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Multi Probe Measurement of Fluctuating Magnetic Field in TPE-2M

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Introduction:

One of the purposes of our TPE-2M [1,2] experiment is to examine the ability of divertor effect and the performance of RFP (Reversed Field Pinch [3]) plasma with divertor. However, the magnetic fluctuation, which will affects the confinement performance of plasma, is observed in some operating conditions. As the confinement of RFP plasma is greatly influenced by the fluctuation property of the confining magnetic field, the time dependences of magnetic fluctuation is measured. The data show that the magnetic fluctuation is excited at the toroidal insulation gap of the plasma stabilizing shell when the plasma current starts, and then it propagates to both sides along the inner surface of the shell. The propagation phenomena of the magnetic fluctuation at plasma start-up phase are similar both for RFP plasma and for paramagnetic plasma. However the property of magnetic fluctuation changes after the RFP configuration is established.

System description and measurement system:

TPE-2M [1,2] is a small RFP type experimental device with major/minor radii = 0.87m/0.27m respectively. To achieve the small ratio of plasma-shell proximity (=1.05), the shell is located inside of the vacuum chamber. Another characteristic is that the device has a poloidal divertor system. However the partly open shell structure destabilizes the confinement property of plasma, which might show the different nature of fluctuation. The experimental result so far shows that the global MHD characteristics of RFP plasma with divertor are similar to those of without divertor [4,5].

The 90 miniature sized magnetic probes for the toroidal magnetic field (Bt) are distributed top and bottom sides of inner surface of the shell around the torus in order to measure the high frequency magnetic field of the plasma fluctuation. As the stabilizing shell is set inside of the vacuum chamber, these probes are designed to endure against the heat flux, besides consideration for the use in the vacuum condition. They are covered by 0.3mm thick molybdenum box. The response time of magnetic probe is 6.4×10^{-6} sec, and the penetration time of molybdenum box is 9.1×10^{-6} sec.

Experimental result:

The toroidal distribution and time resolution of Bt are measured simultaneously with the multi-channel magnetic probes. Figure 1 shows the toroidal distribution of Bt for RFP plasma. The angle in the figure shows the toroidal angle, and the 0 degree point is the toroidal insulation gap. The radial length is proportional to the magnitude of magnetic field. Each line in the figure is the Bt fluctuation at the different times of 0.1, 0.3 and 0.6 ms after the plasma sets up. It can be seen from the figure that some special modes of magnetic

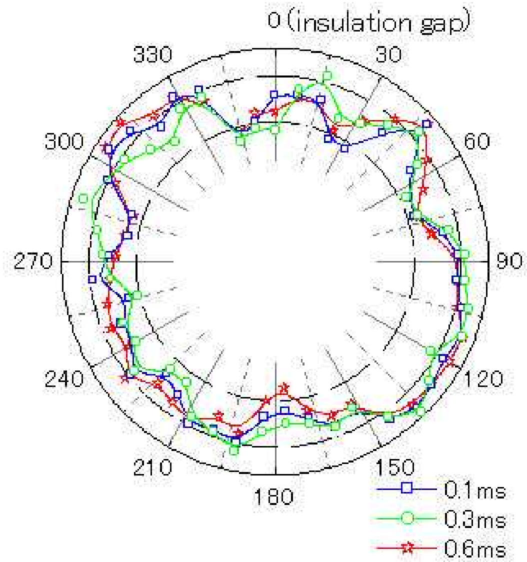

Fig.1 Toroidal Distribution of Bt

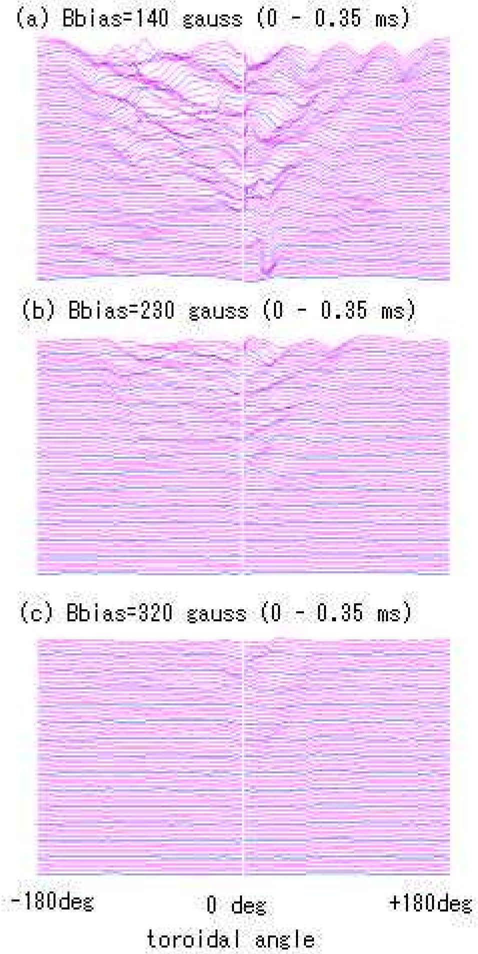

Fig.2 Fluctuation of Bt at Plasma Start-up Phase

fluctuation are excited and propagate in the toroidal direction.

To investigate the origin of magnetic fluctuation, the spatial distribution of Bt at start up phase is measured. Figure 2 (a) shows the test result of the magnetic fluctuation from the most beginning of plasma ignition (t=0) to 0.35 ms.. The horizontal axis shows the toroidal angle and the center position corresponds to the shell insulation gap. The vertical axis shows the deviated value of magnetic field from the average value. Each waved line in the figure shows the toroidal distribution of Bt fluctuation at each 5microseconds. The resultant figure shows that the magnetic fluctuation is excited at the toroidal insulation gap when the plasma current starts, and then it propagates from the insulation gap toward both sides of the torus. Furthermore, it can be recognized that the propagating velocity of the wave to the left side is faster than that of the right side.

Figure 2(b, c) are the results in case of increased bias magnetic field. They show the magnetic fluctuation becomes small with increasing of the bias field. On the other hand, the toroidal loop voltage decreases by 15% when the bias field is increased from 140 gauss to 320 gauss. This suggests that the magnetic fluctuation affects to the loss mechanism of confining plasma. However the propagation velocity of magnetic fluctuation is not influenced by the bias magnetic field. The propagating velocities to the right direction and to the left direction (direction of the plasma current) are about 3km/s and 5km/s respectively. The fluctuation phenomenon at the plasma start up phase is similar to that of the paramagnetic mode. In the experiment of large plasma current, the propagation velocity of the wave does not change though the magnetic fluctuation increases. This suggests that the initial propagation velocity near the insulation gap is not affected by the electromagnetic force and has the peculiar value.

In measuring the magnetic fluctuation for longer time duration than the upper case, the different phenomena from the initial stage are observed by changing the operating conditions. Figure 3(a) shows the appearance of the magnetic fluctuation for 1.6ms from the generation of plasma in the paramagnetic operation of low plasma temperature (Vloop ~ 130 V). The wave velocities to both directions become slow at first and maintain these velocities after that. Figure 3(b) shows an appearance of the magnetic fluctuation in the RFP mode. The same phenomenon in case of the paramagnetic mode is shown until the plasma current reaches the peak value. However, the appearance of the fluctuated wave to the right (+180 degree) direction changes after the set up of RFP plasma. That is, the propagation velocity of the wave gradually slows down when moving to the right, and then it stops and/or starts to move to the left direction. The wave velocities in some different conditions are shown in Table 1(a). The wave velocities in the high plasma temperature condition

(Vloop ~ 80 V) are listed in Table1(b). The fluctuating phenomena in the set up phase are almost the same to that of low temperature case. However, the propagating velocity to the left direction especially changes and becomes fast (several km/s).

As shown in Figure 1, the magnetic distribution accompanies some mode of fluctuations (toroidal mode number) for the toroidal direction, which will be the reflection of dynamo mechanism in RFP. The compositions of toroidal mode number (n) at plasma set up phase (0.2ms), at the peak time of plasma current (0.5ms) and at almost stable phase (1.0ms) are shown in figure 4(a, b). The main n mode is 3-5 at first for both cases. In the paramagnetic mode, the n number becomes large gradually with the time, but it lies in the range of 3-6, as shown in figure 4(a). On the other hand, the main n mode increases with time, and about 1ms later, which is in the stable RFP configuration, the main n becomes around 9 (Figure 4(b)). It is well known that the main n mode in the RFP device is 7-9 [6].

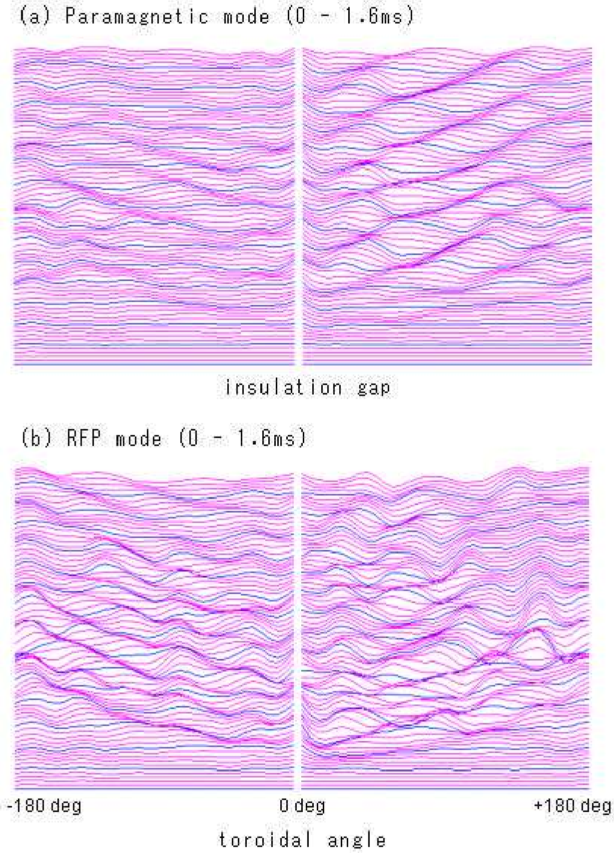

Fig.3 Time Resolution of Bt Fluctuation

Estimation of the wave propagation velocity

It is observed from the above-mentioned experiment that the propagation velocities of the fluctuation waves at the plasma set up phase have the definite values and these velocities to the right and left directions have the different values, which seem to be regardless of the intensity of magnetic field. This result means that the wave propagation velocity at initial phase is composed of two velocity components. One is a velocity component expands equally to both directions (Veq), and another is a velocity component to the direction of plasma current (Vrot). Evaluating these components from Table 1, Veq and Vrot are 4km/s and 1km/s respectively. If the origin of Veq is thought to be an Alfven wave velocity, it becomes about several tens km/s in calculation. Therefore we assume that Veq is the expanding velocity of sound wave in the deuterium gas,

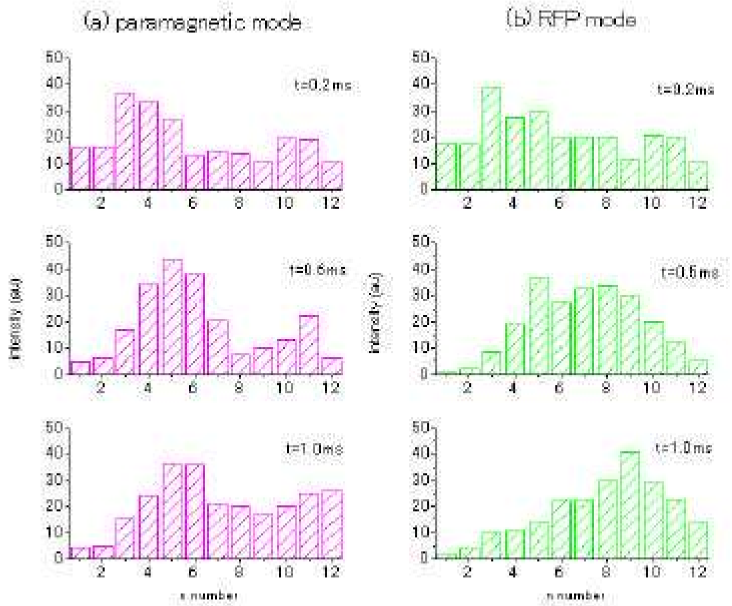

Fig.4 Time Resolution of Toroidal Mode Numbers

which can be calculated as 5.4km/s for the 10000 degrees condition. Although this value is a little large compared with Veq, it can be thought to be nearly equal considering the measurement error. It is assumed that Vrot is caused by the toroidal rotation of plasma particle, but it is necessary to confirm it by other means.

Observing the fluctuation phenomena for more long time duration, the wave velocity of RFP mode plasma has dramatically changed comparing to the paramagnetic mode plasma. It means the velocity component (Vmf) relating to the intensity of magnetic field should be taken account. Estimating these velocity components in the high temperature condition from table 1(b), Vmf is 1.5 - 2km/s for the paramagnetic mode plasma and 2 – 4 km/s for the RFP mode plasma, which are in the directions of plasma current. This difference between RFP mode and paramagnetic mode may come from the difference of magnetic helicity. Anyway it should be thought that the driving force for Vmf is working not by the Alfven wave but by the another unknown force.

Table 1 Wave velocities of toroidal magnetic fluctuations

(a) in case Vloop ~ 130 V

	Paramagnetic mode		RFP mode	
Phase	to Left	to Right	to Left	to Right
Plasma setup phase (0.1ms)	~ 5 km/s	~ 3 km/s	~ 5 km/s	~ 3 km/s
Plasma peak phase (0.5ms)	~ 3 km/s	~ 1.5 km/s	~ 3 km/s	~ 0 km/s
Steady state phase (1.2ms)	~ 3 km/s	~ 1.5 km/s	~ 3 km/s	~ -1 km/s

(b) in case Vloop ~ 80 V

	Paramagnetic mode		RFP mode	
Phase	to Left	to Right	to Left	to Right
Plasma setup phase (0.1ms)	~ 5 km/s	~ 3 km/s	~ 5 km/s	~ 3 km/s
Plasma peak phase (0.5ms)	5 ~ 7 km/s	1.5 ~ 2 km/s	6 ~ 8 km/s	~ 0 km/s
Steady state phase (1.2ms)	5 ~ 7 km/s	1.5 ~ 2 km/s	6 ~ 8 km/s	~ -1 km/s

to Left : to the direction of plasma current

Summary:

The spatial distribution and time resolution of magnetic fluctuation inner surface of the metal shall are measured using multi-channel magnetic probes in TPE-2M. It is observed that a certain mode of magnetic fluctuation is imposed to the confining magnetic fields, and it becomes clear that the fluctuation of magnetic field occurs at the electric insulation gap of metal shell. The wave of magnetic fluctuation expands from the shell gap to both sides of shell inner surface like the surface ripple of the water, and the fluctuating phenomenon of magnetic field dramatically changes between paramagnetic phase and RFP phase after the plasma sets up. The propagation mechanisms of the fluctuated magnetic field are assumed to be influenced by the sound wave velocity determined by the species of filling gas, the rotational force of plasma particles or so, and some unknown force factor.

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