Plasma Rotation and Wall effects on Resistive Wall Mode in JT-60U

M. Takechi, G. Matsunaga, T. Ozeki, N. Aiba, G. Kurita, A. Isayama, Y. Koide,
Y. Sakamoto, T. Fujita Y. Kamada and the JT-60 team

Japan Atomic Energy Agency, Naka, Ibaraki-ken, 311-0193 Japan

e-mail contact of main author: takechi.manabu@jaea.go.jp

Abstract. This paper reports the exploration of the RWM onset using co-, near zero, counter plasma rotation profiles in JT60U. This is the first experimental result which demonstrates the dependence of critical RWM onset of plasma rotation and beta on initial plasma rotation with the variation of the angular momentum input and without magnetic braking. In the JT60U with newly ferretic wall installed, it is possible to produce high beta plasma tightly coupled with the wall (b/a≈1.2) above $\beta_N > \beta_{N.no\text{-}wall\ limit}$. In near-zero plasma rotation, the RWM started to grow at $\beta_N \approx \beta_{N.no\text{-}wall\ limit}$ and with finite plasma rotation, the plasma pressure survives up to much higher β_N level than that with small rotation. The observed critical beta onset β_c and the RWM growth rate γ_{RWM} are discussed along with theoretical predictions using experimentally observed q-, pressure-, and rotation profiles.

1. Introduction

To realize the economical fusion reactor the stabilization of the low n kink-ballooning mode is necessary because the critical beta of the mode is low for the steady state plasma with high bootstrap current fraction. Kink-ballooning mode can be stabilized by conducting wall. However the stabilized mode, so called RWM, has the slow growth time equivalent to the time constant of the wall. The RWM can be suppressed by the plasma rotation and the active magnetic feedback control. The suppression of RWM by the active feedback control is successfully performed in DIII-D plasmas with large plasma rotation [1]. However, it is considered that the reactor such as ITER rotates hardly at all. Therefore, it is very important to know the characteristics of RWM in the plasma with fairly small rotation. The experiments for RWM physics are performed in the several initial rotation.

1. Installation of Rerritic Steeel Tiles and Its Effects on RWM experiment.

Ferritic steel tiles (FSTs) are installed inside the JT-60U vacuum vessel to reduce the toroidal field ripple. The FSTs are set in the low-field-side (LFS) above the outer baffle plates under the TF coils in place of graphite tiles and cover ~10% of the vacuum vessel surface. Before installing ferritic steal tiles, a few large plasmas reached to ideal beta limit, however it is difficult to exceed it due to lack of NB power. Monte-Carlo simulations considering fully 3-D magnetic field structure using the F3D OFMC code indicate that total absorbed power increases by ~ 30% at $B_T < 2$ T for the large volume configuration close to the wall, which had so far suffered from the large toroidal field ripple. Thanks to increase of NBs deposition power, We successfullly achieved high β_N~4.2 exceeding ideal limit at l_i<1.2 and

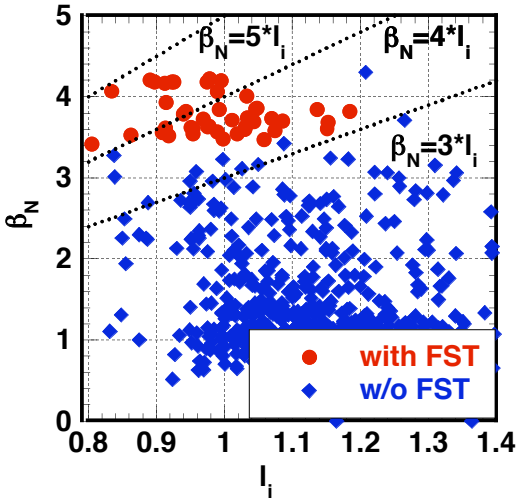

Fig. 1 Achieved β_N as a function of l_i redcircle and blue diamonds show the data with and without FSTs

V_p>70m3 (β_N~3.4 w/o FST) Increase net power of ~3.5 MW corresponding to 2 tangential beams. It means we can change rotation by one-way tangential NB injection for high beta plasmas.

2. Hicg Beta RWM Experiment and stability

Previous RWM experiment was performed on reversed shear plasmas [2]. To increase the achieved beta, we employ the weak shear plasmas. The experiment for RWM is mainly performed on the plasma with the clearance between plasma surface and first wall at low field mid-plane of 20cm, which is equivalent to the ratio of diameter of first wall to plasma of ~1.2 (fig. 2). The PNB of ~20 MW and the NNB of ~3MW are injected simultaneously into the plasma of Ip=0.9MA/ and Bt= 1.58T. The plasma has ITB at r/a<~0.4 and good pedestal after H mode transition. JT-60U has the NBIs with various directions, such as two co tangential, two counter tangential and seven perpendicular positive NBIs (PNBI). In JT-60U, the net NBI power increases for the large volume plasma due to reduction of ripple loss of energetic particles after installation of ferric steel tiles as the first wall. Therefore, we can perform the high beta (β_N>3.5) experiment without some tangential PNBs in order to change the plasma rotation as shown in Fig. 3. Achived beta is ristricted by the m=1 MHD instability. For the co-rotation case, the mode is stabilized for ~120ms and increases as slowly as that for the ctr-rotation (Fig. 4 (a)). On the other hand, for the case of small rotation, the mode is stabilized only for 40ms and increases with relatively fast growth time of τ~10ms (Fig. 4 (b)). The mode onset is decided by coherence between two probes. Fig. 5 shows the dependence of the ratio of critical (highest) β_N and β_N at mode onset on plasma rotation at r/a=0.3. Larger rotation stabilize the mode for more excessive β_N of mode onset. Before collapse at β_N~3.6 n=1 MHD mode starts to emerge from t~6.5s because the coherence between two Mirnov coils separated ~40 degree in the toroidal

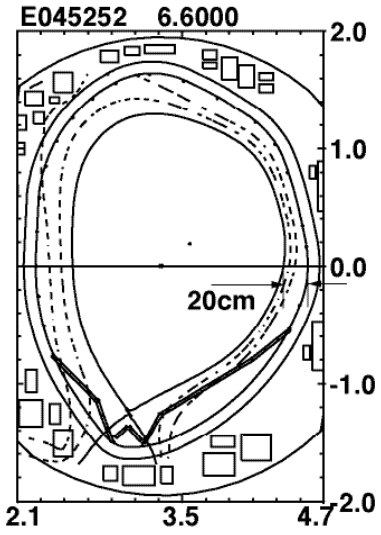

Fig. 2 Poloidal cross-section of the plasma for RWM experiment.

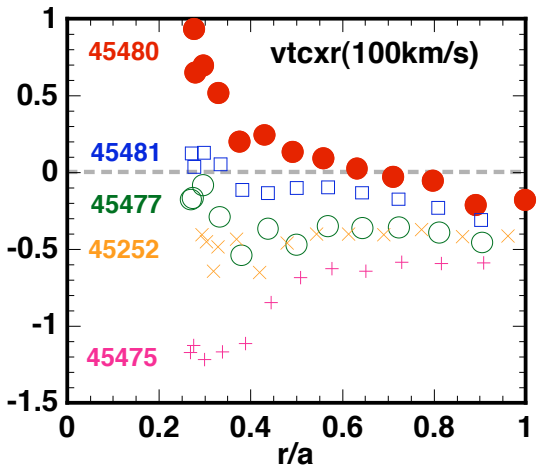

Fig. 3 Toroidal rotation scan for RWM experiment by changing combination of tangential NBIs.

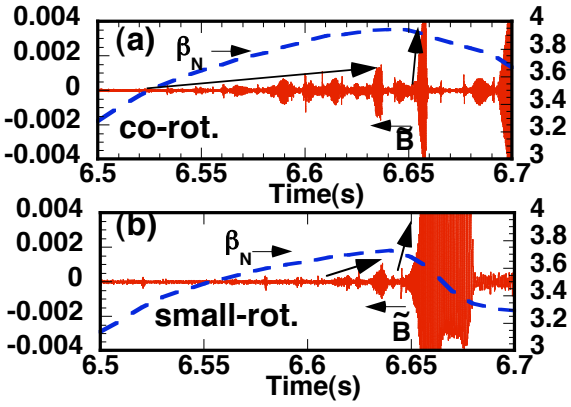

Fig. 4 Temporal evolution of β_N and $\tilde{B}$. for co-direction of E45480 (a) and no-rotation of E45481 (b).

direction suddenly increase and reach to ~1 at this time (Fig. 6 (a)). The main poloidal mode number from magnetic probes is m=3. The mode is observed by ECE at least from r/a~0.1 to 0.8. Therefore the mode is not localized mode. The mode has a balloning structure. The mode amplitude increases with slow growth time of τ~20ms and then rapidly increases with fast growth time of τ~2ms (Fig. 6 (a,b)). The toroidal rotation around r/a<0.4 in the ITB region decrease after the slow growth mode appeared (Fig. 6 (c)). The rotation at r/a>0.4 does not change (Fig. 6 (d)). This change of rotation indicate that RWM is coupled with rotation at r/a<0.4. The MHD instability is investigated by MARG2D code. The kink-balooning mode is unstable without first wall. The dominate poloidal component is m=1 as shown in Fig. 7. This mode structure is consistent with interaction of RWM and rotation observed experimentally. This mode is infernal mode and and critical beta deacrease in the region qmin<1.1 as shown in Fig.8. The experimental minimum q for high beta case is q_{min}~1.08. This mode is stabilised by the wall and ideal wall limit reachs β_N~3.9 for the plasma at d/a=1.2. The critical beta is also affected by the peripheral plasma current. We perform the small current rump down before NB injection to sclape the peripheral current. By this procedure, we achived highest beta β_N~4.2.

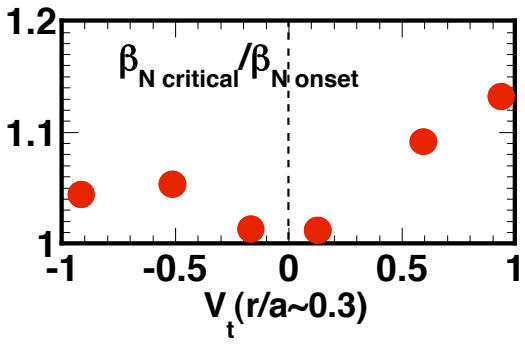

Fig. 5 Dependence of the ratio of critical (highest) β_N and β_N at mode onset on plasma rotation at r/a=0.3. Larger rotation stabilize the mode for more excessive beta of mode onset.

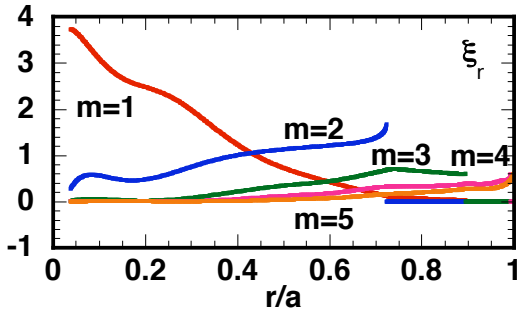

Fig. 7 Displacement of the MHD instability calculated by MARG2D code

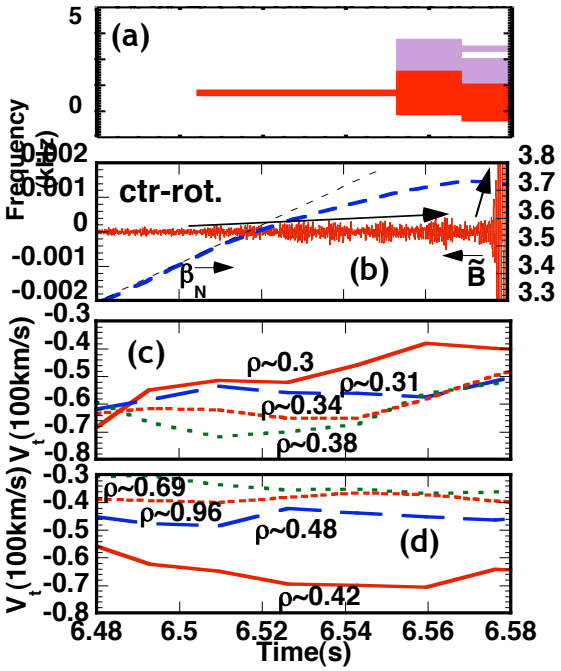

Fig. 6 Temporal evolution of high coherence region (a) β_N and B (b), toroidal rotation at 0.3< r/a <0.4 around ITB (c) and r/a>0.4 (d) for ctr-rotation of E45252. Vt around ITB decrease after slow RWM appearance.

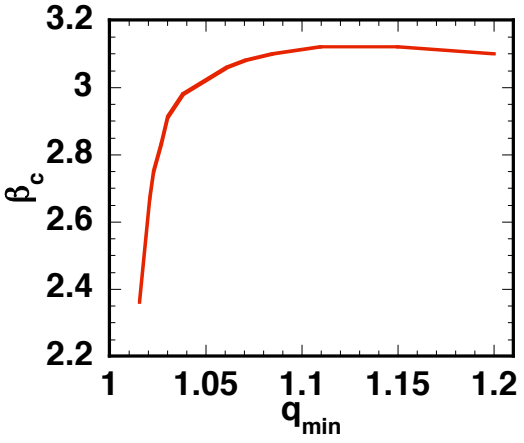

Fig. 8 Criticcl beta as a function of q_{min}

3. High qmin RWM Experiment and critical rotation

This infernal mode is strongly affected qmin. Therefore we increase the qmin around 1.5 to investigate the critical rotation. β_N is kept conarnt and change the tangential NB from ctr-NB to co-NB. In the case of $\beta_N > \beta_{c\ \text{no-wall}}$ the plasma disrupted or collapsed. In the case of no change of tangential NB, no disruption or colapse occured as shown in Fig. 10. To investigate the effect of beta on critial critical rotation, we change the constant β_N. The critical rotation is ~10kHz and it is correspoding to Vt/VA~0.002. This value is much smaller than the previous results of DIII-D and JET. It is important that the critical rotation does not change by changing beta value.

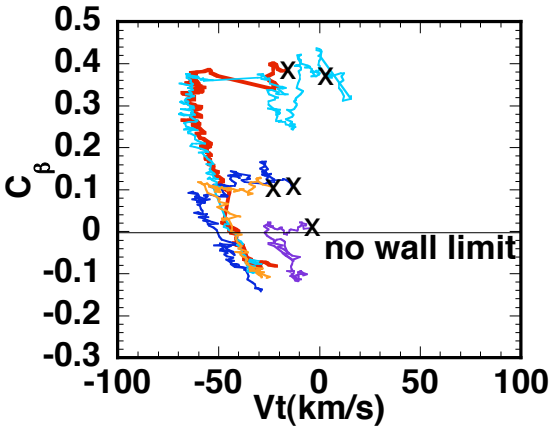

Fig. 11 trajectory of Vt and C_β

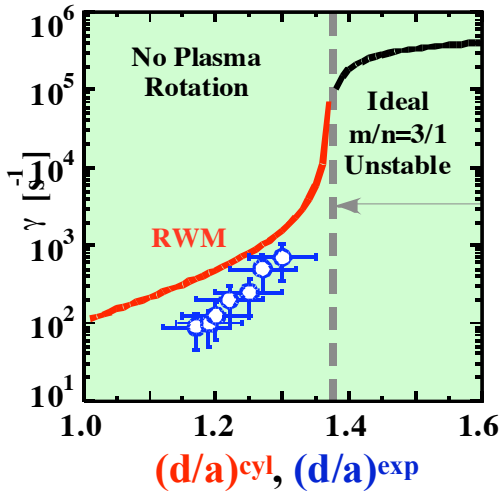

Fig. 12 Dependence of RWM growth rate on d/a, where d and a are diameters of first wall and plasma respectively

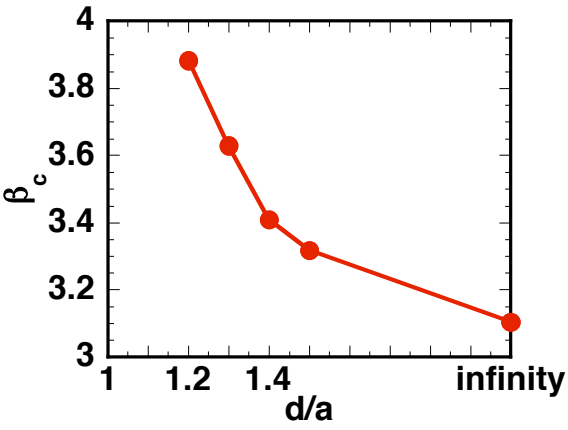

Fig. 9 Criticcl beta as a function of d/a.

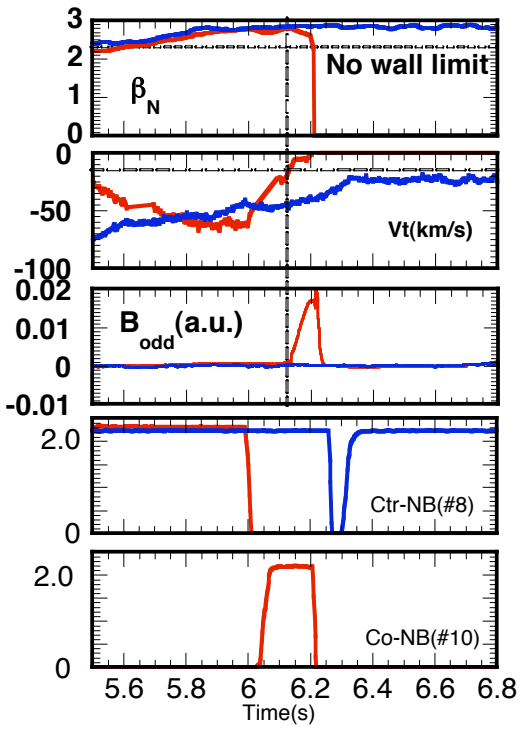

Fig. 10 Waveforms for critical rotation experiment.

4. The effect of first wall on RWM stability.

To clarify the wall effect on RWM, we investigated in the JT-60U OH plasma with slightly low beta. The RWM is induced from m/n=3/1 kink mode. The growth rate increase as the plasma is shifted far from first wall. The experimentally obtained growth rate suits

to the value calculated with finn's analytical solution as shown in Fig. 12.

References

[1] M. Okabayashi, et al., Nucl. Fusion **45** (2005) 1715-1731
[2] S. Takeji,et al., J. Plasma Fusion Res. Vol.78, No.5 (2002) 447-454
[3] J. M. Finn et. al, Phys. Plasmas **2** 198 (1995)