CONTROL OF RFP DYNAMICS WITH EXTERNAL HELICAL FIELDS

S.MASAMUNE, M.IIDA, H.UEDA, Y.SUGIMOTO,
T.MURAKAMI, H.SUGIE, K.OHTA, H.OSHIYAMA
Department of Electronics and Information Science,
Kyoto Institute of Technology,
Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan

Abstract

Attempts have been in progress to control dynamics of the reversed field pinch (RFP) plasma by use of external helical fields in the STE-2. In the quasistatic field experiments, it has been found that combined application of different resonant fields causes enhanced mode coupling. Stability analysis has shown that one of the possible mechanisms for the experimentally observed RFP improvement due to external nonresonant fields is the stabilizing effect of the external current layer to external kink mode which grows in the time scale of shell time constant. In the rotating resonant helical field experiments, it appears that toroidal rotation of the asymmetric toroidal flux disturbance is either acceletared or decelerated depending on the rotation direction of the helical field. No significant effect has been observed on the global plasma parameters under the present limited experimental conditions.

1. INTRODUCTION

In the reversed field pinch (RFP), nonlinear interaction between tearing modes plays important roles in MHD relaxation and subsequent RFP dynamo activities. The interaction brings about phase locking between dominant modes, resulting in field line stochastization. Interaction of the modes with external resonant fields is thought to be responsible for the locked modes. These unfavorable nonlinear phenomena are more pronouced when the RFP plasma is surrounded by the resistive shell due to the gowth of resistive shell modes.

Efforts have been in progress to control dynamics of the instabilities by use of external helical fields in the STE-2 which is equipped with resistive shell. Following the quasistatic helical field experiments [1,2], combined application of the different helical fields has demonstrated the importance in the mode coupling of overlap of the externally produced static islands. Stability analysis has revealed the stabilizing effect of the external current layer on external kink modes. Initial results from rotating resonant helical field experiments will also be discussed.

2. MACHINE DESCRIPTION

The STE-2 is a small size RFP machine (R/a=0.4m/0.1m) which uses a 2 mm thick SS chamber with two poloidal gaps. The quasistatic felical field experiments have been performed with a close fitting 0.5 mm thick copper shell [1,2]. The field penetration time of the chamber τ_w is ~0.2 ms, while that of the shell τ_s is ~2 ms. In a typical discharge, plasma current I_p is $\geq$ 60 kA with discharge duration $\tau_d \leq$1 ms. Four kinds of helical coils produce quasistatic helical fields with M/N=1/±8 and 1/±10, where M (N) is the poloidal (toroidal) mode number of the external field. (m and n will be used to designate the mode numbers of the inherent magnetic fluctuations.) The M/N=1/8(1/10) field is (internally) resonant at r/a ~0.4(0.5). Helical fields with negative N have no resonance between the field reversal surface and the shell ((externally) nonresonant). $|B_{ra}|/B_{\theta a}$ will be referred to as perturbation level, where $|B_{ra}|$ is the external perturbation amplitude of either quasistatic or oscillating field and $B_{\theta a}$, the edge poloidal field. $|\tilde{B}_{ra}|/B_{\theta a}$ will be referred to as the radial magnetic fluctuation level, where $|\tilde{B}_{ra}|$ is the amplitude of the radial field fluctuation amplitude at the edge.

The shell has been removed for the rotating resonant (M/N=1/8) helical field experiments. The rotating field is applied by two pairs of helical coils covering a half of the torus together with

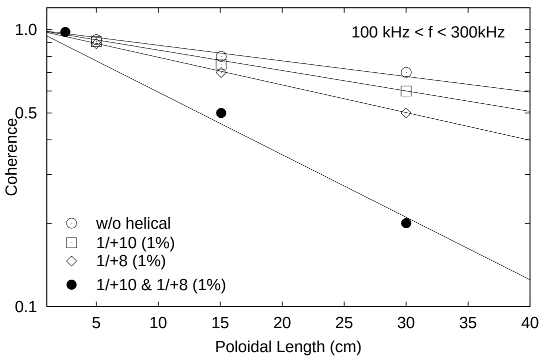

Figure 1: Coherence of the m=1 edge fluctuations vs poloidal length.

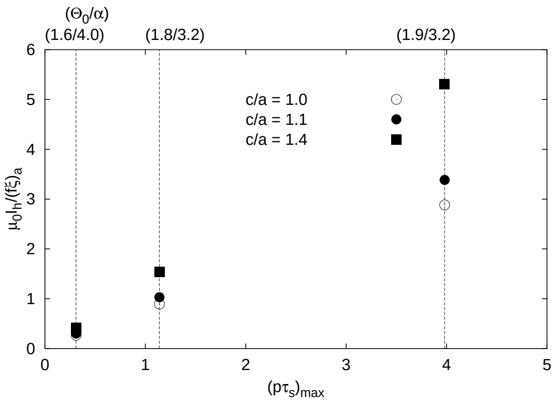

Figure 2: External helical current needed to stabilize the external kink modes.

two alternating current sources with a phase difference of $\pi/2$ with a view to driving toroidal plasma rotation in order to stabilize resistive shell modes (tearing modes). Since we have used LC damping oscillation to obtain the alternating current in the present initial experiment, effective duration of the rotating field is restricted to $\leq$0.4 ms.

3. QUASISTATIC HELICAL FIELD EXPERIMENTS

3.1 Influence of resonant fields

The resonant helical fields have caused deterioration of the RFP plasmas with higher discharge resistance. The deterioration is caused by enhanced coupling of the tearing modes due to overlap of the static and inherent magnetic islands [1,2].

Combined effect of the different helical fields has been studied [4]. Figure 1 shows the coherence of m=1 edge magnetic fluctuations (100 kHz$\leq f \leq$300 kHz) versus poloidal separation length. The coherence γ is related to the spectral width Δk as $\Delta k \propto (1-\gamma)$, which is a measure of the nonlinear mode coupling. The coherence scale length $\Lambda_{||}$ corresponds to the e-folding length of the coherence. When either the 1/8 or 1/10 field is applied separately with 1 % level, $\Lambda_{||}$ descreses only slightly. On the other hand, combined application of these fields has resulted in significant reduction of $\Lambda_{||}$, comparable to the minor radius. It should be compared with the results in ref[2], where 3 % level perturbation was required to observe the same reduction of $\Lambda_{||}$ with 1/10 helical field alone. Combined application of the M/N=1/8 and 1/10 helical fields thus enhances the mode coupling. Analysis of the magnetic island produced by resonant helical field[3] has shown that the combined effect is attributable to sufficient overlap of the static islands. Interaction between static magnetic islands thus plays an important role in mode coupling as well as between static and inherent islands.

3-2. Influence of nonresonant fields

The RFP discharges are slightly improved by the nonresonant helical fields. In these improved discharges, less active conversion of the poloidal magnetic flux into the toroidal flux (RFP dynamo) is implied by the trend of higher pinch parameter Θ ($= B_{\theta a}/ < B_\phi >$, where $< B_\phi >$ is the average toroidal field). Toroidal symmetry of the toroidal flux has been improved significantly, indicating suppression of the m=0 mode coupling [2].

In order to study possible mechanisms for these improvements, we have analyzed stability of the ideal external kink modes in a cylindrical RFP surrounded by a resistive shell at $r=b$ and an external helical current layer at $r=c$ [4]. Assuming the zero Alfvén transit time together with the thin shell approximation, we derived a dispersion relation for the m=1 external kink

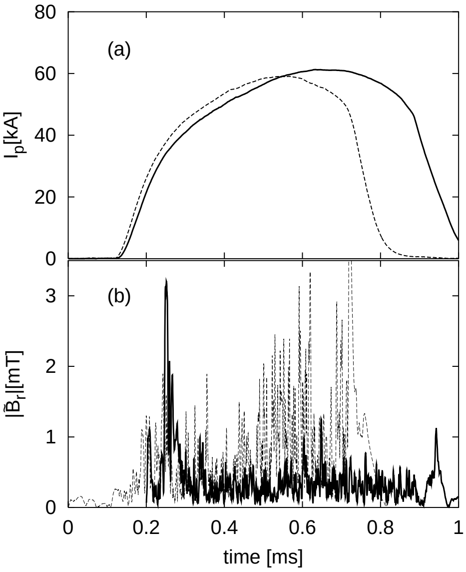

Figure 3: Time evolution of the (a) plasma current and (b) radial magnetic fluctuation level with (bold line) and without (dashed line) the shell.

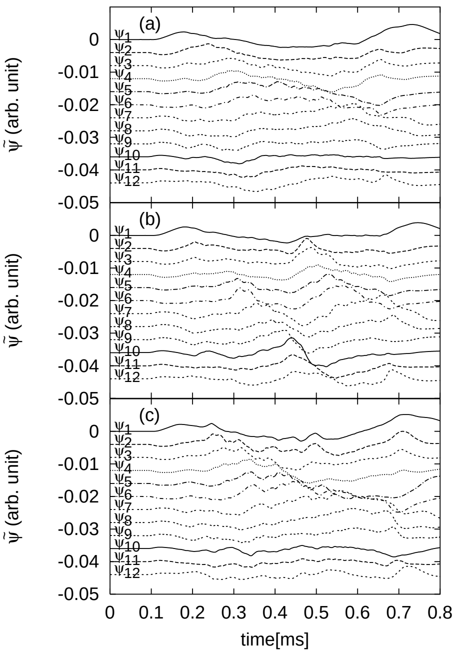

Figure 4: Time evolution of the asymmetric toroidal flux disturbance over a half of the torus, (a) without helical field, (b) with helical field rotating in the CW direction (from top), and (c) with CCW rotating helical field.

modes with normalized growth rate $p\tau_s$. The dispersion relation was then analyzed for the force-free equilibria with $\lambda(=\mu_0\mathbf{j}\cdot\mathbf{B}/B^2)$ characterized by two parameters Θ_0 and α, $\lambda(r) = (2\Theta_0/a)(1-(r/a)^{\alpha})$. Without the helical current, the present analysis gives the results identical to those in ref.[5]; the modes with $-1.2\leq na/R < 0$ are unstable with the maximum growth rate at $na/R \sim -1$, where negative n stands for the external modes. The maximum growth rate $(p\tau_s)_{max}$ is 4.0 for the equilibrium with Θ_0/α=1.9/3.2, 1.1 for 1.8/3.2 and 0.5 for 1.7/3.5, showing the importance of this mode in peaked current profile.

Figure 2 shows the amplitude of the helical current (surface current density amplitude normalized to the edge radial field of the corresponding mode) needed to stabilize the mode with maximum growth rate in the equilibrium specified by Θ_0 and α. Separation of the helical current layer from the plasma surface c/a is chosen as a parameter. The current for stabilization increases with c/a, about $a/2$ separation doubling the required current.

It has thus been shown that one of the possible mechanisms for the experimentally observed improved RFP performance with nonresonant fields is the stabilizing effect of the external helical current on external kink modes. The result has also shown that feed back controlled helical current would be useful for stabilizing the external kink modes.

4. ROTATING HELICAL FIELD EXPERIMENTS

Experiments have started in shell less RFP to drive toroidal plasma rotation by controlling the interaction of the tearing mode with rotating resonant (M/N=1/8) helical field.

Figure 3 shows time behavior of the plasma current and radial magnetic fluctuation level in the RFP with and without the shell. When the shell is removed, reproducibility of the RFP plasmas is degraded, however, plasma current higher than 50 kA can be achieved. The RFP lifetime (τ_{RFP}) has been in the range from 2 to 3 times the chamber time constant, i.e., τ_{RFP} <0.6 ms. Discharge resistance is degraded in the shell less operation; for $I_p \geq$55 kA, the resistance is higher by 30-50 % than that in discharges with shell, while, for $I_p \leq 50$ kA, it is almost the same as in the RFP with shell but deteriorated by the quasistatic resonant field. As shown in Fig.3(b), the average radial magnetic fluctuation level ($f \geq 8$ kHz) is 2-3 times higher than in the RFP with shell. Since the RFP deterioration due to the resonant perturbation in the shell mounted case is attributable to the externally produced magnetic islands as described in the previous section, the results above indicate that the degradation in the shell less RFP is ascribable to the mode coupling enhanced by the higher fluctuation amplitudes in highly resistive boundary

The helical field was applied at 0.3-0.35 ms, after the formation of the RFP configuration at 0.2-0.25 ms. No significant effect on the global PFR parameters has been observed under the present experimental conditions: the perturbation level $|B_{ra}|/B_{\theta a}$ lower than 1 %, oscillation frequency $f \sim 10$ and 15 kHz, and effective duration of $\sim$0.3-0.4 ms.

The M=1 rotating field has no significant effect on the locked mode, a stationary radial field disturbance localized near one of the port holes (and possibly at the poloidal gap also), under the present conditions mentioned above. The radial magnetic fluctuatuion level ($f \geq 8$ kHz) measured inside the chamber has not been influenced significantly either.

Influence of the helical field may be observed in the evolution of the toroidal magnetic flux disturbance. Figure 4 shows time behavior of the asymmetric toroidal magnetic flux disturbance ($f \geq 5$ kHz) over half of the torus with and without the helical field. In standard RFP plasmas without helical field, the disturbance rotates toroidally in the opposite direction to the plasma current (clockwise (CW) from top). When the CW rotating helical field is applied, the rotation velocity of the disturbance appears to be accelerated, as in Fig.4(b). When the helical field rotation is reversed in the counter clockwise (CCW) direction, the disturbance appears to be decelerated, as in Fig.4(c). In this regard, we may note that in the shell mounted case toroidal asymmetry of the toroidal flux perturbation was improved by the quasistatic externally nonresonant helical field [2]. Efforts are to be made to identify the mechanism by which the toroidal flux perturbation (m=0 structure) is influenced by the M=1 external helical field. Further experiments are in progress to search for the conditions under which the rotating helical field has some effects on the dynamics of the m=1 modes.

5. SUMMARY AND CONCLUSION

We have obtained the new results from the helical field experiments in the STE-2. In the quasistatic field experiments, overlap of the static islands produced by expernal perturbations plays an important role in the nonlinear mode coupling. External helical current has a stabilizing effect on external kink mode which grows in the time scale of shell time constant. Initial results from the rotating resonant helical field experiments have shown that the dynamics of the toroidal flux (m=0) is influenced by the rotating field. Further efforts are in progress to search for the conditions under which n=1 mode dynamics is influenced by the rotating helical field.

The present results have revealed that external helical field is promising as a means for controlling the RFP dynamics.

REFERENCES

[1] MASAMUNE,S., IIDA,M., ODA,N., et al., Fusion Energy 1996, IAEA Vienna (1997) **2**, 201.
[2] MASAMUNE,S., IIDA,M., OHFUJI,Y., et al., Plasma Phys. Control. Fusion **40** (1998) 127.
[3] MASAMUNE,S., IIDA,M., OHTA,K., OSHIYAMA,H., J. Phys. Soc. Jpn. **67** (1998) 2977.
[4] MASAMUNE,S., IIDA,M., et al., IAE-RR-98 054 (Proc. Int. Symp. on Plasma Dynamics in Complex Electromagnetic Fields) Inst. Advanced Energy, Kyoto Univ. (1998) 121.
[5] HENDER,T.C., GIMBLETT,C.G., ROBINSON,D.C., Nucl. Fusion **29**, 1279 (1989).