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TE-41-65

AFAPL-TR-65-7

MASTER

THERMIONIC CONVERTER LIFE AND
REPEATABILITY INVESTIGATION

Dr. C. Z. Kamien
J. H. Weinstein
F. Rufeh

Thermo Electron Engineering Corporation
Waltham, Massachusetts 02154

TECHNICAL REPORT AFAPL-TR-65-7

31 January 1965

Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report was prepared by Thermo Electron Engineering Corporation under Air Force Contract AF33(615)-1348, Project No. 8173, Task No. 817305-30.

The work was administrated under the direction of Mr. A. E. Wallis, Project Engineer for the Air Force Aero Propulsion Laboratory, Research and Technology Division.

This report covers the work performed from January 2, 1964, through December 31, 1964. The Thermo Electron Engineering Corporation project manager was Dr. C. Zelman Kamien. Members of the group who contributed to the program include Sotiris S. Kitrilakis, Manager of Research, David P. Lieb, Senior Electronics Engineer, Firooz Rufeh, Research Engineer, and J. H. Weinstein, Deputy Research Manager.

The Thermo Electron Report Number is TE 41-65.

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ABSTRACT

Life-test equipment has been designed and built to make possible testing of converters for long life as well as for cycling evaluation. Furthermore, diagnostic facilities are incorporated in the design of the life-test station. Life tests are currently in progress.

The diagnostic facilities include equipment for the evaluation of gas evolution in the converters during life testing. In order to obtain significant data from the gas sampling effort, a new technique has been developed to analyze the minute quantities of gas which may evolve in the course of diode operation. Results from the outgassing of one converter are presented. The results indicate that copper members of the converter require about three times the outgassing period of any other materials. The predominant gas was found to be hydrogen for copper and hydrogen and carbon monoxide in equal amounts for the emitter and collector.

Design details and life-limiting characteristics of the converter are described. These converters employ rhenium emitters operating at a design temperature of 2000°K and a molybdenum collector at 940°K. The design incorporates a great amount of flexibility in the investigation of different components of the converter. The converter components can be removed and replaced. Initial tests on the series 400 converters yielded an output of 30 watts at 0.7 volt (15 watts/cm²) and 41.25 watts at 0.5 volt (20.6 watts/cm²).

Discussion of a thermionic scanner, its design details and its mode of operation are given. The data obtained by scanning a vapor-deposited rhenium-on-tungsten emitter are discussed.

Publication of this technical documentary report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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INTRODUCTION

This is the final report on Contract AF33(615)-1348, Phase I, covering the period from January 2, 1964, through December 31, 1964. This program is a continuation of the applied research work initiated under Contracts AF33(616)-7411, AF33(616)-8114, AF33(657)-11169, and AF33(657)-10130 on solar thermionic converters, solar thermionic generators, and thermionic converters containing additives.

The objectives of the program are as follows:

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.
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 converters fabricated are of an improved mechanical design which simplifies the method of manufacturing and thus reduces the complexity of the unit. The converter is capable of being repaired, and 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 were fabricated. The life-test stations incorporate a facility for gas sampling by means of a mass spectrometer and other diagnostic facilities such as collector work function determination, inter-electrode spacing measurements, and dynamic and static I-V characteristics. The life-test stations are operated manually as well as automatically. All pertinent data are recorded automatically on a continuous basis.

In addition to the specially designed equipment for gas sampling, a unique technique for the determination of minute quantities of gases which evolve during converter operation has been developed. Among other diagnostic tools, a thermionic scanner has been designed and fabricated which permits the examination of thermionic emitters under equilibrium conditions.

Manuscript released by authors 31 January 1965 for publication as an RTD Technical Report.

CHAPTER 2

SUMMARY

Four life-test stations have been designed and fabricated. Each unit incorporates a vac-ion chamber, electron gun, electron gun power supply and regulator, cesium reservoir power supply and temperature controller, collector power supply and temperature controller, elapsed-time meter and automatic cycling timer, converter load control, and ion-type vacuum pump and power supply. In each life-test console, provisions are made for a variety of diagnostic tests.

A gas analysis system including a calibration unit has been designed and fabricated. A unique technique has been developed to analyze the minute quantities of gases which evolve in a converter during its operation. Since dynamic mass spectrometry cannot be used in the analysis of converter gases, static mass spectrometry has been developed, and the indications show that it will furnish satisfactory results. The complex and difficult task of calibrating the gas sampling unit has been successfully accomplished, and the analysis of gases evolved during outgassing of converters is reported.

A thermionic scanner has been designed and fabricated. A rhenium emitter has been scanned in the thermionic scanner, and the emitter work function has been determined. The emitter work function data are presented and discussed.

The design features and fabrication of thermionic converters are discussed, and performance data is reported. The prototype converter output was 15 watts per cm^2 at 0.7 volt and an emitter temperature of 2000°K . At 0.5 volt and an emitter temperature of 2000°K the converter power output was 20.6 watts per cm^2 . Life testing of three converters has been initiated. To date they have accumulated 100, 400, and 500 hours, respectively, at an operating emitter temperature of 2000°K .

Since interelectrode spacing is an important parameter in the performance of a thermionic converter, a cesium conduction method for the measurement of interelectrode spacing, which was developed by Thermo Electron under another contract, is described, and the theory behind this method is presented.

A demonstrator model and electronic control console were designed, fabricated, performance-checked and delivered to AFAPL. The description of this test system is presented.

CHAPTER 3

CONVERTER LIFE-TEST EQUIPMENT

Careful and accurate life-testing requires the use of an environment which, to the greatest extent possible, is isolated from all outside effects. It must not only be capable of high-vacuum, high-temperature operation with very low impurity and outgassing rates, but it should be isolated as much as possible from human tampering and input power variations. For this reason, Thermo Electron has designed and fabricated four special systems for life-testing of converters.

This life-test equipment includes vacuum chamber, electron gun, electron gun power supply, electron gun power supply regulator, cesium reservoir power supply and temperature controller, collector power supply and temperature controller, elapsed-time meter and automatic cycling timer, converter load control, and ion-type vacuum pump and power supply. In each life-test console provisions are made for diagnostic testing. All controls are on a single console. Figure 1 is a general view of the life-test station. The controls on the left, from the top, are: load panel, elapsed-time meter and automatic cycling timer, cesium power supply and temperature controller, and ion pump power supply. The controls on the right, from the top, are: electron-bombardment power supply and emitter temperature controller, collector power supply and temperature controller, and a Sorensen power supply which supplies the accelerating voltage of the electron-bombardment power supply. There follows a description of each of the major components of the life-test system.

3.1 Vacuum Chamber

Figure 2 shows a cross section of the vacuum chamber including prototype tubulation arrangements for gas sampling. The modified tubulation arrangement for gas sampling is shown in Figure 3. The advantages of one gas-sampling system over the other will be discussed in a later chapter. The vacuum chamber is stainless steel, 7.25 inches i. d. x 9 inches high. It is enclosed with a stainless steel water jacket on the outside to absorb the heat thrown off by the converter and the electron-bombardment 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-bombardment 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.

Figure 1. General View of Life-Test Station

Figure 2. Cross Section of Vacuum Chamber Including Prototype Tubulation Arrangement of Gas Sampling

Figure 3. Modified Tubulation Arrangement of Gas Sampling

A replaceable one-inch Pyrex window is used for pyrometry 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 window assembly is heliarced to the stainless steel bell jar. The design permits 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. The base plate is made of 10-inch diameter, 7-inch high stainless steel pipe 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.

Figure 4 shows the base plate set on top of a 50-liter/sec ion pump. The connection arrangement to the mass spectrometer is shown at the right side of the base plate. All electrical connections to the base plate are made at the back side of the base plate away from the operator of the equipment.

Figure 5 shows the bell jar on top of the base plate. The water lines for cooling the bell jar and the stainless steel bellows valve for roughing down the vacuum chamber are visible. The outgassing of the converter is accomplished through the 11-liter/sec ion pump which is shown at the right. The gas sampling connections to the mass spectrometer are also visible.

3.2 Electron Gun and Converter Support Structure

The heat source for the diode is a bombardment heater (or gun). It 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 an 0.030-inch diameter tungsten filament heated to 2500°K , which 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 sidewall of the converter to prevent 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. Figure 6 shows the electron gun and filament assembled. Figure 7 shows the exploded view of the electron gun and the filament.

Figure 4. Base Plate

Figure 5. Base Plate and Bell Jar

Figure 6. Electron Gun and Filament

Figure 7. Exploded View of the Electron Gun and Filament

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 controlled circuit. A 1-kilovolt dc, 750-milliampere Sorensen MD power supply provides the accelerating voltage. It is regulated at ± 1 percent for line voltage variations, and the output has less than 1 percent ripple. The 10 volts ac is controlled by a course and a fine variable-voltage transformer. The controlled circuit regulates the bombardment current at a desired value in the following manner:

The bombardment current develops a voltage which is compared with 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 this manner the bombardment power is continuously checked and adjusted to a predetermined value of life-testing power requirements. 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 unit circuit current more than 10 percent of the preset value. This provision was incorporated to minimize the possibility of filament burn-out. Figure 8 shows a schematic diagram of the electronic circuit for the electron gun power supply regulator. Figure 9 shows the electron-bombardment power supply control panel.

3.4 Cesium Reservoir Power Supply and Temperature Controller

The power supply for the cesium reservoir heater consists of an 18-volt, 10-ampere ac supply with a variable-voltage transformer and a step-down isolation transformer. The cesium reservoir temperature is controlled by a Minneapolis Honeywell thermocouple-operated controller, which provides time-portioned 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 10 shows a schematic diagram of the power supply for the cesium reservoir temperature control. Figure 11 shows the cesium heater power supply control panel.

Figure 8. Schematic Diagram for the Electron Gun Power Supply and Regulator Circuit

Figure 9. Electron Bombardment Power Supply Panel

Figure 10. Schematic Diagram for Cesium Reservoir, Collector Power Supply, and Temperature Control Circuit

Figure 11. Cesium Heater Power Supply Control Panel

3.5 Collector Temperature Controller and Power Supply

The power supply for the collector heater consists of a 36-volt, 10-ampere 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 10 for the schematic diagram of the power supply for the collector temperature control. Figure 12 shows the collector heater power supply control panel.

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.

A 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 120 minutes. An event counter is also incorporated to record the accumulative number of cycles. Figure 13 shows the schematic diagram for the elapsed-time and automatic counting circuit. Figure 14 shows the time-cycle control panel.

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 ohm. 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-cycle) testing as well as recording current-voltage characteristics. Figure 15 shows the load control panel. A detailed description of the load panel, its electronic circuits, and its function in the life-test units follows.

3.7.1 General

The power output from the converter is absorbed in a water-cooled Ge transistor. The amplification of this unit allows the use of a convenient, relatively low-current device to control load resistance. The controlling transistor base current is derived from an auxiliary power supply and amplifier. The converter current is maintained constant by means of a drive

Figure 12. Collector Heater Power Supply Control Panel

Figure 13. Schematic Diagram for the Elapsed Time Automatic Counting Circuit

Figure 14. Time-Cycle Control Panel

Figure 15. Load Control Panel

regulated by the auxiliary power supply and amplifier. Jacks on the front panel provide access to the converter elements for outside tests. Current and electrode voltage, during life test, are monitored both by 6-inch mirror-scale meters on the panel and by an external 50-millivolt recorder. In order to protect the emitter from overheating, a relay senses the load current and reduces the power input when the load current falls below a predetermined value.

3.7.2 Circuit Description

An overall schematic of this circuit is shown in Figure 16. The controlling power supply senses the current in shunt R_S through control R_C . Output from terminals 5 and 6 is applied to the base of Q_3 to control its effective resistance and, therefore, the load current. The phase relations in this loop are such that variations in current are eliminated. For example, an increase in load current causes increased drop across R_S , which signals the amplifier to decrease the base drive until the load current variation is canceled out.

The load panel may be divided into two portions, a high-current section carrying the converter power, and a low-current controlling section.

In the high-current circuit, Figure 16, Q_3 is a Honeywell MHT 2205 PNP Ge transistor having a very low saturation voltage. This transistor is mounted directly on a water-cooled plate to maximize the heat transfer. R_S is a low-temperature-coefficient air-cooled shunt having a voltage drop of 250 millivolts at 50 amperes. Relay K, connected to one converter lead, operates at a load current of about 30 amperes and releases at about 10 amperes. A contact on this relay causes the emitter bombardment power to decrease when K releases. Jacks J_2 and J_3 are shorted during normal life-testing to connect the converter to the internal load. In this circuit, conventional current flows from the emitter in the converter to the transistor emitter, then through R_S , the panel jacks, and the meter shunt, then back to the converter collector to complete the circuit. A meter switch S_1 disconnects the panel meters when external read-out devices are used.

The low-current control section of the load panel uses a KEPCO Model ABC 7.5-2, which serves the function of an amplifier, auxiliary power source, and reference voltage. A simplified schematic of this supply is shown in Figure 17. DC power from the main rectifier is controlled by the pass resistors, Q_1 and Q_2 , and drives the base of the load transistor Q_3 . The control signal from shunt R_S is compared with a reference voltage developed across Zener diode CR 209 and proportioned by the setting of controls R_L and R_C . The difference signal developed is applied to the amplifier consisting of transistors Q203, Q202, Q201, and Q204. With an

Figure 17. A Simplified Schematic Diagram of the Current-Control Power Supply

increase in load current, the voltage across R_S increases, driving the base of Q203 in the positive direction, thereby increasing its emitter current. This causes an increase in the emitter current of Q202, which is amplified and finally appears as a reduced base current at the load resistor Q_3 , in turn reducing the load current from the converter. The result of this action is that the voltage across shunt R_S is maintained constant within the limits of the amplifier gain and the stability of the reference. From the ABC 7.5-2 specifications, the load regulation is 1 millivolt and the stability 3 millivolts, corresponding to an overall current stability of 4 millivolts out of 150 millivolts at 30 amperes, or about 3 percent in load current.

CHAPTER 4

GAS ANALYSIS

A major restriction in utilizing new methods to obtain quantitative or qualitative analysis of a gas is in the size of the sample, since even the most sophisticated conventional mass spectrometer requires about 0.1 cc (STP) of the sample to give any meaningful results. Conventional gas chromatography requires a larger sample for analysis. Attempts have been made to modify the gas chromatographs to enable them to handle smaller quantities, but still about 0.1 cc of the sample is needed. The quantity of impurities that are generated in a thermionic diode is several orders of magnitude lower than that which can be analyzed by conventional methods.

Conventional mass spectroscopy is based on the detection of gases as they flow through an analyzer towards a vacuum pump. The quantity of the sample must be large enough to allow a constant flow for a finite period of time. If the mass spectrometer is isolated from its vacuum system, it is possible to introduce the smaller quantities of gases in the system and keep them long enough to obtain an accurate analysis. This requires a system free of any leaks with extremely clean surfaces to minimize outgassing and to be able to maintain high vacuum without pumping. Moreover, the outgassing rate from the walls must be so small that an accurate analysis of minute quantities of gases is possible. Therefore, the system must be baked at high temperature to obtain ultra-high vacuum. This prohibits the use of ordinary high-vacuum valves and fittings. In designing such a system, it is important to keep the internal volume small to increase the sensitivity. Calibration of such a system requires special attention, since it is not possible to use a calibrated leak. A system must be developed to deliver from 10^{-7} up to 10^{-5} cc of various gases with an accuracy of a few percent.

4.1 Prototype 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 principal parts of the prototype gas sampling system is presented in Figure 18. With this setup, the pressure of the gas and the types of impurities in the gas can be determined and correlated with converter performance. The test set-up is used as follows:

The system is baked under vacuum to minimize outgassing during operation. Baking temperature is attained by the heaters inside the vacuum chamber. Cesium is then distilled into this chamber. During distillation, valve S₁₄

Figure 18. Schematic of Gas Sampling System.

is closed, heater H_1 is turned on, and the rest of the system is kept cold. Cesium is 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 with cesium pressure in the converter controlled by H_3 . For plasma analysis, cooler C_4 is turned on to condense the cesium into the storage chamber. At this stage, valves 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, diode operation is resumed by closing valve S_{14} while heater H_4 is turned on so that the cesium is transported back to the reservoir.

4.2 Revised Gas Sampling Unit

In the testing of Converter 401-P-2, it was found that the original tubulation design was not adequate for complete success in gas sampling during operation. The problem was the maintenance and control of cesium pressure in the reservoir. A review of the design in Figure 18 revealed that the cesium during operation accumulated at the cold surface of the valve without dropping back into the reservoir, thus starving the converter. Figure 19 shows a schematic diagram of the principal parts of the revised design of the gas sampling system. This test setup is used as follows:

a. Cesium is distilled into the system by breaking the cesium capsule in the loading chamber. During this stage, heater H_1 and cooler C_3 are in operation. The cesium is accumulated in the cesium reservoir. The loading chamber is then pinched off at position A.

b. During converter operation, cooler C_2 is operating while cesium pressure in the converter is controlled by heater H_3 and cooler C_3 .

c. For gas analysis when the converter is not operating, cooler C_3 is used to condense and freeze the cesium to the bottom of the cesium reservoir. The valve to the mass spectrometer is then opened to perform the mass spectrometric analysis.

d. For analysis during converter operation, heater H_3 and cooler C_3 control the cesium pressure for converter operation while cooler C_2 keeps the cesium from escaping from the cesium reservoir. As the cesium rises at this tube, it is condensed and drops back into the reservoir, due to gravity. Since the ratio of cesium reservoir to tube surface area is large, the cesium pressure will be controlled by the conditions prevailing in the cesium reservoir. At this stage, the valve to the mass spectrometer is opened, and the gases evolved from the operating converter are passed through the cesium reservoir and monitored by the mass spectrometer.

Figure 19. Revised Gas Sampling Unit and Cesium Reservoir Design

This revised tubulation design will simplify the gas sampling and will permit the monitoring of the evolution of gases in the converter at any time without perturbing the life-test conditions of the converter.

4.3 Mass Spectrometer

Since the quantity of gases evolved during operation of diodes is small, conventional flow-type mass spectrometers cannot be used. A highly sensitive 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 required sensitivity.

A CEC Model 21-613-1 mass spectrometer, which is the simplified version of 21-620A, is used. It employs a cycloidal-focusing mass analyzer to separate high-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 to 4. This unit has a sensitivity sufficient to detect a partial pressure of N_2 for 5×10^{-11} torr. Unit resolution is achieved up to $m/e = 150$. The complete assembly, including the mass spectrometer chamber, is made of metal and is bakeable up to 250°C. The mass spectrometer system is shown in Figure 20.

4.4 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 here, 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 the introduction of known quantities of gases in the expected mass range. Figure 21 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 of 10^{-4} to 10^{-8} cc (STP) with an accuracy of 1 percent.

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 monometer by a cathetometer. The quantities of gases present in chamber C_B are expanded into $C_M + C_D$, and then chamber C_D is isolated by closing valve S_5 .

Figure 20. Mass Spectrometer and Calibration Unit

Figure 21. Schematic of Calibration System

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 the presence of cesium by opening valve S_8 .

4.5 Experimental Procedure

To achieve the required background pressure and high sensitivity, the system was baked under vacuum at high temperature. The gas sampling system, described above, was constructed and assembled on the converter complete with mass spectrometer and calibration unit. The gas sampling system does not employ ordinary high-vacuum valves, since they contain rubber gaskets and seals not suitable for bakeout at these temperatures.

Ultra-high vacuum has been attained after eliminating minute leaks and after baking-out the system several times. Each of these bakeouts lasted for several days. A leak-tight and well outgassed system was finally attained. The bakeouts were performed at 150-250°C, and a background mass spectrum was obtained after each bakeout. The results are shown in Figures 22 to 26. Table 1 shows a comparison of the background after successive bakeouts. A large reduction in abundance of various peaks is evident. When the mass spectrometer system is isolated from the vacuum system, a small rise in the pressure of various gases is noted. However, this is so small that it does not disturb the accuracy of the analysis. Figure 27 shows a typical calibration run for nitrogen in the mixture of N_2 , CO_2 , H_2 gas. The dashed curves show the behavior of background peaks as a function of time when the system is isolated from its vacuum pump, while the solid curves represent the mass spectrometer reading after the introduction of a calibrating sample. The dominant peaks in the background are 28 and 14, both of which are due to nitrogen. Attempts were made to lower the background further. The results are demonstrated by the dash-dot curve. A great improvement is evident. It has been shown possible to calibrate and operate the system statically and to perform quantitative analysis of minute sample gases. Figures 28 to 30 show how it is possible to get a quantitative analysis of minute quantities of gases. Conventional mass spectrometers require of the order of 1 cc of gas to analyze. In Figures 28 to 30, only 10^{-6} cc of gas was introduced into the system.

Figure 28 shows the comparison of background of mass 28 with the signal when 1.24×10^{-6} cc of nitrogen was admitted to the mass spectrometer with the calibration system. Figure 29 shows that of peak 14 to distinguish N_2^+ from CO^+ . Figure 30 shows a similar analysis when

Figure 22. Background after Bakeout at 150°C - Ionization Current = 50μA

Figure 23. Background after Bakeout at 250°C -
 Ionization Current = 50 μ A

Figure 24. Background after Localized Bakeout -
Ionization Current - $50\mu\text{A}$

Figure 25. Background after Fourth Bakeout -
 Ionization Current = $50\mu\text{A}$

Figure 26. Background after Fifth Bakeout -
Ionization Current - $50\mu\text{A}$

TABLE 1

COMPARISON OF BACKGROUND AFTER SUCCESSIVE BAKEOUTS

<u>Mass</u>	<u>Figure 22</u>	<u>Figure 23</u>	<u>Figure 24</u>	<u>Figure 25</u>	<u>Figure 26</u>
2	2400	630	231	10.5	unknown
12	69	192	16.5	2	1.5
13	10	3	--	--	--
14	180	75	34	16	2.5
15	120	9	--	--	--
16	220	90	12	0.6	0.4
17	159	33	21	1.8	1.2
18	610	110	75	7.5	4.5
19	0.9	--	--	--	--
20	30	0.9	0.9	0.3	--
22	3.6	--	--	--	--
24	2.1	--	--	--	--
25	6	--	--	--	--
26	30	--	--	--	--
27	51	1.7	1.1	--	--
28	3129	4800	650	160	36
29	39	54	5	--	--
30	0.5	9.6	--	--	--
31	0.9	--	--	--	--
32	0.9	--	--	--	--
36	3.3	--	--	--	--
37	3.8	--	--	--	--
38	7.6	--	--	--	--
39	14.4	--	--	--	--
40	180	7.5	1.16	3	0.5
41	36	0.9	--	--	--
42	12	0.3	--	--	--
43	93	0.6	--	--	--
44	135	30.6	9.3	1.1	0.8
45	2	--	--	--	--
46	0.6	--	--	--	--
50	3	--	--	--	--
51	4.5	--	--	--	--
52	4.5	--	--	--	--
53	4.5	--	--	--	--
54	10.5	--	--	--	--
55	9.9	--	--	--	--
56	6.3	--	--	--	--
57	1.8	--	--	--	--
58	24	--	--	--	--

Figure 27. A Comparison of Sample Gases to Background

Figure 28. Comparison of Background of Mass 28 and 14 with the Signal of 1.24×10^{-6} cc of N_2

Figure 29. Comparison of Background of Mass 44 with the Signal of 1.50×10^{-6} cc of CO_2

Figure 30. Comparison of Background of Mass 2 with the Signal of 1.57×10^{-6} cc of H_2

1.50×10^{-6} and 1.57×10^{-6} cc of CO_2 and H_2 were introduced into the system, respectively. As is evident from comparison of signal to background in these three cases, it is possible to analyze smaller quantities of gases with considerable accuracy.

Having succeeded in operation of the mass spectrometer system in the small gas sample range, the diode operation was started. It is of considerable interest to study evolution of gases from the surfaces of the interior parts of the converter and the cesium reservoir during outgassing. It is also important to know which gases are evolved from what surfaces, to be able to trace them to the production and manufacturing of that member. For this reason, previous to cesiating Converter 402-R-2, the cesium reservoir (Figure 18) was heated up to 350°C , and the evolution of gases was monitored periodically.

After the mass spectrometric analysis of the reservoir was concluded, and the extraneous parts of the diode system were being further outgassed, similar analyses of the collector and emitter were made separately. At this stage the impurities in the cesium were determined, and a complete mass spectrometer analysis of the cesiated diode background was taken before putting the unit on life test.

A great deal of confidence has been gained in the technique developed for the analysis of gases in converters. It is evident from the data accumulated up to now that the gas sampling technique is quite successful and will provide an important tool for the study of gas evolution in operating converters. Thermo Electron is now in a position to monitor the gases evolved in a converter, not only after a predetermined operating time, while the converter is cold, but also during life-testing at operating temperatures. Converters 401-P-2 and 402-R-2 had been used as vehicles for checking out the design of the gas sampling unit. Converter 401-P-2 has been used to check out tubulation arrangement during operation, whereas 402-R-2 has been used to check out the facility of the mass spectrometer to accomplish the task. It was found that the mass spectrometric and calibration techniques yield significant and important results.

4.6 Experimental Results

The outgassing of the diode in conjunction with the gas analysis was performed in the following manner:

Before any of the diode members were heated, the background was analyzed and the abundance of various peaks was determined by the mass spectrometer. Then, the cesium reservoir was chosen as a representative copper member of the converter system, and its behavior was monitored during outgassing. With the rest of the system cold, the cesium reservoir was

heated, and the background was analyzed at several temperatures. The dashed line in Figure 31 shows the increase in reservoir temperature with time. During this period the system was pumped with an 8-liter/sec ion pump through two 1/8-inch orifice all-metal valves. The background was analyzed with the mass spectrometer, and a change in various peaks is shown in Figure 31. It is evident from Figure 31 that hydrogen, nitrogen, and carbon monoxide are the dominant gases. Hydrogen dominance is found in peak 2, and nitrogen-carbon monoxide are found from the magnitudes and ratios of peaks 28 and 44, respectively. As expected, as the temperature is increased there is a large rise in gas evolution from the copper surface; then the peaks are reduced due to pumping. It is seen further that the evolution of hydrogen is continuous, whereas that of nitrogen and carbon monoxide is discontinuous. This suggests that hydrogen is actually dissolved in the copper reservoir and is released by diffusion forces, whereas other gases are merely absorbed on the surface and their release mechanism is desorption.

The cesium reservoir temperature was increased up to 350°C and was then held constant. A series of mass spectrometric analyses were performed in short time intervals, and data is shown in Figures 32 through 40 and in Table 2. The data are reduced to actual partial pressure of various gases and are presented in Figure 41. It is clear that hydrogen is by far the dominant component (larger than 90 percent) and is the only gas that shows a pattern that is radically different from what was expected. The abundance of H_2 is probably due to hydrogen-firing of the cesium reservoir, and the discontinuities in level suggest that the release under these conditions is not only by simple diffusion, but it is also by movement of tiny bubbles of the gas inside the metal. This type of behavior has recently been reported elsewhere (Ref. 1). Although the decrease in the abundance of various peaks is rather slow after 5 hours, it can be seen that the discontinuities in hydrogen peaks do not occur after 20 hours, and the magnitude is decreased considerably by this time. From this data, it is concluded that such members of a thermionic diode system, i. e., the hydrogen-fired parts, should be outgassed for longer time periods, since the hydrogen partial pressure, even after 20 hours, is still far from the background before heating that member.

The next step was to investigate the types and quantities of gases evolved from the emitter and collector. The emitter and collector temperatures were raised to 1700° and 600°C, respectively, and a similar periodic mass spectrometric analysis was made. Table 3 shows the raw data, and Figures 42, 43, and 44 show typical original data obtained for this outgassing for the emitter and collector.

This data had been reduced to the partial pressures of the gases. Figure 45 shows the variation of the partial pressure of the gases that are evolved from the emitter and collector surfaces with time. It can be seen

Figure 31. Gas Evolution During Cesium Reservoir Outgassing

Figure 32. Mass Spectrometer Background (Run No. 52) - Ionization Current = $50\mu\text{A}$

Figure 33. Mass Spectrometric Analysis (Run No. 63) during Cesium Reservoir Outgassing of 402-R-2 - Ionization Current = $50\mu\text{A}$

Figure 34. Mass Spectrometric Analysis (Run No. 64) during Cesium Reservoir Outgassing of 402-R-2 - Ionization Current = $50\mu\text{A}$

Figure 35. Mass Spectrometric Analysis (Run No. 65) during Cesium Reservoir Outgassing of 402-R-2 - Ionization Current = 50 μ A

Figure 36. Mass Spectrometric Analysis (Run No. 66) during Cesium Reservoir Outgassing of 402-R-2 - Ionization Current = $50\mu\text{A}$

Figure 37. Mass Spectrometric Analysis (Run No. 68) during Cesium Reservoir Outgassing of 402-R-2 - Ionization Current = 50 μ A

Figure 38. Mass Spectrometric Analysis (Run No. 69) during
 Cesium Reservoir Outgassing of 402-R-2 -
 Ionization Current = $50\mu\text{A}$

53

Figure 40. Mass Spectrometric Analysis (Run No. 71) during Cesium Reservoir Outgassing of 402-R-2 - Ionization Current = $50\mu\text{A}$

TABLE 2
PEAK ABUNDANCE AT VARIOUS STAGES OF OUTGASSING
OF CESIUM RESERVOIR OF 402-R-2

Mass	Run 52	Run 63	Run 64	Run 65	Run 66	Run 68	Run 69	Run 70	Run 71
2	23.1	5700	2460	1950	2850	--	2730	1920	2070
12	3.2	23.7	16.5	15	11.7	8.4	7.2	6.0	5.4
13	0	6.3	7.2	7.8	6.8	5.1	3.9	3.0	2.4
14	0.8	18.0	18.0	17.7	15.5	11.4	9.6	7.5	6.3
15	0.6	59	65	63	54	43	35.0	27.9	22.5
16	1.7	90	90	87	71	57	47.0	38.0	30.0
17	1.2	26	20.5	21	16	12	11.1	9.9	8.4
18	3.4	35	32	33	27	23.1	19.8	18.0	15.6
19	0.8	0	0	0	0.9	0	0	0	0
20	0	0	0	0	0	0	0	0	0
26	0	11.7	12	12	9.9	7.8	6.0	4.5	3.6
27	0	15.9	16.2	15.9	9.0	10.5	8.1	6.9	5.1
28	58.0	345.0	291	249	180	138	112.5	99.0	97.0
29	0.9	8.1	7.8	6.0	4.8	0	3.3	3.0	1.5
30	0.7	2.1	3.0	2.1	1.2	0	0	0	0
38	0.6	0	0	0	0	0	0	0	0
39	0	0	0	0	0.9	0	0	0	0
40	0	6.0	6.0	4.8	3.3	3.0	2.1	2.1	2.1
41	0	6.6	7.5	6.0	4.5	4.2	3.1	2.7	2.7
42	0	9.6	9.3	7.8	5.7	3.1	3.9	3.3	3.0
43	0	4.5	5.1	3.9	2.4	2.1	1.5	1.5	1.5
44	1.3	2.3	3.0	1.8	0.9	0.9	0.6	0.9	0.9
45	0	29.7	24.0	20.4	15.0	12.6	9.6	9.0	9.0

Figure 41. Gas Evolution during Cesium Reservoir Outgassing at 350°C of 402-R-2

TABLE 3
 PEAK ABUNDANCE AT VARIOUS STAGES OF OUTGASSING
 OF EMITTER AND COLLECTOR OF 402-R-2

Mass	Run 80	Run 81	Run 82	Run 83	Run 84	Run 85	Run 86	Run 87	Run 88
2	400	300	225	170	150	135	125	135	135
12	53	56	40	31	27	22	18	16.5	14.4
13	0	1.5	0	0	0	0	0	0	0
14	14	11.5	10.5	7.5	6	5.1	5.4	3.9	3.3
15	10	8.4	6	3.6	3	2.4	2.4	2.4	2.4
16	35	33	24	18.5	15	12	10.5	9.9	9
17	2	1.8	1.5	1	1	1	0	0	0
18	3	3	3	2	2	2	0	0	0
28	1300	900	800	700	570	440	390	340	290
29	15	10.5	10.5	7.5	6.9	6	4.5	3.6	3.6
30	3	2.1	1.8	1.5	1.2	1.2	0	0	0
40	4.5	3.6	3	2.4	2.4	2.4	1.5	1.5	1.5
44	36	24	24	20	17	12.5	11.5	10.5	9.6

Figure 42. Mass Spectrometric Analysis (Run No. 81) during Emitter and Collector Outgassing of 402-R-2

Figure 43. Mass Spectrometric Analysis (Run No. 84) during Emitter and Collector Outgassing of 402-R-2

Figure 44. Mass Spectrometric Analysis (Run No. 87) during Emitter and Collector Outgassing of 402-R-2

Figure 45. Gas Evolution during Outgassing of Emitter (1700°C) and Collector (600°C) of 402-R-2

that, while in the cesium reservoir outgassing, hydrogen is a dominant component accounting for over 90 percent of the gases, in the emitter and collector outgassing, the gases evolved are hydrogen and carbon monoxide at equal quantities amounting together to about 99 percent of the total pressure. It can be concluded that, for the emitter and collector, several hours of outgassing are sufficient, since the partial pressures of the measured components are not reduced very much after about 8 hours, whereas, for the copper components of the converter, such as the cesium reservoir, over 20 hours of outgassing are necessary.

The data from the gases evolved of the cesium capsule indicated primarily the abundance of hydrogen and argon. It is advisable to pump out these gases prior to cesiating the converter.

CHAPTER 5

THERMIONIC SCANNING

The existence of nonuniformity in the emission from refractory metal emitters has been investigated in the past, and ample evidence is presented (Refs. 2-5). The vacuum emission from such surfaces has been investigated in the past with field emission microscopes and similar devices. None of these, however, are capable of performing point-by-point emission measurements in the presence of cesium vapor in equilibrium with the surfaces. Since the thermionic converter has to operate with a cesiated emitter, and since the characteristics of the emitter strongly depend on the presence of cesium, a direct method of measuring point-by-point emission is necessary. Such a device has been previously developed by Thermo Electron, and a similar device suited to accept the emitters under this program has been fabricated. This scanner has successfully been used to produce emission maps of cesiated converter emitters. In the following sections, the principle of operation, as well as the construction of the scanner, are described, and the results of scanning are given.

5.1 Principles of Operation

A thermionic scanner permits the examination of thermionic emitters under equilibrium conditions identical to those which are encountered during converter operation. It permits the continuous scanning of an emitter surface, the recording of the 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 46 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 nonuniform, 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.

Figure 46. Elementary Diode in Magnetic Field

5.2 Description of Scanner

A cross section of the thermionic scanner is shown in Figure 47. The basic features of this 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 support structure (5) is equipped with a multiple-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 leadthrough (10). This leadthrough has an intermediary flange which serves as 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 connecting 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. The cesium reservoir (12) is connected to the tubulation (13).

Figure 48 shows the scanner with electron-bombardment gun before being mounted for test. This scanner includes a vapor-desposited rhenium-on-tungsten emitter. This type of emitter has been incorporated in the prototype converters. Additional scanning tests will be made later in the program with hot-pressed emitters.

5.3 Scanning Results

5.3.1 General

Two types of data have been obtained from the scanning device: cross scans showing the variation of emitter current across a single line of the surface, and display photographs of the emission pattern from the surface. A typical display photo, Figure 49 gives an overall picture of the surface features. The bright areas in this photograph are areas of high emission, while the darker portions are areas of low emission. The total area scanned is approximately $1/8 \times 1/8$ inch. The resolution of the device is, therefore, about 0.003 inch. For current density measurements across the face of the emitter,

Figure 47. Scanner Cross Section

Figure 48. Scanner with Electron Bombardment Gun

Figure 49. Typical Thermionic Scanner Display Photograph

the work functions at various points have been computed. Note that the bright spots are uniformly distributed over the entire surface.

5.3.2 Methods of Data Analysis

Because the light and dark spots are uniform over the surface, a cross scan over one chord of the emitter surface is typical of scans across any other. One chord is therefore chosen, and a series of cross scans is obtained along this single chord, varying the ratio of surface-to-reservoir temperature, T/T_R , with each scan. A calibrating signal is also recorded to allow the determination of emitted current density. Two techniques are used for data analysis: the construction of work function plots which relate work function to the ratio of surface temperature to reservoir temperature, and the computation of work function distribution over the surface area.

Figure 50 is a cross scan across one chord of the vapor-deposited rhenium test surface at a temperature of 780°K and a cesium reservoir temperature of 379°K. If point 1 is chosen for this example, the relative current is observed to be 14 graphical divisions. The calibrating current, which is identical to the number of divisions between the two lines marked "calibration," has been previously determined to be 1.25 μ A. Thus, the actual current at point 1 can be calculated. Dividing by the area of the collector hole (1.2×10^{-5} cm²) gives the current density through the hole. The work function of the surface is obtained by substituting the values for current density and surface temperature in the Richardson equation. This procedure is repeated for a series of cross scans covering a range of surface temperatures, and the values shown in Table 4 are obtained. These values are plotted in Figure 51 as circles.

The points represented by squares in Figure 51 are obtained using point 2 on the cross scans. If several scans are compared (Figures 50, 52, 53), it is observed that the ratio of current at point 1 to that of point 2 decreases as the surface temperature is decreased. This observation is substantiated by Figure 51, where the circles and the squares appear closer together at lower T/T_R values and eventually cross each other. The point with higher values of work function corresponds to a dark spot in the emitter surface and that with lower values to a bright spot. At low emitter temperatures the emission from the two areas becomes the same. This trend in behavior is predicted by the Rasor theory (Ref. 6), as shown by a solid line in Figure 51. The absolute work function values differ considerably between predicted and experimental data points in the region of minimum work function. This has been true in previous data, also.

The bar plots of the work function distribution, Figure 54, also verify these results. To obtain the bar plots, the cross scans are divided into bands

Figure 50. Cross Scan (No. 32) $T_E = 780^\circ\text{K}$, $T_R = 379^\circ\text{K}$
(Vapor-Deposited Rhenium on Tungsten)

TABLE 4
WORK FUNCTIONS

Cross Scan No.	T_E °K	T_R °K	T/T_R	Current Amplitude Division	Calibration Amplitude Division	Relative Amplitude	J A/cm^2	ϕ eV
30	899	379	2.37	27	400	.0675	.0070	1.81
31	845	379	2.23	17	420	.0405	.0041	1.73
32	780	379	2.06	14	1210	.0116	.0012	1.67
33	771	397	1.94	10	900	.0111	.0012	1.65
34	820	397	2.06	53	940	.0564	.0059	1.65
35	863	397	2.17	52	455	.114	.0119	1.69
36	910	397	2.29	51	348	.146	.0152	1.77
37	972	397	2.45	17	160	.106	.0111	1.92
38	996	397	2.51	14	162	.0865	.0090	2.00
39	1013	397	2.56	14	320	.0437	.0046	2.10

Figure 51. ϕ vs T/T_R , Vapor-Deposited Rhenium on Tungsten

Figure 52. Cross Scan (No. 30), $T_E = 899^\circ\text{K}$, $T_R = 379^\circ\text{K}$
(Vapor-Deposited Rhenium on Tungsten)

Figure 53. Cross Scan (No. 38), $T_E = 996^\circ\text{K}$, $T_R = 397^\circ\text{K}$
 (Vapor-Deposited Rhenium on Tungsten)

Figure 54. Work Function Distribution for Vapor-Deposited Rhenium on Tungsten

of equal work-function widths. The total percent of the emitter surface which falls in each bandwidth is recorded and plotted versus work function. At high emitter temperatures there are two peaks corresponding to the bright and dark areas of the surface. However, at lower emitter temperatures, as the minimum work function value is approached, the two peaks merge, as predicted by the Rasor theory.

CHAPTER 6

DESIGN OF CONVERTER PROTOTYPE

Figure 55 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 can be installed back on its diode, or a new one can replace the original emitter, and life-testing or cycling can be continued.
- d. The lower insulator niobium flange makes the final weld with the collector in such 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 eliminates a source of past failures at the collector-radiator braze.
- f. A collector heater is incorporated in the design to facilitate optimization of the collector temperature in addition to optimizing cesium temperature.

6.1 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 56 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 (Ref. 8).

Figure 55. Prototype 401-P-1 Cross Section

Figure 56. Optimized Power Map for Rhenium Emitter

The design conditions corresponding to the design point of Figure 56 are:*

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

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

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

6.1.1 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 of work function required to emit a saturation current equal to the design current density at T_E of the design. For $J_o = 21.43 \text{ A/cm}^2$ 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:

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

6.1.2 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 ($A_E = 2 \text{ cm}^2$):

* Nomenclature Table 5

TABLE 5
NOMENCLATURE

A_E	Emitter area, cm^2	R_{cer}	Thermal resistance of seal insulator, $^{\circ}\text{C}/\text{watt}$
A_i	Area of i-th element, cm^2	S	Cross-sectional area of emitter support per cm^2 of emitter area
C	Circumferential length of emitter support, cm	t	Thickness of emitter support, cm
D_E	Diameter of emitter, cm	T_{CB}	Collector base temperature, $^{\circ}\text{K}$
H_{Cs}	Cesium conduction coefficient, $\text{W}/\text{cm}^2\text{ }^{\circ}\text{K}$	T_{C}	Collector temperature, $^{\circ}\text{K}$
J_o	Output current density, A/cm^2	T_{Cs}	Cesium condensation temperature in diode, $^{\circ}\text{K}$
K	Thermal conductivity, $\text{W}/\text{cm}^2\text{ }^{\circ}\text{C}$	T_E	Emitter temperature, $^{\circ}\text{K}$
k	Boltzmann constant $1/11,600 \text{ eV}/^{\circ}\text{K}$	T_L	Emitter support base temperature, $^{\circ}\text{K}$
L_i	Length of i-th element, cm	V_o	Output voltage, volts
P_{Cs}	Cesium pressure, mm Hg	w	Diode interelectrode spacing, mils
P_o	Output power density, 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_{Cs}	Heat lost by cesium gas conduction, W/cm^2	ϵ_E	Total hemispherical emissivity of emitter at emitter temperature
q_e	Heat lost by electron cooling, W/cm^2	ϵ_{eff}	Effective total hemispherical emissivity
q_E	Total heat flux, W/cm^2	σ	Stephen-Boltzmann constant, $5.67 \times 10^{-12} \text{ W}/\text{cm}^2\text{ }^{\circ}\text{K}^4$
q_{E_s}	Heat lost by conduction to the emitter support, W/cm^2	ϕ_E	Work function of emitter, eV
q_L	Heat flux through the emitter support, watts	ϕ^*	Effective work function (defined by Eq. 2), eV
q_r	Heat lost by interelectrode radiation, W/cm^2		
R_1	Thermal resistance of emitter insulator flange, $^{\circ}\text{C}/\text{watt}$		
R_2	Thermal resistance of collector insulator flange, $^{\circ}\text{C}/\text{watt}$

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

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

For

$$T_{Cs} = 640^\circ K$$

$$P_{Cs} = 9.54 \text{ mm Hg}$$

From Figure 57, which is taken from a research report presented by Thermo Electron at the Colorado Springs Conference (Ref. 7), the value of H_{Cs} at this value of P_{Cs} and at 2 mils spacing is:

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

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

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

6.1.3 Interelectrode Radiation Heat Loss (q_r)

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

and

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

(from Thermo Electron's experimental data).

Therefore,

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

Figure 57. Film Coefficient of Heat Transfer for Cesium versus Cesium Pressure

6.1.4 Collector Temperature Drop

Figure 58 shows the geometrical dimensions of the collector.

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

Figure 58. Basic Dimensions of Collector

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

Therefore

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

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

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

6.1.5 Heat Transfer in Tantalum Spacer

The heat transfer conditions for an element of the tantalum spacer are shown below in Figure 59.

Figure 59. 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 60 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 6.1.4): $T_{CB} = 852^\circ\text{K}$.

If we now let R be the thermal resistance of the path from L to CB, shown in Figure 60, the heat transfer q_2 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 60. 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 effective 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 60.

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:

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

6.2 Design Configuration

The parts on Figure 55 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

6.3 Testing of Converter Prototypes

Four converter prototypes were fabricated. Two of the four converters were utilized for the investigation of the soundness of the design, whereas the others were utilized in the development of the diagnostic and life-test system and procedures. Figure 61 shows Converter 401-P-1 just before outgassing. Figure 62 shows an exploded view of component parts for Converter 401-P-2, including tubulation necessary for the gas sampling operation.

After outgassing of the converter and check-out of the associated instrumentation, the converter was subjected to the following laboratory evaluation:

The input power to the electron-bombardment gun was adjusted to maintain the emitter temperature at 2000°K. As converter thermal equilibrium

Figure 61. Converter No. 401-P-1

Figure 62. Exploded View of Component Parts for Series 401-P-2

was being established, power was applied to the cesium heater, while converter load was continuously adjusted to maintain a constant output voltage across the load.

The recorded cesium reservoir temperature corresponding to the different load currents is represented in Figure 63. From this curve the optimum cesium vapor pressure for the particular load voltage (0.7 volt) can be determined. This optimization curve reflects only one constant collector temperature of 1080°K. This collector temperature is by no means the optimum value, as is demonstrated by the test results of Converter 402-R-1. As a matter of fact, a collector temperature of 1080°K is far higher than the designed temperature. Because of inefficient cooling to the collector, a lower collector temperature could not be obtained. It was found necessary to redesign the cooling unit for further testing of series 400 converters. Such a modification has been incorporated in the testing of Converter 402-R-1.

The initial testing procedure of Converter 402-R-1 was similar to that described for Converter 401-P-1. A redesigned cooling system for the collector was incorporated, and, as the results indicate, the optimum collector temperature is below the collector temperature at which the collector of 401-P-1 had been operated.

Figures 64, 65 and 66 show typical families of current-voltage curves for three different collector temperature conditions. The individual current-voltage curves cross each other, and each curve exhibits a maximum current value at the specific voltage. This fact makes it possible to determine an envelope which is tangent to each current-voltage curve and represents the optimum performance attainable at the particular temperature, spacing, and collector temperature employed. Figure 64 shows a typical family of current-voltage curves for a collector temperature of 873°K, whereas Figures 65 and 66 represent collector temperatures of 953°K and 1023°K, respectively.

Figure 67 shows the optimum power curve for Converter 402-R-1. The performance of Converter 402-R-1 has satisfied the design conditions. The design conditions, as mentioned in section 6.1, were:

$$T_E = 2000^\circ\text{K}$$

$$T_{Cs} = 640^\circ\text{K}$$

$$w = 2 \text{ mils}$$

$$T_C = 940^\circ\text{K}$$

$$P_o = 15 \text{ W/cm}^2$$

$$V_o = 0.7 \text{ volt}$$

$$J_o = 21.43 \text{ A/cm}^2$$

$$A_E = 2 \text{ cm}^2$$

Figure 63. Cesium Reservoir Temperature versus Output Current for Load Voltage 0.7 volt (Tube No. 401-P-1)

Figure 64. Typical I-V Curves for Converter 402-R-1
 ($T_E = 2000^\circ K$, $T_C = 873^\circ K$)

Figure 65. Typical I-V Curves for Converter 402-R-1
 ($T_E = 2000^\circ\text{K}$, $T_C = 953^\circ\text{K}$)

Figure 66. Typical I-V Curves for Converter 402-R-1
 ($T_E = 2000^\circ\text{K}$, $T_C = 1023^\circ\text{K}$)

Figure 67. Maximum Power Curves for 402-R-1
 ($T_E = 2000^\circ\text{K}$, $T_R = 593^\circ\text{K} - 658^\circ\text{K}$, $A = 2 \text{ cm}^2$)

As can be seen by comparing Figures 64 and 65, the optimum output agrees with the design conditions of 42.5 amperes at 0.7 volt, the emitter temperature being 2000°K and the collector temperature between 873°K and 953°K. The cesium temperature is lower than the design temperature, but is between the design temperature and the temperature of 605°K, as can be seen in Figure 56. Converter 402-R-1 has demonstrated an output of 15 watts/cm² at an output voltage of 0.7 volt.

Figure 68 shows a comparison of converter current density between series 300, 310 (Contract No. AF33(657)-11169) and the current 400 series. As can be seen from the curves, the performance of Converter 402-R-1 is superior to the performance of either Converter 301 or 313. The main contribution factor to this improved performance is that the emitters of the 400 series converters are rhenium, as compared with tantalum emitters in the 300 and 310 series converters. Converter 402-R-1 has met the program goals, and it is hoped to exceed them in future developments.

6.4 Life-Test Converters

In the manufacturing of the prototype converters it was found that a number of changes were necessary to reduce the failure rate of the life-test of converters. Figure 69 shows a cross section of the 402-RL series. Figure 70 shows Converter 402-RL-4 after assembly. The major design changes are as follows:

a. The vapor-deposition process of rhenium on tungsten was found to be very unreliable, since the process was based primarily on applying the rhenium on tungsten in an extremely clean environment. If such an environment is not maintained, the rhenium will separate from the tungsten during machining. It was therefore decided to resort to the hot-pressed process, which was found to be more reliable. This process consists of hot-pressing a tantalum-rhenium assembly in vacuum between graphite dies for half an hour at 2900°F and 8000 psi mechanical pressure. Heating is accomplished by electric induction. To prevent migration of carbon from the graphite dies to the tantalum, thin foils of tantalum are wrapped around the assembly to act as diffusion barriers. The rhenium is hot-pressed on tantalum rather than on tungsten, which makes the machining easier and eliminates the molybdenum adapter ring (Figure 55, part 4), which in turn saves one welding step.

b. Welding of the molybdenum collector-radiator (Figure 55, part 9) to the niobium collector-seal flange (Figure 55, part 8) was found to be extremely difficult, and brazing the parts proved to be more reliable. Experience in brazing a similar configuration has been gained from the 300 and 310 series converters, and it has been shown that this braze withstood not only long continuous static operation but also long cyclic operation.

Figure 68. Comparison of Output Current Density

Figure 69. Cross Section of 402-RL Converter

Figure 70. Converter 402-RL-4

c. The collector heater-cooler has been redesigned, and contact between collector-heater has been secured by means of high constant spring force.

6.4.1 Test Results of Converter 402-RL-1

The performance of Converter 402-RL-1 was mapped through families of current-voltage curves for four different collector temperature conditions. Each current-voltage curve corresponds to a specific cesium temperature. By observing the resulting I-V curves, performance envelopes of the converter are obtained. The upper boundary of each envelope is the converter's optimum performance. Figure 71 shows the performance map of Converter 402-RL-1 at an emitter temperature of 2000°K and a collector temperature of 888°K for a range of cesium temperatures of 595°K to 663°K . Figure 72 shows the performance map for a collector temperature of 923°K and cesium temperatures of 603°K to 668°K . Figure 73 shows the performance map for a collector temperature of 948°K and cesium temperatures of 603°K to 663°K . Figure 74 shows the performance map for collector temperature of 973°K and cesium temperatures of 593°K to 668°K . This converter was put on life test and has accumulated over 500 hours to date without degradation.

6.4.2 Test Results of Converter 402-RL-3

The performance of Converter 402-RL-3 is mapped in Figures 75 through 78. The collector temperatures covered were 888°K , 916°K , 948°K , and 973°K , respectively. The cesium temperature range is similar to that covered for Converter 402-RL-1. This converter accumulated over 400 hours life-test hours to date without degradation.

6.4.3 Test Results of Converter 402-RL-4

Figures 79 through 81 show the performance maps of Converter 402-RL-4 at collector temperatures of 998°K , 923°K and 948°K , respectively. This converter has been tested for about 100 hours without degradation.

6.5 Summary of Life-Test Series 400 Converters

Steady-state data has been obtained from Converters 402-RL-1, 402-RL-2, and 402-RL-3. During steady-state evaluation, the input power to the electron-bombardment gun was adjusted to maintain the emitter temperature at 2000°K . As thermal equilibrium was being established, power was applied to the cesium heater while converter load was continuously adjusted to maintain a constant output voltage across the load. The recorded cesium reservoir temperature corresponding to different load currents and collector temperatures was recorded.

Figure 71. Typical I-V Curves for Converter 402-RL-1
 $(T_E = 2000^\circ K, T_C = 888^\circ K)$

Figure 72. Typical I-V Curves for Converter 402-RL-1
($T_E = 2000^\circ K$, $T_C = 923^\circ K$)

Figure 73. Typical I-V Curves for Converter 402-RL-1
 $(T_E = 2000^\circ K, T_C = 948^\circ K)$

Figure 74. Typical I-V Curves for Converter 402-RL-1
($T_E = 2000^\circ K$, $T_C = 973^\circ K$)

Figure 75. Typical I-V Curves for Converter 402-RL-3
 $(T_E = 2000^\circ\text{K}, T_C = 888^\circ\text{K})$

Figure 76. Typical I-V Curves for Converter 402-RL-3
 ($T_E = 2000^{\circ}K$, $T_C = 916^{\circ}K$)

Figure 77. Typical I-V Curves for Converter 402-RL-3
 ($T_E = 2000^\circ\text{K}$, $T_C = 948^\circ\text{K}$)

Figure 78. Typical I-V Curves for Converter 402-RL-3
 ($T_E = 2000^\circ K$, $T_C = 973^\circ K$)

Figure 79. Typical I-V Curves for Converter 402-RL-4
 ($T_E = 2000^\circ\text{K}$, $T_C = 898^\circ\text{K}$)

Figure 80. Typical I-V Curves for Converter 402-RL-4
 $(T_E = 2000^\circ K, T_C = 923^\circ K)$

Figure 81. Typical I-V Curves for Converter 402-RL-4
 ($T_E = 2000^{\circ}K$, $T_C = 948^{\circ}K$)

Figure 82 shows the cesium reservoir temperature versus output current for Converter 402-RL-1. From this curve the optimum cesium vapor pressure for a load voltage of 0.7 volt is at 325°C, and the output current is 31.5 amperes for a collector temperature of 823°K. This corresponds to a power output of 10.5 watts/cm².

Figure 83 shows optimum cesium vapor pressure for Converter 402-RL-2. The optimum output current is 40 amperes at a load voltage of 0.7 volt at a cesium reservoir temperature of 325°C and a collector temperature of 873°K. This corresponds to a power output of 14 watts/cm². This converter has been on life-test for over 100 hours of continuous operation. It is planned to subject this converter to cyclic operation of 55 minutes on — 35 minutes off cycle.

Figure 84 shows the results of steady-state evaluation for Converter 402-RL-3. The optimum output current is 43 amperes at a load voltage of 0.7 volt at a cesium reservoir temperature of 330°C and a collector temperature of 843°K. This corresponds to a power output of 15 watts/cm².

The results presented in Figures 82, 83, and 84 are only preliminary evaluations of the converters, and further analysis of their outputs is planned during the coming year.

Figure 82. Cesium Reservoir Temperature versus Output Current for Load Voltage of 0.7 Volt, Converter 402-RL-1 ($T_E = 2000^\circ\text{K}$, $T_C = \text{Variable}$)

Figure 83. Cesium Reservoir Temperature versus Output Current for a Load Voltage of 0.7 Volt, Converter 402-RL-2 ($T_E = 2000^\circ\text{K}$, $T_C = \text{Variable}$)

Figure 84. Cesium Reservoir Temperature versus Output Current for Load Voltage of 0.7 Volt, Converter 402-RL-3 ($T_E = 2000^\circ\text{K}$, $T_C = \text{Variable}$)

CHAPTER 7

EXPERIMENTAL DETERMINATION OF INTERELECTRODE SPACING

One of the parameters involved in the design of a thermionic converter is the interelectrode spacing, which has substantial effect upon converter performance. Interelectrode spacing during long life-testing may vary, and therefore it is imperative to know the exact spacing of a converter at a particular time and test condition. Converter lifetime and reliability depends upon degradation and/or failure, brought about by, among other factors, changes in interelectrode spacing. The change may be due to the build-up of deposits on the electrodes or the erosion of materials from them. Thus measurements of interelectrode spacing during operation can make a significant contribution to an analysis of test results.

There are several methods by which interelectrode spacing can be determined. One involves theoretical calculation of the relative expansion of the structural members involved. The coefficient of expansion is selected from the literature and the temperature of the members determined either by heat transfer calculations or by experimental measurements. Measuring the temperatures of the structural members may be difficult due to the delicate nature of their construction. Theoretical heat transfer calculations involve nonlinear differential equations which can be solved only by approximate methods. The result is that the final interelectrode spacing calculated by this method is not so accurate as the designer would desire. This is especially true where the expansion coefficients are not known to a high degree of certainty.

Another approach, which is primarily employed in variable-parameter research diodes, is to set the interelectrode spacing using an intricate mechanism which allows for mechanical adjustment by an operator. In this type of operation, the converter operates at a predetermined spacing. The interelectrode spacing is used as an independent variable in the evaluation of thermionic converter operation. Such an approach is not applicable to the type of converter used in this program.

A third method, which is potentially accurate and which is described below, involves the determination of interelectrode spacing by using experimental cesium conduction measurements. Since cesium pressure can be measured accurately and its conduction thus determined, this method can be used to evaluate the interelectrode spacing during actual operation of the converter.

A detailed analysis of the technique for determining spacing through the use of the cesium conduction measurements is given by Kitrilakis and Meeker (Ref. 7). The quantity of heat lost through cesium conduction is related to the spacing as follows:

$$H = \frac{\lambda_m (T_E - T_C) 10^3}{2.5w + 1.15 \times 10^{-2} \left(\frac{T_C + T_E}{P} \right)} \quad (19)$$

where

- H is the heat loss, watts/cm²
- w is the spacing, mils
- T_E is the emitter temperature, °K
- T_C is the collector temperature, °K
- λ_m is the heat conductivity of cesium corresponding to the mean temperature, watts/cm²°K
- P is the cesium pressure, torr

A plot of Equation 19 is shown in Figure 85 for a number of different inter-electrode spacing values. The experimental procedure to determine the cesium conduction as a function of cesium pressure can be summarized as follows:

The emitter and collector temperatures are recorded throughout the run. The power input, Q, is measured for various cesium pressures. When the cesium pressure is below 1 torr, heat loss by cesium conduction is negligible, and therefore the value of power input, Q_B, can be used as a reference point to determine cesium conduction.

$$H = Q - Q_B \quad (20)$$

If H is determined, Figure 85 is used for the determination of the inter-electrode spacing. The drawback in this method is in the difficulty of determining the reference power input, Q_B. A small drift in the power supply can cause an inaccuracy in Q_B, which in turn results in a deviation of the data points from the true values. In order to eliminate this difficulty, Equation 19 can be transformed to the difference equation,

$$\frac{a(\delta_o - \delta)}{H - H_o} - c\delta_o\delta = bw(\delta_o + \delta) + \frac{b^2}{c}w^2 \quad (21)$$

Figure 85. Plot of Equation 19

where

$$a = \lambda (T_E + T_C) \times 10^3$$

$$\delta = \frac{T_C + T_E}{P}$$

$$c = 1.15 \times 10^{-2}$$

$$b = 2.5$$

The subscript zero corresponds to any of the experimental points that are chosen for comparison, and it does not have to be at the point where cesium conduction is zero. Using this transformation, Q_B is eliminated as follows:

$$H - H_o = (Q - Q_B) - (Q_o - Q_B) = Q - Q_o \quad (22)$$

Furthermore, if we define

$$Y = \frac{a(\delta_o - \delta)}{H - H_o} - c\delta_o\delta$$

$$X = \delta_o + \delta$$

then Equation 21 can be written as

$$Y = bwX + \frac{b^2}{c}w^2 \quad (23)$$

A plot of Equation 23 is represented by a straight line with a slope of bw and an intercept at $(b^2/c)w^2$. Figure 86 shows a family of these lines corresponding to various interelectrode spacings. The value of the interelectrode spacing can be determined if the experimental points are plotted on Figure 86.

Figure 86. Plot of Equation 23

CHAPTER 8

DEMONSTRATOR MODEL AND ELECTRONIC CONTROL CONSOLE

The demonstrator model and the electronic control required for delivery under this contract are shown in Figures 87, 88, and 89. Converter 402-RL-4 is also being delivered as part of the demonstrator model. Figure 87 shows Converter 402-RL-4 mounted on the base plate. Figure 88 shows the bell jar and base plate ready for converter operation. The converter is to be operated on a 125-liter/sec Varian Vac-Ion pump and controller which was delivered under Contract No. AF33(657)-11169. In conjunction with the operation of the converter, an electron bombardment (EB 104) power supply is being modified, and the auxiliary electronic equipment has been delivered.

Figure 89 shows a picture of the electronic control console. The console consists of a load panel, cesium heater power supply, collector heater power supply, and time-cycle control panel. The description of the above components is given in Chapter 3. They are identical to those incorporated in the life-test station. The console is provided with outlets for wiring it to any base plate as well as to an automatic multipoint recorder. A special fail-safe arrangement is provided in conjunction with the cooling water outlet, which contains a pressure-sensitive switch. Upon sensing insufficient water pressure, the switch opens. This switch is interlocked with the electron gun power supply, and when it opens all heater power is automatically cut off. The switch does not affect the vac-ion pump, however, thus maintaining the vacuum in the chamber while the converter cools down. When failure occurs for any reason and the electron gun power supply is cut off, the "operation-on" light shuts off, thus indicating that failure occurred. Special provisions are made to override the fail-safe installations, and a reset switch is provided to resume ordinary operation.

The results of the performance tests on Converter 402-RL-4 are summarized in Chapter 6.

All functions and operating procedures were discussed in detail and demonstrated with AFAPL personnel. Discussions were supplemented with operation manuals and other literature.

Figure 87. Demonstrator Base Plate with Converter 402-RL-4

Figure 88. Demonstrator Base Plate and Bell Jar

Figure 89. Electronic Control Console Delivered to AFAPL

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