*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.141 (2006)*

Self-organization and dynamo responses in the RFP plasma

M. Watanabe[1+], H.Tozuka[2], N. Misono[2], Y. Osanai[3], S. Shiina[4] and K. Saito[1]

[1] *Institute of quantum science, Nihon University, JAPAN*
1-8-14 Chiyoda-ku, Kanada-Surugadai, Tokyo 101-8308, Japan
[2] *Department of physics, Nihon University, JAPAN*
[3]*Faculty of engineering, Nippon Institute of Technology, JAPAN*
[4]*National Institute of Advanced Industrial Science and Technology (AIST), JAPAN*
[*]E-mail: <m_watanabe@phys.cst.nihon-u.ac.jp>

1. Introduction and Experimental Set-up

There are many interesting phenomena with MHD relaxation in the reversed field pinch (RFP) plasma [1], e.g. a self-generation of the magnetic field, an anomalous plasma resistance, a strong ion heating, etc. Almost all these phenomenon are caused by dynamo activity with the MHD relaxation. The RFP plasma is one of the toroidal current carrying systems for the nuclear fusion research and its configuration self-organized by dynamo effect. The characteristics of the RFP configuration are the positive toroidal magnetic field in the plasma central region and the reversal of that on the plasma edge. In a general, the toroidal current carrying system, a toroidal loop voltage drives the toroidal plasma current. In the RFP plasma, the poloidal plasma current, which is not driven inductively, is also important for the formation of the RFP configuration. The poloidal plasma current is driven by the dynamo electric field with the plasma fluctuations. The self-generated poloidal plasma current modifies its own magnetic configuration. The reversal of the toroidal magnetic field makes RFP plasma a high magnetic shear. However, the magnetic field lines become stochastic because there are many rational surfaces inside the RFP plasma. Although the dynamo activity is an essential role in the RFP plasma formation and sustainment, the dynamo is deep connected with the plasma fluctuation and the fluctuation is the origin of the serious losses of the particle and energy.

We describe here experimental results of the response time of the dynamo activity in the RFP plasma. To investigate how quick will be the response time of the dynamo activity, the fast oscillating toroidal electric field is applied during the standard RFP discharge. These experimental studies were performed on the ATRAS RFP plasma at the Nihon University. ATRAS is a middle size RFP device with major and minor radii of R=0.5 m and a=0.09 m, respectively. In this research, the typical parameters of ATARS RFP plasma are plasma current of 50kA, pinch parameter of 2.1, reversal parameter of -0.5, and discharge duration time of approximately 1.4ms. There are two ohmic heating coils (OH1+OH2) in ATRAS device. The OH1 is the circuit for the standard RFP discharge and the OH2 is for the additional ohmic heating. The OH2 can operate independently of the OH1 circuit and can oscillate the toroidal loop voltage quickly during the RFP discharge. Figure 1 shows the typical waveform of the toroidal loop voltage in a vacuum discharge with (red and blue lines) and without (black line) the OH2 circuit, respectively. The period of the OH2 circuit is variable by the change of the condenser bank (0.4-4.0mF) and the shortest period is approximately 250μs [2].

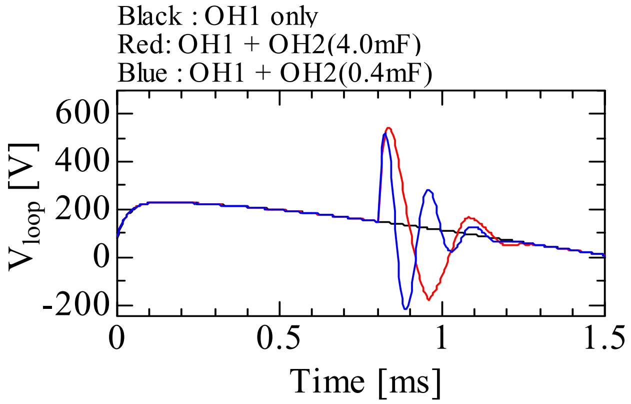

Fig.1: Time development of the toroidal loop voltage with and without the OH2 circuit.

2. Experimental Results

The standard RFP configuration was set up initially and the OH2 circuit oscillates the toroidal loop voltage. Figure 2 shows the typical waveform of the RFP discharge with and without the oscillating toroidal loop voltage, the toroidal plasma current I_p, the toroidal loop voltage V_{loop}, the averaged toroidal magnetic field $<B_t>$, the toroidal magnetic field at the plasma edge B_{tw} and Θ/(1-*F*), respectively. The *F* and *Θ* is the reversal and pinch parameters. The Θ/(1-F) indicates the index of the generation of the toroidal magnetic field by the toroidal plasma current. This value is almost constant in the standard RFP plasma. The oscillating toroidal loop voltage drives

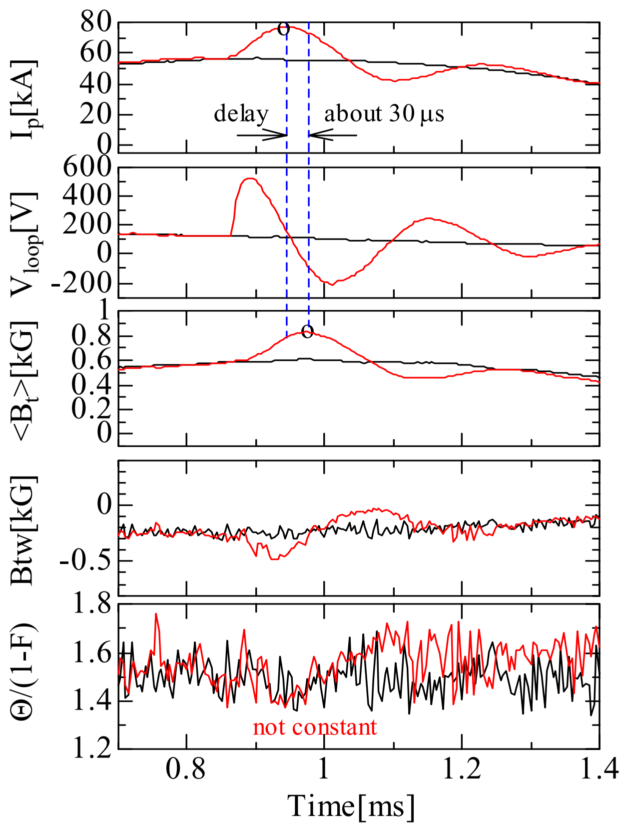

Fig.2: Time evolution of the RFP discharge with (red lines) and without (black lines) the oscillating of the toroidal electric field.

the oscillating toroidal plasma current. The half period of the toroidal plasma current is about 150μs. We can see that the other plasma parameters are also changed under the influence of the oscillation of the toroidal plasma current. One of the interesting responses was the oscillation of the averaged toroidal magnetic field. The oscillating toroidal plasma current oscillates the averaged toroidal magnetic field through the dynamo activity. It is obvious there is phase difference between the oscillating toroidal plasma current and oscillating averaged toroidal magnetic field. The time lag between the peak times of the toroidal plasma current and the averaged toroidal magnetic field is about 30μs.

The toroidal asymmetry of the toroidal magnetic field generation and their rotations were observed in many RFP experiments. Figure 3 show the time evolution of (a) the toroidal plasma current, I_p and the averaged toroidal magnetic field, $\langle B_t \rangle$, which is the spatial average of the toroidal 4 measuring positions (the intervals of an angle of 90 degrees). Figure 3(b) shows the averaged toroidal magnetic fields at the each different position, $\langle B_t \rangle_0 \sim \langle B_t \rangle_{270}$. We can see that the peak times of the each averaged toroidal magnetic fields are difference and it propagates to the toroidal direction. The direction of this toroidal rotation is the opposite to the plasma current and the rotating velocity is approximately 10km/s. The generation of the toroidal magnetic field with the dynamo activity is different at the each position. One of the averaged toroidal magnetic fields at the angle of 270 degrees, $\langle Bt \rangle_{270}$ (red line) is the just decrease phase at the time of the applying of the oscillation (t=0.775ms). On the other hand, $\langle Bt \rangle_{90}$ (green line) is the just increase phase at this time. The time delay of the dynamo response depends on this toroidal asymmetry of the generation of the toroidal magnetic field.

Figure 4 shows dependence of the frequency of the toroidal plasma current oscillation upon the delay time of the dynamo response. The plots of the t_{peaks} indicate the time lag between the peak times of plasma current and the averaged toroidal magnetic field. The plots of the t_{delay} indicate the time lag between the rising times of plasma current and the averaged toroidal magnetic field. We can see that the

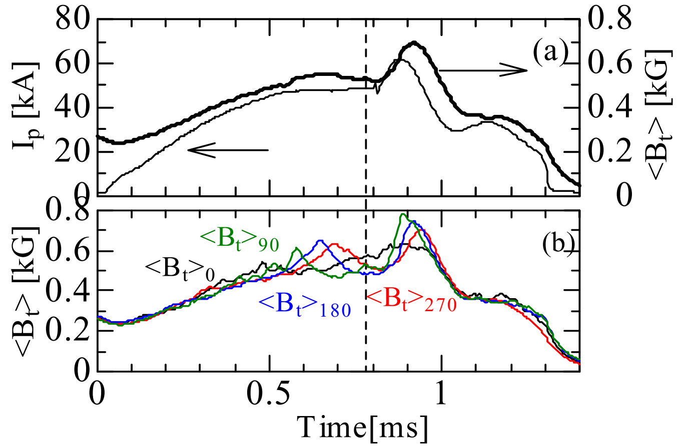

Fig.3: (a) Time evolution of the toroidal plasma current and averaged toroidal magnetic field.
(b) The averaged toroidal magnetic fields at the different positions of the intervals of the 90-degree to the toroidal direction.

t_{peaks} decreases with the frequency. However the t_{delay} is almost constant of 27μs. This result indicates that the delay of the dynamo response in the RFP plasma is related with the toroidal distribution of the dynamo activity.

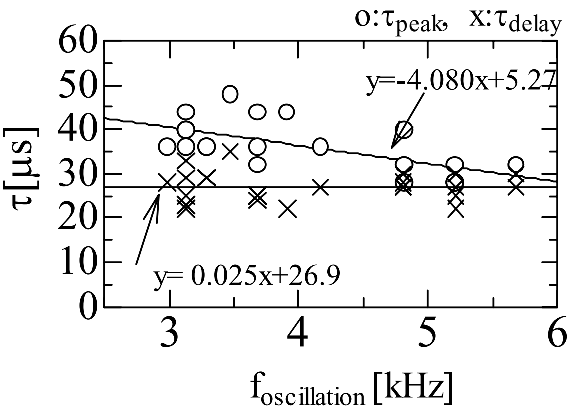

Fig.4: The dependence of the frequency of the oscillation of the toroidal plasma current on the delay times of the dynamo response.

3. Discussions and Conclusion

To investigate the response time of the dynamo activity, the fast oscillating toroidal loop voltage was applied during the standard RFP discharge. In this experiment, the oscillating toroidal plasma current drives the toroidal magnetic field through the dynamo activity. During the oscillation, the phase difference between the toroidal plasma current and the averaged toroidal magnetic field occurs and its time lag between them was about 30μs. This result implies that there is a characteristic time of the dynamo activity and the rising time of the toroidal plasma current will be faster than the global scale of the dynamo response time. Consequently, the Θ/(1-F) value is not constant during the oscillation of the toroidal plasma current. In rough estimate, the resistive diffusion time and the Alfven transit times are about 600μs and 30μs. The relaxation time estimated by the Petschek model is about 140μs. In our experiment, the dynamo response time of the RFP dynamo might be connected with the Alfven transit time. The toroidal asymmetry of the toroidal magnetic field generation occurs in many RFP experiment. This toroidal asymmetry propagates to the toroidal direction. The toroidal asymmetry will be essential for the dynamo quick response. The occurrence of the delay time of the dynamo response depends on this asymmetry and the Alfven transit time.

[1] S.C.Prager, PPCF 34, 1895 (1992).
[2] M.Watanabe, *et al.*, in the CDROM at 31st EPS conference.