§12. Characteristics of Energy Conversion in CUSPDEC Applied to the GAMMA 10 Tandem Mirror

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The cusp-type direct energy converter (CUSPDEC) device consists of a guide field section, a cusp field section, electron collectors at the line cusp side, and ion collectors at the point cusp end. The device is capable of changing the curvature of the magnetic fields from normal to slanted cusp fields. The CUSPDEC uses no obstacles in the plasma to separate electrons from ions. Electrons are collected by a collector without producing space charge. Secondary electrons from the electron collector, if any, do not enter the ion collector because there is no field line connecting the electron and the ion collectors. Secondary electrons from the wall near the ion collector are magnetically insulated. These characteristics inherent to the CUSPDEC are superior to a conventional PDC that uses a grid for separation of electrons.

The cusp field is created by two magnetic coils, A and B. By adjusting the current in the two coils, I_A and I_B, the field line curvature can be varied. Typical values are I_A = 30 A and I_B = 40 A. Electrons are deflected toward the line cusp region along the field lines and ions pass through the null point flowing into the point cusp region and are collected by plates P3 and P4 located at the cusp exit.

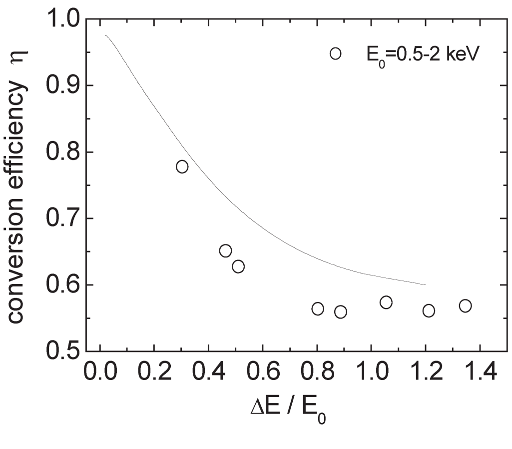

Fig. 1. Measured efficiency of energy conversion in the GAMMA 10 and calculated value for the parabolic profile of energy distribution.

The ion current I on P3+P4 is measured as a function of the decelerating voltage V on the plates to obtain V-I characteristics. The product $P(V) = V \times I$ would be the output power of the CUSPDEC if an appropriate load resistor is connected to the plates. When the average energy and spread of incoming ions are E_0 and ΔE, respectively, the efficiency of energy conversion is given by

$$\eta = P(V = V_{opt}) \,/\, (I_0 \cdot E_0),$$

where $I_0 = I(0)$ and V_{opt} is the value of V that gives a maximum P. The value of η is 1 for $\Delta E / E_0 = 0$. Figure 1 gives measured η obtained in the experiment using end loss plasmas from the GAMMA 10 with ion energies of 0.2-2 keV and electron energies of 0.4-8 keV. The solid curve is the calculated η assuming a parabolic profile of the energy distribution function.

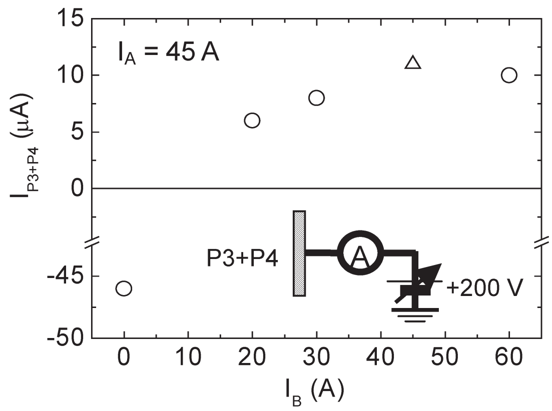

Fig. 2. Current on the ion collector P3+P4 with a fixed decelerating voltage of 200 V as a function of I_B with I_A = 45 A.

We connect a resistor of ~ 200 kΩ, an ammeter, and a dc power supply of 0.2 kV in series to the ion collector and measure I changing I_B as shown in Fig. 2. The polarity of I is negative for $I_B < 10$ A due to a large amount of electron current as a result of insufficient separation of electrons and ions. As the cusp magnetic field lines are more slanted, I changes its polarity from negative to positive, i.e., from power dissipation to power generation, and further increases due to better separation of charged particles.

For more direct demonstration, we use four small neon lamps as a load of the ion collector. The photograph of the lamps placed in a star-shape during a plasma shot is displayed for (a) $I_B / I_A = 0.66$ and for (b) $I_B / I_A = 1.33$ in Fig. 3. The picture in (b) clearly demonstrates that the kinetic energy of plasma ions streaming from the core of the GAMMA 10 is directly converted to electricity. Furthermore, it also demonstrates that the slanted cusp magnetic field for (b) is far more effective than the normal cusp or a similar magnetic field used in (a) in generating electricity.

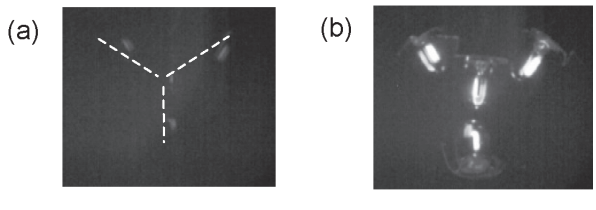

Fig. 3. Photographs of the lamps for I_B / I_A = 0.66 and 1.33.