SIMULATION EXPERIMENTS OF TRAVELING WAVE DIRECT ENERGY CONVERTER ON GAMMA 10 TANDEM MIRROR

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Simulation experiments of traveling wave direct energy converter (TWDEC) on GAMMA 10 tandem mirror have been performed. Following to initial experiments reported previously, full biasing system including measurement system has been constructed. The biasing system has successfully worked showing that energy distribution is shifted corresponding to the bias voltage. Examination of approximated energy distribution functions reveals that the deceleration effect by TWDEC operation is found for an appropriate relative phase difference between modulator and decelerator RFs.

I. INTRODUCTION

Direct energy conversion from kinetic energy of fusion produced particles is an important issue to realize an efficient commercial plant of open magnetic confinement system. An application of a conventional electrostatic converter, however, is limited to an energy around 1 MeV. For high energy ions, such as protons created in D-^{3}He fusion, construction of an efficient converter is difficult because of engineering limitation. A traveling wave direct energy converter (TWDEC) was proposed to overcome this difficulty[1].

A TWDEC consists of a modulator and a decelerator. Incident ions are velocity modulated by RF electric field in the modulator, and bunched in the downstream where the decelerator exists. The bunched ions induce RF currents in the decelerator circuit, then a traveling wave is formed, the field of which decelerates ions. This means conversion of ion energy into RF electricity. Some numerical works on TWDEC reported conversion efficiency around 70%. The authors are continuing experimental works on TWDEC.

The principle of TWDEC is an inverse process of a linear accelerator, so an energy broadening of influx directly affects its efficiency. In the TWDEC project on GAMMA 10, the end-loss flux of which has a wide energy broadening, a simulator of *bias-type TWDEC* was proposed to study the effect of the energy broadening[2]. In the bias-type TWDEC, DC bias voltage can be applied to all electrodes by superposition on RF voltages. Ions with an energy broadening experience an energy shift according to the bias voltage. By the adjustment of the bias voltage, relative energy broadening can be controlled and the characteristics of TWDEC to the energy broadening can be studied.

Following to the initial experiment[3], in which a part of the system was biased. this paper reports the next full bias experiment in which measurement system of a Faraday cup is also biased and deceleration in the simulator can be examined.

In Sec. II, the experimental setup is explained. The experimental results are shown in Sec. III. The contents of the paper are summarized in Sec. IV.

II. EXPERIMENTAL SETUP

In Fig. 1, a schematic illustration of the device used in the experiment is given. This device is installed in the extended tube with magnetic guide coils at the west end of GAMMA 10. All electrodes except the one on the top are biased with the voltage of V_b. The low energy electrons are reflected by this negative bias, and only ions are flowing into the device.

The front three electrodes are for modulation, and the back nine electrodes are for deceleration. The amplitudes of both RF ($V_\mathrm{mod}, V_\mathrm{dec}$) can be controlled independently, and the relative phase difference between both RFs ($\Delta\phi$) can also be settled. The traveling wave voltage for the decelerator can be obtained by transmission lines with appropriate lengths.

The energy distribution of ions is measured by a Faraday cup (denoted by 'FCP' hereafter) which is also biased[4]. The FCP consists of three grids (an ion repeller, a primary electron repeller, and a secondary electron repeller) and one collector plate. The collector current (I_C) is measured by varying the voltage of the

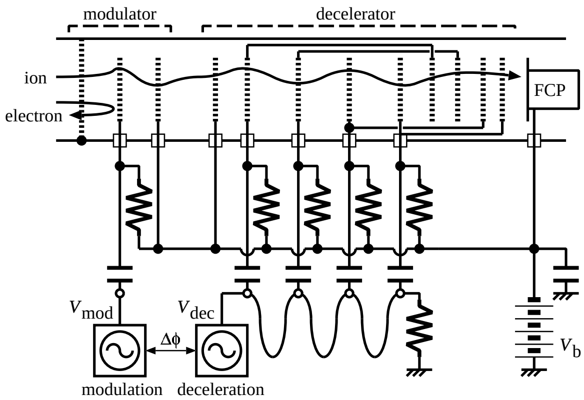

Figure 1: Experimental arrangement.

ion repeller (V_{IR}) with appropriately biasing electron repellers. The time sequence in a shot is explained in the next section.

III. EXPERIMENTAL RESULTS

Figure 2 shows a typical example of time evolutions of signals: (a), (b), and (c) are diamagnetic signal, line density, and signals of FCP, respectively. The TWDEC RFs are applied in the relatively stable period of 60–90 ms, where plasma of GAMMA 10 is maintained by ICRF and no ECH is applied. V_{IR} is swept by a triangle wave of 50 Hz.

An energy distribution function of the flux passing through the TWDEC can be derived by a V_{IR}-I_C characteristic. As raw signals have noise, fluctuations within a sweeping period, and fluctuations among shots, they are processed by moving average and polynomial approximation.

The effect of the bias voltage has been evaluated at first. The energy distribution function without TWDEC operation is expected to be a shifted Maxwellian, and the degree of approximate polynomials has been taken to be 6. Figure 3 shows V_{IR}-I_C characteristics for several bias voltages. The curves in the figure are data during 60–80 ms without TWDEC operation, and normalized by the value on $V_{IR} = 0.1$ kV. The horizontal shift of curves of almost the same amount of $|V_b|$ can be found, thus the particle energy is shifted by the bias voltage.

The variation of energy distribution by TWDEC application is discussed. The energy distribution function with TWDEC application will be more complex than a shifted Maxwellian, so three cases have been considered for the degree of polynomials approximating V_{IR}-I_C characteristics: 6, 7, and 8. Using an approximated function of $I_C(V_{IR})$, an energy distribution function $f(E)$ is obtained by the following equation.

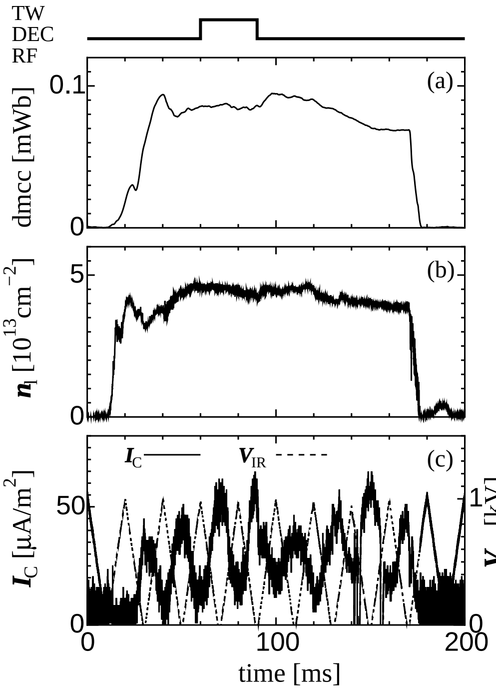

Figure 2: Time evolution of (a) diamagnetic signal, (b) line density, and (c) signals of Faraday cup.

$$f(E) \propto \frac{1}{\sqrt{V_{IR}}} \frac{\partial I_C(V_{IR})}{\partial V_{IR}} \bigg|_{V_{IR}=E/e}. \tag{1}$$

where E is ion energy and e is unit charge.

In Fig. 4, examples of approximated energy distribution functions are shown. Thin solid, dashed, and thick solid curves are for no RF, RF of $\Delta\phi = 0$, and RF of $\Delta\phi = 3\pi/2$, respectively, and those are derived from $I_C(V_{IR})$ of polynomials of degree 8 during 60–70 ms. As for other conditions, $V_b = -0.4$ kV, $V_{mod} = 140\,V_{0p}$, and $V_{dec} = 100\,V_{0p}$. As the functions are approximated ones, negative values or extremely large values

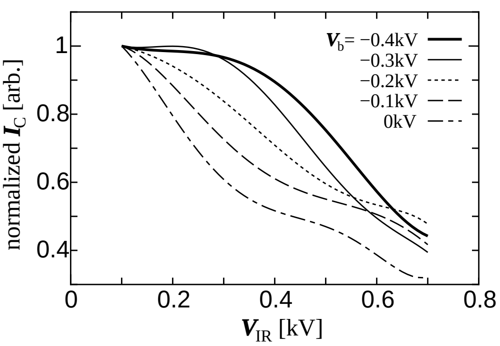

Figure 3: Polynomial approximated V_{IR}-I_C characteristics for several bias voltages.

are found as shown in the figure. As for reliability of the approximation, the values of root mean square deviation on V_{IR}-I_{C} approximation were calculated corresponding to data shown in Fig. 4. They were less than 12.3 %, 7.6 %, and 4.7 % for no RF, RF of $\Delta\phi = 0$, and RF of $\Delta\phi = 3\pi/2$, respectively.

By comparing RF of $\Delta\phi = 0$ with no RF, the distribution function slightly shifts to low energy side. On one hand, significant incline to the low energy side is found for $\Delta\phi = 3\pi/2$. This means average energy of the particles reduces due to RF application, and thus, particle deceleration by TWDEC operation.

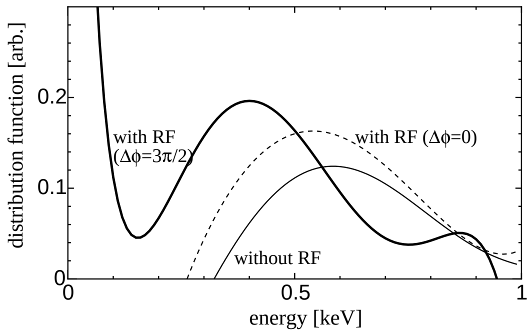

Figure 4: Examples of approximated energy distribution functions. Thin solid, dashed, and thick solid curves are for no RF, RF of $\Delta\phi = 0$, and RF of $\Delta\phi = 3\pi/2$, respectively.

IV. SUMMARY

In this paper, simulation experiments of TWDEC on GAMMA 10 tandem mirror were explained. The full biasing system, which included the FCP of measurement system, was constructed following to the initial experiments. It was shown that the biasing system worked successfully, and energy distribution was shifted corresponding to the bias voltage. By evaluating approximated energy distribution functions, the deceleration effect of end-loss particles was found due to TWDEC operation for an appropriate relative phase difference between modulator and decelerator RFs.

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