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Current Independent Approximation of Tokamak Plasma Asymmetry Factor

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Abstract In this contribution we have presented a current independent approximation of tokamak plasma asymmetry factor based on magnetic probes measurement in IR-T1 tokamak. The main advantage of this technique is that it based only on the one diagnostic (only magnetic probes and not need to plasma current measurement). Based on this method, four magnetic pickup coils were designed, constructed, and installed on outer surface of the IR-T1 tokamak chamber and then plasma asymmetry factor was measured from them. Also the result of this technique was compared with other technique (flux loops technique) and found in agreement with each other.

Keywords Tokamak, Plasma Asymmetry Factor, Magnetic Probes

1. Introduction

The tokamaks are the most promising candidate for a viable commercial fusion reactor. Before this very promising energy source can be harnessed, many scientific and technological problems must first be resolved. One of the principal problems facing magnetic confinement schemes such as the tokamak configuration is the issue of stably maintaining the plasma column within the discharge chamber. In order to accomplish this, a suitably shaped magnetic field structure must be produced.

The tokamak plasma is subjected to several forces in the major radial direction that must be dynamically counterbalanced by an appropriate magnetic Lorentz force in order to maintain plasma equilibrium in the horizontal direction [1-20]. In general, in the low beta tokamaks, radial pressure balance is achieved by the poloidal field, and also toroidal force balance is achieved by interaction of the external vertical field with toroidal current (when inward Lorentz force equal with sum of the three outward forces (hoop force, tire tube force, and 1/R force) due to the toroidal configuration of the tokamak). But, in toroidal force balance problem, the two opposite forces may not be equal, and therefore plasma intend to shift inward or outward, which is a very dangerous for tokamak plasma equilibrium. Therefore, plasma equilibrium study is one of the fundamental problems of the magnetically confined plasmas. Measurement of the tokamak plasma asymmetry factor (Λ) is essential for tokamak experiments. Very of plasma information can be deduced from this parameter, such as the plasma equilibrium state, plasma energy, plasma confinement time, plasma toroidal current profile, and Magnetohydrodynamics (MHD) instabilities [21-50]. In this contribution we presented a current independent approximation of tokamak plasma asymmetry factor only based on magnetic probes measurement in IR-T1 tokamak, which is a small, air core, low beta and large aspect ratio tokamak with a circular cross section, (see Table 1). This technique based on magnetic probes measurement for determination of plasma asymmetry factor will be discussed in section 2. In order to compare of the result, other method is also experimented. Experimental results and comparison between them will be presented in section 3. Summary and conclusion are also will be discussed in section 4.

2. Current Independent Approximation of Tokamak Plasma Asymmetry Factor based on Magnetic Probes Measurement

Because of dependence of the plasma position and plasma current distribution to the magnetic fields distributions around the plasma, therefore magnetic pickup coils give us information about the plasma equilibrium parameters such as the plasma position and plasma asymmetry factor. Poloidal and normal magnetic fields distributions around the plasma are [1, 2]:

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

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

where a, b, R_0, μ_0, and I_p are the plasma radius, chamber minor and major radiuses, free space permeability, and plasma current, respectively, and where:

$$\Lambda = \beta_p + \frac{l_i}{2} - 1 = \ln\frac{a}{b} + \frac{\pi R_0}{\mu_0 I_p}(\Delta B_\theta + \Delta B_r),$$
$$where$$
$$\Delta B_\theta = B_\theta(\theta=0) - B_\theta(\theta=\pi), \quad (3)$$
$$\Delta B_r = B_r(\theta=\frac{\pi}{2}) - B_r(\theta=\frac{3\pi}{2}).$$

Therefore, by rearranging the above equations, a current independent relation for the plasma asymmetry factor obtained:

$$\Lambda = \ln\frac{a}{b} + \frac{R_0}{b}\left(\frac{\Delta B_\theta + \Delta B_r}{B_\theta(\theta=0)+B_\theta(\theta=\pi)}\right), \quad (4)$$

where we used the quasi-cylindrical coordinates (r,θ,ϕ). Indeed, equations (1) and (2) accurate for the low β, large aspect ratio and circular cross section tokamaks as IR-T1.

Based on this technique, in the IR-T1 tokamak four magnetic probes were designed, constructed and installed. Two magnetic probes were located on the circular contour Γ of the radius $b=16.5cm$ in angles of $\theta=0$ and $\theta=\pi$ to detect the tangential component of the magnetic field B_θ and two magnetic probes are also located above, $\theta=\pi/2$, and below, $\theta=3\pi/2$, to detect the normal component of the magnetic field B_r, as shown in the Fig. (1). The magnetic fields measured by the magnetic probes consists of the desired magnetic fields produced by the plasma current as well as unwanted magnetic fields such as that produced by the toroidal field coils. This happens primarily as a result of misalignments of the probes. In order to eliminate, or at least to reduce, these stray magnetic fields, the waveforms to which they correspond are added with suitable polarity to the measured signals via an adjustable gain passive mixer. To accomplish this, the gains are adjusted in the absence of the plasma, while all other fields are present, until the coil signals are zero or as close to zero as possible. After compensation and integration of magnetic probes output, and by substituting the poloidal and normal components of the magnetic fields in Equation (4), plasma asymmetry factor was determined. Experimental results will be presented in the next section.

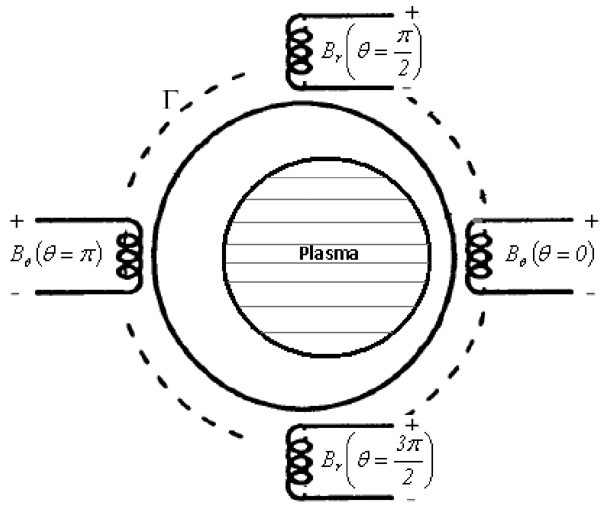

Figure (1). Positions of the four magnetic probes on outer surface of the IR-T1 tokamak chamber

3. Experimental Result and Comparison with Other Technique Result

In order to determination of the IR-T1 tokamak plasma asymmetry factor using this technique, only we needed to determination of the magnetic fields distributions around the plasma. Therefore we designed, and constructed a four magnetic pickup coils, and installed them on outer surface of the IR-T1 chamber. Then, we measured the asymmetry factor by substitution of output of magnetic probes after compensation and integration into Eq. (4).

The result of this technique and comparison with other method (flux loops technique) are presented in the Fig. (2). These figures show that the results of two techniques are in good agreement with each other. The acceptable differences between them are because of (1) approximation in measurements of magnetic fields distribution around the plasma because of discrete probes measurements and (2) large aspect ratio approximation, and (3) possible error in compensation of excessive magnetic flux.

Table 1. The range of plasma 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	$0.7\text{-}1.5\times10^{13}\ cm^{-3}$

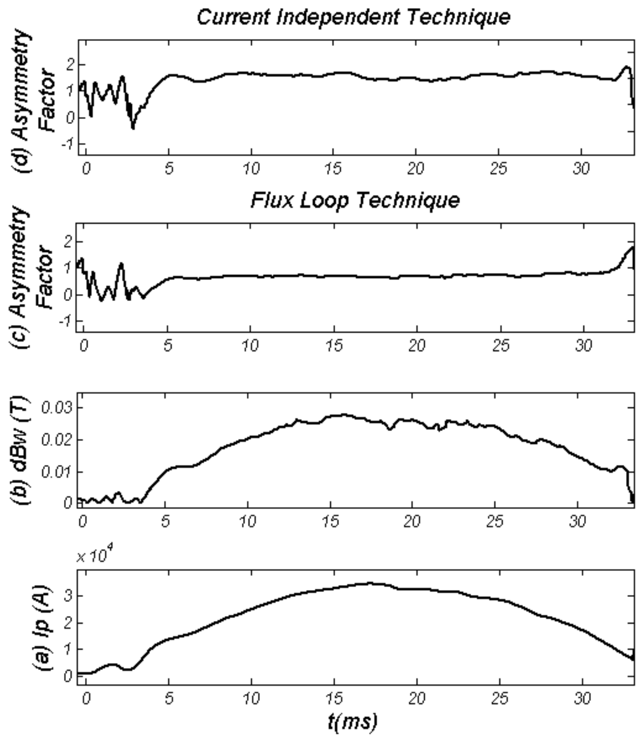

Figure (2). Time evolution of (a) Plasma current, (b) differences of poloidal magnetic fields at high field side and low field side of tokamak, (c) IR-T1 tokamak plasma asymmetry factor which determined by the flux loop technique, and (d) plasma asymmetry factor which measured using the current independent method

4. Summary and Conclusions

We presented a current independent approximation of tokamak plasma asymmetry factor based on magnetic probes measurement in IR-T1 tokamak. The main advantage of this technique is that it based only on the one diagnostic (only magnetic probes and not need to plasma current measurement). Based on this method, four magnetic pickup coils were designed, constructed, and installed on outer surface of the IR-T1 tokamak chamber and then plasma asymmetry factor was measured from them. Also the result of this technique was compared with flux loops technique and found in agreement with each other. The acceptable differences between them are because of (1) approximation in measurements of magnetic fields distribution around the plasma because of discrete probes measurements and (2) large aspect ratio approximation, and (3) possible error in compensation of excessive magnetic flux.

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, A. Salar Elahi et al., J. Plasma Physics 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 (5), 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, 045501, (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 (2), 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 (1), 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 (1), 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 (2), 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 (2), 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 (3), 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 (3), 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 (2), 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 (2), 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 (2), 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 (2), 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 (2), 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. 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. 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. Fusion Energy 31 (2), 191-194, (2012), 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 Transactions on 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., Radiation Effects & Defects in Solids 168 (9), 636-641

(2013), 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, J. Fusion Energy 32 (1), 103-106, (2013), 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-^7Li with Minimized Radioactivity, M. Ghoranneviss, A. Salar Elahi, H. Hora, G.H. Miley et al., Laser and Particle Beams 30 (3), 459-463, (2012), DOI: 10.1017/S0263034612000341.

[48] Design and Fabrication of Emissive Biased Limiter and its Effect on Tokamak Plasma, M. Ghoranneviss et al., Radiation Effects and Defects in Solids 168(1), 42-47, (2013), DOI: 10.1080/10420150.2012.706610.

[49] New Approaches on Application of Multipole Moments for Determination of Toroidal Plasma Shift, A. Salar Elahi et al., Radiation Effects and Defects in Solids 168 (9), 654-663, (2013), DOI: 10.1080/10420150.2012.706609.

[50] Design and Construction of Hot Limiter Biasing System for the Tokamak, A. Salar Elahi et al., Radiation Effects and Defects in Solids 168 (9), 642-653, (2013), DOI: 10.1080/10420150.2012.706607.