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ELECTROMAGNETIC AND INDUCED CURRENT ANALYSIS ON DIFFERENT TOROIDAL AND POLOIDAL SHAPED COILS USED IN TOKAMAKS: CASE STUDY

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Abstract – *This paper is mainly concentrate on electromagnetic analysis in different finite element IES software..For this analysis data for coils taken from NOVILO TOKAMAK and ADITYA TOKAMAK.There are three different kind magnetic coils like central solenoid ,Toroidal Filed coils and Poloidal filed coil used for confining plasma inside toroidal vessel.To verify magnetic filed induced at centre of coils with pulsed induced current is a challenging task, theoretically which can be equally calculated by a FINITE ELEMENT ANALYSIS package, so a same assembly for given data of those two tokamak has been modeled and meshed in IES software FEA package with same load data as given in the Theoretically. Theoretical and analysis results have been compared.*

***Index Terms** : Pulsed Electromagnetic coil, NOVILO and AADITYA TOKAMAK FEA, IES & Software.*

I. INTRODUCTION

The simplest magnetic field in a torus would be a purely toroidal magnetic field in which all the field lines form circles passing round the torus. However, a plasma placed in such a field cannot come to an equilibrium force balance. The pressure of a toroidal plasma would cause it to expand and the toroidal magnetic field is unable to provide a balancing force. The result would be a very rapid loss of the whole plasma[1].

In the tokamak this difficulty is overcome by passing a toroidal current through the plasma itself. This current produces a poloidal magnetic field, whose field lines pass the "short way" round the plasma, as shown in Figure 1.

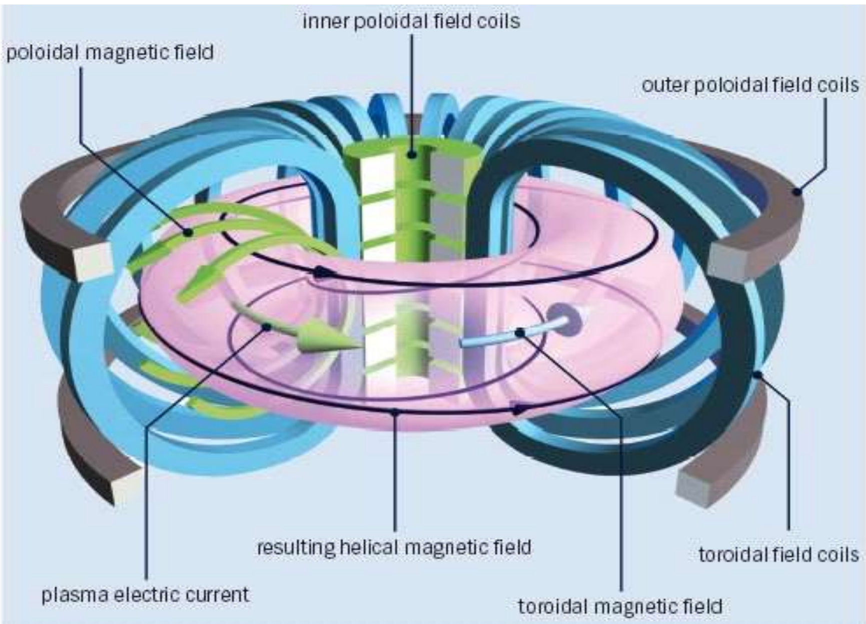

Fig-1: COILS used in TOKAMAK

This encircling magnetic field is able to hold the plasma in place and to provide an equilibrium force balance. The way in which the toroidal and poloidal magnetic fields combine is illustrated in Figure 1, the resulting field lines taking a helical path around the torus. In small tokomak most of air is used as a core of central solenoid, around which no. of coils are placed. It is required for the breakdown the gas inside the vessel for generating the plasma. **T**oroidal coils are used to create the field, which allows the plasma to circulate and to stay at the centre of the vacuum vessel. T.F. Coil is used for first ionizing the gas & then confining the plasma. Poloidal coils are used to control the plasma position during the Machine operation, in order to avoid touching of it to the walls at the starting of the system.

It is the area where the plasma is created. Its walls are covered by elements in carbon components .It is main component of tokomak which has no. of ports on it. It Placed Inside the Toroidal field coils and outside the central solenoid coils.

Simulate this coil in ANSYS software. For this coil make model and do meshing with boundary. From experiment result take some input for the ANSYS simulation . At the centre of coil get the magnetic field almost same which is nearest to the theoretical.

II. NOVILO TOKAMAK

Novillo tokamak has been taken as benchmark problem and analyzed in IES software.[6]

2..1 CENTRAL SOLENOID COIL FOR NOVILLO TOKAMAK

Table .2.1 :Electrical Parameter of Central Solenoid Coil

Electrical parameter	**Given Value**
NI MAT	1.72
N	228
I KA	0.86
a_1 m (inner Dia.)	0.07
a_2 m (Outer Dia)	0.085
L mH	0.057
R mOhm	6.7
NO.OF Coil	1

Table:2.2, Toroidal magnetic Field Coils for Novillo Tokamak

TF COIL parameter	**Given Parameter**
Major radius R_o m	0.23
Minor Radius a_p m	0.06
Major radius for TF Coil R_m m	0.26
Radius of TF Coils a_m m	0.16 ,0.14
No. turns N	360
No. of Coils	12
No. of Turn per Coils	30
No . of layer on vessel along Major radius	6
No . of layer on along vessel	5
Capacitance of Capacitor for Fast bank	62 µF
Resistivity of copper ρ_l	0.82 mΩ/m
Ampere turn of TF Coil	540774.1495
Current in TF Coil I_{TF} , A	1500
Inductance of coil mH	8.96
Resistance of coil ohm	0.29

Table:2.3 Poloidal Field Coil Coil Novillo Tokamak

Given data		
Elect. Para.	PF1	PF2
NI AT	11850	15800
No. of turn per coil	15	20
I KA	0.79	0.79
a_1 m (inner Dimen.)	1.365	0.36
a_2 m (Outer Dimen)	1.44	0.396
Z_c (centre height)	0.25 &-0.25	0.25 &-0.25
L mH	2.1	3.7
R mOhm	103	133
NO.OF Coil	2	2

2.2 E.Mag Analysis Central Solenoid Coils of Novillo Tokamak

IES : Boundary Element Method, 3D Brick, Element :500

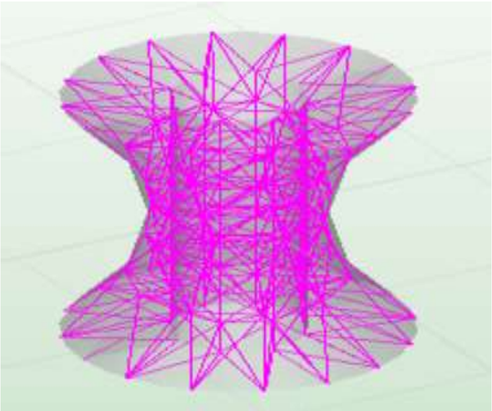

Figure 2.1 : Meshed model of central Solenoid coil

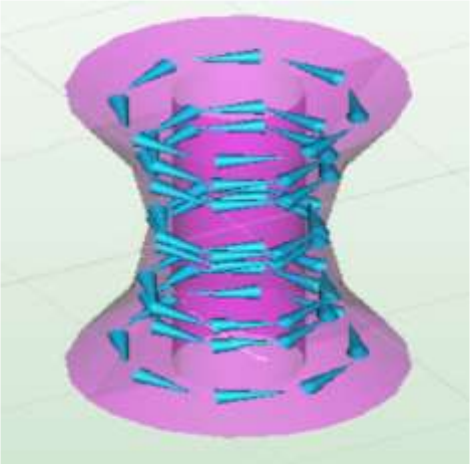

Figure 2.2. : Current Direction profile for Cs Coil

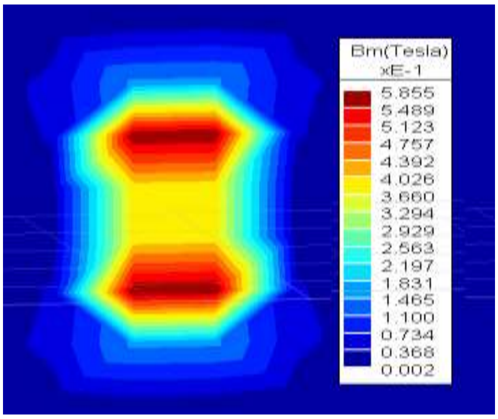

Figure 2.3. : Magnetic Field Contour

Table .2.4 : Comparison Result of CS Coil for Novillo Tokamak

	Expected Value of Literature	Result Of IES Software
Magnetic Field at Centre Of Coil ,Tesla	0.710	0.4123

2.3. E.Mag Analysis Toroidal Field Coils of Novillo Tokamak

IES : Boundary Element Method,3D Brick, Element :2500

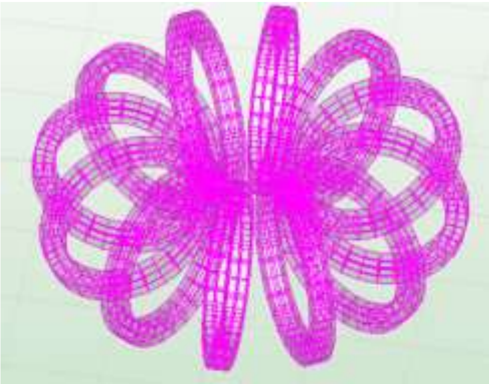

Figure 2.4 : Meshed model For TF Coils of Novillo Tokamak

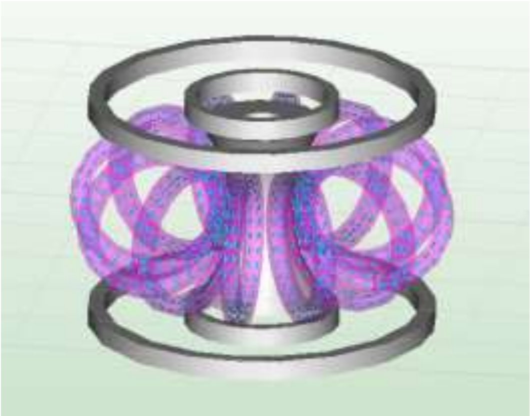

Figure 2.5: Current Injected in TF Coil

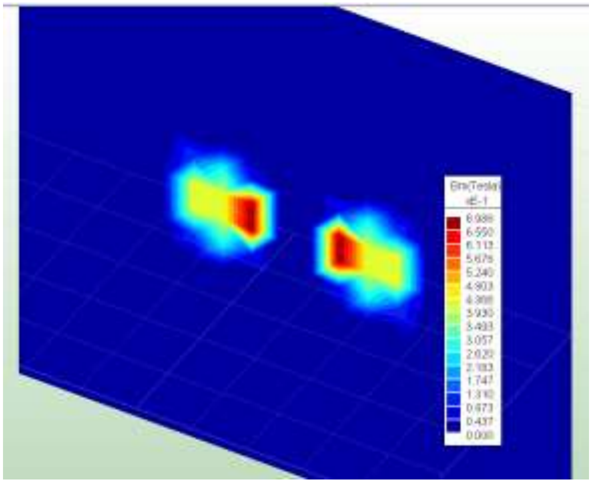

Figure 2.6 : Magnetic Field Plot of Novillo Tokamak

Table 5 :Comparison Result of TF Coil for Novillo Tokamak

Magnetic Field at Centre Of Coil ,Tesla	Expected Value of Literature	Result Of IES Software
	0.467	0.47

2.4 E.Mag Analysis Poloidal Field Coils of Novillo Tokamak

IES SOFTWARE : Boundary Element Method, 3D Brick, Element :600

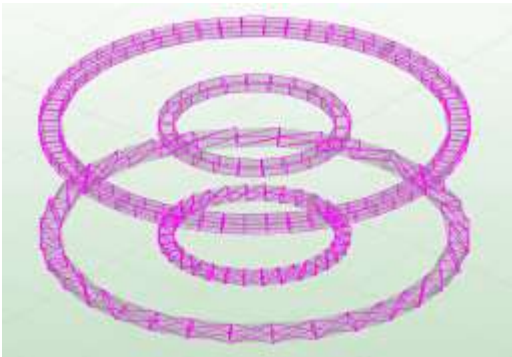

Figure 2.7: meshed of Novillo Tokamak

Figure 2.8 : Current flow in PF COIL of

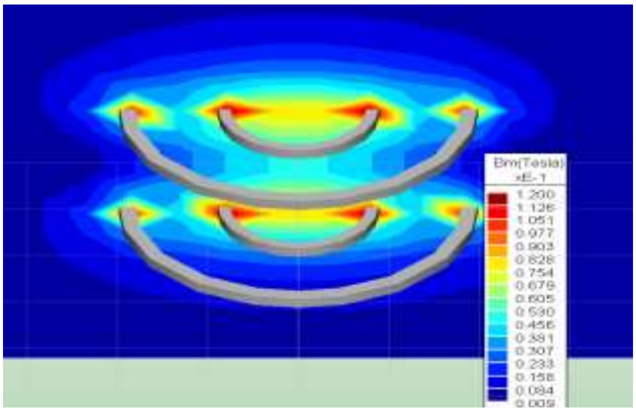

Figure 2.9: Magnetic Field Of PF Coil

Table 6 : Comparison Result of PF Coil for Novillo Tokamak

	Expected Value of Literature	Result Of IES Software
Magnetic Field at Centre Of Coil ,Tesla	0.280	0.386

2.5. E.Mag Analysis Magnetic Field Coils of Novillo Tokamak

IES SOFTWARE : Boundary Element Method 3 D Brick Element :33400

Figure 2.10 Model

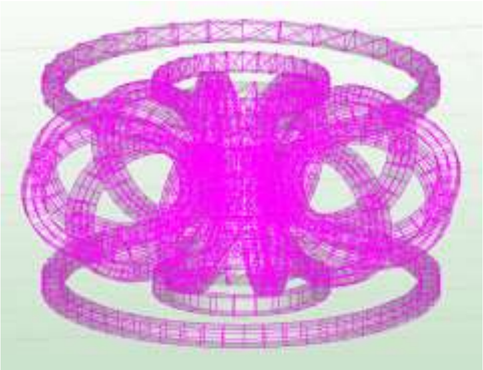

Figure 2.11: Meshing 5000 brick elements

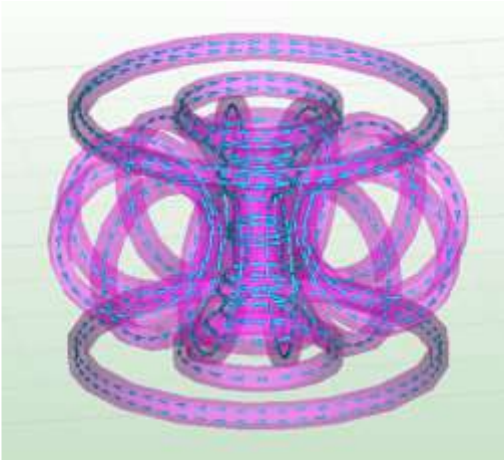

Figure 2.12 : Current injection

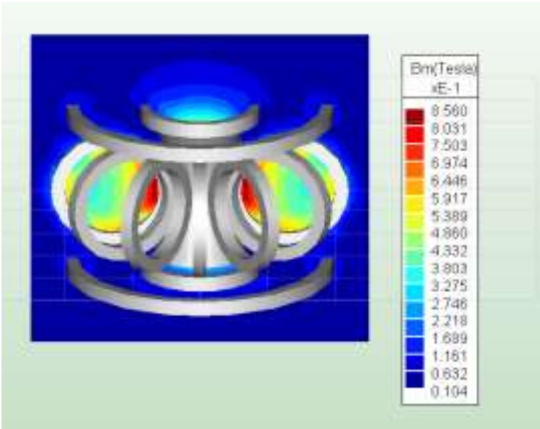

Figure 2.13: field solution

Here the magnetic field contour of NOVILLO toakamak gives out 0.47 T at the centre of the T.F. coil while literature gives it to be 0.47 T.

III. ADITYA TOKAMAK

3.2 ADITYA Tokamak : Magnetic Field Coils

Table 3.1: Electrical Parameter of Central Solenoid Coil of ADITYA tokamak

Elect. Para.	CS -1	CS -2	CS -3	CS-4
NI KAT	3306	988*2	19*2	38*2
N	174	52*2=104	2	4
I KA	19	19	19	19
a_1m(inner radius)	0.175	0.275	1.2	1.5
a_2 m (Outer radius)	0.275	0.410	1.23	1.53
Z_c (centre height)	0.0	0.78 & -0.78	0.70 &0.7	0.60 & -0.6

L mH	5.6	1.80*2	0.0180*2	0.056*2
R mOhm	3.54	1.6*2	0.11*2	0.787*2
No of coil	**1**	**2**	**2**	**2**
B T	**3.24**	**5.24**	**4.83**	**5.02**

Table 3.2: Electrical Parameter of Toroidal and Poloidal Magnetic Field Coil of ADITYA tokamak

TOROIDAL FIELD COIL		POLOIDAL FIELD COIL	
Elect. Para.	**TF**	**PF1**	**PF2**
NI MAT	5.626	**0.28**	**0.36**
N	120	**28*2**	**36*2**
I KA	46.88	**10**	**10**
a_1 m (inner Dimen.)	0.40	**0.425**	**1.365**
a_2 m(Outer Dimen)	0.465m	**0.5**	**1.44**
Z_c (centre height)	-	**0.725 &-0.725**	**1.025 &-1.025**
L mH	4	**0.92**	**9.2**
R mOhm	7.4	**7.3**	**27.4**
Major radius R_o m	0.80	**-**	**-**
NO.OF Coil	20	**2**	**2**
B T	1.5	**1.30**	**1.31**

3.3 E. MAG analysis of Magnetic field Coils of ADITYA tokamak

Aditya tokamak has been analysed in IES software as a case study. The E-MAG analysis data are equally matching to the data given in ADITYA design report. Modelling, meshing and Magnetic field solutions are shown in the figures below.

3.3.1 E.Mag Analysis central solenoid Coils of ADITYA Tokamak

IES : Boundary Element Method, 3 D Brick,Element :6780

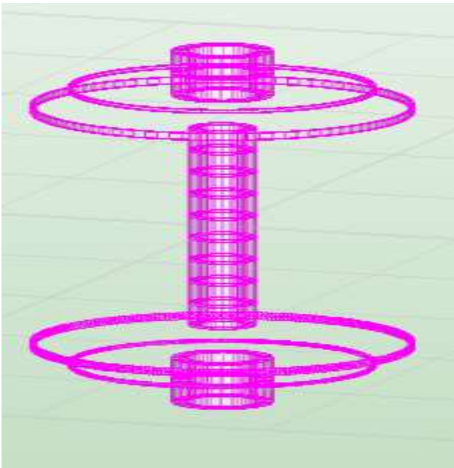

Figure 3.2: . Meshed model of C.S. coil

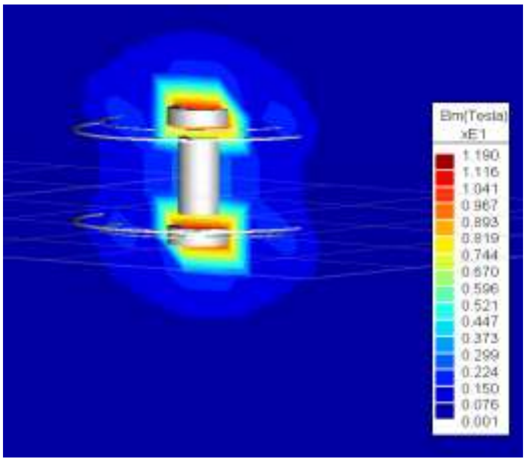

Figure 3.3 : . Flux Density plot of C.S. coil

Table 3.3 : Comparison Result of CS Coil of ADITYA Tokamak

Magnetic Field at Centre Of Coil ,Tesla	Expected Value of Literature	Result Of IES Software
	3.24	2.271

3.3.2 E.Mag Analysis Toroidal Field Coils of ADITYA Tokamak

IES SOFTWARE : Boundary Element Method, 3 D Brick,Element :28600

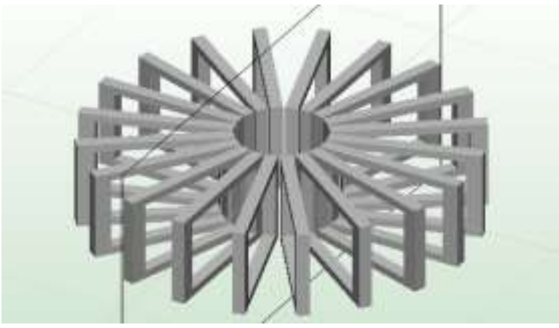

Figure 3.4: Model of TF Coil of

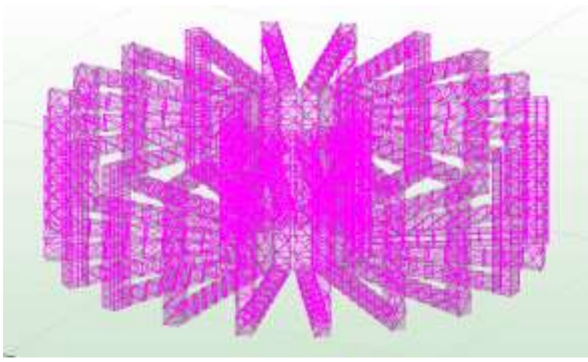

Figure 3.5: Meshed Model of TF Coil OF ADITYA

Here the magnetic field counter of ADITYA toakamak gives out 1.696 T at the centre of the T.F. coil while literature gives it to be 1.5 T.

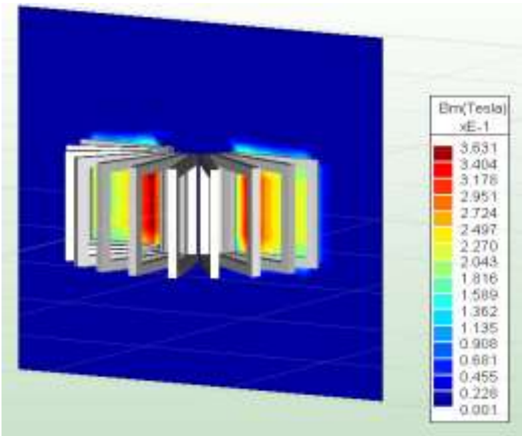

Figure 3.6 : MGNETIC Field at centre of TF Coil

Table 3.4 : Comparison Result of TF Coils of ADITYA Tokamak

Magnetic Field at Centre Of Coil ,Tesla	Expected Value of Literature	Result Of IES Software
	1.5	1.696

3.3.3 E.Mag Analysis Poloidal Field Coils of ADITYA Tokamak

IES SOFTWARE : Boundary Element Method, 3 D Brick, Element :3870

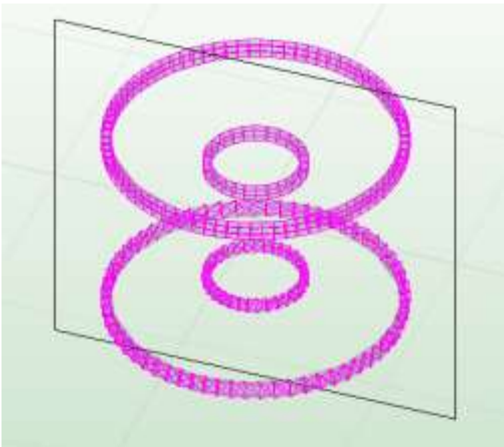

Figure 3.8 Meshed model of poloidal Field Coil

Figure 3.9 :Current injected in Poloidal Field Coil

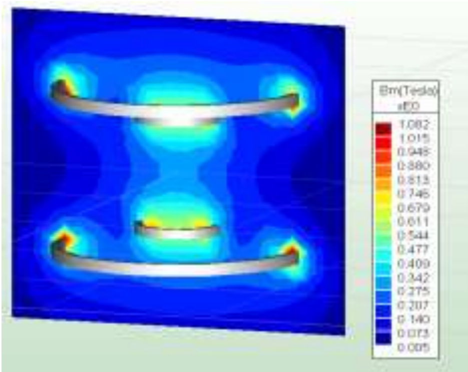

Figure 3.10: Magnetic Field Contour

Table 3.5 : Result of PF Coil of ADITYA Tokamak

Magnetic Field at Centre Of Coil , Tesla	Expected Value of Literature	Result Of IES Software
	0.1366	0.275

5.2.2.4 E.Mag Analysis Magnetic Field Coils of ADITYA Tokamak

IES SOFTWARE : Boundary Element Method, 3 D Brick,Element :39250

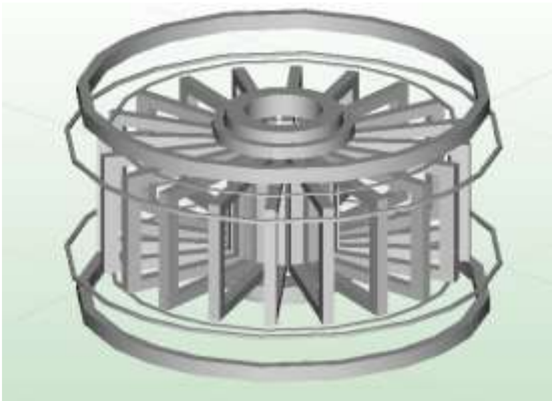

Figure 3.11 . Modeling of magnetic field coils

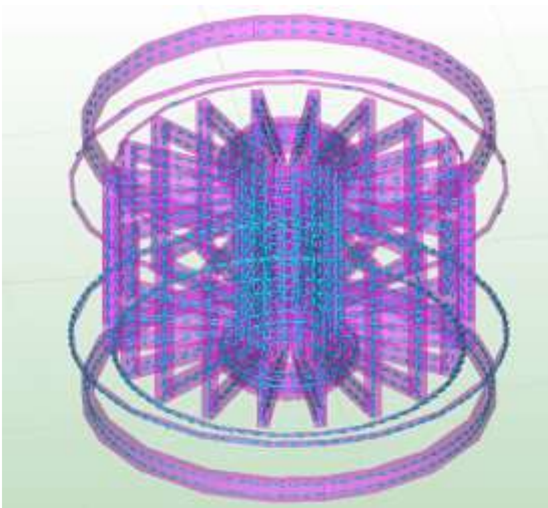

Figure 3.12 : Current injected in Magnetics Field coils of ADITYA

Here the magnetic field counter of ADITYA toakamak gives Almost same Value as given in literature .

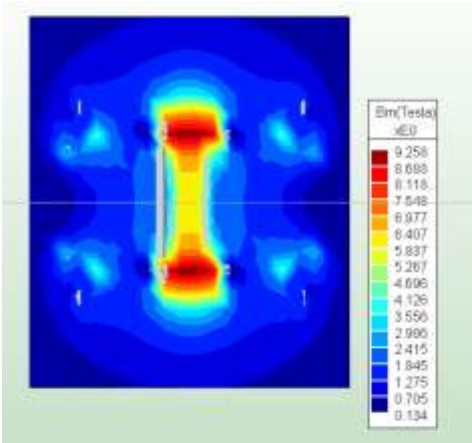

Figure 3.13 Magnetic field contour

Table 3.6 Comparison Between Practical And Ansys Result

Parameters	**Practical**	**Ansys Result**
Inner coil current	80A	80A
Outer coil current	7.01A	7.21A
Magnetic field at center Z axies	0.288T	0.2187589 T

The calculated induced current in *the graph is 7.01A in practical and 80* A in FEA package. The two obtained currents are matching in tolerable limits.

IV. CONCLUSION

From above Electromagnetic analysis foe Different Magnetic coils used in tokomak getting comparison between practical and FEA software result validated . There is difference in result due to actual geometry of Tokomak after manufacture not considered. Optimized result has been obtained with increasing the air volume and boundary condition for Finite element analysis software .In result table mismatching some where which is because of the inductance mismatch as well as discrete load data entry in ANSYS. This analysis validate all result of practical and FEA software analysis. Based on above case study design, electromagnetic analysis and experiment on magnetic coils of TOKAMAK.

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