Journal of the Physical Society of Japan
Vol. 57, No. 2, February, 1988, pp. 665-666

Parameter Dependence of Antenna Loading for the Ion Bernstein Wave in a Tokamak

Shunjiro SHINOHARA, Osamu NAITO* and Kenro MIYAMOTO

Department of Physics, Faculty of Science, University of Tokyo, Bunkyo-ku, Tokyo 113

(Received November 9, 1987)

Recent results obtained by an ion Bernstein wave (IBW)[1] have shown attractive means of auxiliary heating in tokamaks.[2-5] Although a study on antenna coupling of IBW using a E_z type antenna (the antenna current is parallel to the toroidal field) is important from a view point of an efficiency of the energy transfer, there are only few results on antenna loading studies.[6] The larger antenna length along the toroidal direction is desirable from ref. 6 to obtain good antenna coupling in addition to have the larger antenna surface. In this present paper, the dependence of plasma loading on various parameters by the E_z antenna, considering the above conditions, is investigated in TNT-A[7,8] tokamak. Before the study of antenna loading of the E_z antenna, the excitation and propagation of IBW have been checked.[9,10]

Typical experimental parameters are the followings; major radius $R=40$ cm, minor radius $a=8.8$ cm, elongation ratio $\kappa=1.2$, plasma current $I_p=4$–6 kA, loop voltage $V_l=5$–7 V, mean plasma density $\bar{n}_e=(3\text{–}8)\times 10^{12}\ \text{cm}^{-3}$, central electron and ion temperatures $T_e(0)\sim 30$ eV, $T_i(0)\sim 15$ eV, respectively, discharge duration time$=$20–30 ms, ratio of radiated power to ohmic power$=$0.5–0.7.

A cross-sectional view of the E_z antenna, located on the low field side of the torus, has a copper central conductor, 0.8 cm thick and 10 cm wide, and is 30 cm long along the toroidal direction. Single screens of the Faraday shield with 0.1 cm thickness are used to reduce the excited electric field perpendicular to the antenna current. This antenna is located at the nearly same radial position as the fixed limiter, $a=8.8$ cm.

* Present address: Naka Fusion Research Establishment, Japan Atomic Energy Research Institute, Ibaraki 311-02.

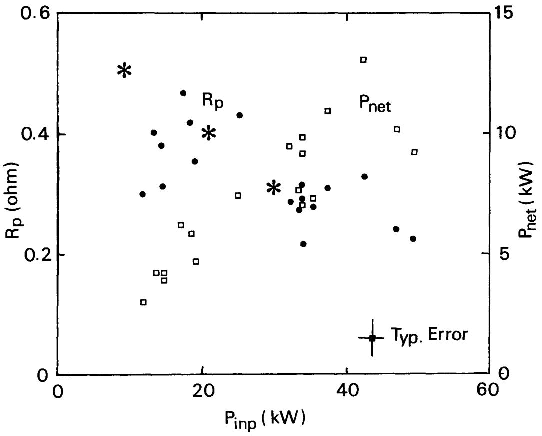

Fig. 1. Dependence of plasma loading resistance R_p (closed circles) and net power P_{net} (open boxes) on input power P_{inp} with various conditions; $n_H/(n_H+n_D)=0.15$ and 0.85, $f=7.8$ MHz, $f/f_D=2.5$–3.0 and $\bar{n}_e=7\times 10^{12}\ \text{cm}^{-3}$. Plasma loading for fast magnetosonic wave case (asterisks) with $f=5.6$ MHz and $f/f_D=2$ are also shown (arbitrary unit is used to adjust the vertical axis).

The dependence of plasma loading R_p and the net RF power P_{net} on the input power P_{inp} is studied, as is shown in Fig. 1. Loading resistance is defined as $R=P_{inp}/I^2$, where I is the antenna current. The net RF power absorbed by the plasma is calculated as $P_{net}=P_{inp}\times(R-R_c)/R=P_{inp}\times(R_p/R)$. Here, R, R_p and R_c are total, plasma and vacuum loading resistances, respectively. The R_p value decreases with the increase in P_{inp}, and P_{net} up to 13 kW is obtained with $P_{inp}<50$ kW. The cause of this decrease with P_{inp} is not clear, but plasma parameters near the antenna surface may play an important role (a decrease in the electron density and an increase in the electron temperature near the plasma surface are found). In addition to the former IBW antenna (ref. 6), this trend is also observed by the fast magnetosonic wave;[11] for comparison, plasma loading for the case of this wave[12] is also shown.

The relation between plasma loading R_p and the toroidal field B_t with the fixed frequency $f=7.8$ MHz is studied. A weak dependence of B_t, i.e., $f/f_D=2.5$–4 (f_D: deuteron cyclotron frequency), is found, which is consistent with the results in ref. 6 and in Alcator C,[13] and is also with the fast magnetosonic wave case.[11] It is also found that the dependence of plasma loading on the concentration $n_H/(n_H+n_D)$ is weak (n_H and n_D: hydrogen and deuterium densities, respectively).

Figure 2 shows the dependence of R_p on the mean plasma density $\bar{n}_e$ with $f/f_D=5$. From this, a relatively strong increase in R_p with the increase in $\bar{n}_e$ is found. This feature is the same with that of ref. 6 ($f/f_D=4$), but the threshold of $\bar{n}_e$ (the minimum value of the electron density to have plasma loading)$=(2\text{–}3)\times10^{12}$ cm^{-3} and absolute value of $R_p\sim0.1\ \Omega$ are different from the previous results ($\bar{n}_e=(4\text{–}5)\times10^{12}$ cm^{-3}, $R_p\sim0.05\ \Omega$).

Finally, the relation between R_p and f is studied. As is shown in Fig. 3, a strong dependence of R_p on f with the fixed toroidal field $B_t=3.33$ kG is found, regardless of the harmonic number of f/f_D. This dependence is roughly expressed as $R_p \propto f^{1.7}$, whereas $R_p \propto f^{3.3}$ in the previous fast wave heating experiments in TFR.[14] According to ref. 15 in the limited case of $f\sim2f_D$, the inverse dependence of R_p on f is found. From ray tracing calculations,[10] a ray does not propagate into the plasma due to the strong electron damping when the parallel refractive index n_z is greater than ~100 in the TNT-A device. Uses of Sy's formula and upper limit of $n_z\sim100$ lead to the nearly same dependence of R_p on f with the experimental one. However, the further analysis is needed in order to get the qualitative agreements.

In conclusion, parameter dependence of plasma loading R_p is investigated in the TNT-A tokamak for the ion Bernstein wave. The R_p value increases with $\bar{n}_e$ and f, but it is weakly dependent on B_t and inverse dependent on P_{inp} are found.

This work has been partly suported by a Grant-in-Aid for Scientific Research for the Japanese Ministry of Education.

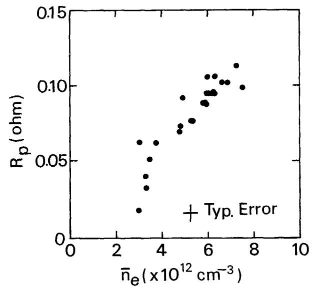

Fig. 2. Dependence of plasma loading R_p on mean plasma density $\bar{n}_e$; $n_H/(n_H+n_D)=0.1$, $f=5.2$ MHz and $f/f_D=5$.

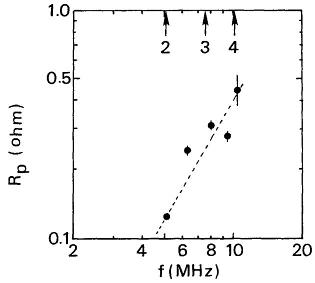

Fig. 3. Dependence of plasma loading R_p vs operating frequency f with $n_H/(n_H+n_D)=0.9$, $B_t=3.33$ kG and $\bar{n}_e=6\times10^{12}$ cm^{-3}. Dotted line shows frequency dependence of $R_p \propto f^{1.7}$, and locations of harmonic number f/f_D of deuteron cyclotron frequency are also shown.

References

1) I. B. Bernstein: Phys. Rev. **109** (1958) 10.
2) M. Ono, T. Watari, R. Ando, J. Fujita, Y. Hirokura *et al.*: Phys. Rev. Lett. **54** (1985) 2339.
3) M. Ono, R. Bell, S. Bernabei, P. Beiersdorfer, A. Cavallo *et al.*: in *Plasma Physics and Controlled Nuclear Fusion Research* (1986) (*Proc. 11th Int. Conf. Kyoto, 1986*) IAEA, Vienna (1987) Vol. 1, p. 477.
4) S. Shinohara, O. Naito, Y. Ueda, H. Toyama and K. Miyamoto: J. Phys. Soc. Jpn. **55** (1986) 2648.
5) M. Porkolab, P. Bonoli, K. I. Chen, C. Fiore, R. Granetz *et al.*: in *Plasma Physics and Controlled Nuclear Fusion Research* (1986) (*Proc. 11th Int. Conf. Kyoto, 1986*) IAEA, Vienna (1987) Vol. 1, p. 509.
6) S. Shinohara, O. Naito and K. Miyamoto: Nucl. Fusion **26** (1986) 1097.
7) K. Toi, S. Itoh, Y. Kawai, N. Hiraki, K. Nakamura *et al.*: in *Plasma Physics and Controlled Nuclear Fusion Research* (1980) (*Proc. 8th Int. Conf. Brussels, 1980*) IAEA, Vienna (1981) Vol. 1, p. 721.
8) S. Shinohara, K. Sakuma, Y. Nagayama and H. Toyama: J. Phys. Soc. Jpn. **52** (1983) 94.
9) O. Naito, S. Shinohara and K. Miyamoto: J. Phys. Soc. Jpn. **56** (1987) 2988.
10) S. Shinohara, O. Naito, K. Ida and K. Miyamoto: Jpn. J. Apply. Phys. **26** (1987) 505.
11) S. Shinohara, N. Asakura, O. Naito and K. Miyamoto: J. Phys. Soc. Jpn. **53** (1984) 1746.
12) Y. Ueda, O. Naito, S. Shinohara, K. Miyamoto and H. Toyama: J. Phys. Soc. Jpn. **55** (1986) 806.
13) Y. Takase, J. D. Moody, C. L. Fiore, F. S. McDermott, M. Porkolab and J. Squire: Phys. Rev. Lett. **59** (1987) 1201.
14) K. Theilhaber and J. Jaquinot: Nucl. Fusion **24** (1984) 541.
15) W. N.-Cy Sy, T. Amano, R. Ando, A. Fukuyama and T. Watari: Nucl. Fusion **25** (1985) 795.