§6. Active Deceleration Experiments in TWDEC Simulators

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For D–^{3}He fusion, energy recovery of fast protons of 14.7 MeV is one of the most important issues. Traveling wave direct energy converter(TWDEC) was proposed as an efficient device. In a TWDEC, a fast proton beam is velocity-modulated, and the bunched proton beam excites traveling wave in a transmission circuit. Energy of proton beam is recovered via deceleration by the traveling wave field.

We are continuing fundamental experiments in a TWDEC simulator[1)] and a separate new simulator which is in preparation. The experiments are divided into two modes: one is for voltage induction process on decelerator electrodes and we call this mode as ‘passive decelerator’. The other is for beam deceleration process and we call this mode as ‘active decelerator’. In this report, we show an empirical scaling of energy recovery for various experiments in the active decelerator mode.

Active decelerator experiments are performed by using a setting shown in Fig. 1. Helium plasma is produced in the ion source region, and by applying DC high voltage($V_{\rm ex}$) to an extraction electrode, a helium ion beam flows into the deceleration region. A beam modulation RF voltage $V_{\rm mod}$ is also applied to the extraction electrode. Another RF voltage $V_{\rm dec}$ synchronized with $V_{\rm mod}$ is supplied to a transmission circuit. The circuit consists of coaxial cables, the length of which is designed to supply appropriate time delays between electrodes. In a real TWDEC, $V_{\rm dec}$ is induced by the proton beam itself. In the simulator, however, fundamental researches are performed by controlling $V_{\rm dec}$ externally to examine the interaction between the beam and the deceleration field.

The scaling of energy recovery is summarized in Fig. 2. For unified treatment of various results, we introduce modified beam energy E^* and modified efficiency for unit wave length η_1^*. Using $V_{\rm dec}$, $E^* = E_{\rm ex}(V_{\rm dec}/V_{\rm dec0})$ is defined, where $E_{\rm ex} \simeq eV_{\rm ex}$ is an initial beam energy and $V_{\rm dec0}$ is 200 V$_{\rm 0p}$. Efficiency for unit wave length η_1 is also modified by $\eta_1^* = \eta_1(J_1(1.84)/J_1(X))$ where J_1 is a Bessel's function of the first kind and X is a bunching parameter. The variation of $V_{\rm mod}$ is taken into account with the variation of X.

Open circles are for experimental data, and filled circles are for numerical calculations[2)]. The gray elliptical region indicates numerical calculation for real TWDECs. The dashed ellipse indicates an expected region in the new simulator. In the numerical calculations, the structure of decelerator is optimized according to an equation:

$$\frac{\lambda(z)}{\lambda_0} = \left\{1 + \frac{3}{2}\frac{E_{\rm M0}}{V_{\rm ex}}z\right\}^{1/3},$$

where z is an axial coordinate in which the origin is at the entrance of the decelerator, and $E_{\rm M0}$ is wave field strength at $z = 0$. $\lambda(z)$ and λ_0 are wavelength of traveling wave at z and the one at $z = 0$, respectively. In the present simulator, this optimization is not necessarily applied. In the new simulator, however, the decelerator is designed by taking account of the above equation.

According to the definition of E^*, η_1^* increases as E^* in the same simulator because beam divergence is smaller for larger $E_{\rm ex}$, and larger deceleration is obtained with a shorter length for larger $V_{\rm dec}$. In the present simulator, $E^* = 10^3 \sim 10^4$ eV, and the experimental data are consistent with this expectation.

The best value of η_1^* is expected to be 20±4% which is obtained by interpolation of numerical results. In the new simulator, around those values of η_1^* are expected in $E^* = 10^4 \sim 10^5$ eV.

Reference
1) H. Takeno, *et al.*: Jpn. J. Appl. Phys. **39**(9A), 5287 (2000).
2) Ishikawa, M., *et al.*: Ann. Rep. NIFS(2002-2003) 358.

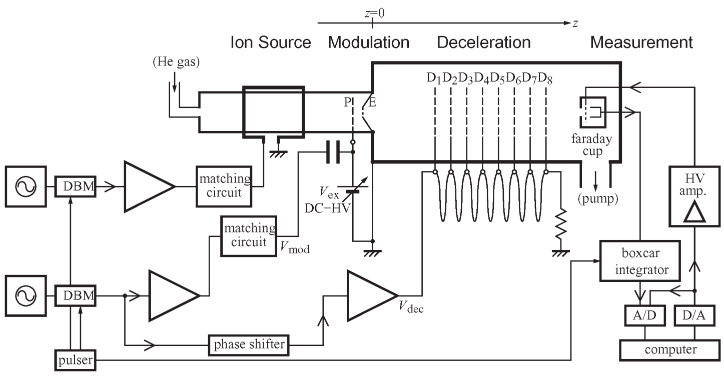

Fig. 1 A setting of active decelerator mode of the TWDEC simulator.

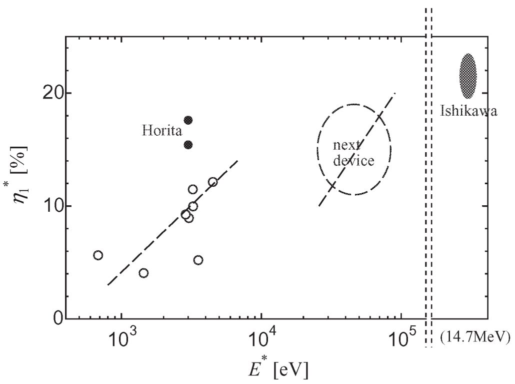

Fig. 2 Scaling of energy recovery.