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A new concept of thermionic converter

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Abstract : The parameters of a new type of thermionic converter which has a number of concentric electrodes, is computed. The obtained theoretical efficiency of this new type of converter is nearly the efficiency of the ideal thermionic converter. The obtained results are explained by the reduction of the radiation loss from the emitter due to the electrode configuration. Efficiencies as high as 20% are expected from this type of converter now in construction.

The earth applications of thermionic converters are conditioned by the increase of efficiency up to 20% or more.

The analysis of the efficiency increase above the actual figure of 10-12% have been considered in /1/. The use of noble gas addition to cesium vapors, triode configuration with pulsed or auxilliary discharge can change only with some percents the value of efficiency. A significant increase of efficiency can be obtained if the work function of the collector is decreased under 1.2 eV or 1 eV. Unfortunately no stable surface with such a low work function at high temperature of the collector has been found.

In the present paper, we are considering a new concept of thermionic converter in which efficiencies as high as 20% might be usual.

The efficiency η of an usual converter is given by the relation :

$$\eta = \frac{\varphi_e - \varphi_c}{\varphi_e + 2kT_e + (\sigma \varepsilon_e T_e^4 - \sigma \varepsilon_c T_c^4) J_s^{-1} + Q_e J_s^{-1}} \qquad (1)$$

where φ_e and φ_c are the work functions of the emitter respectively of the collector, T_e is the temperature of the emitter, T_c is the temperature of the collector, σ is the Stefan-Boltzmann constant, Q_e is the thermal energy loss per second via electrical conductors from the emitter and J_s is the Richardson saturation current of the emitter. The efficiency according to the eq.1, is reduced due to the radiation loss from the emitter and thermal loss through the electrical connections.

The proposed new type of thermionic converter has a concentric multielectrode construction (see fig.1). The central electrode (1) is heated by the incomming thermal energy and we shall consider this electrode as emitter. The last electrode (the electrode number n) is the collector.

If r is the radius of an electrode, we have :

$$r_1 < r_2 < r_3 < r_4 < \ldots < r_n \qquad (2)$$

Between the temperatures of the electrodes we have the relation :

$$T_1 > T_2 > T_3 > T_4 > \ldots > T_n \qquad (3)$$

where T_1 is the temperature of the emitter and T_n the temperature of the collector.

In this new concept, the converter is assumed to work at low current in the external circuit. Lets consider in the figure 2, the energy diagram between two adiacent electrodes - the electrodes p and p+1. If J is the current generated by the converter, the following equation can be written for the electrodes p and p+1

$$J = AT_p^2\, e^{-\frac{\varphi_p + V_{p,p+1}}{kT_p}} - AT_{p+1}^2\, e^{-\frac{\varphi_{p+1}}{kT_{p+1}}} \qquad (4)$$

which is valid for $V_{p,p+1} \geqslant 0$.

From this equation results the value of $V_{p,p+1}$ as

$$V_{p,p+1} = \ln\left[AT_p^2\left(J + AT_{p+1}^2\, e^{-\frac{\varphi_{p+1}}{kT_{p+1}}}\right)^{-1}\right] - \varphi_p \qquad (5)$$

which can be rewritten as

$$V_{p,p+1} = \ln \left[\frac{T_p^2 \, e^{\frac{\varphi_{p+1}}{kT_{p+1}}}}{T_{p+1}^2 \, (1+\alpha_{p+1})} \right]^{kT_p} - \varphi_p \qquad (c)$$

where

$$\alpha_{p+1} = J \left(A T_{p+1}^2 \, e^{-\frac{\varphi_{p+1}}{kT_{p+1}}} \right)^{-1} \qquad (7)$$

Equation (6) can be replaced by

$$V_{p,p+1} = 2kT_p \ln\left(\frac{T_p}{T_{p+1}}\right) - kT_p \ln\left(1+\alpha_{p+1}\right) + \frac{T_p}{T_{p+1}} \varphi_{p+1} - \varphi_p \qquad (8)$$

The energy diagram for the multielectrode converter is given in the fig.3.

The output voltage of this type of converter will be according to the diagram in fig.3,

$$U = \varphi_1 - \varphi_n + \sum_{p=1}^{n-1} V_{p,p+1} \qquad (9)$$

From the eqs. 8 and 9 results

$$\begin{aligned} U = {} & 2kT_1 \ln\frac{T_1}{T_2} + 2kT_2 \ln\frac{T_2}{T_3} + \ldots\ldots + 2kT_{n-1} \ln\frac{T_{n-1}}{T_n} + \\ & + \frac{T_1 - T_2}{T_2}\varphi_2 + \frac{T_2 - T_3}{T_3}\varphi_3 + \ldots\ldots + \frac{T_{n-1} - T_n}{T_n}\varphi_n - \\ & - kT_1 \ln(1+\alpha_2) - kT_2 \ln(1+\alpha_3) - \ldots\ldots - kT_{n-1} \ln(1+\alpha_n). \end{aligned} \qquad (10)$$

If the number of electrodes is enough high ($n > 1$), the difference between T_p and T_{p+1} is not much high, and consequently we can use the approximation

$$\ln\left(\frac{T_p}{T_{p+1}}\right) = \ln\left(1 + \frac{T_p - T_{p+1}}{T_{p+1}}\right) \approx \frac{T_p - T_{p+1}}{T_{p+1}} \qquad (11)$$

With this approximation, the eq.(10) becomes[x)]

$$U = 2k(T_1 - T_n) + \sum_{p=1}^{n-1} \frac{T_p - T_{p+1}}{T_{p+1}} \varphi_{p+1} - \bar{c} \qquad (12)$$

where

$$\bar{c} = kT_1 \ln(1+\alpha_2) + kT_2 \ln(1+\alpha_3) + \dots + kT_{n-1} \ln(1+\alpha_n) \qquad (13)$$

The efficiency of this new type of converter will be

$$\eta = \frac{U.J}{J(\varphi_1 + 2kT_1)} = \frac{2k(T_1 - T_n) + \sum_{p=1}^{n-1} \frac{T_p - T_{p+1}}{T_{p+1}} \varphi_{p+1} - \bar{c}}{\varphi_1 + 2kT_1} \qquad (14)$$

The energy losses from the emitter due to the radiation and thermal conductivity of the electrical connections can be neglected. Indeed, due to the small current the electrical conductors between converter and external charge have small cross sections. In the same time, due to the electrodes structure, the radiation loss is negligible.

According to the eq.(14), the efficiency depends on the electrodes work function. Lets assume that the work function of electrodes depends on T_p/T_R according to the equation

$$\varphi_p = a \frac{T_p}{T_R} \qquad (15)$$

where a is a constant, T_p is temperature of the electrode p and T_R is the temperature of cesium reservoir.

In this case from the eqs. (14) and (15) the equation for the efficiency is

$$\eta = \frac{2k(T_1 - T_n) + \varphi_1 - \varphi_n - \bar{c}}{\varphi_1 + 2kT_1} \qquad (16)$$

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x) We point out once more that the eq.(12) is valid only for $V_{p,p+1} \geq 0$

In fact, for a number of electrodes enough high, we can neglect the terms $2k(T_1 - T_2) - \bar{\varepsilon}$

The efficiency now is equal with the efficiency of an ideal converter. We can expect in this case an incresed value of efficiency of the new type of converter, even for a practical one. Of course, because the output voltage of the new type of converter is the same with that of classical converter but the current is much smaller, the output power density is expected to be much smaller for multielectrode converter. That means that for the same output power, the units with multielectrode configuration must be larger in size than "clasical thermionic diode. Such an increase in size is acceptable for earth application if the efficiency is increased up to 20%.

More detailed theoretical paper will be published soon, as well as an experimental one concerning the preliminary data obtained using a multielectrode thermionic converter, which is now in construction.

References

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/2/ G.Musa, A.Popescu, A.Baltog, D.Popescu, I.Mustaţă, N.Niculescu, L.Năstase and A.Cormoş, Review Paper on Thermionic Energy Conversion Researches at IFTAR, preprint P.P.1, (1977)

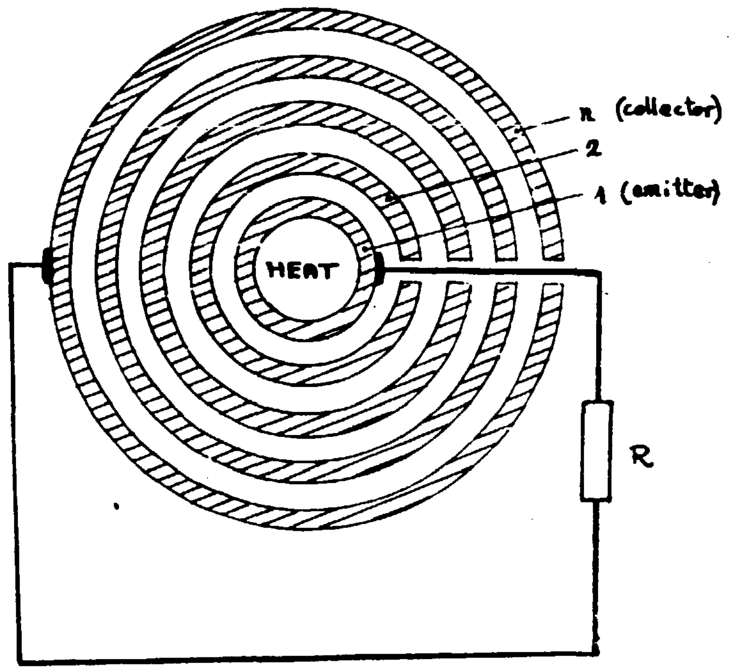

Fig. 1

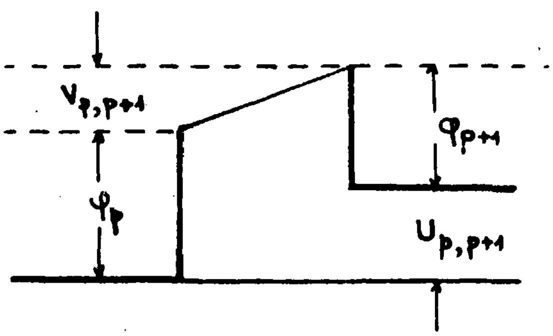

Fig. 2

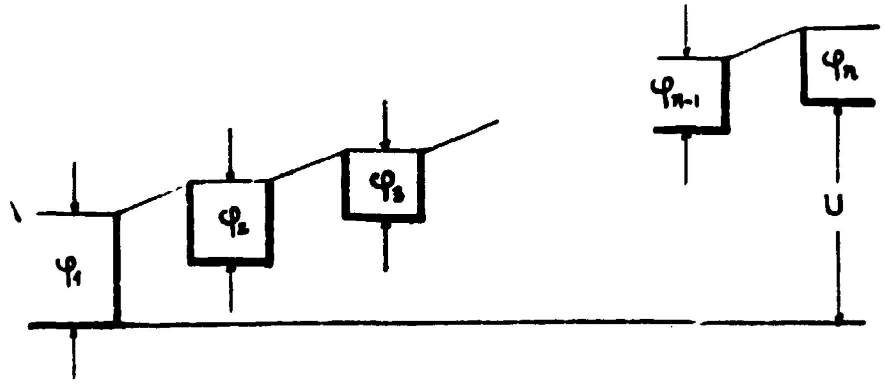

Fig. 3