Journal of Nuclear and Particle Physics 2014, 4(1): 36-41
DOI: 10.5923/j.jnpp.20140401.06

The Effects of Plasma Internal Inductance on the Plasma Horizontal Displacement in the Circular Cross Section Tokamaks

Ahmad Salar Elahi*, **Mahmood Ghoranneviss**

Plasma Physics Research Center, Tehran Science and Research Branch, Islamic Azad University, Tehran, Iran

Abstract In this paper we investigated the effects of internal inductance on plasma horizontal displacement in IR-T1 tokamak. For this purpose, a diamagnetic loop with its compensation coil, and also two magnetic probes were designed, constructed, and installed on outer surface of the IR-T1 tokamak chamber, and then the poloidal beta and poloidal magnetic field measured. Moreover a few approximate values of the internal inductance for different possible profiles of the plasma current density are also calculated. Then, the plasma horizontal displacement was determined for different values of the plasma internal inductance. Experimental results show that by increasing the values of internal inductance from one, plasma column shifted inward.

Keywords Tokamak, Plasma Horizontal Displacement, Plasma Internal Inductance, Diamagnetic Loop, Magnetic Probe

1. Introduction

Tokamak plasma equilibrium is one of the important problems of the fusion programs. Plasma equilibrium is a condition which plasma pressure is balanced by electromagnetic force (Lorentz force). Tokamak plasma equilibrium is a significant fraction of the fusion program studies in order to achieve tokamaks optimized operation and become close to Lawson criterion. Determination of precise plasma position during confinement time is essential to transport it to the control system based on feedback. Magnetic diagnostics, in particular toroidal flux loop (diamagnetic loop) are commonly used in tokamaks to measure the variation of toroidal flux induced by the plasma. From this measurement, the total diamagnetic energy content and the confinement time of the plasma can be obtained as well as the poloidal beta. If the internal inductance is known from the anyway, then measurement of the Shafranov parameter and poloidal magnetic field gives a value of the plasma horizontal displacement. The value of l_i is determined by the radial distribution of toroidal current profile of the plasma[1-13].

In this paper we presented combination of the diamagnetic loop and magnetic probes for determination of the poloidal Beta and poloidal magnetic field, and moreover an approximate calculations for determination of the plasma internal inductance, and therefore the plasma horizontal displacement in IR-T1 Tokamak, which is a small, low β_p and large aspect ratio tokamak with a circular cross section (see Table 1). Details of the theoretical approach for determination of the plasma horizontal displacement based on a diamagnetic loop and magnetic probes measurements will be presented in section 2. Details of approximate calculations for determination of the internal inductance will be presented in section 3. Experimental results will be discussed in section 4. Summary and discussion will be present in section 5.

Table 1. Main parameters of the IR-T1 tokamak

Parameters	Value
Major Radius	45 cm
Minor Radius	12.5 cm
Toroidal Field	〈 1.0 T
Plasma Current	〈 40 kA
Discharge Time	〈 35 ms
Electron Density	$0.7\text{-}1.5\times 10^{13}\ \text{cm}^{-3}$

2. Theoretical Approach for Determination of the Plasma Horizontal Displacement Based on a Diamagnetic Loop and Magnetic Probes

* Corresponding author:
Salari_phy@yahoo.com (Ahmad Salar Elahi)
Published online at http://journal.sapub.org/jnpp

Shafranov parameter and therefore the plasma horizontal displacement relate to the distribution of magnetic fields around the plasma current. Therefore, those can be written in terms of the tangential and normal components of the magnetic field on the contour Γ (see Fig. (2)). Distribution of the poloidal and radial magnetic fields are can be written in the first order of the inverse aspect ratio as follows, respectively[1]:

$$B_\theta = \frac{\mu_0 I_p}{2\pi \mathrm{b}} - \frac{\mu_0 I_p}{4\pi R_0} \times \left\{ \ln\frac{a}{b} + 1 - \left(\Lambda + \frac{1}{2}\right)\left(\frac{a^2}{b^2} + 1\right) - \frac{2R_0\Delta_s}{b^2} \right\} \cos\theta, \tag{1}$$

$$B_r = -\frac{\mu_0 I_p}{4\pi R_0} \times \left\{ \ln\frac{a}{b} + \left(\Lambda + \frac{1}{2}\right)\left(\frac{a^2}{b^2} - 1\right) + \frac{2R_0\Delta_s}{b^2} \right\} \sin\theta \tag{2}$$

where R_0 is the major radius of the vacuum vessel, Δ_s is the Shafranov shift, I_p is the plasma current, a and b are the minor plasma radius and minor chamber radius respectively, and Λ is the Shafranov parameter. These equations accurate for low β plasma and circular cross section tokamaks as IR-T1, and where:

$$\Lambda = \beta_p + l_i / 2 - 1 \tag{3}$$

where β_p is the poloidal beta, and l_i is the plasma internal inductance.

Rearranging of the Eq. (1) give us:

$$\Delta H = \frac{\pi \mathrm{b}^2}{\mu_0 I_p}\langle B_\theta \rangle + \frac{\mathrm{b}^2}{2\mathrm{R}_0}\left[\ln\frac{a}{b} + 1 - \left(\frac{a^2}{b^2} + 1\right)\left(\Lambda + \frac{1}{2}\right)\right], \tag{4}$$

where

$$\langle B_\theta \rangle = B_\theta(\theta = 0) - B_\theta(\theta = \pi). \tag{5}$$

Therefore, with combination of the poloidal magnetic field and poloidal beta measurements, and also calculation of the internal inductance, the plasma horizontal displacement can be determined from Eq. (4).

Magnetic probes consist of a coil in solenoidal form, which whose dimensions are small compared to the gradient scale length of the magnetic field. A total magnetic flux passed through such a coil is $\Phi_B = nAB$, where n is the number of turns of coil, A is the average area of cross section of coil, and B is the local magnetic field parallel to the coil axis.

On the other hand, diamagnetic loop measures the toroidal diamagnetic flux for the purpose of measurement of the poloidal beta and thermal energy of the plasma. The toroidal flux that produced by the plasma is related to the total perpendicular thermal energy of the plasma. This diamagnetic flux is usually measured with the diamagnetic loop. The relation between diamagnetic flux and the poloidal beta derived from simplified equilibrium relation is[2-4]:

$$\beta_p = 1 - \frac{8\pi\, \mathrm{B}_{\varphi 0}}{\mu_0^2 I_p^2}\Delta\Phi_D, \tag{6}$$

where $\Delta\Phi_D = \Phi_{total} - \Phi_{vacuum}$,

and where $\Phi_{vacuum} = \Phi_T + \Phi_O + \Phi_V + \Phi_E$,

Where $B_{\phi 0}$ is the toroidal magnetic field in the absence of the plasma which can be obtained by the magnetic probe or diamagnetic loop, I_p is the plasma current which can be obtained by the rogowski coil, Φ_T is the toroidal flux because of toroidal field coils, Φ_O and Φ_V are the passing flux through loop due to possible misalignment between ohmic field and vertical field and the diamagnetic loop and Φ_E is the toroidal field due to eddy current on the vacuum chamber. These fluxes can be compensated either with compensation coil or dry runs technique. Extremity, calculation of the plasma internal inductance is discussed in the next section.

3. Approximate Methods for Calculation of the Plasma Internal Inductance

The internal inductance of the plasma per unit length, normalized to $\mu_0 / 4\pi$ can be determined from the conservation of zeroth order magnetic energy:

$$l_i = \frac{L_i / 2\pi R_0}{\mu_0 / 4\pi} = \frac{2}{\mu_0^2 I_p^2 R_0} \int_{Plasma} B_\theta^2(r) d^3V \tag{7}$$

For typical profile of the poloidal field which correspond to flat current density profile J_0 (usually accurate for low beta tokamak), as:

$$\begin{cases} J = J_0 \rightarrow B_\theta = B_{\theta a}\dfrac{r}{a} & \mathrm{r} < \mathrm{a} \\ \mathrm{J} = 0 \rightarrow \mathrm{B}_\theta = B_{\theta a}\dfrac{a}{r} & \mathrm{a} < \mathrm{r} \le \mathrm{b} \end{cases}, \tag{8}$$

where $B_{\theta a} = \dfrac{\mu_0 I_p}{2\pi a}$.

Then first approximate value for the internal inductance can be easily obtained by substituting Eq. (9) in Eq. (8):

$$li_1 = \frac{1}{2} - 2\ln\frac{a}{b}, \tag{9}$$

where this relation for IR-T1 tokamak parameters equal to value of 0.994.

Second approximate value for the internal inductance can be determined from the well-known Bennett current density profile, as:

$$\begin{cases} J = \dfrac{I_p}{\pi}\dfrac{a^2}{\left(r^2+a^2\right)^2} & \mathrm{r} \le \mathrm{a} \\ \mathrm{J} = 0 & \mathrm{a} < \mathrm{r} < \mathrm{b} \end{cases}, \quad (10)$$

therefore, the poloidal magnetic field profile can be obtained:

$$\begin{cases} B_\theta = \dfrac{\mu_0 I_p}{2\pi}\left[\dfrac{\mathrm{r}}{\mathrm{r}^2+a^2}\right] & \mathrm{r} \le \mathrm{a} \\ \mathrm{B}_\theta = \dfrac{\mu_0 I_p}{4\pi\ \mathrm{r}} & \mathrm{a} < \mathrm{r} < \mathrm{b} \end{cases}, \quad (11)$$

and then second approximate value for internal inductance can be obtained:

$$li_2 = \frac{1}{2}\left(\ln\frac{4b}{a} - 1\right), \quad (12)$$

where this relation for IR-T1 tokamak parameters equal to value of 0.332.

In general case, for the large aspect ratio and circular plasma, the current density distribution is[2]:

$$\begin{cases} J = J(0)\left(1-\dfrac{r^2}{a^2}\right)^{\upsilon} & \mathrm{r} \le \mathrm{a} \\ J = 0 & \mathrm{a} < r < b \end{cases}, \quad (13)$$

The poloidal magnetic field profile can be obtained:

$$\begin{cases} B_\theta = \dfrac{\mu_0 J(0) a^2}{2(\upsilon+1) r}\left(1-\left(1-\dfrac{r^2}{a^2}\right)^{\upsilon+1}\right), & \mathrm{r} \le \mathrm{a} \\ B_\theta = \dfrac{\mu_0 J(0) a^2}{2(\upsilon+1) r} & \mathrm{a} < \mathrm{r} < \mathrm{b} \end{cases} \quad (14)$$

where

$$\upsilon = \frac{q(a)}{q(0)} - 1 = \frac{\pi\, \mathrm{a}^2 J(0)}{I_P} - 1 \quad (15)$$

If we assume a more peaked current profile with central safety factor $q(0) \approx 1$, then the values of the internal inductances can be determined from substituting the Eq. (14) in Eq. (7), as a function of the υ. Results presented in Table 2 and Figure (1).

Table 2. Dependence of the Internal Inductance to the values of υ for IR-T1 tokamak parameters

υ	**Internal Inductance (li_3)**	υ	**Internal Inductance (li_3)**
0	0.994	6	2.428
1	1.410	7	2.548
2	1.710	8	2.656
3	1.942	9	2.754
4	2.132	10	2.842
5	2.292	11	2.924

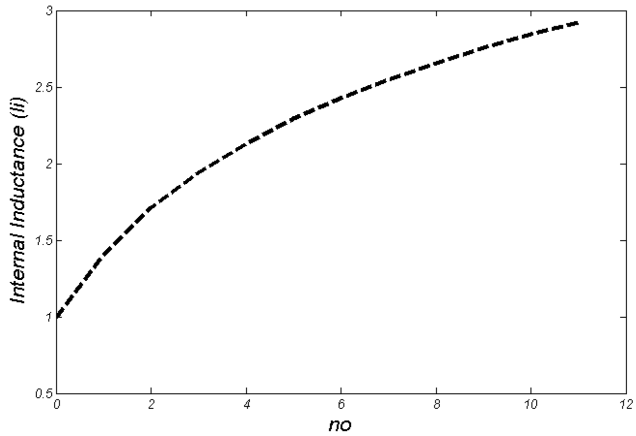

Figure (1). Dependence of the Internal Inductance to the values of υ for IR-T1 tokamak parameters

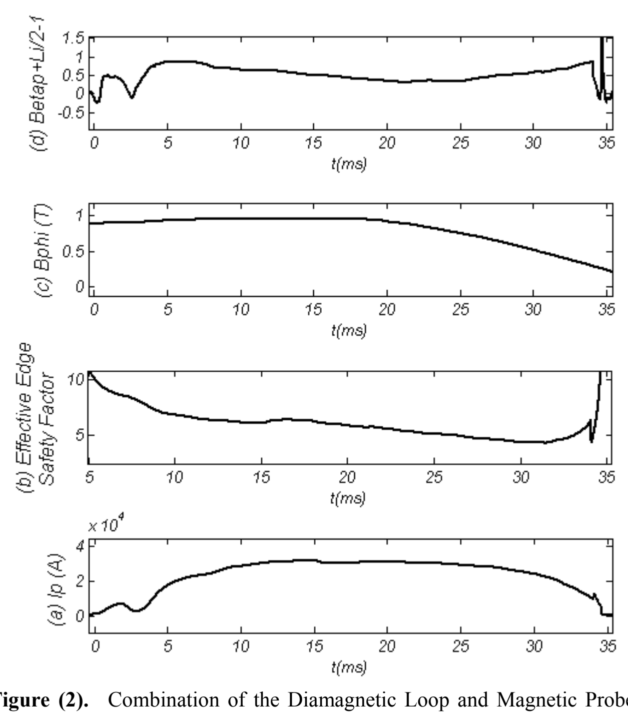

Figure (2). Combination of the Diamagnetic Loop and Magnetic Probe Results: (a) Plasma Current, (b) Effective Edge Safety Factor, (c) Toroidal Magnetic Field, and (d) Shafranov Parameter

Our experiments show that the value of υ which proportional to the edge safety factor reduced from 8 to 1 along time interval of plasma current (see Figure (2)). Therefore, according to recent method, IR-T1 tokamak plasma internal inductance reduced from 2.5 to 1.2 along the time interval of plasma current.

4. Experimental Results

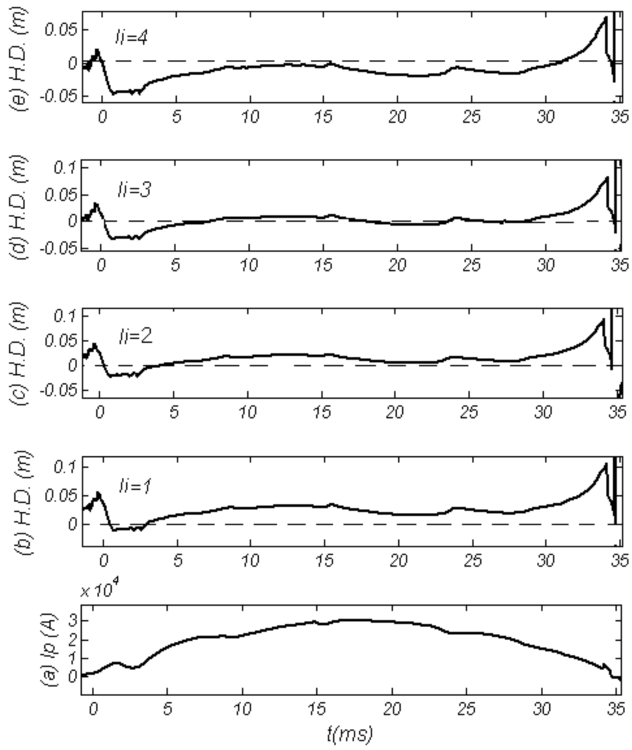

Figure (3). (a) Plasma current, (b) Horizontal Displacement (H.D.) obtained with combination of the magnetic probe, diamagnetic loop, and approximate values of the internal inductance (Eq. (4)), for li=1, (c) H.D. for li=2, (d) H.D. for li=3, and (e) H.D. for li=4. As shown, by increasing the internal inductance from one, plasma shifted inward

According to above discussion, two magnetic probes were designed and installed on outer surface of the IR-T1 in radius of $b = 16.5cm$ in angles of $\theta = 0$ and $\theta = \pi$ to detect the tangential component of the magnetic field B_θ. Also a diamagnetic loop with its compensation coil were constructed and installed on outer surface of the IR-T1. Design parameters of the magnetic pickup coils present in Table 3. Diamagnetic loop and its compensating coil also were constructed and installed on the IR-T1 tokamak. Its characteristics are also shown in Table 3.

After measurement of $\langle B_\theta \rangle$ from magnetic probes, I_p from rogowski coil, poloidal beta from diamagnetic loop and substituting them and the approximate values of internal inductance in to Eq. (4), the plasma horizontal displacement were obtained.

Results presented in the Fig. (3). As shown, by increasing the internal inductance from one, plasma shifted inward.

Table 3. Design parameters of the magnetic probe and diamagnetic loop

Parameters	Magnetic Probe	Diamagnetic Loop
R (Resistivity)	33 Ω	100 Ω
L (Inductance)	1.5mH	20mH
n (Turns)	500	170
S (Sensitivity)	0.7mV/G	0.5V/G
f (Frequency Response)	22kHz	5kHz
Effective nA	0.022 m^2	16 m^2
d (Wire Diameter)	0.1mm	0.2mm
d_m (Coil Average Radius)	3mm	175mm

5. Summary and Conclusions

Array of magnetic probes and also diamagnetic loop have been designed, constructed, and installed on outer surface of the IR-T1 tokamak chamber. The poloidal component of the magnetic fields and also diamagnetic flux signal obtained, and therefore the poloidal field and poloidal beta were measured from them. Then, a few approximate values of the internal inductance calculated. Therefore the plasma horizontal displacement determined.

Results show that by increasing the values of internal inductance from one, plasma column shifted inward.

REFERENCES

[1] Determination of Plasma Position using Poloidal Flux Loops and Comparison with Magnetic Probes Measurement in IR-T1 Tokamak, A. Salar Elahi et al., IEEE Trans. Plasma Science 38 (2), 181-185, (2010), DOI: 10.1109/ TPS.2009. 2037965.

[2] A Modified Flux Loop for Determination of Plasma Position in IR-T1 Tokamak, A. Salar Elahi et al., IEEE Trans. Plasma Science 38 (9), 3163-3167, (2010), DOI: 10.1109/ TPS.2010. 2066289.

[3] Analytical and Experimental Approach in Plasma Displacement Measurement in IR-T1 Tokamak, M. Emami, M. Ghoranneviss, A. Salar Elahi and A. Rahimi Rad, J. Plasma Phys. 76 (1), 1-8, (2009), DOI: 10.1017/ S0022377809008034.

[4] A Novel Technique for the Measurement of Plasma Displacement in IR-T1 Tokamak, A. Salar Elahi et al., Fusion Engineering and Design 85, 724–727, (2010), DOI: 10.1016/ j.fusengdes.2010.04.034.

[5] Comparison between Flux Loops and Magnetic Probes in Determination of Shafranov Parameter in IR-T1 Tokamak, A. Salar Elahi et al., Phys. Scripta 80, 045501, (2009), DOI: 10.1088/0031-8949/80/04/045501.

[6] Two Experimental Methods for Measurement of Plasma

Displacement in IR-T1 Tokamak, A. Salar Elahi et al., Phys. Scripta 80, 055502, (2009), DOI: 10.1088/0031-8949/80/05/055502.

[7] Time Evolution of the Energy confinement Time, Internal Inductance and Effective Edge Safety Factor on IR-T1 Tokamak, A. Salar Elahi et al., Phys. Scripta 81 (5), 055501, (2010), DOI: 10.1088/0031-8949/81/05/055501.

[8] Experimental Determination of Plasma Position Based on Two Analytical Methods in IR-T1 Tokamak, A. Salar Elahi et al., Phys. Scripta 82, 025502, (2010), DOI: 10.1088/0031-8949/82/02/025502.

[9] The First Results of Electrode Biasing Experiments in the IR-T1 Tokamak, M. Ghoranneviss, A. Salar Elahi et al., Phys. Scripta 82 (3), 035502, (2010), DOI: 10.1088/0031-8949/82/03/035502.

[10] Theoretical and Experimental Approach in Poloidal Beta and Internal Inductance Measurement on IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 28 (4), 346-349, (2009), DOI: 10.1007/s10894-009-9198-x.

[11] Effects of Resonant Helical Field (RHF) on Equilibrium Properties of IR-T1 Tokamak Plasma, A. Salar Elahi et al., J. Fusion Energy 28 (4), 416-419, (2009), DOI: 10.1007/s10894-009-9215-0.

[12] Effects of Resonant Helical Field on Plasma Internal Inductance in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 28 (4), 408-411, (2009), DOI: 10.1007/s10894-009-9213-2.

[13] RHF Effect on Shafranov Parameter and Shafranov Shift in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 28 (4), 412-415, (2009), DOI: 10.1007/s10894-009-9214-1.

[14] Measurement of Plasma Energy Confinement Time in Presence of Resonant Helical Field in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 28 (4), 394-397, (2009), DOI: 10.1007/s10894-009-9210-5.

[15] Measurement of Plasma Poloidal Beta in Presence of Resonant Helical Field in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 28 (4), 404-407, (2009), DOI: 10.1007/s10894-009-9212-3.

[16] Two Semi-Empirical Methods for Determination of Shafranov Shift in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 28 (4), 390-393, (2009), DOI: 10.1007/s10894-009-9208-z.

[17] Comparative Measurements of Plasma Position Using Multipole Moments Method and Analytical Solution of Grad–Shafranov Equation in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 28 (4), 385-389, (2009), DOI: 10.1007/s10894-009-9207-0.

[18] Comparison between Discrete Magnetic Coils and Multipole Coils for Measurement of Plasma Displacement in IR-T1 Tokamak, A. Rahimi Rad, M. Ghoranneviss, M. Emami, and A. Salar Elahi, J. Fusion Energy 28 (4), 420-426, (2009), DOI: 10.1007/s10894-009-9216-z.

[19] Plasma Magnetic Fluctuations Measurement on the Outer Surface of IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 1-4, (2010), DOI: 10.1007/s10894-009-9218-x

[20] Investigation of Effects of Toroidal Field Ripple on Plasma Poloidal Beta in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 22-25, (2010), DOI: 10.1007/s10894-009-9221-2.

[21] TF Ripple Effects on Plasma Energy Confinement Time in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 29-31, (2010), DOI: 10.1007/s10894-009-9224-z.

[22] Measurement of the Shafranov Parameter in Presence of the Toroidal Field Ripple in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 26-28, (2010), DOI: 10.1007/s10894-009-9223-0.

[23] Study of Effects of the Effective Edge Safety Factor on the Energy confinement Time in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 32-35, (2010), DOI: 10.1007/s10894-009-9227-9.

[24] Experimental Study of Effects of the Internal Inductance on the Energy Confinement Time in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 36-40, (2010), DOI: 10.1007/s10894-009-9226-x.

[25] Plasma Horizontal Displacement Measurement Using Flux Loops in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 62-64, (2010), DOI: 10.1007/s10894-009-9232-z.

[26] Determination of the Plasma Internal Inductance and Evaluation of its Effects on Plasma Horizontal Displacement in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 76-82, (2010), DOI: 10.1007/s10894-009-9234-x.

[27] Demonstration of Shafranov Shift by the Simplest Grad–Shafranov Equation Solution in IR-T1 Tokamak, A. Rahimi Rad, M. Emami, M. Ghoranneviss, A. Salar Elahi, J. Fusion Energy 29 (1), 73-75, (2010), DOI: 10.1007/s10894-009-9236-8.

[28] Effects of Alfvenic Poloidal Flow and External Vertical Field on Plasma Position in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 83-87, (2010), DOI: 10.1007/s10894-009-9235-9.

[29] Relations between the Plasma Diamagnetic Effect and Plasma Basic Parameters in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (1), 88-93, (2010), DOI: 10.1007/s10894-009-9237-7.

[30] Differences between the Toroidal and Poloidal Flux loops in the Measurement of Plasma Position in Tokamaks, A. Salar Elahi et al., J. Fusion Energy 29 (3), 209-214, (2010), DOI: 10.1007/s10894-009-9260-8.

[31] Measurements of the Plasma Current Density and Q-Profiles in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (3), 232-236, (2010), DOI: 10.1007/s10894-009-9264-4.

[32] A Simplified Technique for the Determination of Plasma Displacement in IR-T1 Tokamak, A. Salar Elahi et al., J. Fusion Energy 29 (3), 251-255, (2010), DOI: 10.1007/s10894-009-9267-1.

[33] Comparative Measurements of the Asymmetry Factor in Tokamaks using the Magnetic Probes, Poloidal and Toroidal Flux Loops, A. Salar Elahi et al., J. Fusion Energy 29 (3), 279-284, (2010), DOI: 10.1007/s10894-010-9275-1.

[34] Design, Construction, and Installation of Movable Electrode Biasing System on the IR-T1 Tokamak, M. Ghoranneviss, A. Salar Elahi et al., J. Fusion Energy 29 (5), 467-470, (2010), DOI: 10.1007/s10894-010-9307-x.

[35] Biasing Effect on Modifying of the Tokamak Plasma Horizontal Displacement, A. Salar Elahi et al., J. Fusion Energy 29 (5), 461-465, (2010), DOI: 10.1007/s10894-010-9305-z.

[36] Measurement of the Plasma Boundary Shift and Approximation of the Magnetic Surfaces on the IR-T1 Tokamak, A. Salar Elahi et al., Brazilian J. of Physics 40 (3), 323-326, (2010).

[37] A Novel Optical Technique based on Image Processing for Determination of Tokamak Plasma Displacement, A. Salar Elahi et al., J. Fusion Energy 30 (2), 116-120, (2011), DOI: 10.1007/s10894-010-9359-y.

[38] Effect of Limiter Biasing on Runaway electrons in Tokamaks, M.R. Ghanbari, M. Ghoranneviss, A. Salar Elahi et al., Phys. Scripta 83, 055501, (2011), DOI: 10.1088/0031-8949/83/05/055501.

[39] Multipole Moments based Study on Determination of Toroidal Plasma Equilibrium Position and Shift, A. Salar Elahi, J of Fusion Energy 30 (6), 477-480, (2011), 477-480, DOI: 10.1007/s10894-011-9408-1.

[40] Determination of Tokamak Plasma Displacement based on Vertical Field Coil Characteristics, A. Salar Elahi et al., Fusion Engineering and Design 86, 442–445, (2011), DOI: 10.1016/j.fusengdes.2011.03.121.

[41] Analytical Technique for Determination of Toroidal Plasma Displacement, A. Salar Elahi et al., J of Fusion Energy 31 (2), 191-194, (2011), DOI: 10.1007/s10894-011-9452-x.

[42] Measurement of Runaway Electrons Energy by Hard X-ray Spectroscopy in a Small Circular Cross-section Tokamak, M.R. Ghanbari, M. Ghoranneviss, A. Salar Elahi and S. Mohammadi, Radiation Effects & Defects in Solids 166 (10), 789–794, (2011), DOI: 10.1080/10420150.2011.610320.

[43] Design and Manufacturing of the Electrode Biasing System for the Tokamak, A. Salar Elahi et al., IEEE Trans. Plasma Science 40 (3), 892-897, (2012), DOI: 10.1109/TPS.2012.2182990.

[44] First Results of Movable Limiter Experiments and its Effects on the Tokamak Plasma Confinement, A. Salar Elahi et al., Accepted for publication in Radiation Effects & Defects in Solids (January 2012), DOI: 10.1080/10420150.2011.650171

[45] Investigation of Tokamak Plasma Fluctuations using Power Spectrum and FFT Analysis of Mirnov Coils Oscillations, Z. Goodarzi, M. Ghoranneviss and A. Salar Elahi, Accepted for the publication in J Fusion Energy (March 2012), DOI: 10.1007/s10894-012-9526-4.

[46] Controlling the Energy of Runaway Electrons by Emissive Limiter Biasing in Tokamaks, M.R. Ghanbari, M. Ghoranneviss, A. Salar Elahi et al., Phys. Scripta 85 (5), 055502, (2012), DOI: 10.1088/0031-8949/85/05/055502.

[47] Laser Fusion Energy from $P–^{7}Li$ with Minimized Radioactivity, M. Ghoranneviss, A. Salar Elahi, H. Hora, G.H. Miley et al., Accepted for the publication in Laser and Particle Beams (May 2012), DOI: 10.1017/S0263034612000341.

[48] Design and Fabrication of Emissive Biased Limiter and its Effect on Tokamak Plasma, M. Ghoranneviss et al., Accepted for the publication in Radiation Effects and Defects in Solids (June 2012).

[49] New Approaches on Application of Multipole Moments for Determination of Toroidal Plasma Shift, A. Salar Elahi et al., Accepted for the publication in Radiation Effects and Defects in Solids (June 2012), DOI: 10.1080/10420150.2012.706609.

[50] Design and Construction of Hot Limiter Biasing System for the Tokamak, A. Salar Elahi et al., Accepted for the publication in Radiation Effects and Defects in Solids (June 2012), DOI: 10.1080/10420150.2012.706607.

[51] Estimating Time dependence of Edge Plasma Turbulence in IR-T1 Tokamak, K. Mikaili Agah, M. Ghoranneviss, A. Salar Elahi et al., Accepted for the publication in J. Fusion Energy (July 2012), DOI: 10.1007/s10894-012-9563-z.