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Improved Energy confinement in tokamak by modification magnetic field

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***Abstract* — In this paper the effect of magnitude of ohmic magnetic field (B_{ohmic}) on plasma current, plasma resistance (R_P), plasma confinement time (τ_E) and energy of plasma (U) in IR-T1 tokamak have been investigated. For this purpose the experiment have been done in three steps. In each experiment, all factors have been fixed, and only the ohmic magnetic field was changed. For this purpose the diamagnetic signal was measured by diamagnetic loop. The MHD oscillation was detected by mirnov coils in which mount around the tokamak. To analysis the MHD oscillation, the fast Fourier transform (FFT) was applied to the mirnov coils signal. The results show that by increasing the amount of B_{ohmic}, the magnitude of β_P, τ_E, U increase too. If the magnitude of B_{ohmic} is selected correctly then the τ_E and U energy can be reached to their maximum amplitude .it means that, the plasma confinement can be increased with the correct set of initial condition.**

***Keywords*— confinement time, energy of plasma, poloidal beta, tokamak.**

I. Introduction

Fusion energy may play a vital role in preventing the possible future energy crisis [1]. The largest experiment that will play an important role for the future of commercial fusion energy, is the International Thermonuclear Experimental Reactor (ITER) with a planned start of operations around 2020 and DEMO, a demonstration power plant with a planned start of operations around 2050 [2]. ITER will be constructed as a so called Tokamak, meaning that magnetic fields will be used to confine the plasma within a torus and thereby allowing the fusion reaction to take place without the extreme heat destroying the reactor vessel [3]. Many experiments have been done to explore the effect of different factors on plasma confinement. For example different type of bias applied to the plasma [4] or the resonant magnetic perturbation field applied to the plasma [5] and so on. One of the parameter in which measured during these experiments is energy confinement time. It can be measured straightly during the plasma discharged in tokamak. In this paper the effect of initial ohmic magnetic field magnitude on energy confinement time have been investigated. For this purpose plasma resistance (R_P) calculated and then the energy confinement time calculated from equation (1) [4]:

$$\tau_E = \frac{3\mu_0 R_0 \beta_P}{8R_P} \qquad (1)$$

In which τ_E is the confinement time and β_P is the poloidal beta. β_P can be calculated from diamagnetic signal, $\Delta\varphi$, according equation (2):

$$\beta_P = 1 - \frac{8\pi B_T}{(\mu_0 I_P)^2}\Delta\varphi \qquad (2)$$

The aim of this experiment is to measure the plasma energy. It can be obtained from equation (3):

$$U = \frac{3\mu_0 \beta_P I_P^2 V}{8\pi^2 a^2} \qquad (3)$$

The more information about other parameters in equations (1),(2) and (3) is list in table 1.

TABLE I. INTRODUCE PARAMETER IN EQUATION (1),(2) AND (3)

parameter	Name of parameter
I_P	Plasma current
R_0	Major radius
a	Minor radius
R_P	Plasma resistance
μ_0	Permeability of free space
B_T	Toroidal magnetic field
V	Plasma volume

To investigate the effect of B_{ohmic} magnitude on Magneto Hydro Dynamic (MHD) oscillation in plasma, the fast Fourier transform (FFT) method has been applied to the signal in which detected by mirnov coils [6]. The experimental set up is

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introduced in sec 2. The results and discussion about them are presented in section 3. And the conclusions about experimental results are given in section 4.

II. Experimental set up

The experiment was carry out in ohmic heating air core IR-T1 tokamak. The main parameters of this tokamak are list in table 2. The aim of this experiment is to investigate the effect of ohmic magnetic field magnitude on energy confinement time.

TABLE II. MAIN PARAMETERS OF THE IR-T1 TOKAMAK.

parameter	Value
Major Radius	45 cm
Minor Radius	12.5 cm
Toroidal Field	$< 1T$
Plasma current	$< 40kA$
Discharge Duration	$< 35m\sec$
Electron Density	$0.7-1.5\times10^{13}cm^{-3}$

For this purpose the diamagnetic signal was measured by diamagnetic loop (figure 1). The MHD oscillation was detected by mirnov coils in which mount around the tokamak as shown in figure 2.

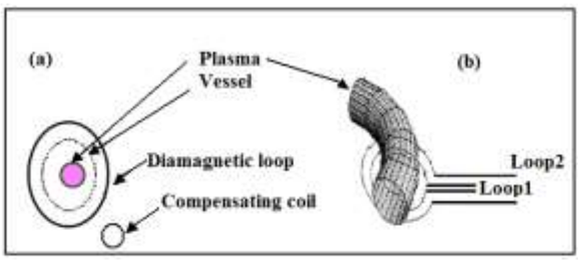

Figure 1. (a) Diamagnetic coil and compensating coil, (b) Two concentric magnetic loops

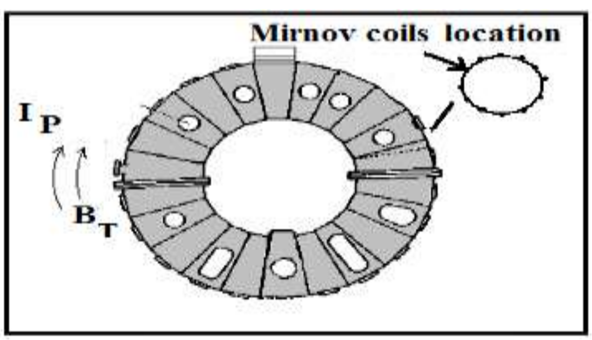

Figure 2. Schematic drawing of IR-T1 and locations of Mirnov coils .

There are four types of magnetic field in IR-T1 tokamak in which the plasma can be confined by them. They produced by magnetic coils. There are 16 toroidal magnetic coils in which the toroidal magnetic field produced by them. Also there are 6 coils in which produce vertical magnetic field. Two of them are at the top and bottom of tokamak and the other two 2 are in the sheath of the central solenoid. The plasma current is produced by ohmic magnetic field. This field is generated by Helmholtz and primary coil in tokamak. In this experiment the magnitude of toroidal magnetic field is around $B_T \approx 0.6-0.9Tesla$. The vertical magnetic field of top part (B_{Vup}) and down part (B_{Vdown}) were fixed at $3Tesla$ and $1.4Tesla$. And only the magnitude of ohmic magnetic field varied. The experiment was done in three steps. At the first step the ohmic magnetic field was fixed at $2.7\ Tesla$. In the next step all the parameter were fixed and only the amount of ohmic magnetic field increased up to $3\ Tesla$. Finally the amount of it was fixed at $3.22\ Tesla$. The experimental results are present in the following section.

III. Experimental results

In this work the effect of magnetic field magnitude on energy confinement time has been investigated. For this purpose, the experiment has been done in three steps. In all steps $B_T \approx 0.6-0.9Tesla$, B_{Vup}, B_{Vdown} were fixed at $3Tesla$ and $1.4Tesla$. and only the magnitude of ohmic magnetic field changed. At the first step ohmic magnetic field was fixed at $2.77Tesla$. At the next step, it increased up to $3Tesla$. Finally it fixed at $3.22Tesla$. The time evolution of plasma current has been shown in figure 3. The plasma current depend on the magnitude of B_{ohmic}. With increased the magnitude of b the amplitude of plasma current increased. It reached to its maximum amount in the presence of $B_{ohmic} = 3\Omega$. And in the higher magnitude of B_{ohmic} it didn't change remarkability.

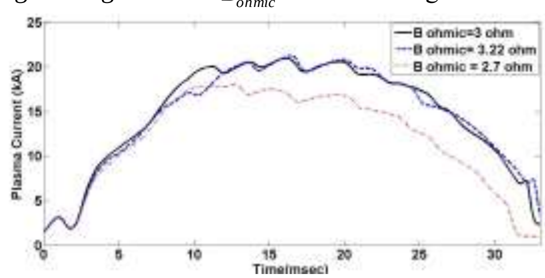

Figure 3.The time evolution of plasma current in the presence of B_{ohmic} with $B_{ohmic} = 2.7\Omega$, $B_{ohmic} = 3\Omega$, $B_{ohmic} = 3.22\Omega$

The energy confinement time (τ_E) can be calculated from plasma resistance (R_P) and poloidal beta (β_P). As shown in figure (4), in the time interval, in which the plasma current is flat, τ_E goes to maximum value. It reached to its higher amount in the presence of $B_{ohmic} = 3\Omega$. On the other hand R_P decreases while plasma current is flat. And the minimum magnitude of R_P can be realized with applied $B_{ohmic} = 3\Omega$. β_P changed slowly in different situations

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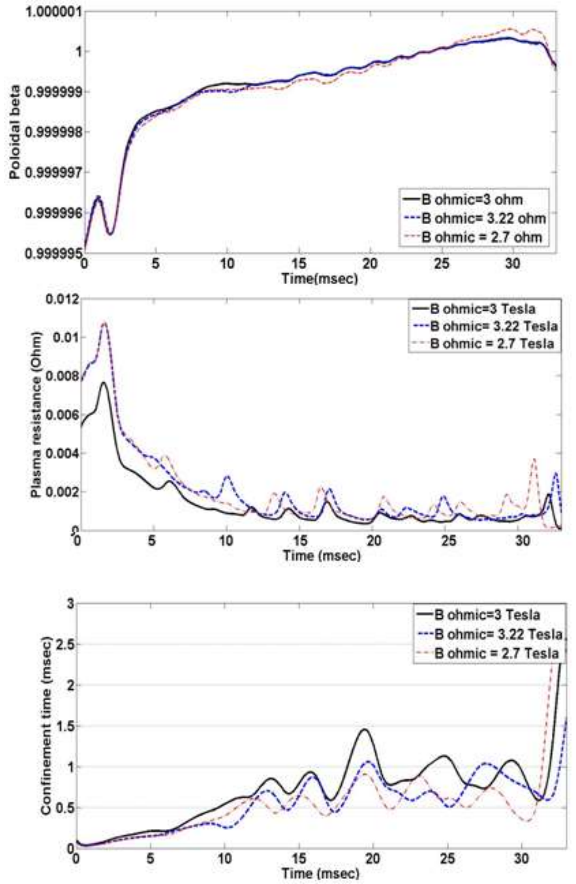

Figure 4. The time evolution of (a) poloidal beta (b) plasma resistance, (c) confinement time in the presence of B_{ohmic} with $B_{ohmic}=2.7\Omega$, $B_{ohmic}=3\Omega$, $B_{ohmic}=3.22\Omega$

The energy can be obtained from poloidal beta. As shown in figure 5, the amplitude of plasma energy depend on B_{ohmic}. The energy amplitude has direct relation with the ohmic field. It has its minimum amount in the presence of $B_{ohmic}=2.7\Omega$. But at higher amount of B_{ohmic} they don't have much difference.

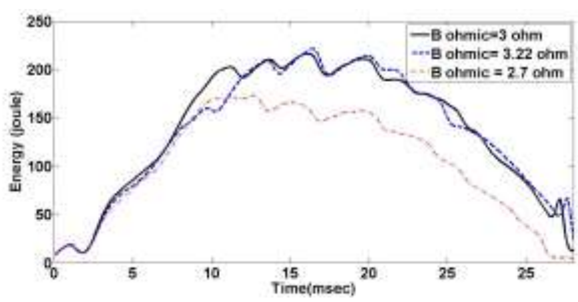

Figure 5. The time evolution of plasma energy in the presence of B_{ohmic} with $B_{ohmic}=2.7\Omega$, $B_{ohmic}=3\Omega$, $B_{ohmic}=3.22\Omega$

The FFT analysis of MHD oscillation has been shown in figure 6. With increased the magnitude of B_{ohmic}, the amplitude of MHD oscillation decreased. It means that B_{ohmic} can effect on MHD oscillation. While the amplitude of MHD oscillation decreased, the energy confinement time increased.

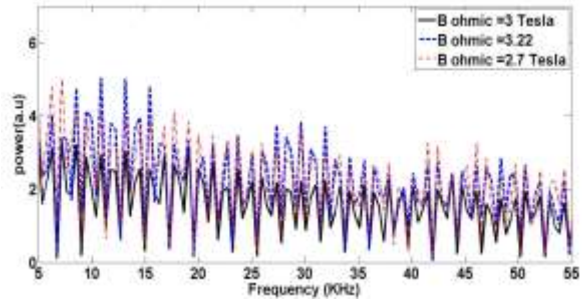

Figure 6. FFT of oscillations detected by Mirnov coils positioned at equatorial outer side mid-plane for plasma discharges B_{ohmic} with $B_{ohmic}=2.7\Omega$, $B_{ohmic}=3\Omega$, $B_{ohmic}=3.22\Omega$

IV. Conclusion

In this work the effects of the variation of the ohmic magnetic field (B_{ohmic}) on poloidal beta (β_P), plasma confinement time (τ_E), plasma resistance (R_P) and plasma energy (U) have been investigated. With changed the magnitude of B_{ohmic}, β_P increased. Consequently it can effect on the amplitude of τ_E and U. in the time interval, in which the plasma current is flat, τ_E goes to maximum value. It reached to its higher amount in the presence of $B_{ohmic}=3\Omega$. On the other hand R_P decreases while plasma current is flat. β_P changed slowly in different situations. the amplitude of U depends on B_{ohmic}. It has its minimum amount in the presence of $B_{ohmic}=2.7\Omega$. With increased the magnitude of B_{ohmic}, the amplitude of MHD oscillation decreased. It means that B_{ohmic} can effect on MHD oscillation. While the amplitude of MHD oscillation decreases, τ_E increases. Set the value of ohmic magnetic field is an important factor in which to be considered before each shot. If the magnitude of B_{ohmic} is selected correctly then τ_E and U energy can be reached to their maximum amplitude .it means that, the plasma confinement can be increased with the correct set of initial condition.

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