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TOPICAL REPORT

**THERMAL FLUX IN A RESEARCH
PARAMETRIC CONVERTER**

D. Lieb

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Prepared by
Thermo Electron Corporation
85 First Avenue
Waltham, Massachusetts 02154

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I INTRODUCTION

Thermionic converter performance characterization requires the collection and presentation of a large amount of current-voltage data. For maximum utility, these data should be geometry-independent with respect to both the electrical and the thermal characteristics of a device. The research guard ring, parametric converter shown in Figure 1 defines a one-dimensional planar region between the collector and emitter electrode surfaces. Data obtained from the active region will be essentially independent of area and characteristic of both the electron surface conditions and the cesium pressure in the interelectrode space. Because the electrode temperature measurements must be made in the body of the electrode, heat flux dependent corrections must be applied to the readings to determine geometry-independent surface temperatures. A similar difficulty arises in the measurement of electrode voltage; however, because of the relatively low flux levels, a correction is required only for the emitter sleeve voltage drop. This calculation is relatively straightforward and will not be considered at this time. Thus, a coherent set of current-voltage curves requires that, during the experiment, the surface temperatures, rather than the measured temperatures, be maintained constant at the desired values.

The thermal heat flux through a converter may be conveniently considered as having three components: a geometry- and temperature-dependent external radiation and conduction one, a temperature-dependent, internal radiation and cesium conduction one, and a current-dependent, electron cooling one. For most experiments with the parametric converter, the first term does not contribute to the

temperature drop between the measuring point and the surface, but only adds to the required input power. The second and third terms can be lumped together and their magnitude evaluated from either the emitter input power or a collector heat flux measurement. Because of the large magnitude of the electron cooling term, the average current over the J-V curve will have the largest influence on the corrections to be made. Under dynamic sweeping or pulsed current operation, the converter is at high current conditions for only a small fraction of the time; relatively small corrections as compared to those for static techniques are required. The relation between collector current and thermal flux is an important one which can be established through static current experimentation. These data are useful both for performance testing and surface temperature calculations, and for converter design efficiency calculations.

Both collector and emitter electrodes require surface temperature correction factors. However, since the collector usually operates near a relatively broad optimum temperature and since performance is strongly dependent on emitter temperature, the emitter correction is the more important. On the other hand, the relatively low temperature of the collector simplifies the problem of accurate measurement; for this reason, heat flux experimental procedures in the parametric converter use a special heat choke section on the collector body. The heat choke data then provide the necessary information to establish the validity of the emitter corrections.

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Figure 1. Research Variable Parameter Converter.

II. SURFACE TEMPERATURE CORRECTIONS

A. EMITTER TEMPERATURE

The emitter electrode presents the most critical problem because of the extreme sensitivity of the J-V characteristic to the surface temperature. Furthermore, because of the high temperatures involved, great difficulties are associated with obtaining accurate readings. In the research converter, an optical pyrometer sighting on a hohlraum in the back of the emitter body measures the temperature. The readings are corrected for the temperature drop through the body.

The corrections to be applied to the measured emitter temperature are dependent upon the device geometry and the heat flux through the emitter. Figure 2 is a schematic of the parametric converter and indicates the thermal flux components. The bombardment heat input, Q_B , is applied to the back surface of the emitter. The radiation, cesium conduction, and electron cooling fluxes (Q_R , Q_C , and Q_E) contribute to the temperature drop across the emitter while the back and side radiation and the sleeve conduction (Q_{RB} , Q_{RS} , and Q_S) represent fluxes which have negligible effect. The pyrometer sights on the 5:1 hohlraum in the back face of the emitter. There is a distance of about 50 mils from the bottom of the hohlraum to the emitting surface. Corrections must be determined for the gradients along the hohlraum and between the hohlraum and the surface.

An empirical calibration curve was determined, using a

simulated emitter structure as shown in Figure 3. The hohlraum at the equivalent location of the emitting surface was used to establish the surface temperatures over a wide range of bombardment power input and observed hohlraum temperatures. From this type of data, a table giving hohlraum temperature as a function of surface temperature and bombardment power can be constructed (Table I). For convenience in taking data, an additional column which includes bell jar window and pyrometer corrections is tabulated. This calibration assumes that the thermal flux relations in the mock-up are similar to those in the converter. Except for nonuniformities in Q_E and slight changes in Q_{RS} due to differences in radiation shielding, the assumption is valid. Table I can then be used for all types of data to reduce the observed emitter temperatures to emitting surface values.

Under conditions of dynamic testing, the heat load on the emitter varies during the sweep cycle from a maximum in the high current region to a minimum near the ignition region. While the rate of change is much faster than the thermal time constant of the bulk emitter, it is possible that the emitting surface has a time constant comparable to the sweep rate. The magnitude of this effect is about two to five Kelvins.

Another factor influencing the effectiveness of the emitter surface temperature is the radial variations due to nonuniformities in the heat flux. First, most of the input power is concentrated over the central region of the emitter, with the outer 50 to 70 mils being shielded by the electron beam gun structure. Further, there are

Figure 2. Schematic of Converter Showing Heat Flux.

Figure 3. Emitter Calibration Setup.

TABLE I
EMITTER SURFACE TEMPERATURE

T_E Surface 1800°K

T_E °K Hohlraum	Power in Watts	T_E °C Observed
	150	1508
	175	1510
1811	200	1512
1813	225	1514
1815	250	1516
1817	275	1518
1819	300	1520
1820	325	1521
1822	350	1523
1824	375	1525

T_E Surface 2000°K

T_E °K Hohlraum	Power in Watts	T_E °C Observed
2010	300	1697
2011	325	
2012	350	1698
2013	375	1699
2014	400	1700
2015	425	1701
2016	450	1702
	475	
2017	500	1703

large side radiation and sleeve conduction heat losses at the emitter edges, as well as the electron cooling due to guard current. This electron cooling radial flux will be dependent on the portion of the J-V curve being examined; in the different regions, the importance of the flux will change as the ratio of guard to collector current varies. Guard-collector voltage balance will affect the current ratio and may have a significant influence on the emitter temperature uniformity. Under high-current conditions, except in the saturation region, the surface temperature will tend to become more uniform, since the higher temperature portion will emit more current and will thus be subject to a greater electron cooling load. These factors may cause deviation from the projected one-dimensional geometry, but are expected to be small because of the conductivity of the emitter body.

B. COLLECTOR TEMPERATURE

The lower assembly, consisting of the collector body plus the guard ring (Figure 2), forms the collector half of the converter. The collector section is arranged so that the upper, high-temperature portion is nearly isothermal with the guard, and all heat transfer occurs by conduction through the stem. The two upper thermocouples will therefore accurately reflect the heat input to the collector face. Because the upper thermocouple is situated about 150 mils below the collector surface, its readings must be corrected to find electrode surface values. This may be done by adding a term proportional to the difference in temperature between the upper two thermocouples

III. EXPERIMENTAL TECHNIQUES AND RESULTS

A. DYNAMIC SWEEP DATA

The data-taking procedure may be summarized as follows. The converter heat inputs are adjusted to approach the desired conditions; the thermal flux to the emitter and that from the collector are obtained from the input power and thermocouple readings. Using the data from the correction charts, the heat inputs are readjusted and collector-guard voltage balance is adjusted. This cycle is continued until the desired surface temperatures are obtained; the J-V characteristics are then recorded. At high thermal fluxes, the procedure can be quite prolonged, as slight changes in temperature or current can have pronounced effects upon the surface temperature.

With dynamic sweep testing because of the reduced duty cycle (somewhat less than 50 percent), the thermal flux becomes much less important and the iteration time is considerably shortened. Typically, at 1900°K, the power input to the emitter varies from 220 watts at a collector current of 5 A/cm² to 335 watts at a collector current of 36 A/cm². Because the guard current electron cooling is included in the emitter input, guard-collector balance can have a significant effect on these values and on the radial distribution of the heat flux.

For dynamic testing, balance was approximated to within 0.1 volt over the J-V curve, matching the knee closely. Adjustable series resistors in the collector and guard leads served as the balancing elements. This technique allows close balancing in this

converter geometry, except in the saturation region, where the guard-collector current ratio changes rapidly with voltage

B. STATIC DATA

Static testing requires that all conditions be set to produce a single point on the J-V characteristic. With large values of current, the electron cooling of the emitter becomes the dominant factor in determining the temperature. Typical power input requirements at 1800°K range from 185 watts at 3 A/cm² to 320 watts at 23 A/cm². The dynamic curve covering the same current range required 225 watts. Comparing the data obtained under these widely differing heat loads thus serves as a sensitive check on the accuracy of the various corrections used to obtain surface temperatures.

Adjusting the converter to the desired J-V point is greatly simplified if the point is approached along a constant current path, since the electron cooling of the emitter will remain nearly constant. Balance between collector and guard may be established at the operating point using an auxiliary guard load circuit. In addition to its direct effect on the J-V curve, the static balance condition will change the radial distribution of the electron current and result in varying degrees of surface temperature uniformity.

C. THERMAL FLUX EXPERIMENTS

Heat flux measurements were obtained for a wide variety of points on the J-V characteristics. Figure 4 summarizes the data in terms of the heat flux through the collector heat choke. A calculated thermal resistance of 3.3 watts/C was used to convert the

Figure 4. Collector Heat Flux as a Function of Collector Current.

thermocouple readings to heat flux values. An empirical value will be obtained after disassembly of the converter.

Figure 5 shows a plot of collector heat flux as a function of bombardment current. The values are well correlated at each emitter temperature. The dependence of side and back heat losses on the emitter temperature accounts for the two lines. The observed 25-watt power difference corresponds to the 100° temperature difference between the lines; Assuming a total surface area of 6 cm^2 with an emissivity of 0.4, the calculated power difference due to radiation is about 36 watts, which is within the expected range. The values on the chart include almost a two-to-one variation in emitter input power, yet only show a spread of about ± 10 watts in the line for each temperature. Since the surface temperature calculations require that the flux through the collector region be known accurately, this plot shows that less than 5 percent error will be made at 1700°K or higher if bombardment power rather than collector heat choke values are used. However, the constant side and back radiation losses must be estimated with care, since they amount to 50 percent or more of the input power.

The intercept on the input power axis represents the total emitter input required to maintain the surface at the operating temperature without allowing any heat transfer through the basic diode structure. Diode efficiency calculations customarily exclude all of this power except the emitter lead component. In the geometry of the parametric converter, most of the power represented by the intercept does not contribute to the change in temperature (ΔT) across the emitter. Figure 6, the chart obtained from the

Figure 5. Collector Heat Flux as a Function of Emitter Input.

Figure 6. Temperature Correction from Emitter Calibration.

calibration structure, shows similar characteristics, but indicates a slight heat flux through the emitter at the values of power obtained from Figure 5. A ΔT of about eight degrees is indicated from Figure 6; note, however, that this value is the ΔT from the hohlraum in the back face of the emitter to that of the surface, and is not necessarily identical to the ΔT evaluated from the heat flux.

The relation between output current and thermal flux can be examined using the plot of Figure 4, which shows collector heat flux as a function of static collector current. The cesium conduction and radiation losses correspond roughly to the intercept for zero, J_C , and indicate a heat flux of 9.9 watts/cm². Measurements in the converter at zero J_C have a value of 8.3 watts/cm². Figure 4 shows that the heat input to the collector has a slope of approximately 2.1 watts per ampere of collector current. The points on this chart are taken in the power region from J-V curves having both high and low cesium pressures and at 1700 and 1800 °K emitter surface temperatures. The excellent fit of all the data to the 2.1 watts/amp line indicates that throughout the power region this relation is a good approximation of the heat input to the collector. The heat balance relation in the converter then indicates that the electron cooling of the emitter would be 2.1 watts/amp plus the output power of the converter.

D. RELATION BETWEEN STATIC AND DYNAMIC DATA

The correlation between static and dynamic data was examined by plotting the J-V characteristic for both modes on a single sheet of paper. Figure 7 shows such a plot for an emitter

temperature of 1800°K. Also shown on the plot is the guard J-V curve, which illustrates the degree of balance for the dynamic curve. Both sets of data were taken with the emitter surface temperature adjusted according to the calibration chart (Table I). On curves having a pronounced saturation region, the agreement was good. With curves extending into high current densities (Figure 8), a deviation between the static and dynamic modes appears. The static points show about 40 mv less voltage than the dynamic in the vicinity of the de-ignition point and about 10 mv more at high current densities. This trend is quite general and is summarized in Figure 9, which shows plots taken with many different emitter and cesium temperature conditions.

The effects of changes in electrode and reservoir temperatures were examined in an effort to determine the magnitude of their influence. The following corrections were required to match the low current points: emitter temperature, +25°K; collector temperature - could not match, maximum correction was 5 mv for + 10°K; cesium temperature, about - 16°K; spacing-could not match but improved towards zero. These corrections are too large to be applied directly, since they exceed the range of probable error. The possibility of transient electrical or plasma effects influencing the dynamic data must be considered. Such effects would occur because of the high rate of change of current and voltage during dynamic testing.

Figure 9 also shows the ratio of input power for the static point to that for a dynamic curve. As the ratio deviates from unity, mismatch becomes greater, although it is relatively larger at the lower current densities.

Figure 7. J-V Curve Showing Static Data Points.

Figure 8. High Current J-V Curve Showing Static Data Points.

Figure 9. Summary and Comparison of Static and Dynamic Data.

E. PULSE EXPERIMENTS

A series of pulse measurements at varying duty cycles were made to examine the rate of change phenomena. In these tests, the converter was pulsed from a low to a high current static point. The percent of time at the high current could be varied to move from a condition approximating low current static data to one approximating the high current data. Figure 10 shows the points that were taken. As the dwell time at a particular point was increased, the readings tended to match the static data points. Figure 11 shows a typical current-voltage pulse; notice that there is no curvature for the end points, which would indicate a rise time effect. The voltage versus time curve of Figure 12 shows a pulse rise time of about 1 millisecond, followed by a very flat plateau. The pulse circuit turns "off" the converter in this time and conditions remain stable until the next "on" pulse. Therefore, it is apparent that there are no transient effects occurring during the pulse time.

The deviations observed between static and dynamic data must be due to long-term effects extending over several cycles. The only likely source for this phenomenon is some heat flux-dependent parameter which is not being controlled. At this time, no solution has been found, but some possibilities are emitter or collector radial temperature gradients, guard temperature variations, or variations in other extraneous structures such as the emitter shield or sleeve.

Figure 10. Effect of Duty Cycle on Static Data Points.

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Figure 11. Pulse Current Voltage Characteristic.

Figure 12. Voltage vs Time Characteristic for Pulse Experiment.

IV. CONCLUSIONS

Performance data for the thermionic converter are in their most useful form if they are independent of geometry. The corrections required to establish constant surface temperature can be assumed to be linearly related to the input power to the emitter. Because of the lower values of heat flux associated with dynamic (as opposed to static) data techniques, maintaining constant surface temperatures is much simpler with dynamic methods. Comparisons of the data obtained from the two methods show excellent agreement (10 mv or better) throughout the range of useful operation.

Results from heat balance tests indicated a preliminary value of 2.1 watts/A for electron heating of the collector. This value is somewhat lower than expected and may be suspect because of thermocouple calibration variations. However, the electron heating of the collector was found to be proportional to collector current over a wide range of operating conditions in the power producing region. This relation can greatly simplify efficiency calculations.

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