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POSSIBLE SOURCE OF INSTABILITY IN THE COLLISIONLESS THERMIONIC DIODE

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SUMMARY

It is shown that cusps occur in the density distributions derived from the collisionless thermionic diode analysis. The possible effect of these cusps on diode stability and the collisionless current-voltage characteristics are discussed.

INTRODUCTION

An earlier article (ref. 1) showed that time-independent self-consistent solutions of the collisionless thermionic diode yielding continuous current-voltage characteristics can be obtained. The results showed an inflection in the current-voltage curves at zero anode potential. Recently, these results were reevaluated preliminary to further studies. In this evaluation, however, the nondimensionalized electron and ion densities were separately evaluated and plotted. McIntyre's notation (see ref. 2) was used with $\alpha = 0.1$ to solve the following equation:

$$\eta''(\xi) = \frac{1}{2}\left[n_e(\xi) - \alpha n_i(\xi)\right] \tag{1}$$

for

$$\alpha = n_i^+(0)/n_e^+(0)$$

$$\xi = x/L_c$$

$$L_c^2 = kT/8\pi e^2 n_e^+(0)$$

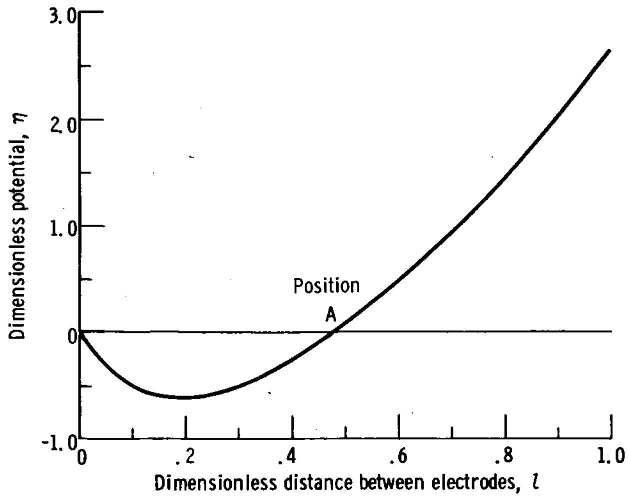

Figure 1. - Potential distribution.

$$n_e(\xi) = n_e(\xi)/n_e^+(0)$$

$$n_i(\xi) = n_i(\xi)/n_i^+(0)$$

$$\eta(\xi) = eV/kT$$

where $n_e(\xi)$ and $n_i(\xi)$ are the electron and ion densities, respectively; x is the distance normal to the emitter; and T is the emitter temperature. For a typical potential distribution, such as that shown in figure 1, the densities may be expressed in the following form (ref. 2):

$$n_e(\xi) = e^{\eta}\left[1 + E(\eta - \eta_{min})\right] \qquad \xi \leq \xi_m$$

$$= e^{\eta}\left[1 - E(\eta - \eta_{min})\right] \qquad \xi \geq \xi_m \tag{2}$$

$$n_i(\xi) = e^{-\eta}\left[1 + E(n_a - \eta) - 2E(-\eta)\right] \qquad \eta \leq 0$$

$$\doteq e^{-\eta}\left[1 + E(n_a - \eta)\right] \qquad \eta \geq 0 \tag{3}$$

where $E(\eta) = \mathrm{erf}\sqrt{\eta}$.

SYMBOLS

$E(\eta)$	erf $\sqrt{\eta}$
J	net electron current density to collector
J_{eo}	emitted electron current density
k	Boltzmann constant
L	interelectrode spacing
L_c	characteristic length
ℓ	dimensionless distance between electrodes
$n_e^+(0)$	electron emission density
$n_i^+(0)$	ion emission density

$n_e(\xi)$ electron density

$n_i(\xi)$ ion density

T emitter temperature

x distance normal to emitter

η_a dimensionless potential at collector

$\eta(\xi)$ dimensionless potential

η_{min} dimensionless potential of minimum

ξ dimensionless distance normal to emitter

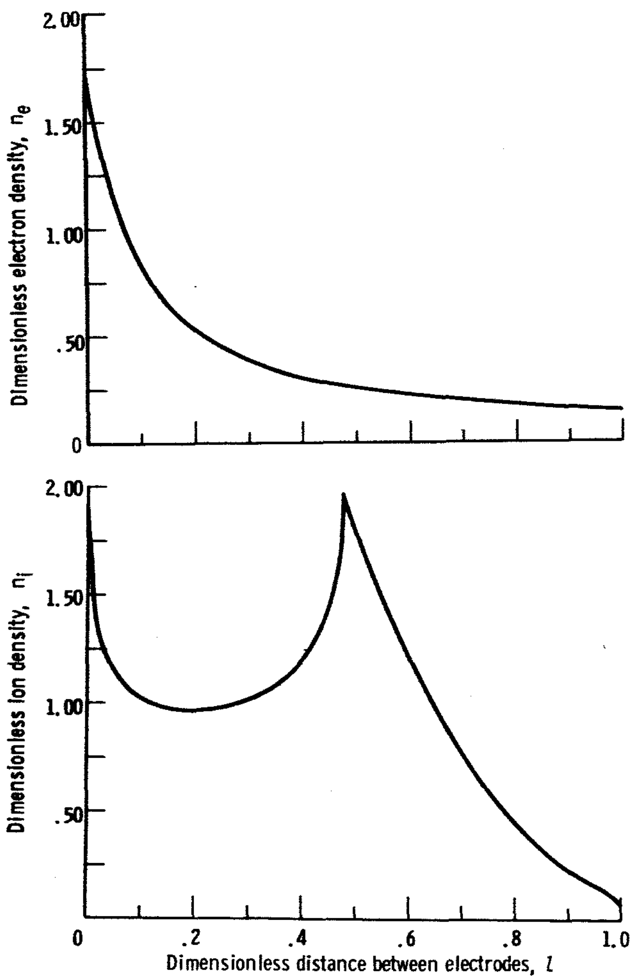

Figure 2. - Electron and ion-density distributions.

DISCUSSION

Figure 2 shows the nondimensionalized electron and ion densities. For greater clarity, the abscissa in this figure is given in units of $\ell = x/L$ (instead of ξ), where L is the interelectrode spacing.

Of greatest interest here is the form of the ion-density distribution. For the potential distribution of figure 1, almost all the ions are reflected back to the emitter; hence, a value of nearly 2 was obtained for the ion density at the emitter. In addition, because no collisions occur, the ion density at the position of zero potential inside the diode must be the same as the density at the emitter. At the potential minimum, between the two points of zero potential, the ions have their highest velocity, and, therefore, a relative minimum in the ion density exists. To the right of position A in figure 1, the ions are in a retarding field and, hence, the ion density decreases. Equation (3) shows the ion density distribution to have

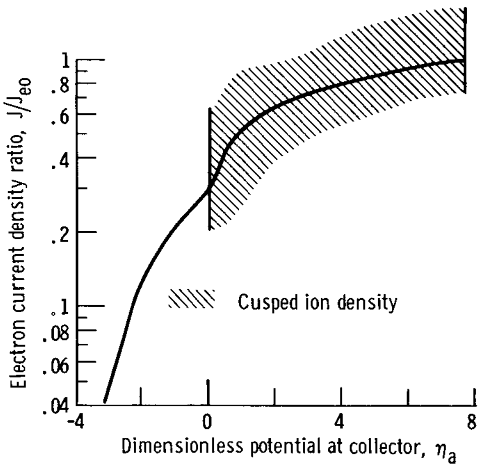

Figure 3. - Current-voltage curve showing region of cusped ion-density distribution for $\alpha = 0.2$.

infinite slope at three places: the emitter, position A (approaching from the left), and the collector.

A cusped ion distribution will occur only when the potential distribution passes through zero in the interelectrode space; that is, for the electron-rich case no cusp will exist for negative collector potentials or for positive potentials so high that the potential minimum is at the emitter. Figure 2(a) of reference 1 is redrawn in figure 3, and the region of cusped ion-density distributions for $\alpha = 0.2$ is indicated. Here, J_{eo} is the emitted electron-current density, J is the net electron-current density to the collector, and η_a is the dimensionless potential at the collector. This region is totally in the electron-retarding range of the current-voltage characteristic ($J/J_{eo} < 1$).

CONCLUSION

That stable, time-independent diode operation could be maintained in the cusped region of figure 3 does not seem probable. Shimoda (ref. 3) reiterates the observations of other experimentalists, though, that low-frequency oscillations in thermionic energy converters do not occur in the electron-retarding range but only in the temperature-saturated part of the current-voltage curve. Breitwieser (ref. 4), however, shows that the correlation of temperature-saturation with a plateau in the current-voltage curve is often spurious. The observation of an apparent temperature-saturation condition, consequently, does not preclude the existence of a potential minimum or potential distribution, as shown in figure 1. In other words, the experimental observations do not eliminate the possibility that the cusped nature of the ion distribution is a source of low-frequency oscillations. Furthermore, some nonoscillatory current-voltage curves obtained experimentally may actually be time-averaged results of high-frequency oscillations. In either case, the time-independent solution (ref. 1) depicted in the cusped region of figure 3 may not be observed. A time-dependent analysis has not, as yet, been undertaken.

For ion-rich emission ($\alpha > 1$), the situation is simply reversed. The potential is then a reflection about the zero potential of figure 1. Figure 2 then describes the electron density distribution. The onset of a cusp would occur here as the anode potential became negative.

It is to be expected that many phenomena contribute to thermionic diode instabilities. The qualitative comments here with regard to a possible source of instability must be corroborated by more analytical studies and experiment.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 12, 1966.

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