§1. New Design of Neutral Beam Injector for LHD

Kaneko, O., Inoue, N., Ohyabu, S., Okamoto, M., Murakami, S., Watari, T., Fujiwara, M.

The neutral beam injection system for LHD is scheduled to construct a 15 MW system by the end of FY 1998. In this plan, we designed the maximum beam energy 125keV for hydrogen and 250keV for deuterium. This energy was determined by the condition that a half of the injected power is deposited inside the half minor radius of plasma whereas the shine-through of the beam is below 30% under the target plasma density from 1 to 10 x $10^{19}m^{-3}$.

In order to realize this high energy neutral beam system, it was necessary to develop a high current negative ion source. The R&D for large negative ion sources has been carried out in our institute, and recently we have succeeded to get high negative ion current with the designed beam energy and current density[1,2].

On the basis of these R&D results, the beam energy of neutral injection for LHD was reconsidered from the physical point of view, and we have decided to increase the beam energy up to 180keV for hydrogen. The reasons of this change are described below.

Beam deposition

Recent experimental evaluation of absorption of high energy neutral beam supports the multi-step ionization in plasma[3]. According to Janev et. al.[4], the cross section would be 30% larger in the high density LHD plasma (n_e = 1 x $10^{20}m^{-3}$) if we consider the multi-step ionization process. In other words, we have to increase the beam energy from 125 keV to more than 170 keV so as to keep the ionizing mean free path unchanged as we planned before.

Because the confinement of helical plasma is improved as plasma density, a high performance plasma is expected in high density operations. The deposition profile of the beam in this high density plasma can be improved if the beam energy is increased. Therefore higher energy beam is preferable, but the constraints come from the heat load in the neutral beam line and/or of the beam armor plate.

Shine-through

The multi-step ionization depends on the plasma density, and is not effective when it is low. This means that the shine-through becomes larger at the low plasma density than that we estimated in the previous design, if we increase the beam energy. So the beam energy should be limited by the heat load on the beam armor.

New design of neutral beam line

From our R&D results on the negative ion source, we think it possible to increase the beam energy keeping the beam current almost the same, that is, to increase the power density of the ion source. We have newly designed a 15 MW injection system by two beam lines. The beam energy is determined as 180 keV to keep the heat load on the beam dump under the value including a reasonable margin.

Beam armor

Based on the newly designed neutral beam line, the maximum heat load on the armor is estimated to be 17 MW/m^2 without plasma, and 3.4 MW/m^2 when the plasma density is 2 x $10^{19}m^{-3}$. Because the divertor plate of LHD is designed to receive 5 MW/m^2 for 10 seconds, this heat load is acceptable. However in practical sense, the beam armor should cover a large area of 2 m^2, and the shape of inner wall of LHD is rather complicated, so that the heat removal condition becomes severe. Therefore this heat load is considered to be almost a upper limit to design the armor.

We will start to construct a neutral beam injection system with this new specification next year.

References

1) Ando ,A., Tsumori, K., Oka, Y., Kaneko, O., Takeiri, et. al., Pys. of Plasmas 1 (1994) 2831 .
2) Takeiri, Y., Ando ,A., Kaneko, O., Oka, Y., Tsumori, et. al., Rev. Sci. Instrum. 66 (1995) 2541.
3) Tobita, K., Itoh, T., Sakasai, A., Kusama, Y., Ohara, et.al., Plasma Physics and Controlled Fusion 32 (1990) 429.
4) Janev, R.K., Boley, C.D., and Post, D.E., Nucl. Fusion 12 (1989) 2125.