J. Plasma Fusion Res. SERIES, Vol.1 (1998) 219–221

The Recent Experimental Results in the TU-Heliac

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(Received: 30 September 1997/Accepted: 17 January 1998)

Abstract

Alternating axial plasma current effects on heliac plasma equilibrium are reported. This plasma current can rewind a magnetic line of force in the direction of increasing or decreasing rotational transform. These experiments are performed in plasma sustained only by low frequency ($\omega < \omega_{ci}$, ω_{ci}: ion cyclotron frequency) ohmic heating, and a stable plasma can be produced in the magnetic well configuration case. However, in the magnetic hill configuration the plasma current crashes as it increases. Furthermore this crash occurs only when the plasma current flows along the co direction to the toroidal field, of which direction corresponds to the direction of decreasing rotational transform. In this current crash case a low frequency oscillation is also observed in ion saturation current signals. This oscillation strongly depends on the plasma current and the magnetic field strength.

Keywords:

helical axis stellarator, heliac, plasma current, ohmic heating, instability, rotational transform, magnetic well, magnetic hill

1. Introduction

We have studied the low frequency ($\omega < \omega_{ci}$, ω_{ci}: ion cyclotron frequency) ohmic heating plasma production in TOHOKU UNIVERSITY Heliac[1]. This plasma production method is convenient for basic experiments: measurements of magnetic surface structures [2], estimation of the particle confinement time for an electron by breakdown time [3-4] and sustaining a target plasma for an electrode biasing experiment [5]. This method is also convenient for estimating inductive current effects on plasma equilibrium. Studies of axial plasma current effects on plasma equilibrium are important for helical fusion devices. Because if we can not design to minimize a bootstrap current, in a high beta plasma the bootstrap current may cause the rearrangement of an optimum vacuum rotational transform profile. In the present experiment, we forcibly flowed an axial plasma current along the co and counter directions to the toroidal field in a heliac plasma by an induced low frequency electric field in order to change rotational transform angle and evaluate the axial plasma current effects on plasma equilibrium.

2. Experimental Results

The low frequency ohmic heating power (f = 18.8 kHz, P_{max} = 35 kW) is supplied to RF coils which are wound outside toroidal field coils like vertical field coils. The following results are obtained in the plasma at $n_e = 2 \sim 8 \times 10^{11}$ cm^{-3} and $T_e \sim 10$ eV (argon $p \sim 4 \times 10^{-3}$ Pa).

In the standard magnetic well configuration case (vacuum magnetic well depth is 2.3 %, toroidal field $B_t > 0.06$ T) the axial plasma current causes no significant effect. Typical wave form of plasma current obtained from the Rogowski coil is shown in Fig. 1 (a). The alternating plasma current flows symmetrically along the co and counter directions to the toroidal field,

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and has sinusoidal wave forms. Nevertheless in magnetic hill configurations the plasma current crashes with increasing plasma current or decreasing magnetic field strength. Furthermore this crash occurs only when the plasma current flows along the co direction to the toroidal field as shown in Fig. 1 (b). This current direction corresponds to the direction to decrease rotational transform.

In this current crash case the low frequency oscillation (f < 1 kHz) is also observed in triple-Langmuir-probe ion saturation current as shown in Fig. 2 (b) and in floating potential signals. This oscillation strongly depends on the plasma current, the magnetic field strength and the magnetic well depth. This dependence is shown in Figs. 3 (a), (b) in which open, solid circles and triangles denote stable, unstable and marginal shots, and the plasma current I_p is evaluated from the root mean square of the Rogowski coil signal. In the experiment for studying the dependence on the magnetic well depth, we carefully select the magnetic configurations which have the same rotational transform $\iota_0/2\pi = 1.55$ at the magnetic axis using the flexibility of heliac. Figures 3 (a) and (b) clearly show that the plasma current for the marginal shots increases with

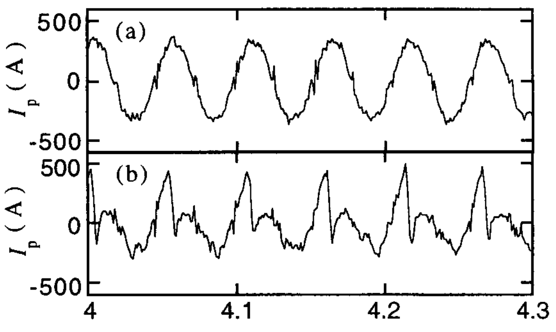

Fig. 1 Typical plasma current wave forms: (a) magnetic well configuration case, toroidal magnetic field B = 0.062 T, RF output power P_{RF} = 34 kW, magnetic well depth 2.3%, (b) magnetic hill configuration case, B = 0.077 T, P_{RF} = 34 kW, magnetic well depth -1.5%.

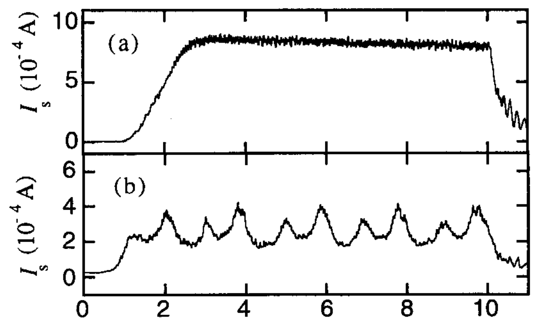

Fig. 2 Typical ion saturation current signals: (a) magnetic well configuration case, toroidal magnetic field B = 0.054 T, RF output power P_{RF} = 15 kW, magnetic well depth 4.1%, (b) magnetic hill configuration case, B = 0.054 T, P_{RF} = 23 kW, magnetic well depth -1.5%.

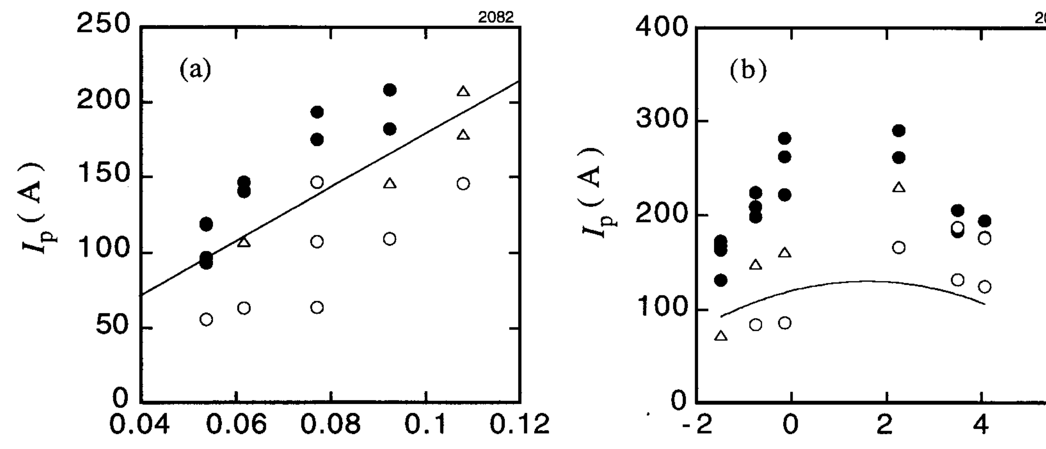

Fig. 3 Dependence of the observed instability on the plasma current, (a) the magnetic field strength and (b) the magnetic well depth. Open, solid circles and triangles denote stable, unstable and marginal shots. In (a) magnetic well depth is -1.5% and in (b) toroidal magnetic field B = 0.054 T. The solid line indicates the calculated plasma current which decreases the rotational transform at the magnetic axis to 3/2, assuming a flat current distribution.

increasing the magnetic field strength and the magnetic well depth. In Figs. 3 (a) and (b) the solid line indicates the calculated plasma current which decreases the rotational transform at the magnetic axis to 3/2, assuming a flat current distribution. The value 3/2 corresponds to the rotational transform for the nearest and the most dangerous rational surface in the TU-Heliac. Figure 3 (a) shows that stable and unstable shots are clearly separated by this line. The critical current is proportional to the magnetic field strength. Hence, this suggests that the change in the rotational transform affects the stability for this magnetic hill configuration. However in Fig. 3 (b) stable and unstable shots are not clearly separated by this line, particularly in the magnetic well region, which may indicate that the criterion of the observed instability is determined by not only rotational transform but other factors, for example, magnetic well depth.

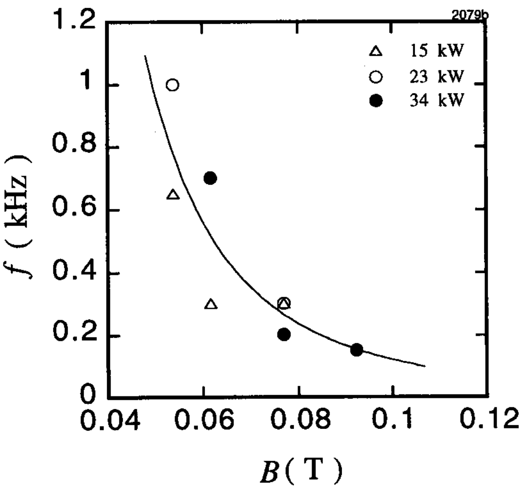

Fig. 4 Dominant frequency of the oscillation which appears in the ion saturation current. Magnetic well depth is −1.5%. Triangles, open and solid circles denote that RF output power P_{RF} = 15, 23 and 34 kW.

Figure 4 shows the dominant frequency of the oscillation which appears in the ion saturation current. This frequency is inversely proportional to about the third power of the toroidal field. Thus this oscillation does not depend on a magnetic tension. It seems that the suppression of this instability depends on the confinement characteristics. However, we have not yet identified the kind of the observed oscillation. The causality between the oscillation and the confinement characteristics is not quite clear. Measurements of the toroidal, poloidal and radial mode number are necessary to clarify what kind of instability has appeared.

3. Summary

We forcibly flowed an axial plasma current along the co and counter directions to the toroidal field in a heliac plasma in order to evaluate the inductive current effects on plasma equilibrium. The plasma current crashes when the plasma current exceeds the critical value which is proportional to the magnetic field strength, and this critical current in the magnetic well configuration case is about 2 times as large as that in the magnetic hill case. This current crash appears only when the current flows along the co direction to the toroidal field, of which direction corresponds to the direction of decreasing rotational transform. Furthermore, in this current crash case the low frequency oscillation appears in ion saturation current signals.

Acknowledgment

We are grateful to Shigeru Inagaki and Norihiko Sasaki for their useful discussions. Thanks are also due to Hajime Sasao, Junichiro Ono and Yasunobu Kawano for assistance with the experiments.

References

[1] S. Kitajima *et al., Proc. 10th Int. Conf. on Stellarator,* EUR-CIEMAT **26**, 16 (1995).

[2] B. D. Blackwell *et al.,* Nucl. Fusion **25**, 1485 (1985).

[3] D. Wróblewski and J. L. Shohet, Phys. Fluids **29**, 1979 (1986).

[4] J. N. Talmadge and D. T. Anderson, Nucl. Fusion **28**, 1879 (1988).

[5] S. Inagaki *et al.,* Jpn. J. Appl. Phys. **36**, 3697 (1997).