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Study of Plasma Current Density and Q-profiles for Circular Cross Section Tokamak

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Author's contribution

The whole work was carried out by the author MA.

Short Research Article

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ABSTRACT

In this paper the current density J(r) and safety factor q(r), profiles are obtained for circular cross section HT-7 tokomak. For this purpose discrete poloidal magnetic probes along with the diamagnetic loop can be utilized for the measurement. Here Plasma internal inductance (l_i) is studied by theoretical and experimental approach for circular cross section HT-7 Tokamak plasmas. Moreover, a few approximate values of the internal inductance for the different possible profiles of the plasma current density are also calculated. From the results, current density and q-profiles are obtained.

Keywords: Tokamak; plasma internal inductance; magneto-hydrodynamic.

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1. INTRODUCTION

The most advanced approach towards the achievement of the relevant fusion reactor parameters is the confinement of a plasma within a magnetic field in a so-called tokamak [1,2]. Tokamaks are one of the leading candidates for magnetically confined fusion owing to their good particle and energy confinement.

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The safety factor, q, is so called because of the role it plays in determining tokamak plasma stability. In general terms, higher values of q lead to greater stability. It also appears as an important factor in transport theory. In an axisymmetric equilibrium each magnetic field line has a value of q. The field line follows a helical path as it goes round the torus on its associated magnetic surface. Knowledge of the q profile in a tokamak is fundamental for the understanding of the MHD properties of the plasma. Near the plasma edge, q may be determined with accuracy from magnetic measurements, but this becomes increasingly inaccurate as extrapolations are made towards the plasma centre. Several methods of determining q(r) such as the Faraday rotation method and a ruby laser scattering technique have been developed [3-12].

In this paper the current density J(r) and safety factor q(r), profiles are obtained for circular cross section HT-7 tokomak [1-2], (see Table 1). For this purpose discrete poloidal magnetic probes along with the diamagnetic loop can be utilized for the measurement. Here Plasma internal inductance (l_i) is studied by theoretical and experimental approach [12], for circular cross section HT-7 Tokamak plasmas [13].

Table 1. Parameter of the circular cross section HT-7 tokamak

Parameter	Value
Major Radius	1.22 m
Minor Radius	0.25m
Toroidal Field	1- 2.5 T
Plasma Current	$100-250kA$
Discharge Time	$\sim 300s$
Electron Density	$1-6\times10^{19}\,m^{-3}$

The internal inductance of the plasma per unit length normalized to $\mu_0/4\pi$ is obtained from the conservation of zeroth order magnetic energy [11-14] as:

$$l_i = \frac{L_i/2\pi R_0}{\mu_0/4\pi} = \frac{2}{\mu_0^2 I_p^2 R_0}\int B_\theta^2(r)d^3V \tag{1}$$

where I_p is the plasma current. R_0 and r are the circular cross section HT-7 tokamak [1-2] major and minor radii. For typical profile of the poloidal field which correspond to flat plasma current density profile J_0 (usually is the case for low beta plasma tokamak) [14] is:

$$J = J_0 \rightarrow B_\theta = \frac{B_{\theta a} r}{a} \qquad r < a$$
$$J = 0 \rightarrow B_\theta = \frac{B_{\theta a} a}{r} \qquad a < r \le b \tag{2}$$

where $B_{\theta a} = \frac{\mu_0 I_p}{2\pi a}$, a and b are the plasma and chamber radiuses respectively.

Therefore, the first approximate value for the internal inductance [14] can be easily obtained by substituting Eq. 2 in Eq. 1:

$$l_{i1} = \frac{1}{2} - 2\ln\frac{a}{b} \tag{3}$$

This relation for circular cross section HT-7 tokamak [1-2] plasmas parameters (see Table 1) is equal to 0.727.

The second approximate value for the internal inductance can be easily obtained from the well-known Bennett current density profile [11-14], as:

$$J = \frac{I_p a^2}{\pi(r^2 + a^2)^2} \qquad r \le a$$
$$J = 0 \qquad a < r < b \tag{4}$$

$$B_\theta = \frac{\mu_0 I_p}{2\pi}\left[\frac{r}{r^2 + a^2}\right] \qquad r \le a$$
$$B_\theta = \frac{\mu_0 I_p}{4\pi r} \qquad a < r < b \tag{5}$$

Than the second approximate value for the internal inductance can be easily obtained [14] :

$$l_{i2} = \frac{1}{2}(\ln\frac{4b}{a} - 1) \tag{6}$$

This relation for circular cross section HT-7 tokamak [1-2] plasmas parameters (see Table 1) is equal to 0.250.

In general case, for the large aspect ratio and circular plasma , the current density distribution is [8,14] is given as

$$J = J(0)\left(1 - \frac{r^2}{a^2}\right)^{\upsilon} \qquad r < a$$
$$J = 0 \qquad a < r < b \tag{7}$$

The Poloidal magnetic field profile can be obtained [14]:

$$B_\theta = \frac{\mu_0 J(0) a^2}{2(\upsilon+1) r}\left(1 - \left(1 - \frac{r^2}{a^2}\right)^{\upsilon+1}\right), \qquad r \le a$$
$$B_\theta = \frac{\mu_0 J(0) a^2}{2(\upsilon+1) r} \qquad a < r < b \tag{8}$$

Where

$$J(0) = \frac{I_p q(a)}{\pi a^2 q(0)} = \frac{I_p(\upsilon+1)}{\pi a^2} \tag{9}$$

The geometrical parameters of the circular cross section HT-7 tokamak are shown in Table 1:

Where $q(a)$ and $q(0)$ are the edge and central safety factor respectively. The values of the internal inductance can be easily obtained by substituting Eq. 8 in Eq. 1 as a function of the υ .

The results are given in Table 2 and Fig. 1:

Table 2. Dependence of Internal inductance (l_{i3}) to the values of υ for circular cross section HT-7 tokamak plasmas

Sr. No.	υ	Internal inductance (l_{i3})	Sr. No.	υ	Internal inductance (l_{i3})
1	0	0.821	7	6	2.073
2	1	1.347	8	7	2.183
3	2	1.461	9	8	2.303
4	3	1.596	10	9	2.496
5	4	1.713	11	10	2.699
6	5	1.863	12	11	2.823

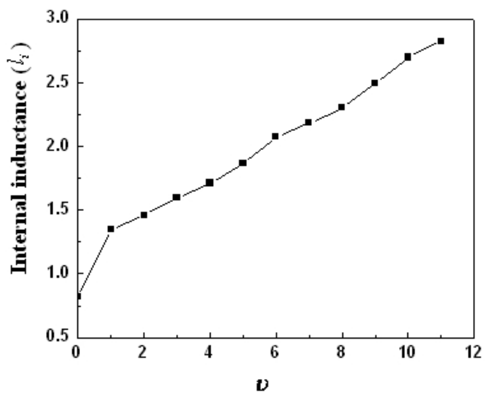

Fig. 1. Dependence of the Internal inductance (l_{i3}) to the values of υ for circular cross section HT-7 tokamak plasmas.

2. PLASMA INTERNAL INDUCTANCE (l_i) BY DISCRETE POLOIDAL PROBES ALONG WITH THE DIAMAGNETIC LOOP

But the final approximate method for the measurement of plasma internal inductance on circular cross section HT-7 tokamak is experimental method [13]. Discrete poloidal magnetic probes along with the diamagnetic loop can be utilized in measurement of the Plasma internal inductance (l_i). In this method [13] firstly Shafranov parameter is obtained from the magnetic probe measurements and then the values of the poloidal beta which obtained by the diamagnetic loop is subtracted from it as:

$$l_{i4} = 2(\Lambda - \beta_p + 1) \tag{10}$$

Using the signals of magnetic measurement and arithmetic listed above [13], β_p and l_i are obtained, as well as some other parameters. In Fig. 2 [13], IPA is the plasma current, NE3 is the electron density, PLHB is the plasma position including Shafranov shift that measured by flux loops directly, VP is the loop voltage, and PLHI is the inject power of lower hybrid current drive (LHCD). Betap is the poloidal beta β_p, Li is the internal inductance l_i, Dx is the geometric displacement of plasma ∇_g, a_p is the plasma radius *a*, lambda is the asymmetry factor Λ [13]. After breaking down, β_p is rising from 0 to 400 ms until the plasma current turned into the equilibrium state [13]. The geometric displacement of plasma ∇_g moves into inside from 0 to 200 ms, then moves from inside to center from 200 to 400 ms, the whole equilibrium process is about 400 ms [13]. In the whole discharge time, the width of the current channel becomes narrow when the plasma current moves to inside and becomes wide when the plasma current moves back to center [13]. The plasma radius a_p is varied by the geometric displacement of plasma, and l_i is determined by the Λ and β_p [13]. All these parameters are turned into the steady state after 400 ms [13]. Moreover, a few approximate values of the internal inductance for the different possible profiles of the plasma current density are also calculated [14]. From the results, current density and q-profiles are obtained.

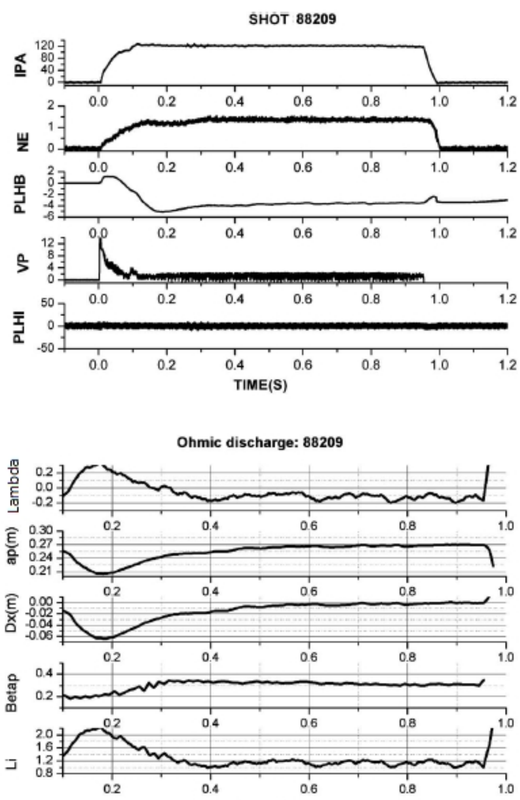

Fig. 2. Ohmic discharge [13]

3. MEASUREMENTS OF THE CURRENT DENSITY AND Q-PROFILES

The radial profile of safety factor [12], q(r), usually has its minimum value at, or close to, the magnetic axis and increases outwards. In the case of large aspect-ratio and circular cross-section the behavior of q is simply determined by the toroidal current profile, I(r) [12]:

$$q(r) = \frac{2\pi r^2 B_\phi}{\mu_0 R_0 I(r)} = \frac{r B_\phi}{R_0 B_\theta} \tag{11}$$

Substituting Eq. (8) into the approximation for q(r) given by Eq. (11) leads to the required q(r) [12]:

$$q(r) = \frac{2\pi a^2 B_\phi}{\mu_0 I_p R_0} \frac{r^2/a^2}{\left[1 - \left(1 - \frac{r^2}{a^2}\right)^{\upsilon+1}\right]} \tag{12}$$

From the above results, experimental results of determinations of the current density and q-profile [12] are presented in the Figs. 3 and 4.

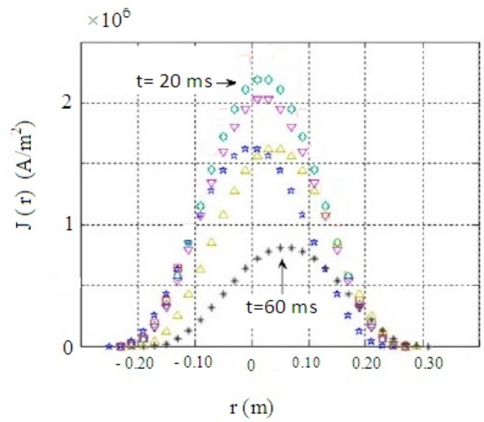

Fig. 3. Current density profiles at different times of target shot for circular cross section HT-7 tokamak.

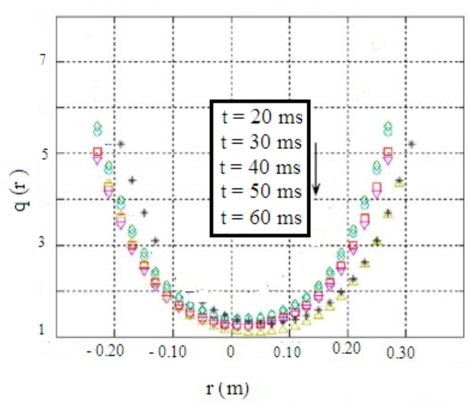

Fig. 4. Q-profiles at five different times of target shot on circular cross section HT-7 tokamak.

4. CONCLUSION

We have calculated, a few approximate values of the internal inductance for the different possible profiles of the plasma current density. For this purpose discrete poloidal magnetic probes along with the diamagnetic loop can be utilized for the measurement. From the results, current density and q-profiles are obtained.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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