

Calculation of resonant helical magnetic fields on IR-T1 tokamak

M. Boroumand¹, P. Khorshid²

¹*Plasma Physics Research Centre, Science and Research Branch, Islamic Azad University, Tehran, Iran*

²*Department of Physics, Mashhad Branch, Islamic Azad University, Mashhad, Iran*

Abstract. The effect of externally applied resonant helical magnetic fields (RHF) on plasma column of IR-T1 tokamak was calculated. In many experimental researches RHF has been used to increase or decrease the resonance on the behaviour of the plasma column. At the beginning of this work, toroidal magnetic field calculated using the Biot-Savart law with help of numerically calculations using Gauss-Legendre in toroidal coordinates. The equation of helical windings that they mounted on vacuum chamber in a spiral modes ($L=2, n=1$) and ($L=3, n=1$), using Green function has been calculated. The coordinate system defined on a torus and an electric current applied to create a magnetic field and the magnetic field of RHF disorders of the confinement were calculated in the whole space. In this study, the shape and structure of the toroidal magnetic field before and after the application of RHF with a computational method calculated. The results shown that the magnetic resonance field in the absence of plasma flow on the direction of the magnetic field confining the plasma column is performed, it was observed that the resultant structure for $L=2$ is symmetric in 180 degrees but in the $L=3$ is less symmetric.

1. Introduction

Plasmas are confined in tokamaks by magnetic field lines on nested axisymmetric toroidal magnetic surfaces. These fields on the path of plasma particles affect and cause confinement. There are two groups of magnetic field in a tokamak which play a very important role in the creation and formation of plasmas. In link main of field in tokamak, is toroidal magnetic field which is produced by coils outside the vacuum chamber where the polar circle perpendicular around the torus cross-section [1]. This field has been calculated by using the Biot-Savart law with help of numerically calculation in toroidal coordinate [8]. The lines of magnetic field are twisted magnetic surfaces of tours. As a result, lines located on magnetic surfaces have a spiral shape around the circle and direction of the field. Alters from one level to another and confinement is placed in. [2]. In many tokamaks strong resisting instabilities are responsible for different types of disruption in plasmas. When plasma are created through ohmic heating fields resonance surfaces are formed and created perturbation and as a result, plasma confine is decreased and if not controlled, plasma will be completely destroyed as a result of crashing against wall. Therefore, on way to avoid these instabilities or limiting them is to apply to

perturbation resonance magnetic field (RHF) which is produce by conductors wound externally around the tokamak tours. In laboratories, influence of this field in eliminating instabilities and also hydrodynamic MHD mode has been observed [3]. Most of the major disruption are related to the $(m=2, n=1)$ island, the growth of $(2,1)$ mode could be influenced by applying a perturbation magnetic field [2]. The aim of this paper is to calculation of resonant helical magnetic field at the $(L=2, n=1)$, $(L=3, n=1)$ mode where L represents the number of toroidal rounds, and n represents the direction of the poloidal round and influence of perturbation magnetic field on the toroidal magnetic field is plasma IR-T1 tokamaks.

2. Toroidal Coordinate

Orthogonal systems of coordinates are chosen according to the symmetries in a given physical problem. IR-T1 tokamak is an ohmically heated air core tokamak with major radius $R=0.45\text{m}$ and minor radius $r=0.125\text{m}$ defined by two poloidal limiters. The vacuum chamber has circular cross-section with two toroidal breaks and minor radius $b=0.15\text{m}$ with a toroidal magnetic field of $B_t \approx 0.6-0.8\text{T}$. Because of type of cross section of IR-T1 tokamak, toroidal coordinate used for our calculations so that (η, ξ, φ) appear as a rotation around the z axis of two dimensional bipolar coordinates as shown in figure 1. Their relationship with rectangular coordinates (x, y, z) is given by equ. 1.

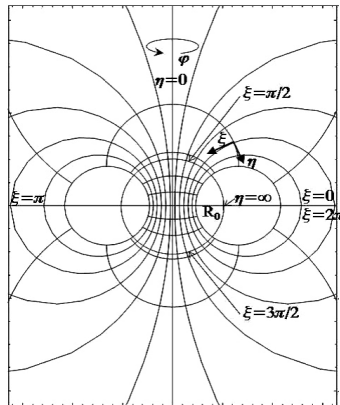


FIG. 1. Graphical representation of the toroidal coordinates system on the X-Z plane ($\varphi=0$). The toroids are generated by rotating the graph around the Z axis.

$$\begin{aligned} x &= a \frac{\sinh \eta \cos \varphi}{\cosh \eta - \cos \xi} \\ y &= a \frac{\sinh \eta \sin \varphi}{\cosh \eta - \cos \xi} \\ z &= a \frac{\sin \xi}{\cosh \eta - \cos \xi} \end{aligned} \quad (1)$$

with radii $r = a \operatorname{csch} \eta$ (minor radii) centered at $R = a \coth \eta$ (major radii) away from the z axis. The aspect ratio of the tori is defined as $\varepsilon = \frac{R}{r} = \cosh \eta$.

3. Calculation of resonant helical magnetic fields (RHF)

The RHF in IR-T1 tokamak is an external magnetic field which can improve the plasma confinement. This field is produced by two winding with optimized geometry conductors wound externally around the tokamak tours with a given helicity. The minor radius of these helical winding are 0.22m ($L=2, n=1$) and 0.23m ($L=3, n=1$) in the calculation presented here, the current through the helical windings was between $100-400\text{A}$, which is very low compared

with the plasma current itself (25-35 kA). Using Maxwell's equations, this field is calculated as follows: [10] with considering $\vec{\nabla} \cdot \vec{B} = 0$, $\vec{B} = \vec{\nabla} \times \vec{A}$ and $\vec{\nabla} \times \vec{B} = \mu_0 \vec{J}$ so,

$$A_i(\vec{r}) = \frac{\mu_0}{4\pi} \int \frac{J_i(\vec{r}') d^3\vec{r}'}{|\vec{R} - \vec{R}'|} \quad (3)$$

we are dealing with system in which its spiral current with period n round over torus which major radii R is wraps. Consequently there is a pitch angel α , which is not fixed the path length and depends on the aspect ratio and defined as follows,

$$\alpha = \tan^{-1} \left(\frac{n}{\varepsilon + \cos(n\theta + \varphi_{0j})} \right) \quad (4)$$

That ε would be aspect ratio and φ_{0j} is the place where begins wrap torsional and current density then would be: $J_\varphi = I_H \cos \alpha \delta(\eta' - \eta) \delta(\xi' - \xi) (h_\theta h_\varphi)^{-1}$ and $J_\xi = I_H \sin \alpha \delta(\eta' - \eta) \delta(\xi' - \xi) (h_\eta h_\varphi)^{-1}$ in which:

$$\begin{aligned} A_\varphi(r) &= \int J_\varphi G_{DE} d\eta' d\xi' d\varphi' \\ A_\xi(r) &= \int J_\xi G_{DE} d\eta' d\xi' d\varphi' \end{aligned} \quad (5)$$

That G_{DE} is Green Function within the vacuum chamber which is defined as follows [6],

$$\begin{aligned} G(\eta, \xi, \varphi, \eta', \xi', \varphi') &= \frac{1}{\pi} \sqrt{\cosh^{-1} \eta' - \cos \xi'} \sqrt{\cosh \eta - \cos \xi} \\ &\sum_{n=0}^{\infty} \sum_{m=0}^{\infty} \epsilon_n \epsilon_m (-1)^m \frac{P_{\frac{n-m+\frac{1}{2}}{2}}}{Q_{\frac{n+m+\frac{1}{2}}{2}}} \cos n(\xi - \xi') \cos m(\varphi - \varphi') P_{n-\frac{1}{2}}^m(\cosh \eta) Q_{n-\frac{1}{2}}^m(\cosh \eta) \end{aligned} \quad (6)$$

in which $m=2,3$ represents number of toroidal round and n represents number of poloidal round then the magnetic field can be $\vec{B} = \vec{\nabla} \times \vec{A}$.

4. Discussion

With using Dirichlet bounded condition, Ampere Law and Vector potential for $(L=2, n=1)$ and $(L=3, n=1)$ modes resonant magnetic field is calculated, obtained results from calculation this field for $(L=2, n=1)$, $(L=3, n=1)$ mods then would be; The intensity of resonant magnetic field in $(L=2, n=1)$ mode shift its direction in four place; this is where its size is reduce in minimum, however, as illustrated in Figure (2) the intensity of the field rise to its maximum around $r=0.45m$, but the more get closer to the edges of HFS and LFS, the intensity of the field decreases. Field intensity in $(L=3, n=1)$ mode shifts direction in six spots and in these spots its amount decreases to minimum. As illustrated in Figure (3) resonant field on the LFS edge is in its highest and as we move toward the HFS edge the intensity field decrease. When resonant magnetic field in the absence of plasma current on the directional magnetic field plasma column was performed, it was observed that the structure of resultant field for $L=2$ is symmetric in 180 degree and for $L=3$, this symmetric is decreased as shown in figure (4).

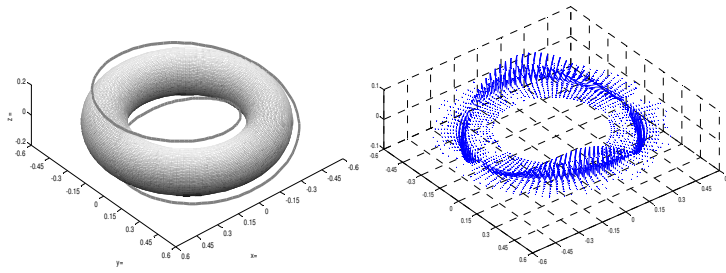


FIG.2. The resonant helical magnetic field in ($L=2$, $n=1$) mode.

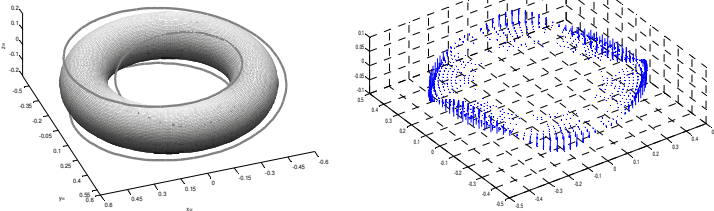


FIG.3. The resonant helical magnetic field in ($L=3$, $n=1$) mode.

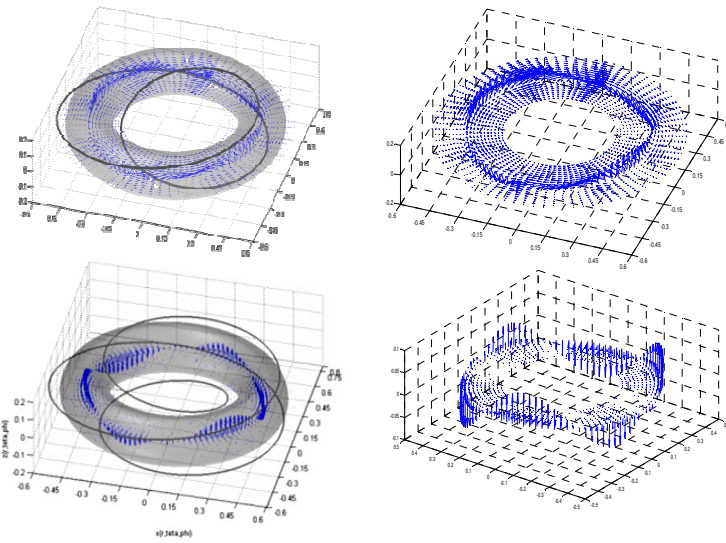


FIG.4. Influence of RHF on toroidal magnetic field in plasma column.

5. conclusion

The shape and structure of the toroidal magnetic field before and after the application of RHF with a computational method calculated. The results shown that the magnetic resonance field in the absence of plasma flow on the direction of the magnetic field confining the plasma column is performed, it was observed that the resultant structure for $L=2$ is symmetric in 180 degrees but in the $L=3$ is less symmetric. It was also observed that the intensity of perturbation resonating magnetic field in the edges area for $L=3$ is higher, therefore it could be deduced that the influence of RHF is focused more in the edges.

References

- [1] F. F. Chen, "Introduction to Plasma Physics and Controlled Fusion", 2th Edition, Los Angeles, 1984.
- [2] J. Wesson, Tokamak, Oxford University Press, New York, 1997.
- [3] S. Elgriw, D. Liu, T. Asai, A. Hirase and C. Xiao, Control of magnetic island in the STOR-M Tokamak using resonance helical field, Nucl. Fusion **51** (2011) 113008.
- [4] Philip M. Morse and H. Feshbach, Method of Theoretical Physics, McGraw-Hill (1953).
- [5] Julio. J. E. Herrera and E. Chaver Alarcon, 3D MAPTOR Code for Computation of Magnetic Field in Tokamaks, Fusion Energy (2010) (Proc. Conf. Vienna 2010) IAEA, Vienna (2010).