Approximate Methods for the Calculation of Plasma Internal Inductance for Circular Cross Section Tokamak

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ABSTRACT
Calculation of Plasma internal inductance ($l_i$) is essential in Tokamak plasma research. Much more plasma parameters such as the plasma current density profile, magnetohydrodynamics instability, and plasma energy confinement time can be determined by using this parameter. Discrete poloidal magnetic probes along with the diamagnetic loop can be utilized in measurement of the Plasma internal inductance ($l_i$). In this paper Plasma internal inductance ($l_i$) is studied by theoretical and experimental approach for HT-7 Tokamak plasmas. The results of two methods are in good agreement with each other.

Keywords: Tokamak; Plasma Internal Inductance; Magneto-Hydrodynamic

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.

Plasma inductance control is an essential profile control tool for Tokamaks that can be utilized to extend pulse duration [2], access to advanced regimes, reduce vertical instability growth rate, and improve experiment reproducibility.

In this work we present measurement of Plasma internal inductance ($l_i$) [3-5], which is essential in Tokamak plasma research. Much more plasma parameters such as the plasma current density profile, magnetohydrodynamics instability, and plasma energy confinement time can be determined by using this parameter. Discrete poloidal magnetic probes along with the diamagnetic loop can be utilized in measurement of the Plasma internal inductance ($l_i$). In this paper we present theoretical calculation of Plasma internal inductance ($l_i$) for HT-7 Tokamak [1,2], (see Table 1). The Plasma internal inductance ($l_i$) is also studied for Tokamaks [3-5] by theoretical and experimental approach.

2. Theoretical Calculation of Plasma Internal Inductance ($l_i$)
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 [3,4] as:

$$ l_i = \frac{L_i}{\mu_0/4\pi} = \frac{2}{\mu_0^2} \int B^2(r) d^3V $$

where $L_i$ is the plasma current.

$$ J = J_0 \rightarrow B_\phi = \frac{B_{0b}r}{a}, r < a $$

$$ J = 0 \rightarrow B_\phi = \frac{B_{0a}r}{a}, a < r \leq b $$

where $B_{0b} = \frac{\mu_0 I_p}{2\pi a}$, $a$ and $b$ are the plasma and chamber radiiues respectively.

Therefore, the first approximate value for the internal inductance can be easily obtained by substituting Equation (2) into Equation (1):

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Table 1. Parameter of the HT-7 Tokamak.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Radius</td>
<td>1.22 m</td>
</tr>
<tr>
<td>Minor Radius</td>
<td>0.25 m</td>
</tr>
<tr>
<td>Toroidal Field</td>
<td>1 - 2.5 T</td>
</tr>
<tr>
<td>Plasma Current</td>
<td>100 - 250 kA</td>
</tr>
<tr>
<td>Discharge Time</td>
<td>~300 s</td>
</tr>
<tr>
<td>Electron Density</td>
<td>$1 - 6 \times 10^{19} m^{-3}$</td>
</tr>
</tbody>
</table>

\[
l_i = \frac{1}{2} - 2 \ln \frac{a}{b} \quad (3)
\]

This relation for 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 [3,4], as:

\[
J = \frac{I_P a^2}{\pi \left(r^2 + a^2\right)^{\nu/2}}, r \leq a \quad (4)
\]

\[
J = 0, a < r < b
\]

\[
B_\theta = \frac{\mu_0 I_p}{2\pi} \left[\frac{r}{r^2 + a^2}\right], r \leq a \quad (5)
\]

\[
B_\theta = \frac{\mu_0 I_p}{4\pi r}, a < r < b
\]

Then the second approximate value for the internal inductance can be easily obtained:

\[
l_{i2} = \frac{1}{2} \left(\ln \frac{4b}{a} - 1\right) \quad (6)
\]

This relation for HT-7 Tokamak [1,2] plasmas parameters (see Table 1) is equal to 0.250.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>(\nu)</th>
<th>Internal inductance ((l_i))</th>
<th>Sr. No.</th>
<th>(\nu)</th>
<th>Internal inductance ((l_i))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.821</td>
<td>7</td>
<td>6</td>
<td>2.073</td>
</tr>
<tr>
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<td>1</td>
<td>1.347</td>
<td>8</td>
<td>7</td>
<td>2.183</td>
</tr>
<tr>
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<td>1.461</td>
<td>9</td>
<td>8</td>
<td>2.303</td>
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<tr>
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<td>3</td>
<td>1.596</td>
<td>10</td>
<td>9</td>
<td>2.496</td>
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<tr>
<td>5</td>
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<td>1.713</td>
<td>11</td>
<td>10</td>
<td>2.699</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>1.863</td>
<td>12</td>
<td>11</td>
<td>2.823</td>
</tr>
</tbody>
</table>

4. Conclusions

We have described calculation of Plasma internal inductance \((l_i)\) [3-5], which is essential in Tokamak plasma.
Much more plasma parameters such as the plasma current density profile, magnetohydrodynamics instability, and plasma energy confinement time can be determined by using this parameter. Discrete poloidal magnetic probes along with the diamagnetic loop can be utilized in measurement of the Plasma internal inductance ($l_i$).

Discrete poloidal magnetic probes along with the diamagnetic loop can be utilized in measurement of the Plasma internal inductance ($l_i$). In this paper Plasma internal inductance ($l_i$) is studied by theoretical and experimental approach for HT-7 Tokamak plasmas. The results of two methods are in good agreement with each other.

REFERENCES


