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§25. Installation of Lost Fast Ion Probe

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Confinement of energetic ions/alpha particles is an important issue for efficient heating and sustainment of a burning plasma. However, steep gradient of energetic ion pressure causes energetic ion driven MHD instabilities such as toroidal-Alfvèn engenmodes (TAEs[1]) and energetic particle modes (EPMs[2]). These instabilities are of practical importance because transport or loss of energetic particles leads to low efficiency of heating. In order to understand loss mechanisms of energetic ions by these instabilities, direct measurement of distribution of pitch angle (χ= arccos($v_{\|}/v$)) as well as energy of those lost ions is of critical importance. We have adopted a scintillator-based lost-fast-ion probe (LIP) for this purpose in LHD, because it was successfully employed in CHS[3]. This paper describes essence of the design study of LIP to apply to LHD experiment[4].

The primary target of measurement by this LIP is co-going beam ions having small-χ that may escape from the confinement region and be lost at the outboard side of the torus, because co-going NB ions would be anomalously transported toward the outboard by TAE[5]. In CHS, Anomalous losses of co-going NB ions correlated with EPM and TAE activities successfully measured by elevating the LIP from the midplane at the outboard side[3]. Referring to these results, the outboard side of the LHD is supposed to be suitable for detecting energetic ions ejected by AEs effectively.

To select the LIP head position, orbit calculation of energetic ions was carried out for the reference configuration of R_{ax}=3.6 m at two different B_t values of 0.75 T and 1 T to evaluate the number of detectable ions at that position. The numbers of such lost orbits were evaluated by changing the radial position of the LIP head along the probe shaft parallel to the horizontal plane. Figure 1 shows the counts of lost ions as a function of the detector head position in the horizontal direction, where 750 particles are launched from the LIP head, having various energies and pitch angles in each position. The counts of lost ions are evaluated with retracting the position of the LIP head outward in the accessible range of LIP (from R=4.46 m to R=4.6 m) by every 20 mm step.

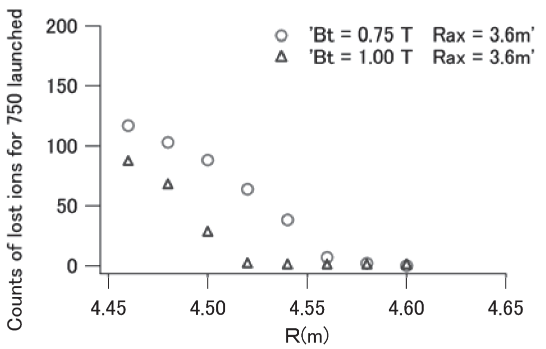

Fig.1 Counts of lost energetic ions from the plasma can be detected with LIP, where 750 particles having various energies and pitch angles.

The LIP head is attached to a long stainless steel shaft of 3 m long. It is horizontally inserted at the place shifted upward by 210 mm from the equatorial plane of the LHD through a diverter leg, to the inner most position (R=4.46 m) by a pneumatic motor. A stainless steel shaft is partially covered with a graphite sleeve of 380 mm long and 5 mm thick, to protect the LIP against high heat flux flowing from a main plasma along divertor leg as shown Fig.2. The scintillator box of LIP is made of stainless steel and covered with molybdenum plates to protect the heat load.

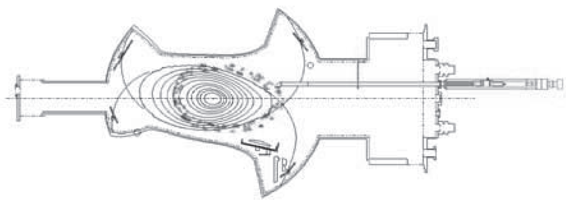

Fig.2 Schematic view of LIP placed at the innermost position. Triangles designate an example of Poincare plots of the orbits of lost ion with 150 keV energy and 35.0 degrees pitch angle.

The LIP head is shown in Fig. 3 with hit point area of energetic ions. The size of the LIP head is 58 mm (width) × 52 mm (length) × 66 mm (height), but has a defective part near the aperture. The angle between the side surface of the LIP and the aperture is selected to be 21 degrees. It was decided by the magnetic vector of the probe head position to be able to evaluate the scintillation pattern easily, and to catch energetic ions effectively. Hence, the normal vector of the aperture is 113 degrees with respect to the local magnetic field direction at the innermost position. The front aperture has 3 mm width and 1 mm height whereas the rear aperture has 24.1 mm width and 1 mm height.

In Fig. 3, calculated hit point area of lost ions having the range of 1.5 to 15 cm in gyroradius and 35 to 50 degrees in pitch angle is shown on the scintillator screen. As a scintillator material, YAG:Ce (P46) is adopted, because it has high luminosity and short decay time even at high temperature. Scintillator-plate is composed by P46 deposited on a quartz plate coated with aluminum, and emits green light (550 nm).

The LIP designed in this study can detect lost ions in the case that the direction of B_t is clock wise (CW) as seen from the top. The LIP will not be able to detect any lost-ion flux when B_t is directed to be counter-clock-wise (CCW) because the gyromotion of energetic ions becomes opposite for the CW-B_t case; they are blocked by the apertures of the LIP box and can not reach the scintillator surface.

1) Cheng, C, Z. et al. : Phys.Fluids **29** (1986) 11
2) Chen, L. : Phys. Plasmas **1** (1994) 5
3) Isobe,M. et al. : Nucl. Fusion **46** (2006) S918.
4) Ogawa, K. et al. : accepted in Plasma Fusion Res.
5) Osakabe,M. et al. : Nucl. Fusion **46** (2006) S911

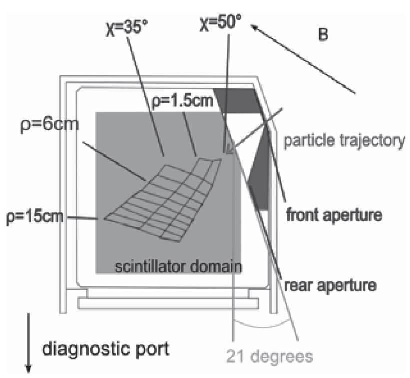

Fig.3 Schematic view of the probe head and expected arrival area of energetic ions.