INSTITUTE OF PLASMA PHYSICS

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RESEARCH REPORT

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Asymmetric Flux Generation and Its Relaxation in Reversed Field Pinch

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Abstract

The toroidally asymmetric flux enhancement ("dynamo effect") and the axisymmetrization of the enhnaced fluxes that follows in the setting up phase of Reversed Field Pinch are investigated on the STP-3(M) device. A rapid increase in the toroidal flux generated by the dynamo effect is first observed near the poloidal and toroidal current feeders. Then, this inhomogeneity of the flux propagates toroidally towards the plasma current. The axisymmetrization of the flux is attained just after the maximum of plasma current. The MHD activities decrease significantly after this axisymmetrization and the quiescent period is obtained.

In Reversed-Field Pinch (RFP) plasmas, the generation of toroidal magnetic flux, termed as dynamo effect, plays an essential role both in the setting up phase and in the sustainment phase. Extensive studies on the dynamo effect have been made experimentally and theoretically in recent years, and we can find them in an excellent review.[1] Experimentally, the relation between the magnetic flux generation and MHD activities has been studied; the MHD instabilities are identified from the data of magnetic field fluctuations[2-4] and the internal MHD activities are studied by the soft X-ray measurements.[3-6] These experimental results qualitatively agree with the theoretical prediction[3,4,7] of the nonlinear 3-D MHD simulation in that the toroidal flux generation can be explained by the nonlinear evolution of multiple $m = 1$ resistive modes, where m is the poloidal mode number. In these previous investigations on flux generation, the toroidal asymmetry or toroidal non-uniformity of the flux generation has not been found experimentally, and furthermore no theoretical prediction of asymmetric flux generation is made yet. In this paper we describe the toroidally asymmetric flux generation and the associated relaxation phenomena which are for the first time observed in the STP 3(M) RFP experiments.

In the setting up phase, the flux generation occurs at a localized toroidal location. The generated non-uniformity of toroidal flux travels in the toroidal direction until the toroidal uniformity of flux is realized. Immediately after that, the fluctuation of plasma current is reduced significantly, and the quiescent period (Q.P.) is obtained. This is the first observation of toroidally asymmetric flux generation and the related phenomena in RFP plasmas.

Experimental Apparatus

The experiments are carried out on the STP-3(M) device. It uses a 0.4 mm thick stainless-steel toroidal vacuum vessel (liner) with a major radius of 0.5 m and a minor radius of 0.1 m, surrounded by a 2.1 cm thick conducting shell. Figure 1 shows a plane view of this device together with the arrangement of experimental diagnostics. The toroidally resolved measurement of the toroidal magnetic flux is made by five flux loops wound onto the outer surface of the liner, whose toroidal locations are shown in Fig.1. The streak photographs of the plasma column are taken through the horizontal and vertical ports simultaneously. The visible light emitted from the plasma is observed by pindiodes at two toroidal locations. The fluctuation of the plasma is observed as a time derivative of the plasma current.

Experimental Results

Typical waveforms of the plasma current I_p and the toroidal magnetic field at the wall (or $B_z(a)$) are shown in Fig.2(a). In the STP-3(M) experiment, the plasma current has been driven up to 150 kA, which corresponds to the average current density of 6.2 MA/m^2. The duration of the plasma current was about 1.6 ms.

The electron temperature is estimated to be about 150 eV from the conductivity of the plasma with the assumptions that the value of effective ion charge Z_{eff} is unity and that the geometrical factor is 4. The time behavior of the toroidal magnetic flux at five toroidal locations, $\Phi(j)$, ($j = 1, \ldots, 5$) is shown in Fig.2(b) together with that of the time derivative of plasma current dI_p/dt. Hereafter we concentrate our attention upon the nonunivormity of the magnetic flux in the toroidal direction. At the initiation of the discharge, the toroidal magnetic flux decreases uniformly. It begins to increase immediately after the formation of RFP configuration. Toroidally asymmetric behavior of the flux is observed in this phase, as shown in Fig. 2(b). A rapid increase in the flux is first observed in the $\Phi(1)$ signal. Then, the enhancement of toroidal flux propagates toroidally in the direction of plasma current (dotted line on the left). After the toroidal rotation of this travelling flux in more than one turn (dotted line on the right), the toroidal flux re-distributes uniformly in the toroidal direction about 0.5 ms into the discharge. The attainment of the uniformity of toroidal flux is referred to as the flux relaxation. The plasma current takes its maximum value just before this time. Immediately after the toroidal flux relaxation, the fluctuation of plasma current is reduced significantly, and the quiescent period (Q.P.) is obtained, as shown in Fig.2(b). These phenomena are observed almost all the time when the stable RFP discharge with the quiescent period is obtained.

The velocity of the propagation of the toroidal flux is about 10^6 cm/s, which is nearly equal to the Alfvén velocity. The flux signal $\Phi(1)$ is obtained by the flux loop located near the toroidal and poloidal current feeders. Error fields due to these current feeders may enhance the localized toroidal flux.

In Fig.3, the streak photographs taken through the horizontal and vertical ports simultaneously at the port (8) are shown together with the time behavior of toroidal flux signal $\Phi(5)$. The asymmetric flux enhancement accompanies a luminous radiation from the plasma column. The mode structure of this luminous radiation is studied by these streak photographs and measurements of visible light at two toroidal locations. The toroidal and poloidal mode numbers thus determined, m and n, are 0 and 1, respectively. The velocity of the toroidal propagation of luminous radiation is found to be about 10^6 cm/s, which is in good agreement with that of the toroidal flux. This luminous radiation is probably due to the enhanced interaction between the plasma and wall which is caused by MHD instabilities. The mode structure of magnetic field fluctuation is under analysis, which will be published elsewhere.

Summary

The toroidally asymmetric dynamo effect and the toroidal flux relaxation that follows in the RFP setting up phase have been investigated in the STP-3(M) experiments. The results are summarized as follows: 1) A rapid increase in the toroidal flux generated by dynamo effect is first observed under the toroidal and poloidal current feeders. 2) This inhomogeneity of the flux propagates toroidally towards the plasma current. 3) Re-axisymmetrization of the flux (toroidal flux relaxation) is observed just after the maximum of plasma current. 4) The MHD activities

are reduced significantly and the quiescent period is attained just after the toroidal flux relaxation. 5) The phenomena 1)-4) are observed almost all the time when the stable RFP discharge with the quiescent period is attained. 6) The asymmetric flux enhancement accompanies luminous radiations from the plasma column which has the mode numbers of $m = 0$ and $n = 1$. These observations indicate that the relaxation of the plasma into the near minimum energy state does not necessarily advance axisymmetrically. The flux enhancement associated with the relaxation of the plasma takes place locally in the toroidal direction for various reasons. The non-uniformity of the magnetic field mainly due to the error field probably is believed to cause this localized flux enhancement or dynamo effect. The experimental results indicate that the axisymmetrization of the toroidal flux enhanced by the dynamo effect (toroidal flux relaxation) is required for the RFP plasma to relax into the near minimum energy state, or to attain the quiescent period. The behavior of streal photographs and visible light emission indicates that the MHD instabilities with mode number of $m = 0$ and $n = 1$ play an important role in the axisymmetrization of toroidal flux.

References

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Figure Captions

Fig.1 A plane view of STP-3(M) device and the arrangement of experimental diagnostics.

Fig.2 (a) Typical waveforms of plasma current (I_p) and toroidal magnetic field (B_z) at the wall.

(b) The time behaviors of the toroidal flux at five toroidal locations and the time derivative of plasma current (dI_p/dt).

Fig.3 Comparison between the streak photograph taken through the Port (8) and the time behavior of toroidal flux $\Phi(5)$.

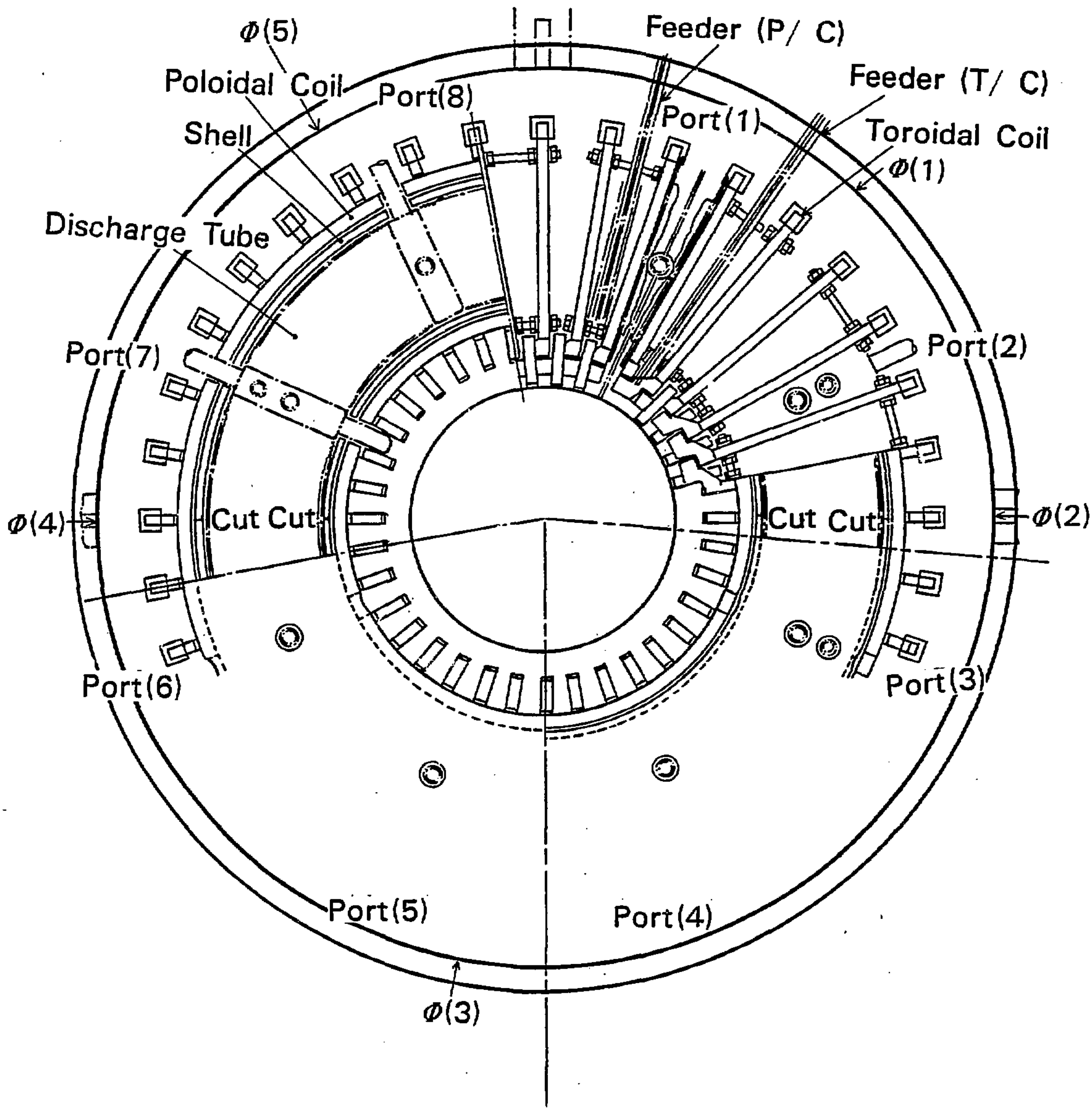

Φ(5)
Poloidal Coil
Shell
Discharge Tube
Port(8)
Feeder (P/ C)
Port(1)
Feeder (T/ C)
Toroidal Coil
Φ(1)
Port(7)
Port(2)
Φ(4)
Cut Cut
Cut Cut
Φ(2)
Port(6)
Port(3)
Port(5)
Port(4)
Φ(3)

Fig. 1

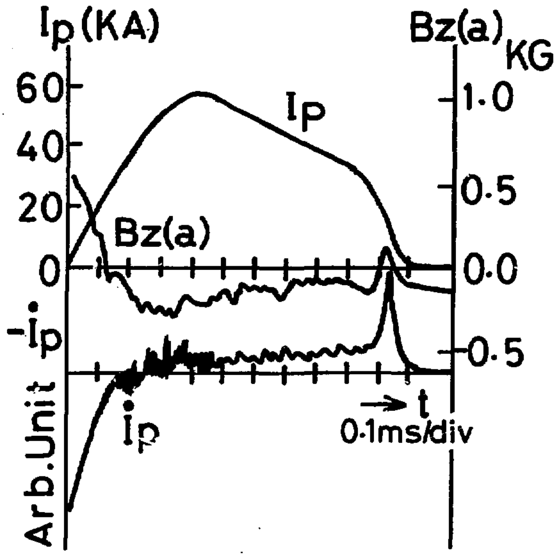


Fig. 2-(a)

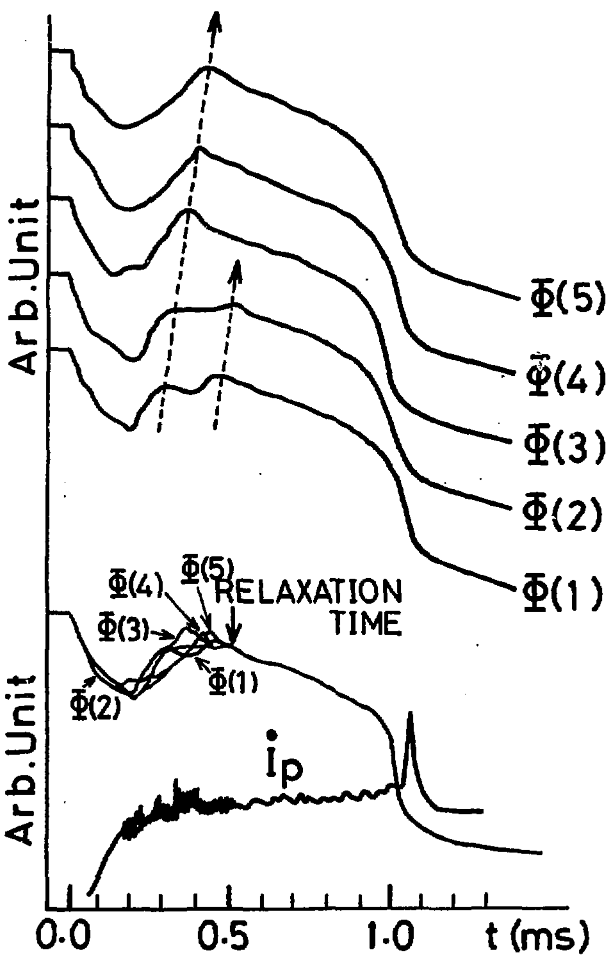
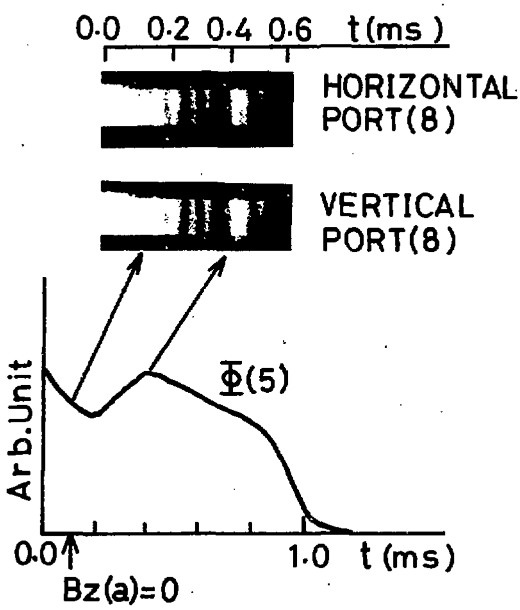

Arb.Unit
Φ(5)
Φ(4)
Φ(3)
Φ(2)
Φ(1)
Arb.Unit
Φ(4)
Φ(5)
RELAXATION
TIME
Φ(3)
Φ(1)
Φ(2)
$\dot{i}_p$
0.0
0.5
1.0
t (ms)

Fig. 2-(b)



0.0
0.2
0.4
0.6
t(ms)
HORIZONTAL PORT(8)
VERTICAL PORT(8)
Arb.Unit
Φ(5)
0.0
1.0
t (ms)
Bz(a)=0

Fig.3