active, bombardment power will be reduced about 30% if the diode output current disappears for any reason. The emitter is thus protected from excessive

temperatures when the electron cooling load has been lost. Running time will be registered on the console whenever the bombardment current is greater than 80 mA.

D. DETAILED DESCRIPTION OF PANELS

1. Vac-Ion Pump

Refer to Ultek Manual No. C-1342 for details. Figure 25 shows the modification to allow power to be taken from the circuit breaker in order to operate all control circuits.

2. Power Plug Box

Figure 23 is the schematic of the console power circuit and shows the contactor and interlocks. Three independent 30 A circuit breakers (CB_1 , CB_2 , and CB_3) on the flexaplug protect all circuits. As an added protection, a 5-wire connection to the power line is used to provide an alternate ground path for fault currents in case the regular grounding strap is disconnected. The fan is always "on" and requires no maintenance. The vac-ion pump is also connected ahead of main contactor K_1 and is consequently controlled by its own circuit breaker. K_1 in turn controls all panels except HV41000, which is controlled by its own circuit breaker CB_4 and contactor K_2 .^{*} All power for the control circuits is taken from the vac-ion pump circuit breaker and consequently disappears in case of vacuum leak or overheating of the vac-ion pump. In series with the coil actuating circuit are the operate off-override switch and the water flow switch (S_1).

The opening of any of these contacts or a power failure causes the contactor (K_1) to drop out, cutting off all power to the console. Because of the normally open contact (K_{1A}) in the coil-hold circuit,

^{*}Power for contactor K_2 is obtained from panel EB104RC. Consequently, K_1 controls also this panel, indirectly.

the start button PB_1 must be pushed to re-energize the console. Emitter over-temperature and water flow protection can be bypassed for test purposes by setting the operate switch, S_1 , in the override position and pressing the start button, PB_1 . The EB supply is interconnected with the power circuit through the four-point cable, P_4 . An additional 1-amp fuse in the electron accelerating supply panel protects this line. Any difficulty causing the power circuit to turn off will also release the high voltage contactor K_2 in the bombardment supply, shutting off the bombardment voltage. This circuit will be described more fully in the EB supply and power panel paragraph.

3. Electron Bombardment Supply Panel EB104RC and Power Panel HV41000

The electron bombardment power supply of the console provides the two sources of power that are necessary for electron bombardment. The first is the ac filament supply, which provides the power necessary to heat the filament of the electron-bombardment gun to temperatures that will allow sufficient emission of electrons. The second source of power is a high-voltage dc supply, which provides the potential to accelerate the electrons emitted by the filament. Figure 27 is a schematic of EB supply panel EB104RC, and Figure 26 is a schematic of high voltage supply HV41000. The two are interconnected by an 8-point cable (P_8) and a 2-point high voltage cable (P_2) and perform as an integral unit.

a. Electron-accelerating Supply (HV4100) - see Figure 26

The electron-accelerating supply provides a maximum output of 1000 volts at 4 amperes. The output voltage of this supply provides the potential between the filament of the electron-bombardment gun

Figure 27. Electron Bombardment Power Supply, HV 41000.

and the emitter to be heated. This potential accelerates the electrons to the speed necessary to heat the surface against which they impinge. The supply consists of a controlled, three-phase, full-wave rectifier circuit. A specially-designed silicon bridge (BR_1) provides the rectification. The dc output is controlled by varying the amount of alternating current fed to the rectifier. The ac input to the rectifier is controlled by three Powerstats which are electrically connected in a four-wire "Y" system, but which are mounted on a common shaft (VT_1). This circuit provides 0 to 208 volts from center arm to center arm of any two Powerstats. The output of the Powerstats is connected to the delta primary of the power transformer, TR_1 . The secondary of the transformer is a "Y" connection with a neutral, and is zig-zag wound to prevent core saturation. Capacitor C_1 , in series with limiting resistor R_1 , stores enough energy to prevent damage to the rectifier in case of arc-over or short in the emitter EB circuit until the protection circuits operate. A series resistor R_2 , between the positive terminal of the rectifier and the meter relay, limits the short circuit current to 160 amperes.

The overload-protection system operates as follows: The meter relay M_1 fills the dual role of current meter and sensing device for the overload-protection system.* When M_1 senses an overload, the value of which is preset by the operator, it de-energizes relay K_3 . K_3 then opens the circuit to contactor coil K_2 , causing it to drop out and shut down the power from the high voltage circuitry. At the same time, the circuit breaker CB_4 of panel HV 41000 is energized, cutting off the primary of high voltage transformer TR_1 from the variable transformer, VT_1 . This is done to reduce

* It also provides the signal to the servo-controlling EB current. See paragraph D3b in this section.

circuit inductance and thus achieve a fast breakdown of the dc bombardment voltage. Resistor R_3 is protecting the contacts of meter relay M_1^* . 110 Vdc power supply comprising power transformer TR_5 , surge resistor R_{22} , full-wave bridge BR_2 , filter capacitor C_2 and bleeder resistor R_{21} is providing power for the above circuit. Nonreset timer T_1 , activated when relay K_4^* closes, registers accumulated operating time of the bombardment current. Fuse F_1 protects the control circuits. Panel HV41000 is mounted on chassis slides and can be pulled out by the handle provided (after releasing 4 holding screws) to inspect or replace the high voltage components. CAUTION: No interlock is provided.

b. Electron Bombardment Panel (EB104RC) - see Figure 27

This panel provides power for the operation of the EB filament. For convenience, it also incorporates the starting controls and indicators of HV41000 and the measuring instruments of both power supplies. Circuit breaker CB_5 is controlling all input power. Neon pilot PL_2 indicates power is on. Coarse filament control, variable-transformer VT_2 controls filament transformer TR_2 . TR_2 primary is in series with trimming transformer TR_3 , which is in turn controlled by fine filament control, variable-transformer TR_3 , or through a mechanical clutch by servo-motor SM_1 . The bandspread ratio between VT_2 and VT_3 is approximately 1:12. Fuse F_2 protects transformers VT_3 and TR_3 .

Ac ammeter M_2 , its current transformer TR_4 in series with the EB heater, indicates heater current. M_2 terminals are wired to connector P_{12} pins 1-2 for remote current indication.

* Components K_3 , BR_2 , TR_5 , C_2 , R_3 , R_{21} , R_{22} , and M_1 are located on panel EB104RC.

Ac voltmeter M_3 across TR_2 secondary monitors EB filament voltage. Protection switch S_3 operates as follows: In the "off" position, the input power of the bombardment filament is adjusted manually by VT_2 (coarse filament control) and VT_3 (fine filament control). In the "auto" position, the input power to the bombardment filament is controlled so as to keep the electron bombardment current constant. This is accomplished by comparing the voltage developed across the bombardment current meter (M_4) with a reference potential derived from a mercury cell (B_1). The difference voltage is amplified by a chopper input ac amplifier (A_1) and applied to a two-phase servo motor (SM_1). This motor then drives adjustable transformer VT_3 in the filament circuit in the proper direction to maintain the desired power output; that is, increased filament current if electron current decreases and vice versa. A screwdriver adjustable gain control (R_4) is also provided to compensate for the time constants in the loop and to maintain stable control free from hunting. The reference voltage is adjustable by means of a 10-turn potentiometer (R_5) which is calibrated directly in current (trimming resistor R_6 , range resistor R_7). Protection resistor R_8 modifies the set point of R_5 to reduce the effective value of the set point control R_5 by about 30% of the reading when protection relay K_6 is open (see Paragraph C1i). Thus, under no-load current conditions with emitter protection "on", the servo will null at a current 30% less than the setting, and with emitter protection "off" or converter load current flowing, the servo will null at a current equal to the set point value.

The "set" position of S_3 (spring return to "off"), simplifies the initial manual adjustment of filament current by disconnecting

the servo-motor. (The "null" pilot PL_3 will dim when the setting of VT_3 corresponds to the set point of R_5).

The external "sense input" jack (J_1) on the front panel provides access to the servo system. Inserting a standard PL55 plug breaks the regular current sense circuit. External signals such as those from pyrometers or thermocouples may then be connected to this plug and the temperature controlled by the set point knob, R_5 . This knob has full-scale balance capability of 0.5 volt, and, therefore, the input signal should be in the range of 10 to 500 mV. The servo will then function in a manner similar to that described above. (R_9 is the range resistor for external signals.)

The remainder of the panel consists of dc voltmeter M_4 and associated multiplier resistors R_{10} and R_{11} (to indicate bombardment voltage) as well as the attenuator network R_{12} , R_{13} , R_{14} , and R_{15} (for connection to a remote recorder, connector P_{12}). Also, meter relay M_1 , in association with multiplier switch S_4 and shunts R_{16} and R_{17} , monitors EB current in two ranges (0 - .8 and 0 - 4 amps). Link L_1 reduces shunt error due to wiring resistance. Resistors R_{18} , R_{19} , and R_{20} attenuate the EB current signal for remote reading (connector P_{12}).

The functions of M_{1A} , R_7 , K_3 , TR_5 , BR_2 , R_{21} , R_{22} , PB_2 , PB_3 , and PL_4 are explained in paragraph D3a. Relay K_4 , in series with the high voltage line, closes when bombardment current exceeds 80 mA and illuminates the protection light in the console (paragraph C1g), and also starts the elapsed time meter in panel HV41000. Diodes D_1 , D_2 , and D_3 protect K_4 and M_1 from transients, flashovers, or short-circuits in the converter. P_3 is the EB filament connection and P_{3A} the high voltage connection leading to panel HV41000.

4. Cesium Heater Power Supply (HS1515A)

Cesium heater power supply HS1515A, shown in Figure 28, is largely self-explanatory. On-off switch S_5 controls the power to a proportional triac controller Honeywell R-7161-P (A_2) calibrated from 0 - 420° C. Q_1 , a triac, is opening proportionately in response to a signal from a chromel-alumel thermocouple installed near the cesium reservoir of the converter. Fuse F_4 protects the circuit. Pilot light PL_5 indicates that variable transformer VT_4 is receiving power. This pilot light will glow brighter when more power is called for and will dim when less power is required. Isolating step-down transformer TR_6 converts the output of VT_4 to a suitable low-voltage, high-current power to drive the cesium reservoir heater of the converter. Ac ammeter M_5 and ac voltmeter M_6 indicate heater current and voltage continuously. However, as both instruments are sensitive to power line harmonics, their readings will be useful only for reference.

5. Collector Heater Power Supply (HS2550)

This supply (Figure 29) is entirely conventional. On-off switch S_6 controls power to the variable transformer VT_5 ; neon pilot PL_6 indicates that the power is on. VT_5 output is converted to low-voltage, high-current power by isolating step-down transformer TR_7 . Fuse F_5 protects the circuit (ac). Ammeter M_7 and ac voltmeter M_8 indicate heater current and voltage continuously. As the output of this power supply is sinusoidal, these meters will show the actual I and V values of heater power ($\pm 3\%$).

Figure 28. Cesium Heater Power Supply HS 1015 D and HS 1515 A.

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Figure 29. Collector Heater Power Supply (HS 2550A).

6. Collector Heater Power Supply (HS2525)

Figure 30 is a schematic diagram of collector heater power supply HS2525. On-off switch S_7 controls power to an on-off type Honeywell controller model R-7161-B (A_3), which responds to a signal from a chromel-alumel thermocouple installed near the collector of the converter. This controller is calibrated from 0 - 1000°C. The output of this controller activates the coil of relay K_5 .

Variable transformer VT_6 (also controlled by S_7) powers the third collector heater* by means of isolation step-down transformer TR_8 . Fuse F_6 protects the circuit. Ac ammeter M_9 and ac voltmeter M_{10} indicate heater current and voltage. In series with the heater line, and responding to the collector thermocouple, the contact of K_{5A} causes the collector heater to cycle on and off in order to maintain the desired collector temperature. The output of this power supply is sinusoidal; accordingly, M_9 and M_{10} will show actual heater current and voltage values ($\pm 3\%$) when K_5 is on.

7. Upper and Lower Load Panel (LP200)

This panel is actually made up of three sections which perform as an integral unit: upper load panel LP200 (Figure 31), lower load panel SL220R (Figure 32), and Lambda LMD_3 power supply, installed on brackets behind the lower load panel under the vac-ion pump (Figure 33).

a. The upper load panel contains the meters, current control circuits, protection relay, and output jack of the converter. In

* In typical converters. The other two are powered manually by HS2550.

Figure 31, a schematic diagram of this panel, S_8 , is the on-off switch controlling neon pilot PL_7 and is wired to pins 11 and 12 of connector P_{12} in order to supply ac power to LMD_3 . The converter current taps are connected to high-current output jacks J_2 , J_3 , and J_4 . The collector is brought out directly to J_4 (red), the emitter, through an air-cooled 200-amp, 50-millivolt shunt, R_{23} to J_3 (black), or through an additional emitter protection shunt R_{24} to J_2 (yellow). (On panel LP200, J_2 is marked "load," J_3 "emitter," and J_4 "collector.") The function of the emitter protector relay is described in paragraph Clh.

Precision 10-turn potentiometer R_{25} (marked "load current") is wired in series with the output of shunt (R_{23}) to pins 7 and 8 of connector P_{12} . The "sense" circuit of LMD_3 is plugged into these pins. Adjusting R_{25} impresses part of the voltage drop across R_{23} to the sense terminals 3 and 6 of LMD_3 . This signal, suitably amplified by LMD_3 , is used to drive the base of transistors Q_2 through Q_5 in the lower load panel and thus vary the effective load of the converter. The phasing between the voltage drop across R_{25} and the base drive of Q_2 through Q_5 is adjusted so that a constant current condition exists for the converter. A calibration control on LMD_3 assures that all losses in the interconnecting cables, jacks, shunts, etc., are compensated for and the actual current and voltage of the converter is indicated on the measuring instruments at all times and for all settings of R_{25} . This control, whose location is shown in Figure 31, is to be nulled when the dial of R_{25} is set at zero. (The converter should be producing current; S_9 should be "on" and then R_{25} is adjusted slowly until M_{11} reads 0).

Figure 30. Regulated Collector Heater Power Supply (HS 2525).

Figure 31.

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Figure 32. Lower Load Panel Model SL 220R.

Figure 33. Schematic Diagram of Regulated Power Supply.

Precision dc ammeter and dc voltmeter M_{11} and M_{12} , respectively, read converter I and V when meter switch S_9 is on. Outside recorder connections are brought out at pins 1 and 2 of P_{12} for amps and 3 and 4 through attenuation network R_{26} and R_{27} for volts. In order to reduce error, the voltage tap of the converter is brought out to an independent set of terminals at the base plate and connected internally to the emitter and collector of the converter. Voltage jacks J_5 (black) and J_6 (red), marked "emitter" and "collector," respectively, provide access to these taps. Normally, J_6 (collector) tap is grounded to the console frame by a separate connection on the baseplate collector leadthrough.

Meter switch S_9 disconnects the panel meters M_{11} and M_{12} when external read-out devices are desired. It also disconnects protection relay K_{6A} contact. The function of K_6 is described in paragraph C1g.

b. The high-current circuit of panel LP200 is brought out to the lower load panel by interconnecting pigtails. Normally, jack J_2 (yellow) is connected to jack J_7 (yellow) through a yellow pigtail and jack J_4 (red) to jack J_8 (red) through a black pigtail. In case emitter protection is not desired, relay K_6 can be bypassed by connecting J_2 (yellow) to J_7 (yellow) and J_4 (red) to J_9 (black). In the lower load panel SL220R (Figure 32), Q_2 through Q_5 is a bank of 4 Solitron MHT 2205 PHP Germanium transistors having a very low saturation voltage. Resistors R_{28} through R_{31} equalize the load between Q_1 , Q_2 , Q_3 , and Q_4 . Diodes D_4 through D_9 provide power to the transistor bank. All the above semiconductors are mounted on a common, water-cooled heat sink to maximize heat transfer. D_5 through D_9 are reverse polarity to allow galvanic connection with the collectors of MHT2205. Ac

power for the diodes is provided by transformer TR_9 having a delta primary and a double wye secondary to provide six-phase inputs to the rectifiers. This transformer is rated 300 amps at 2 volts. Center-tapped choke CH_1 equalizes the load between the two secondaries of TR_9 . The center tap of CH_1 is connected to J_8 (and through the yellow pigtail to the converter emitter, as described earlier). The output of LMD_3 is also connected to J_6 . The emitters of load transistors Q_1 through Q_4 are brought out to jack J_7 and through the yellow pigtail to the converter collector.

In this circuit, conventional current flows from the emitter of the converter to the meter shunt, the panel jacks J_2 and J_7 , the transistor emitters, through the transistor, the collectors, the heat sink, the rectifiers, power transformer TR_9 , choke CH_1 , panel jacks J_4 and J_8 and back to the converter collector to complete the circuit. Varying the base drive of the load transistors under the control of LMD_3 and R_{25} changes their effective series resistance and thus provides a means of controlling the converter current.

The primary voltage of TR_9 is manually controlled by a three-phase variable transformer VT_7 in a wye connection. Connector P_4 brings out the base drive from power supply LMD_3 to the transistor bank. Pin 13 of P_4 connects to the + output (pin 6) of LMD_3 and the bases of Q_2 through Q_5 . Pin 16 connects to T_6 and the - output of LMD_3 (pin 4). Circuit breaker CB_6 disconnects VT_7 from the power line and protects the circuits.

Neon pilot PL_8 indicates when TR_9 is on. Diode network D_{10} through D_{15} protects the load transistors from transients and surges due to shorts or arc-over in the converter EB circuit.

c. The function and adjustment of LMD_3 is described in D7b. Figure 33 shows the circuit diagram of the power supply and the modification necessary to adapt LMD_3 to the present circuit.

ERRATA SHEET

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TOPICAL REPORT - LIFE TEST ON FOUR ELECTRICALLY-HEATED
THERMIONIC DIODES WITH FLUORIDE VAPOR-
DEPOSITED TUNGSTEN EMITTERS

Dated 30 June 1969

- (1) The figure on page I-23 (Figure 15. Plot of Voltage versus Time for the Four Diodes) should be replaced by the attached figure. Note change in title of figure as well as in figure itself.

Figure 15. Electrode Power Density and Cesium Reservoir Temperature versus Time for Diodes WAF1, WAF2, WFG1, and WFG3.