§62. A Consideration of Heavy Ion Beam Probe on a Spherical Tokamak

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The heavy ion beam probe (HIBP) is a very powerful diagnostic tool for magnetically confined plasmas, because it can measure directly potential in the core region of high temperature plasmas with a good spatial/temporal resolution. We can utilize this tool to study confinement and turbulence physics related to the radial electric field. This system is usually expensive, because the high voltage accelerator is needed to inject the ion beam into the plasma core on the condition of strong magnetic field strength (> 1 T) in ordinal magnetically confined systems. However, the toroidal magnetic field strength of spherical tokamaks is weak compared with conventional tokamaks, so costs of HIBP on such a spherical tokamak may be reasonable.

In Fig.1, the acceleration energy of probe beam, E_b, is shown as a function of the magnetic field strength, B, when Larmor radius is assumed to be 1 m. Calculation results for several sorts of ions (mass number), Li(7), Na(23), K(39), Rb(85), Cs(133), are shown in this figure. The required acceleration voltage on the condition of B = 0.1 T, is 69 keV (Li), 21 keV (Na), and 3.6 keV (Cs). A few tens keV is suitable for good focusing property of probe beam, so Li or Na is an appropriate choice for the probe beam.

Quest is a spherical tokamak, of which major/minor radius is about 0.68 m / 0.4 m. Its maximum troidal magnetic field strength is 0.25 T. The vacuum magnetic field configuration produced by 8 toroidal coils is assumed and the orbit of ion beam for HIBP is calculated. Here, the toroidal magnetic field strength is assumed to be 0.1 T at the major radius of 0.5 m. In Fig.2, the orbit of primary (singly charged) beam injected from the upper port and secondary (doubly charged) beam formed on the Z=0 plane are shown. The acceleration energy of beam is 50 keV / 21 keV in Fig. 2a and 90 keV / 37 keV in Fig.2b, for the ion beam of Na / Cs. Since the size of toroidal coil (about 4 m x 2.5 m) is large, the relatively high acceleration energy is required for the probe beam. The secondary beam current is expressed as follows,

$$I_s = 2I_p n_e < \sigma_1 v_e > w / v_b$$

$$\times \exp\left[-\int_{l1} n_e < \sigma_1 v_e > / v_b dl - \int_{l2} n_e < \sigma_2 v_e > / v_b dl\right] . \quad (1)$$

Here, I_s is secondary beam current, I_p primary beam current, n_e electron density, $<\sigma_1 v_e>$ / $<\sigma_2 v_e>$ are the averaged rate coefficient of the collision between primary/secondary beam ions and electrons. v_b is the velocity of probe beam. w is the sample volume length. By using this equation, the secondary beam current expected in QUEST is estimated. For simplicity, the attenuation of beam is neglected. In the case of $n_e \sim 10^{19}$ m^{-3}, $T_e \sim 100$ eV, $w \sim 0.005$ m, $v_b \sim 2.4 \times 10^5$ m/s (40 keV, Cs), $<\sigma_1 v_e> \sim 10^{-7}$ cm^3/s, the ratio of I_s/I_p is about 4.2×10^{-4}. In this case, secondary beam current is 42 nA for the primary beam current of 100 μA, which is sufficient to measure potential with a good accuracy. However, when the electron density $n_e \sim 10^{18}$ m^{-3}, the secondary beam current becomes small (~ 4 nA). A very sensitive detector, such as micro channel plates (MCP), may be required for the secondary beam detector. Further optimization of probe beam orbit is in progress.

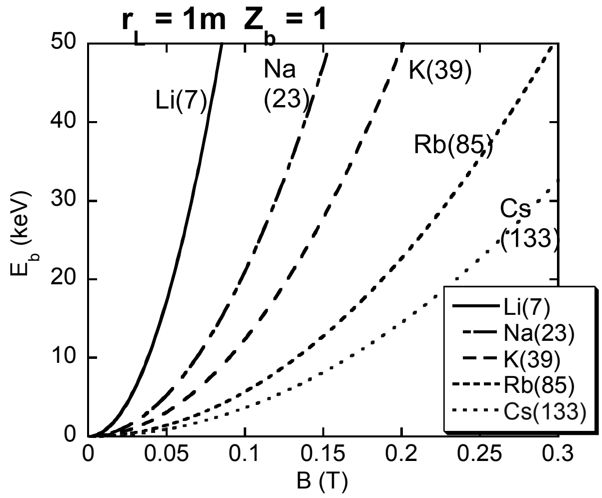

Fig. 1. The acceleration energy of single charged probe beam, E_b, is shown as a function of the magnetic field strength, B, when the Larmor radius of ion is assumed to be 1 m.

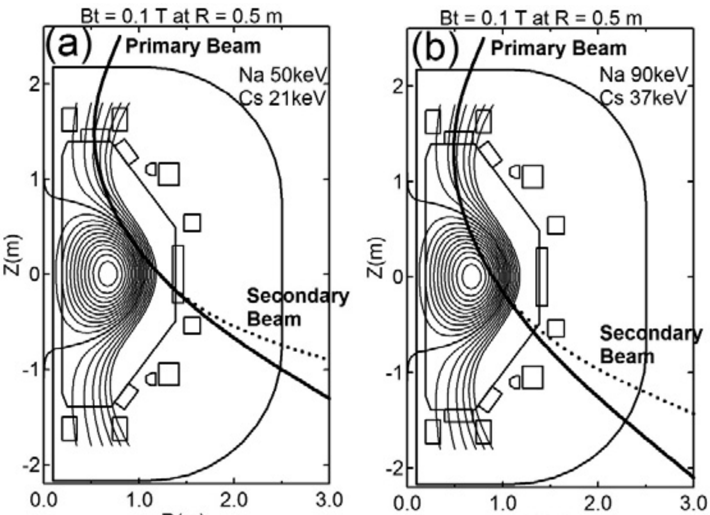

Fig. 2. The calculation result of probe beam orbit in QUEST is shown. The magnetic field strength is assumed to be 0.1 T at R = 0.5 m. (a) The acceleration energy of probe beam is 50 keV/21 keV, (b) 90 keV / 37 keV when Na/Cs is applied to probe beam ions.