*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-4.067 (2008)*

Effects of lowering aspect ratio on magnetic fluctuations in RFP

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The reversed field pinch (RFP) is one of the magnetic confinement concept for compact high-beta plasmas. The quasi-single helicity (QSH) RFP state is a candidate for confinement improvement where the single dominant tearing mode grows significantly larger than the remaining modes and the associated large magnetic island is immersed in otherwise stochastic core region[1, 2]. Within the large magnetic island of the dominant mode, favorable confinement has been realized. Recent equilibrium analysis have shown that by lowering the aspect ratio (A), mode rational surfaces are less densely spaced in the core region in the RFP. Therefore, the low-A RFP may expand the region to which the dominant single island can grow without interacting the neighboring islands and bring about simpler MHD dynamics.

To explore the above-mentioned attractive low-A regime in RFP, we have been promoting a research program on RELAX (REversed field pinch of Low Aspect ratio eXperiment)[3]. RELAX is the low-A RFP machine, which has the world's lowest aspect ratio of 2 (R = 0.5 m/a = 0.25 m) and uses 4-mm thick SS vacuum vessel with a field penetration time of $\sim$1.5 ms. It is operated without any other shell structure, and therefore, the vacuum vessel acts as a resistive shell.

The RELAX is equipped with two toroidal arrays of 14 pick-up coils (top and bottom), which are equally spaced in the toroidal direction except at the two poloidal gaps and a poloidal array of 6 pick-up coils at one toroidal location. These coils are located just inside the inner surface of the vacuum vessel. There also has a radial array of coils inserted from top to r/a = 0.6 location to measure the radial profile of fields in the outer region. The pick-up coils signals are sampled at a frequency of 2 MHz and numerically integrated. We use f > 2 kHz component of them as the magnetic fluctuation.

Figure 1 shows typical time traces of the plasma current I_{p}, loop voltage V_{loop}, edge toroidal field B_{tw} and average toroidal field $< B_{\mathrm{t}} >$. The operational regime of RFP discharge paraneters to date are as follows: the maximum plasma current of 40-60 kA, discharge resistanse $V_{\mathrm{loop}}/I_{\mathrm{p}}$ of 1 - 3 mOhm, and discharge duration of about 1.5 - 2.5 ms. The regime of Θ and F values are as folows: Θ from 1.5 to about 3, and F from $\sim$0 to -1.5. The discharge regime has been extended to higher Θ and deeper reversal regime when compared with those of medium- and high-A RFP experiments, which might imply less active dynamo action in the low-A RFP.

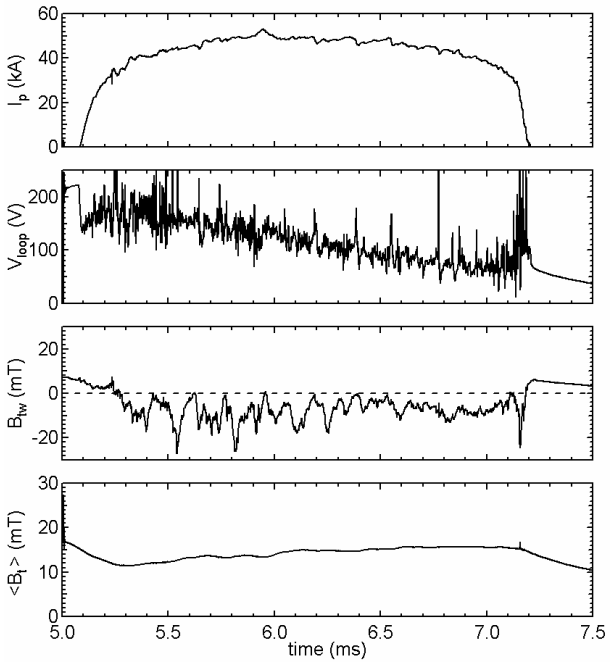

Figure 1: Typical time traces of the plasma current I_p, loop voltage V_{loop}, edge toroidal field B_{tw} and average toroidal field $< B_t >$ in flat-topped RELAX discharge.

Equilibrium configurations in RELAX have been studied with the help of an equilibrium reconstruction code RELAXFIT, which was modified from the MSTFIT code to extend the applicability of the code to low-A equilibrium regime. So far, in RELAX, experimental constraints for the reconstruction are magnetic profiles in the outer region of the plasma ($0.6 < r/a < 1$) measured with above-mentioned diagnostic system. Figure 3 shows the typical radial profile of the safety factor q of RELAX RFP plasma calculated from the reconstructed field profiles. The radial coordinate is the average radius of the corresponding magnetic surface. Since the core value of q is higher than 1/3, $m = 1/\ n = 3,4,5$ modes are important as the internally resonant tearing modes. This is in agreement with the behavior of the edge magnetic fluctuations. The lowering A changes the toroidal mode number of $m = 1$ modes carrying significant portion of the edge magnetic fluctuation power as a result of the change in q profile depending on the A.

We have studied the behavior of the edge magnetic fluctuations in RELAX over a wide range of discharge conditions. As one of the main features, in most round-topped discharges, we have observed quasi-periodic growth and succeeding decay of a single helical mode[5]. During the growth of the mode, the phase of it does not change much, whereas the phase changes rapidly during the decay phase. In most cases, toroidal mode number of the growing mode is 4, twice of the A. When the dominant mode grows, the spectral index N_s becomes lower than 2, which means the magnetic energy of the dominant mode equaling the total energy of the remaining

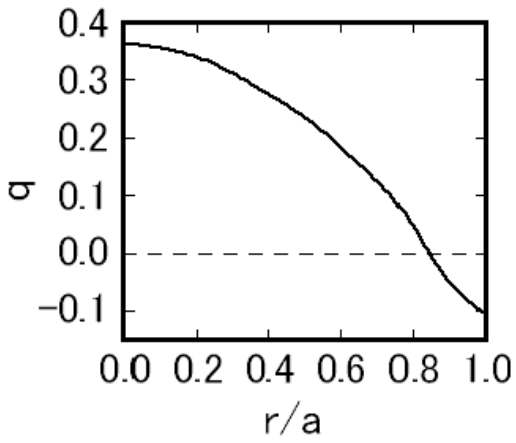

Figure 2: A typical *q* profile of RELAX RFP plasma measured with the help of an equilibrium reconstruction code RELAXFIT.

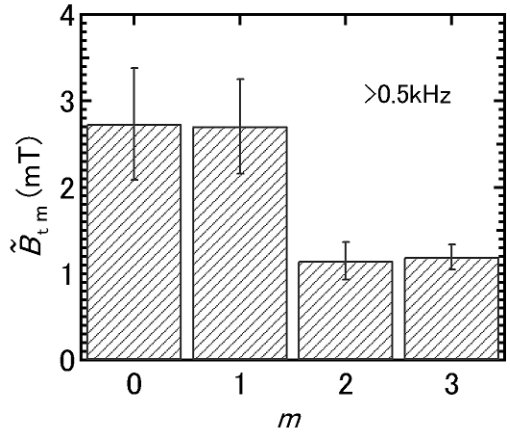

Figure 3: Poloidal mode spectrum of RELAX

modes and the resultant toroidal mode spectrum has the characteristic of the QSH RFP state with a lower dominant toroidal mode number than in other RFPs.

Another feature is that the relative amplitude of m = 2,3 modes are higher than in medium- or high-A RFPs, as is shown in Fig.3. Nonlinear coupling between the dominant m = 1 modes have been considered to be the origin of m = 2 mode. We have estimated the role of nonlinear coupling of the dominant m = 1 modes in exciting the higher modes by using the technique of bi-spectral analysis.

Figure 4 shows the results of bi-coherence spectrum obtained in RELAX plasmas. The bi-coherence spectrum obtained from the edge toroidal field fluctuations shows that the bicoherence between two m = 1 modes is about 0.03, indicating that the coupling of m = 1 tearing

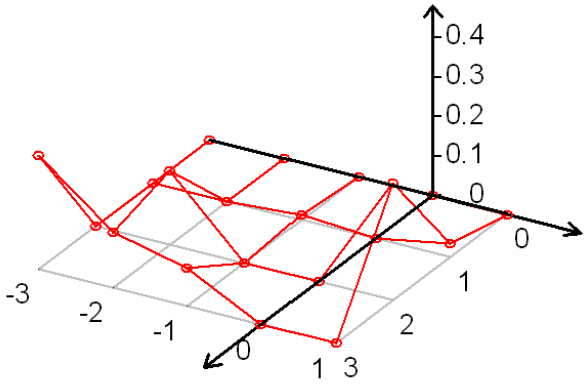

Figure 4: Bi-coherence spectrum of edge toroidal magnetic fluctuations in RELAX.

fluctuations to *m*=2 component is rather weak. The bi-coherence spectrum in Fig.4 should be compared with the spectrum from MST RFP plasmas[6], where the bi-coehence was 0.35, much higher than in the present result. It is clear that the mode coupling is weaker in RELAX than in MST, whose aspect ratio is 3. It may also indicate that nonlinear coupling is not the major cause of the *m* = 2 modes in RELAX. It should be noted that this results of the bi-coherence may be an indication of less densely spaced mode rational surfaces in the core region in low-*A* RFP configuration. One of the possible cause of relatively large amplitudes of higher *m* modes is a toroidal effect, which are under investigation.

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