18PB-012

Evaluation of heating efficiency property of perpendicularly injected NB in LHD high beta plasma
LHD高ベータ放電における垂直NBIの加熱効率

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We evaluate the heating efficiency of perpendicularly injected NB by using the Monte-Carlo code (MORH) which can evaluate the heating power with including the re-entering fast ions. We roughly evaluate a heating efficiency by using the measurements of stored energy in the experiments of the perp-NB modulation. The evaluated heating efficiency is almost 0.2.

1. Introduction

In the Large Helical Device (LHD), the reactor-relevant high-beta plasmas with the volume averaged beta value, <β>~5%, are achieved in low field strength [1]. The high-beta discharge with higher field strength is attempted.

In the higher field strength of LHD, a heating efficiency of a perpendicularly injected neutral beam (perp-NB) becomes higher than that in the low field strength. To optimized heating power, the heating power of perp-NBs needs to be properly evaluated.

In LHD, when magnetic axis shifts to a torus outside such as the high beta plasma, perpendicularly injected fast ions tend to be the re-entering fast ions which re-enter in the region of the LCFS after they have once passed out of the LCFS. Therefore, it is important for evaluation of the heating power of the perp-NB to include the re-entering fast ions.

In this study, the Monte-Carlo code (MORH[2]) which can calculate the heating power with re-entering fast ions is used. We investigate the property of the heating efficiency of the perp-NB by changing a position of magnetic axis and a magnetic strength. In addition, the heating powers are roughly evaluated by using the measurement of stored energy in experiments of a perp-NB modulation as a first step and we compare the results with results of the MORH.

2. Property of heating power of perp-NB

To investigate the property of heating efficiency of perp-NB, we evaluate the heating efficiency of perp-NB (initial energy of fast ions E_{nbi0}=40 keV) in vacuum magnetic fields of magnetic axis R_{ax} =3.6 m, 3.75 m and 3.9 m with field strength B_0= 3.0 T, 1.5 T, 1.0 T and 0.75 T. In this evaluation, the plasma density and temperature is assumed to be 3x10^{19} m^{-3} and 1 keV with reference to the high beta plasma with B_0 = 1 T. In the high beta plasma with B_0 = 1 T, a typical positon of a magnetic axis shifted by a beta effect is ~3.8 m.

Figure 1 shows the field strength dependence of the heating efficiency of the perp-NB in each position of magnetic axis. In Fig. 1, the dashed and solid lines show the heating efficiency without and with re-entering fast ions, respectively. From Fig. 1, the heating efficiencies decrease with decrease in the field strength, in the case without re-entering fast ions, the heating efficiency with R_{ax}=3.75 m and B_0 = 1T is about 0.3. In the case with re-entering fast ions, the heating efficiency is about 0.7 with R_{ax}=3.75 m and B_0 = 1T. The difference of the heating efficiency between cases with re-entering fast ions and without re-entering fast ions in R_{ax}=3.9 m become larger than that in R_{ax}=3.75 m. Since the re-entering fast ions repeatedly pass through the outer region of LCFS, there is the potential to be lost due to a charge exchange reaction with neutral particles. Therefore, it is important for the evaluation of the heating power of perp-NB to take into account a fast ion loss due to the charge exchange reaction.

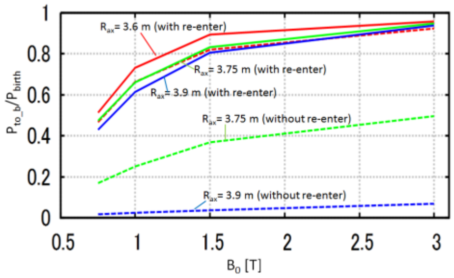

Fig. 1 Field strength dependence of heating efficiency.

3. Heating efficiency evaluated from LHD experiments.

In this section, we roughly evaluate a heating efficiency by using the measurements of stored energy in the experiments of the perp-NB modulation.

The stored energy evaluated from diamagnetic current (W_{dia}) consists of stored energies of bulk plasma (W_{th}) and fast ions (W_f) as follows.

$$\frac{2}{3}\frac{dW_{dia}}{dt} = \frac{2}{3}\frac{dW_{th}}{dt} + \frac{dW_{f\perp}}{dt} \quad (1).$$

From the energy conservation, the time variation of stored energies of bulk plasma is given by

$$\frac{dW_{th}}{dt} = -\frac{W_{th}}{\tau_E} + \frac{W_f}{\tau_{relax}} \quad (2)$$

where, τ_E is the energy comfinment time of plasma and τ_{relax} denotes the relaxation time of fast ion energy. And, the stored energies of fat ions in each NB are given from

$$\frac{dW_{NB\_n}}{dt} = P_{birth\_n} - \frac{W_{NB\_n}}{\tau_{relax}} - \frac{W_{NB\_n}}{\tau_{loss}}$$
$$= P_{abs\_n} - \frac{W_{NB\_n}}{\tau_{relax}} \quad (3).$$

Here, P_{abs_n} is roughly heating power of fast ions. When the component of fast ions assume to be NB,

$$W_f = W_{f\|} + W_{f\perp}$$
$$= \sum(1-\alpha_n)W_{NB\_n} + \sum \alpha_n W_{NB\_n} \quad (4)$$

where

$$\alpha_n = \frac{W_{NB\_n\perp}}{W_{NB\_n}} \quad (5).$$

It is assumed to hold the last-minute steady state after "on" or "off" of NB modulation and the heating power of fast ions is rough evaluated by time variance of W_{dia} as follows.

$$\frac{dW_{dia}}{dt} = \pm\sum \alpha_n \frac{3}{2} P_{abs\_n}$$
$$\sim \pm\frac{3}{2} P_{abs\_prep-NB} \quad (6),$$

where plus and minus shows the "on" and "off" of NB modulation.

Using the equation (6), the heating power of perp-NB are roughly evaluationed by measurement of the stored energy from diamagnetic current in the high beta experiments ($B0$=1.0 T, R_0=3.6 m, gamma = 1.2) of perp-NB modulation (see Fig. 2). In these experiments, the volume averaged beta value is ~ 2.7 with electron disity (ne)~ 3.0 x 10^{19} m^{-3}. In the Fig. 2, the evaluated heating efficiency is almost 0.2. Its value is close to the heating efficiency in the case without re-entering fast ions with R_{ax}=3.75 m. Magnetic axis R_{ax} in these experiments is ~ 3.8 m and its heating efficiency is the value between results with R_{ax}=3.75 and R_{ax}=3.9. In these experiments, since τ_E ~ 20 ms, the energy loss of plasma may have an effect on this evaluation. In the future, we will develop the more accurate evaluation method.

4. Summary

In order to optimize the heating power of the perp-NB in the high beta plasma, we evaluate the property of the heating efficiency by using the Monte-Carlo code (MORH) which can evaluate the heating power with including the re-entering fast ions. In addition, we roughly evaluate a heating efficiency by using the measurements of stored energy in the experiments of the perp-NB modulation.

The heating efficiencies decrease with decrease in the field strength. In the case without re-entering fast ions, the heating efficiency with R_{ax}=3.75 m and B_0 = 1T is about 0.3. The difference of the heating efficiency between cases with re-entering fast ions and without re-entering fast ions becomes larger when magnetic axis shifts to torus outside. Since the re-entering fast ions might be lost due to a charge exchange reaction with neutral particles, it is important for the evaluation of the heating power of perp-NB to take into account a fast ion loss due to the charge exchange reaction.

The heating powers roughly evaluated by measurement of the stored energy from diamagnetic current in the high beta experiments of perp-NB modulation is almost 0.2. its value is close to the heating efficiency in the case without re-entering fast ions with R_{ax}=3.75 m and B_0 = 1T.

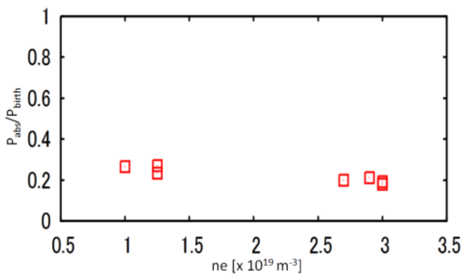

Fig.2 Heating efficiency roughly evaluated from LHD experiments

Acknowledgments

This work is supported by General Collaboration Research of NIFS (NIFS13KNSR002).

References

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