§4. Nuclear Fusion Energy Extraction from D-^{3}He Experiment in LHD

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Demonstration of extraction of net electric power from fusion device is an urgent issue for the social cognition that nuclear fusion energy can solve the energy and environmental issues on the earth.

High power is injected into the plasma for the production and sustainment. Then fusion products should be discriminated from plasma particles for the clear demonstration of net fusion power extraction. Furthermore, effective acquisition performance is necessary to get sufficient power for the operation of some home electric appliances.

We have studied the possibility of discrimination and acquisition of 14.67 MeV protons by the D-^{3}He reaction in the LHD.

$$\mathrm{D} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He}\,(3.67\,\mathrm{MeV}) + \mathrm{p}\,(14.67\,\mathrm{MeV}) \qquad (1)$$

In the LHD magnetic field configuration, the $\boldsymbol{B} \times \boldsymbol{\nabla} B$ drift motion enhance the adiabaticity of passing particles with $v_\parallel > 0$. Then, passing particles with $v_\parallel > 0$ can be confined over the LCFS. The displacement of particle orbits from the magnetic surface, Δ, can be estimated as poloidal Larmor radius, as following

$$\Delta \simeq \sqrt{\frac{E}{M_p}}\frac{M_p}{qB_p} \simeq \begin{cases} 0.043 \quad \mathrm{m} \quad \text{for 180 keV} \\ 0.40 \quad \mathrm{m} \quad \text{for 15 MeV} \end{cases} \qquad (2)$$

where B_p is the poloidal magnetic field (estimated as 1 T) and E, M_p and q are energy, mass and charge of proton, respectively. In the LHD, therefore, fusion products 14.67 MeV protons, can be confined over the chaotic field line region with large margin though co-NBI orbits ($E = 180$keV) does not exceed the chaotic field line region whose width is the order of the 0.1 m.

To evaluate semiquantitatively the extraction rate of fusion energy from D-^{3}He experiment in the LHD, we have studied numerically the collisionless orbits of fusion products, 14.67 MeV protons, under the following assumptions. The magnetic field is a standard one ($R_{\mathrm{ax}} = 3.6\,\mathrm{m}$, $B_{\mathrm{ax}} = 2.75\,\mathrm{T}$, $\gamma = 1.254$). Birth points of the fusion products are assumed to be uniform inside the magnetic surface designated by normalized minor radius $\rho \simeq 0.8$ as shown by white-solid line oval in Fig. 1. Initial pitch angles are isotropically distributed. The ICRF antenna (3.5UL antenna), which is maximally drawn to the vacuum vessel wall ($d = 0.07$ m) is used as an acquisition system of the fusion products.

Poincaré plots of the fusion products, 14.67 MeV protons, in the poloidal cross-sections specified by toroidal angle $\phi = 2\pi/5$, $\pi/2$ and $3\pi/5$ are shown in Fig. 1.

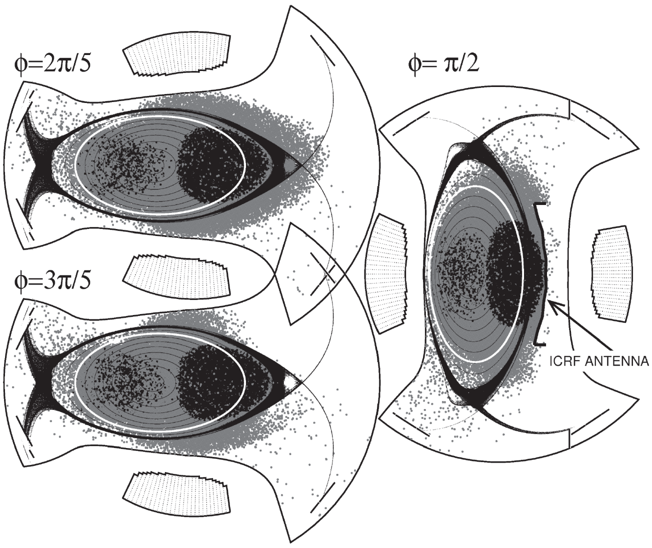

Fig.1 Poincaré plots of fusion products, 14.67 MeV protons. Black dots are puncture plots of confined particles. White-solid lines represent the magnetic surface of outer boundary for birth points of fusion product. Poincaré plots of lines of force are overlapped with extremely small dots.

Numerical results are summarized in the Table.1. Present studies show that if an appropriate acquisition system is installed outside the chaotic field line region, the acquisition rate $R_{15\mathrm{MeV}}$ for 14.67 MeV protons in the LHD D-^{3}He experiment can be estimated roughly as

$$0.12 \lesssim R_{15\mathrm{MeV}} \equiv \frac{\text{collected protons}}{\text{total generated protons}} \lesssim 0.28 \qquad (3)$$

Evaluation of fusion power in the LHD D-^{3}He experiment will be reported in elsewhere. Direct power generation project from D-^{3}He experiment in LHD is under way.

total particle number	42,242	100.00 %
confined particles	2,013	4.77 %
vacuum vessel wall	23,430	55.47 %
diverter tiles	6,073	14.38 %
3.5UL ICRF antenna	10,726	25.39 %

Table 1. Summary of the numerical computation for the extraction of 14.67 MeV protons from D-^{3}He Experiment in the LHD