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ENGINEERING CORPORATION

Report No. TE 60-64

FIRST QUARTERLY PROGRESS REPORT
FOR
THERMIONIC CONVERTER LIFE AND
REPEATABILITY INVESTIGATION

2 January 1964 to 31 March 1964

by

Dr. C. Z. Kamien

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Task No. 817305-30

Prepared for

Flight Vehicle Power Branch
AF Aero Propulsion Laboratory
Research and Technology Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

Approved by:

Jerome H. Weinstein
Deputy Manager

FOREWORD

This report is the first Quarterly Technical Report, prepared by Thermo Electron Engineering Corporation, on Air Force Contract AF 33(615)-1348 under Task Number 817305-30.

The work is being administered under the direction of AF Aero-Propulsion Laboratory, Research and Technology Division. Mr. A. E. Wallis is project engineer for the Aero-Propulsion Laboratory.

The report covers the work performed from 2 January 1964 through 31 March 1964 at Thermo Electron Engineering Corporation, Waltham, Massachusetts.

The work covered by this report was accomplished under Air Force Contract AF 33(615)-1348, but this report is being published and distributed prior to Air Force review. The publication of this report, therefore, does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

This report is unclassified.

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ABSTRACT

This report covers the work accomplished during the first three-month period of a thirty-six-month program which is a continuation of the applied research work initiated under Contracts AF 33(616)-17411, AF 33(616)-8114, AF (657)-11169, and AF 33(657)-10130 on solar thermionic converters, solar thermionic generators and thermionic converter additives.

The two major goals of the program are: 1) to develop a clear understanding of the factors which affect the life and performance of thermionic converters through the use of adequate diagnostic tools, and 2) to acquire the technology and techniques necessary to design and fabricate experimental converters having long life and high power output on a repeatable and predictable basis.

Towards these goals, life test equipment has been designed to enable testing any converter for long-sustained life as well as for cyclic life evaluations. Furthermore, diagnostic facilities are incorporated in the design of the life test stations. In addition to the life test equipment, a cesium vapor, repairable thermionic converter has been designed and fabricated.

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TABLE OF CONTENTS

<u>Chapter</u>		<u>Page</u>
	List of Illustrations	vii
	List of Tables	ix
1	Introduction	1
2	Summary	2
3	Design of Life Test Equipment	3
	3.1 Vacuum Chamber	3
	3.2 Electron Gun and Converter Support Structure	6
	3.3 Electron Gun Power Supply and Regulator	7
	3.4 Cesium Reservoir Temperature Controller and Power Supply	7
	3.5 Collector Temperature Controller and Power Supply	9
	3.6 Elapsed Time Meter and Automatic Timer	9
	3.7 Converter Loading	11
	3.8 Mass Spectrometric Analysis	11
	3.8.1 Gas Sampling Unit	11
	3.8.2 Mass Spectrometer	15
	3.8.3 Calibration	16
4	Design of Converter Prototype	18
	4.1 Design Calculations	20
	4.1.1 Electron Cooling Heat Loss (q_e)	20
	4.1.2 Cesium Conduction Heat Loss (q_{Cs})	23
	4.1.3 Interelectrode Radiation Heat Loss (q_r)	23
	4.1.4 Collector Temperature Drop	25
	4.1.5 Heat Transfer in Tantalum Spacer	26
	4.2 Design Configuration	29
5	Design of Thermionic Scanner	30
	5.1 Principles of Operation	30
6	Plans for the Second Quarter	34

page blank

LIST OF ILLUSTRATIONS

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
3.1	Complete Life Test Stand	4
3.2	Vacuum Chamber Cross Section	5
3.3	Schematic Diagram for the Electron Gun Power Supply and Regulator Circuit	8
3.4	Schematic Diagram for Cesium Reservoir, Collector Power Supply, and Temperature Control Circuit	10
3.5	Schematic Diagram for the Elapsed Time and Automatic Metering Circuit	12
3.6	Schematic Diagram for the Converter Loading Electronic Circuit	13
3.7	Schematic of Gas Sampling System	14
3.8	Schematic of Calibration System	17
4.1	Prototype 401-P-1 Cross Section	19
4.2	Optimized Power Map for Rhenium Emitter	21
4.3	Film Coefficient of Heat Transfer for Cesium Versus Cesium Pressures	24
4.4	Basic Dimension of Collector	25
4.5	Energy Balance Emitter Spacer Element	26
4.6	Basic Insulator Assembly	28
5.1	Scanner Cross Section	31
5.2	Elementary Diode in Magnetic Field	33

page blank

LIST OF TABLES

TABLE

PAGE

IV-1

Nomenclature

22

CHAPTER 1

INTRODUCTION

This is the first quarterly report on Contract AF 33(615)-1348 covering the period from 2 January 1964 to 31 March 1964. This program is a continuation of the applied research work initiated under Contracts AF 33(616)-7411, AF 33(616)-8114, AF 33(657)-11169, and AF 33(657)-10130 on solar thermionic converters, solar thermionic generators and thermionic converter additives.

The objectives of the program are. 1) to develop a clear understanding of the factors which affect the life and performance of thermionic converters through the use of adequate diagnostic tools, and 2) to acquire the technology and techniques necessary to design and fabricate experimental converters having long life and high power output on a repeatable and predictable basis.

In order to achieve the above objectives, the converter shall be of an improved mechanical design which should simplify the method of manufacturing and thus reduce the complexity of the unit. The converter shall be capable of being repaired, then continuing its operation on the life test units.

In order to enhance the probability of successful life testing, and to remove to as great a degree as possible any external effects, four carefully designed and specially manufactured life test stations with completely integrated auxiliary equipment, are to be fabricated. The life test stations are to incorporate facility for gas sampling by means of a mass spectrometer as well as automatic, unattended, continuous data recording.

CHAPTER 2

SUMMARY

During the first quarter, the design of the life test station has been completed. This design incorporated a vacuum chamber, electron gun, electron gun power supply, electron gun power supply regulator, cesium reservoir temperature controller and power supply, collector temperature controller and power supply, elapsed time and automatic cycling timer, converter load control, and ion-type vacuum pump and power supply. In each life test console, provisions are made for gas sampling.

The design and fabrication of the first prototype of the 400 series has been completed. This prototype has a rhenium emitter and a one piece molybdenum collector radiator unit. The main feature of this design is that a minimum of brazing is utilized in the construction of the converter. All critical parts of the converter are electron beam welded and these welds are grindable so that the part can be removed for inspection or replacement.

A calibration unit has been designed and fabricated to calibrate the mass spectrometer for the analysis of converter internal gases.

All of the above units are currently being assembled.

CHAPTER 3

DESIGN OF LIFE TEST EQUIPMENT

The life test equipment includes vacuum chamber, electron gun, electron gun power supply, electron gun power supply regulator, cesium reservoir temperature controller and power supply, collector temperature controller and power supply, elapsed time and automatic cycling timer, converter load control, and ion-type vacuum pump and power supply. In each life test console, provisions are made for gas sampling. All controls are on a single console. Figure 3.1 shows a simplified cross section of the vacuum chamber and a schematic sketch of the entire unit. There follows a description of the major components of the life test system.

3.1 Vacuum Chamber

Figure 3.2 shows a cross section of the vacuum chamber including the tubulation arrangement for gas sampling. The vacuum chamber is stainless steel, 7.25 inches I. D. by 9 inches high. It is enclosed with a stainless steel water jacket on the outside to adsorb the heat thrown off by the converter and the gun. This type of arrangement presents a uniform radiation environment to the converter radiators. The cooling water outlet contains a pressure-sensitive switch which, upon sensing insufficient water pressure, opens. This switch is interlocked with the electron gun power supply and when it opens all heater power is automatically cut off, thus providing a fail-safe arrangement with respect to the cooling of the unit. The switch does not affect the ion pump, however, thus maintaining the vacuum in the chamber while the converter cools down.

A replaceable 1 inch pyrex window is used for pyrometer observations. The window is protected against deposits by a nickel gate which is pivoted out of the line of sight during observations with the aid of a small permanent magnet. The

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Figure 3.1 Complete Life Test Stand

Figure 3.2 Vacuum Chamber Cross Section

window assembly is heliarced to the stainless steel bell jar. This design permits easy replacement of the window if contaminated or damaged, or if the nickel gate requires adjustment.

A Parker Gask-O-Seal, which has negligible sublimation at 10^{-8} mm Hg and a relative leak rate which is small in comparison with the stainless steel, is used to seal the chamber to the base plate. This base plate is made of 10-inch diameter, 7-inch high stainless steel tube and has provisions for all necessary feedthroughs, such as electrical, water, gas sampling, and rough-down valve. All leadthroughs are of metal-ceramic construction and are welded to the base plate. After the chamber has been mechanically pumped below 10 microns, a 50-liter/sec (Ultek) ion pump takes over. Roughing is accomplished through a stainless steel bellows valve. Thermocouple lead wires pass through RETMA octal-type sockets.

3.2 Electron Gun and Converter Support Structure

The heat source for the diode is a bombardment heater (or gun). The gun is designed to be supported from the same structure as the diode. Consideration has been given to the easy positioning of either the entire heater or the filament alone. The electron source consists of a 0.030-inch diameter tungsten filament heated to 2500°K and has an estimated life of 15,000 hours. The filament can be replaced if necessary without disassembly of the entire heater. A tantalum shield is provided which prevents bombardment of the side wall of the converter to eliminate extraneous heating by stray electrons. A copper heat sink is provided to prevent overheating of adjacent parts. The filament design is aimed at achieving the most uniform heat distribution on the diode face within the limitations of wire emitters. The entire unit was designed for maximum versatility and cleanliness.

The support structure is designed to provide a high degree of versatility in positioning the diode as well as the electron gun.

3.3 Electron Gun Power Supply and Regulator

The electron gun power supply is a self-contained unit and provides a maximum of 50 amperes at 10 volts ac to the filament. This current is regulated by a control circuit. A 1-kV dc 750-ma Sorensen MD power supply provides the accelerating voltage. It is regulated at $\pm 1\%$ for line voltage variations and the output has less than 1% ripple. The 10 volts ac is controlled by a coarse and a fine variable-voltage transformer. The control circuit regulates the bombardment current at the desired value in the following manner. The bombardment current develops a voltage which is compared to a given reference voltage. The difference between the bombardment voltage and the reference voltage, if different from null, is chopped and amplified and drives a servo motor which adjusts the fine variable voltage transformer in the bombardment filament circuit. In this manner the bombardment power is continuously checked and adjusted to a predetermined value of life testing power requirement. Whenever the bombardment current approaches the preset upper or lower limit, the meter relay shuts off. This relay actuates a switch which shuts off the high voltage as well as the elapsed time meter. As an added precaution, the servo-motor cannot increase the bombardment filament circuit current more than 10% of the preset value. This provision was incorporated to minimize the possibility of filament burnout. Figure 3.3 shows a schematic diagram of the electronic circuit for the electron gun power supply and regulator.

3.4 Cesium Reservoir Temperature Controller and Power Supply

The power supply for the cesium reservoir heater consists of an 18-volt 10 amperes ac supply with a variable voltage transformer and a stepdown iso-

Figure 3.3 Schematic Diagram for the Electron Gun Power Supply and Regulator Circuit

lation transformer. The cesium reservoir temperature is controlled by a Minneapolis Honeywell thermocouple operated controller, which provides time proportioned on-off switching. The controller is equipped with a temperature indicating dial which enables one to read directly the cesium reservoir temperature. A voltmeter and ammeter are provided so that the power input to the heater can be determined. Figure 3.4 shows a schematic diagram of the power supply for the cesium reservoir temperature control.

3.5 Collector Temperature Controller and Power Supply

The power supply for the collector heater consists of a 36-volt 10 amperes ac supply with a variable voltage transformer and a stepdown isolation transformer. The collector temperature is controlled in the same manner as the cesium reservoir temperature. See Figure 3.4 for the schematic diagram of the power supply for the collector temperature control.

3.6 Elapsed Time Meter and Automatic Timer

An elapsed time meter is provided which records the time during which a converter in the life test unit operates above a predetermined emitter temperature. The meter reads up to 10,000 hours and is actuated by a relay switch. The terminals of the relay switch are shorted until the bombardment current reaches the value corresponding to the required emitter temperature at which point the terminals of the relay switch are unshorted and the relay activates the meter. The timer operates only when the bombardment current is within preset limits.

An automatic timer is provided which allows the automatic cycling of the converter by starting and stopping the emitter bombardment current. This timer can be adjusted to any combination of off-on cycles desirable up to

	Collector	Cesium
T ₁	30V, 15 amp F79U	12V, 11 amp F29U
T ₂	21B	10B
F	5 A	2 A
M ₁	30 V ac	15 V ac
M ₂	15 amps ac	15 amps ac
T _C	0-860°C	0-420°C

Figure 3.4 Schematic Diagram for Cesium Reservoir and Collector Power Supply and Temperature Control Circuit

Figure 3.4 Schematic Diagram for Cesium Reservoir, Collector Power Supply, and Temperature Control Circuit

120 minutes. An event counter is also incorporated to record the accumulative number of cycles. Fig. 3.5 shows the schematic diagram for the elapsed time and automatic metering circuit.

3.7 Converter Loading

The converter is loaded by means of a power transistor which dissipates the converter's output. It allows a continuous variation of converter load from 50 ohms down to 0.003 ohms. Converter output current and voltage are indicated on two 6" mirror scale meters. The load can be programmed to maintain either constant output current or constant output voltage during life testing. Provisions are also available for dynamic (60 cycles) testing as well as recording current voltage characteristics. Fig. 3.6 shows the schematic diagram for the converter loading electronic circuit.

3.8 Mass Spectrometric Analysis

For each life test unit, provisions are made to allow repeated analysis of the plasma at any time during the life test. The mass spectrometric system consists of three sections:

3.8.1 Gas Sampling Unit

A gas sampling unit is incorporated in each life test station. Analysis of the plasma is accomplished without use of ultra high vacuum valves or fittings which are at high temperatures. A schematic diagram of the principle parts of the gas sampling system is presented in Fig. 3.7. With this setup, the pressure of the gas and the type of impurities in the gas can be determined and correlated with converter performance. The test setup is used as follows:

The system is baked under vacuum to minimize outgassing during operation. Baking temperature is attained by the heaters inside the

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Figure 3.5 Schematic Diagram for the Elapsed Time and Automatic Metering Circuit

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Figure 3.6 Schematic Diagram for the Converter Loading Electronic Circuit

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Figure 3.7 Schematic of Gas Sampling System

vacuum chamber, and by a hot chamber which surrounds the components of the system outside the vacuum chamber.

Cesium is distilled into the system from a metal capsule to eliminate the impurities caused by glass capsules.

During this stage, valve S_{14} is closed, heater H_1 is turned on and the rest of the system is kept cold. Cesium is hence distilled to the reservoir and the cesium capsule is pinched off at position A.

During converter operation, heaters H_3 and H_4 and cooler C_2 are operating while cesium pressure in the converter is controlled by heater H_3 .

For plasma analysis, cooler C_4 is turned on to condense the cesium into the storage chamber. At this stage, valve S_{12} and S_{11} are closed and valves S_{13} and S_{14} are opened to perform the mass spectrometric analysis. At the end of the mass spectrometric analysis, to resume operation of the diode, valve S_{14} is closed and heater H_4 is turned on so that cesium is transported back to the reservoir.

3.8.2 Mass Spectrometer

Since the quantity of gases evolved during operation of diodes is small, conventional flow type mass spectrometers cannot be used. A high sensitivity mass spectrometer which can be operated statically is needed. This means that it must be capable of maintaining ultra high vacuum while isolated from its vacuum system. A further restriction is imposed on the internal volume of the mass spectrometer chamber since a large volume will reduce the partial pressure of gases below the sensitivity.

The CEC Model 21-613-1 mass spectrometer which is a simplified version of 21-620A has these characteristics. It employs a cycloidal-focusing mass analyzer to separate higher molecular-weight compounds without the necessity of a large-size analyzer assembly. This is used for mass 12 to mass 150. An auxiliary 180° controller is used to obtain masses from 2-4. This unit has a sensitivity sufficient to detect a partial pressure of N_2 of 5×10^{-11} torr. Unit resolution is achieved up to $m/e = 150$.

3.8.3 Calibration

For quantitative analysis, mass spectrometers must be calibrated. To achieve most accurate results, calibration procedure must try to duplicate the conditions under which the unknown gases are analyzed. Hence the standard method of calibrating mass spectrometers could not be used since it employs a dynamic system. It is also important to calibrate for all of the gases that are expected to be present, preferably before each analysis.

The calibration method used for this system is based on introducing known quantities of gases in the expected mass range. Fig. 3.8 shows a schematic diagram of the calibration system. The system is designed to produce accurate results without employing intricate units such as micromanometers. It is based on successive expansions of minute quantities of gases and is capable of delivering any desired quantity in the range 10^{-4} - 10^{-8} cc S. T. P. with an accuracy of 1%.

Needle valves S_1 and S_2 are used to produce the desired pressure in chambers C_A and C_B . The pressure is read accurately from the manometer by a cathotometer. The quantity of gases present in chamber C_B is expanded into $C_M + C_D$ and then chamber C_D is isolated by closing valve S_5 . Since the volume of chambers C_B , C_M and C_D have been measured accurately, the pressure in C_D can be calculated. Knowing the pressure, volume, and temperature of chamber C_D , the quantity of gases present is specified.

Calibration can also be carried out in presence of cesium by opening valve S_8 .

Figure 3.8 Schematic of Calibration System

CHAPTER 4

DESIGN OF CONVERTER PROTOTYPE

A prototype design of the 400 series has been completed. Figure 4.1 shows the cross section for prototype 401-P-1. The basic features of the series 400 converter are as follows:

- a. The emitter material is tungsten with a pyrolytic deposition of rhenium on the emission face. The addition of rhenium improves the life and performance of the diode.
- b. The emitter support is fabricated from tantalum tubing and welded to the emitter through a molybdenum adapter.
- c. The emitter support is welded to a tantalum flange which acts as a shield on the emitter sleeve. This tantalum flange is welded to the upper insulator niobium flange. This construction will enable convenient grinding off of welded portions and removal of the emitter for investigation or scanning without disturbing the other parts of the diode. The same emitter could be installed back on its diode or a new one could replace the original emitter and life testing or cycling continued.
- d. The lower insulator niobium flange makes the final weld with the collector in a manner that the insulator assembly can be ground off and replaced.
- e. The collector and radiator are made of one piece of molybdenum so that the radiator to collector braze is eliminated from this design. This essentially eliminates a source of past failures at the collector-radiator braze.

Figure 4.1 Prototype 401-P-1 Cross Section

- f. A collector heater is incorporated in the design to facilitate optimization of the collector temperature in addition to optimizing cesium temperature.

4.1 Design Calculations

For the purpose of the design calculations, the conditions for the prototype were taken from the map of maximum power density versus voltage for rhenium-molybdenum combination. Figure 4.2 shows such a map which is based upon data obtained by Thermo Electron under the emitter materials research program sponsored by the Office of Naval Research and the Advanced Research Project Agency.

The design conditions corresponding to the design point of Figure 4.2 are:*

$$\begin{array}{ll} T_E = 2000^\circ\text{K} & P_o = 15 \text{ w/cm}^2 \\ T_{Cs} = 640^\circ\text{K} & V_o = 0.7 \text{ volts} \\ W = 2 \text{ mils} & J_o = 21.43 \text{ amps/cm}^2 \\ T_C = 940^\circ\text{K} & A_E = 2 \text{ cm}^2 \end{array}$$

The heat input required to the diode can best be determined by calculating each major heat loss term and adding them as follows:

$$q_E = q_e + q_{Cs} + q_r + q_{E_s} \quad (1)$$

4.1.1 Electron Cooling Heat Loss (q_e)

The most precise expression known for the evaluation of electron cooling losses, which is in close agreement with research data, is:

$$q_e = (\phi_E + 2kT_E) J_o \quad k = \frac{1}{11,600} \text{ ev/}^\circ\text{K} \quad (2)$$

The sum $\phi_E + 2kT_E = \phi^*$ can be accurately estimated by equating it to the value

*Nomenclature Table IV-1

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Figure 4.2 Optimized Power Map for Rhenium Emitter

TABLE IV.1

NOMENCLATURE

A_E	Emitter area, cm^2	R_2	Thermal resistance of collector insulator flange, $^\circ\text{C}/\text{watt}$
A_i	Area of i th element, cm^2	R_{cer}	Thermal resistance of seal insulator, $^\circ\text{C}/\text{watt}$
C	Circumferential length of emitter support, cm	S	Cross sectional area of emitter support per cm^2 of emitter area
D_E	Diameter of emitter, cm	t	Thickness of emitter support cm
H_{Cs}	Cesium conduction coefficient, $\text{w}/\text{cm}^2\text{-}^\circ\text{K}$	T_{CB}	Collector Base temperature $^\circ\text{K}$
J_o	Output current density, amps/cm^2	T_C	Collector temperature, $^\circ\text{K}$
K	Thermal conductivity, $\text{w}/\text{cm}^2\text{-}^\circ\text{C}$	T_{Cs}	Cesium condensation temperature in diode, $^\circ\text{K}$
k	Boltzmann constant 1.38 $\times 10^{-16}$ 605.8 $\text{ev}/^\circ\text{K}$	T_E	Emitter temperature, $^\circ\text{K}$
L_1	Length of 1th element cm	T_L	Emitter support base temperature, $^\circ\text{K}$
P_{Cs}	Cesium pressure, mm Hg	V_o	Output voltage, volts
P_o	Output power density, w/cm^2	W	Diode interelectrode spacing, mils
q_{Cs}	Heat lost by cesium gas conduction, w/cm^2	ϵ_C	Total hemispherical emissivity of collector at a temperature equal to the geometric average of the emitter and collector temperatures
q_e	Heat lost by electron cooling, w/cm^2	ϵ_E	Total hemispherical emissivity of emitter at emitter temperature
q_E	Total heat flux, w/cm^2	ϵ_{eff}	Effective total hemispherical emissivity
q_{Es}	Heat lost by conduction to the emitter support, w/cm^2	σ	Stephan Boltzmann constant, $5.67 \times 10^{-12} \text{ w}/\text{cm}^2\text{-}^\circ\text{K}^4$
q_L	Heat flux through the emitter support, watts	ϕ_E	Work function of emitter, ev
q_r	Heat lost by interelectrode radiation, w/cm^2	ϕ^*	Effective work function (defined by Eq. 3), ev
R_1	Thermal resistance of emitter insulator flange, $^\circ\text{C}/\text{watt}$		

of work function required to emit a saturation current equal to the design current density at T_E of the design. For $J_o = 21.43 \text{ amps/cm}^2$ and $T_E = 2000^\circ\text{K}$, Richardson's equation gives:

$$\phi^* = kT_E \ln \left(\frac{120}{J_o} T_E^2 \right) = 2.91 \text{ ev} \quad (3)$$

Therefore:

$$q_e = 2.91 \times 21.43 = 62.5 \text{ w/cm}^2 \quad (4)$$

4.1.2 Cesium Conduction Heat Loss (q_{Cs})

Since the interelectrode gap is small, cesium conduction losses are assumed to occur only across the gap facing the area of the emitter ($A_E = 2 \text{ cm}^2$):

$$q_{Cs} = H_{Cs} (T_E - T_C) \quad (5)$$

$$P_{Cs} = \frac{2.45 \times 10^8}{\sqrt{T_{Cs}}} \times 10^{-3870/T_{Cs}} \quad (6)$$

for $T_{Cs} = 640^\circ\text{K}$
 $P_{Cs} = 9.54 \text{ mm Hg}$

From Figure 4.3, which is taken from a research report presented by Thermo Electron at the Colorado Springs Conference, the value of H_{Cs} at this value of P_{Cs} and at 2 mils spacing is:

$$H_{Cs} = 6.85 \times 10^{-3} \text{ w/cm}^2 \cdot ^\circ\text{K}$$

Substituting the value of H_{Cs} in Equation (5):

$$q_{Cs} = 6.85 \times 10^{-3} (2000 - 940) = 7.26 \text{ w/cm}^2 \quad (7)$$

4.1.3 Interelectrode Radiation Heat Loss (q_r)

$$q_r = \epsilon_{\text{eff}} \sigma (T_E^4 - T_C^4) \quad (8)$$

Figure 4.3 Film Coefficient of Heat Transfer for Cesium versus Cesium Pressure

and

$$\epsilon_{eff} = \left[\frac{1}{\epsilon_E} + \frac{1}{\epsilon_C} - 1 \right]^{-1} = 0.18 \quad (9)$$

(from Thermo Electron's experimental data).

Therefore,

$$q_r = 0.18 (5.67 \times 10^{-12}) (2000^4 - 940^4) = 15.56 \text{ w/cm}^2 \quad (10)$$

4.1.4 Collector Temperature Drop

Figure 4.4 shows the geometrical dimensions of the collector.

$$\Delta T_{coll} \approx \sum_i \frac{q L_i}{k A_i} \approx \sum_i \frac{q_E A_E L_i}{k A_i} = \text{total collector temperature drop} \quad (11)$$

Figure 4.4

Basic Dimensions of Collector

$$q_E = q_e + q_{Cs} + q_r - P_o = 70.31 \text{ w/cm}^2$$

Therefore

$$\Delta T_1 = \frac{70.31 (2) (0.050) (2.54)}{1.17 \left[\pi \left(\frac{0.680}{2} \right)^2 \right] (2.54)^2} = 6.8^\circ \text{C}$$

Similarly:

$$\Delta T_2 = 81.2^\circ \text{C}$$

Hence

$$\Delta T_{\text{coll}} = \Sigma \Delta T_i = 6.8 + 81.2 = 88^\circ \text{K}$$

and

$$T_{CB} = 852^\circ \text{K}$$

4.1.5 Heat Transfer in Tantalum Spacer

The heat transfer conditions for an element of the tantalum spacer are shown below in Figure 4.5.

Figure 4.5
Energy Balance on Emitter Spacer Element

$$dq_1 = (\pi D dx) \epsilon_{\text{eff}} \sigma (T_x^4 - T_C^4) \quad (12)$$

$$dq_2 = \pi (D + 2t) dx \epsilon_{\text{eff}} \sigma (T_x^4 - T_C^4) \quad (13)$$

$$q_x = -k \pi (D + t) t \left(\frac{dT}{dx} \right)_x \quad (14)$$

$$q_{x+dx} = k \pi (D + t) t \left[\left(\frac{dT}{dx} \right)_x + \left(\frac{d^2T}{dx^2} \right) dx \right] \quad (15)$$

Equations (12), (13), (14), and (15) may be combined in an energy balance on the element and the results are:

$$\frac{d^2T}{dx^2} = \frac{2\epsilon_{\text{eff}} \sigma (T_x^4 - T_C^4)}{kt} \quad (16)$$

The boundary conditions for $X = L$ can be found by imposing the collector base temperature as the temperature of the lower insulator flange. Figure 4.6 shows the remainder of the diode structure that connects the point at $X = L$ to the collector at point CB where the temperature is T_{CB} . The value of T_{CB} has been calculated from the collector heat transfer analysis (see section 4.1.4): $T_{CB} = 852^\circ\text{K}$.

If we now let R be the thermal resistance of the path from L to CB , shown in Figure 4.6, the heat transfer q_L and temperature T_L are related by the expression:

$$\frac{T_L - T_{CB}}{q_L} = R = R_1 + R_{\text{cer}} + R_2 \quad (17)$$

Generally:

$$R = \frac{L}{kA}$$

Figure 4. 6
Basic Insulator Assembly

Solving for R_1 , R_{cer} , and R_2 we get:

$$R_1 = 2.503^\circ\text{C/watt}$$

$$R_{cer} = 1.405^\circ\text{C/watt}$$

$$R_2 = 2.153^\circ\text{C/watt}$$

For R_{cer} , the effect area of the ceramic was assumed equal to 1/3 of the actual area because of the two dimensional character of the heat transfer distribution in the ceramic plane, as shown in Figure 4. 6.

Equation (17) gives the relationship:

$$T_L = 6.06 q_2 + 852^\circ\text{K} \quad (18)$$

which is the boundary condition that must satisfy the solution of Equation (16). Solving Equation (16) numerically, the seal temperature is found to be 995°K and the heat loss through the spacer to the radiator

$$q_{Es} = 21.38 \text{ w/cm}^2$$

The total heat flux required by the diode is then:

$$q_E = q_e + q_{Cs} + q_r + q_{Es} = 106.7 \text{ w/cm}^2$$

4.2 Design Configuration

The parts on Figure 4.1 are as follows:

- 1,2 Emitter, rhenium pyrolytically deposited on tungsten
- 3 Emitter support, tantalum
- 4 Emitter support adapter, molybdenum
- 5 Emitter grindable flange, tantalum
- 6 Emitter seal flange, niobium
- 7 Emitter-collector insulator, aluminum oxide
- 8 Collector seal flange, niobium
- 9 Collectors-radiators, molybdenum
- 10 Emitter output lead, copper
- 11 Collector output lead, copper
- 12 Radiator thermocouple, iron-constantan
- 13 Collector thermocouple, iron-constantan
- 14 Insulator thermocouple, iron-constantan
- 15 Collector heating coils, sheathed heater
- 16 Collector cooling straps, copper

CHAPTER 5

DESIGN OF THERMIONIC SCANNER

A scanner has been designed. Figure 5.1 shows the scanner cross section. The basic features of the scanner are as follows:

The emitter (1) is attached to the emitter sleeve (2) through an adapter ring (3). Heat is rejected by a molybdenum radiator (4). A supporting structure (5) is equipped with a demountable weld flange. A tantalum shield (6) is provided.

The emitters are mounted and demounted by welding the flange and cutting the weld open, respectively. Sufficient length has been incorporated into the flange to allow the replacement of the emitter several times. The collector (7) has a larger area than the emitter. This is to allow electrons to be collected even when the electron stream is deflected at a 45° angle. A small hole in the collector (8) is provided to allow the electrons to pass through to the probe (9). The small hole is approximately 0.0025 inch in diameter. The probe (9) is connected by a molybdenum rod of substantial cross section to a probe leadthrough (10). This leadthrough has an intermediary flange which serves for additional insulation between the collector and the probe, and may be used as a bias control. At the end of the molybdenum rod, a provision is made for attaching a thermocouple and clamping to the water reservoir, which maintains the probe temperature as close to water temperature as possible. The main collector is connected to the body and to the emitter via upper leadthrough (11). This scanner has a fixed spacing, therefore the leadthrough is of a rigid design. A cesium reservoir (12) is connected at the tubulation (13).

5.1 Principles of Operation

This thermionic scanner permits the examination of thermionic emitters under equilibrium conditions identical to those which are encountered during

Figure 5.1 Scanner Cross Section

converter operation. It permits the continuous scanning of an emitter surface; the recording of emission current maps; the determination of the local work function at any point on the surface and the observation of changes of the thermionic emission pattern with time, temperature, and pressure.

The elementary diode shown in Figure 5.2 releases electrons from the heated emitter and, with an applied accelerating field from emitter to collector, a glow discharge is produced in the cesium vapor. A strong magnetic field (B) in the direction parallel to the general flow will confine the electron paths to small radius helices extending from emitter to collector. If the emitter is non-uniform, the same pattern will be present in the current reaching the collector because of the collimating effect of the magnetic field. A small diameter hole in the collector will allow electrons to pass through and impinge on an auxiliary collector or probe to produce an output current. Changing the direction of the field by the addition of orthogonal fields B_x and B_y will, in turn, deflect the helices so that the probe will in effect see a different portion of the emitter. In this manner the entire face of the emitter may be scanned.

64-R-4-25

Figure 5.2 Elementary Diode in Magnetic Field

CHAPTER 6

PLANS FOR THE SECOND QUARTER

The following items of work are planned for the second quarter of the program:

1. Complete assembly of 4 life test units.
2. Complete assembly of gas-sampling system and make initial gas-sampling tests on converter 401-P-2.
3. Complete assembly of scanner and scan first sister emitter.
4. Complete assembly of converter 401-P-1 and acceptance test.
5. Complete assembly and test of converter 402-P-2.
6. Fabricate and test converter 402-R-1.
7. Fabricate converter 402-R-2.

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