"STRUCTURAL ANALYSIS OF DIVERTOR & BAFFEL OF STEADY STATE TOKAMAK (SST-1) FOR ELECTROMAGNETIC LOAD & THERMAL LOADS USING ANSYS SOFTWARE"

A Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY
IN
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(CAD/CAM)

By

Vipnesh Kumar Sharma
(Roll No. :-03mme12)

Department of Mechanical Engineering
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY OF SCIENCE & TECHNOLOGY,
AHMEDABAD 382 481

MAY 2005

Certificate

This is to certify that the Major Project Report entitled "STRUCTURAL ANALYSIS OF DIVERTOR & BAFFEL OF STEADY STATE TOKAMAK (SST-1) FOR ELECTROMAGNETIC LOAD & THERMAL LOADS USING ANSYS SOFTWARE " submitted by Mr. VIPNESH KUMAR SHARMA (Roll No.03MME12) towards the partial fulfillment of the requirements for the award of Degree of Master of Technology in Mechanical Engineering (CAD/CAM) of Nirma University of Science and Technology is the record of work carried out by him/her under my/our supervision and guidance. The work submitted has in my/our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of my/our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Project Guide/Guides.

Mr. B. A. Modi
Senior Lecturer
Instituteof Technology Nirma University

Dr. Y. C. Saxena
Senior Professor
Institute for Plasma Research.
Bhat, Gandhinagar – 382 428.
Gujarat (India)

Mr. N. RAVI PRAKASH
Engineer 'SD'
Institute for Plasma Research
Bhat, Gandhinagar – 382 428.
Gujarat (India)

(Prof. A.B. Patel)
Head of Dept. Mechanical Engg. Dept.
Institute of Technology
Nirma University

(Dr. H.V. Trivedi)
Director,
Institute of Technology
Nirma University

Examiners:

i.

ii.

iii.

iv.

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Abstract

With the advancement of developing technology for achieving fusion energy as the viable global energy source, the events of launching projects to develop advanced fusion devices are on their way in almost all countries. Tokamak is a Russian acronym for toroidally confined magnetic device for producing and confining plasma. Recent tokamaks are built with an aim to confine plasma for a long pulse duration of about 1000 seconds or more. Such an experimental plasma fusion device to operate at steady state called Steady State Superconducting Tokamak-1 (SST-1) is being developed at the Institute for Plasma Research, India. The machine will be operating with hydrogen plasma for a steady state operation of 1000 seconds pulse with the help of superconducting electromagnets and related technologies. From the history of existing tokamaks, it is obvious that the electromagnetic loadings due to plasma instabilities are highly detrimental in nature. These electromagnetic loads are the design drivers for all the subsystems components and supporting structures of all subsystems of the tokamak.

Up to recent days, all the above mentioned designs have been achieved with dedicated software codes that are developed at the user ends. The codes are having a limitation of carrying out the simulation in actual model or in three dimensions. In addition, the codes are inbuilt with more approximations both in geometries as well as the type of loadings. Hence a software program with more promising results is sought by the fusion community. ANSYS is the software that has been keenly programmed with many a sort of problems in electromagnetic for which ANSYS has provided more accurate and better solution for the actual geometry in existence.

As a part of dissertation work, a detailed study on the Structural analysis for thermal and electromagnetic loads at transient conditions for divertor and baffles is needs to carry out. The eddy currents are produced on the stabilizer cage surrounding the plasma in SST-1 due to the change in position of plasma due to instabilities. The resulting electromagnetic forces on components due to the induced currents have to be analyzed for the components. The divertor and baffle plates are designed indigenously and final design has been completed and the component is under fabrication. The actual geometry of stabilizers has been modified with bolt holes and other requirements in the tokamak. The vacuum vessel of sst-1 machine will be baked to a temperature of 200 ^{0} C and component will be at 350 ^{0} C. There will be induced thermal loads on the components due to differential thermal expansion during the baking process & the induced stresses have to be analyzed.

The project work has to evaluate the exact currents that will be induced on the components with the actual modeling of geometry and with a mapped meshing. The works also involves the theoretical back for the complete mechanism to compare the analysis results.

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NOMENCLATURE

SST-1	Steady state Superconducting Tokamak-1
ITER	International Thermonuclear Experimental Reactor
PFC	Plasma Facing Component
IDP	Inboard Divertor Plates
ODP	Outboard Divertor Plates
BAF	Baffle
OABAF	Outboard Auxiliary Baffle
IPS	Inboard Passive Stabilizer
OPS	Outboard Passive Stabilizer
VDE	Vertical Displacement Event
LHCD	Lower Hybrid Current Drive
ELM	Edge Localized Mode
MHD	Magneto Hydrodynamic.
ICRH	Ion Cyclotron Resonance Heating
NBI	Neutral Beam Injection
T	Tesla
KA	Kilo Ampere
FEA	Finite Element Analysis
FE Model	Finite Element Model
TF coil	Toroidal Field Coil

CONTENTS

1.1. Tokamaks

The tokamak is the most successful device developed so far to attain the conditions for fusion. It is a toroidal device (shaped like a car tire) in which a vacuum vessel contains a plasma ring confined by twisting magnetic fields. The word tokamak is an acronym for the Russian words ***to*roidal'naya *ka*mera *ma*gnitnoi *k*atushki**, meaning toroidal chamber and magnetic coil. [1]

1.2. Tokamak configuration

The transient electric current that circulates in the primary coil of a tokamak induces a current in the plasma ring, which both heats the plasma and produces the poloidal magnetic field. The other important component is the toroidal magnetic field, which is generated by electric currents circulating in the toroidal field coil rings around the torus. In addition, the currents circulating in the position control coils generate auxiliary magnetic field components that modify the poloidal field, equilibrating the plasma ring and controlling its position. It is the combination of toroidal and poloidal magnetic fields that leads to the improved confinement of tokamak plasmas. [1]

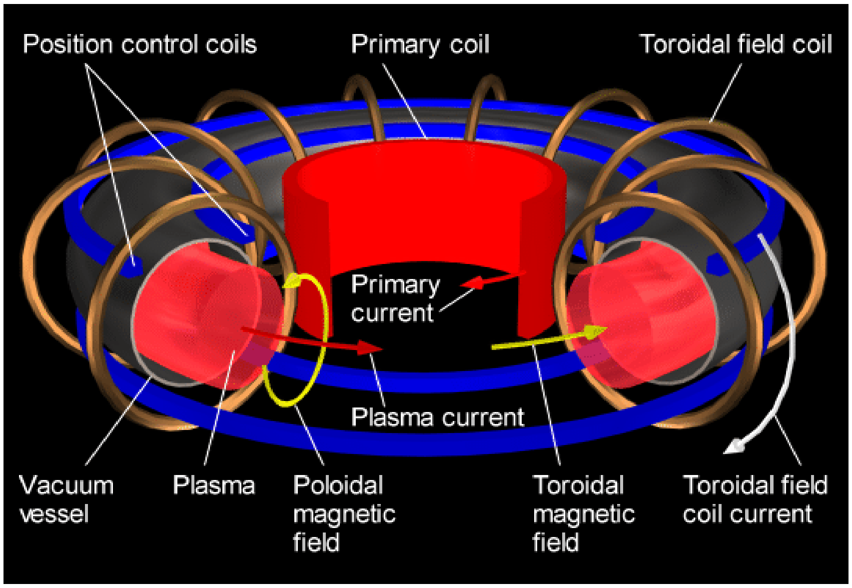


Fig 1.1 Main component of Tokamak type Magnetic confinement system

1.3 Principle of Fusion reactor (Tokamak)

For a long time the Fusion community has attempted to define what the future current generating fusion reactor might be like. Studies have been carried out, which set out the outlines and the details of what a fusion reactor could be. In addition to these forecasts, the detailed engineering studies performed in the ITER project, which, although not totally representative, have, all the same, precisely defined most of the main components of the reactor. The diagram of the principle of the electro-generating reactor is shown in Fig 1.2.

The deuterium-tritium fuel mixture is injected (1) into a chamber, where, thanks to a system of confinement it goes into a plasma state and burns (2). In doing so, the reactor produces ash (helium atoms) and energy in the form of fast particles or radiance (3). The energy produced in the form of charged particles and radiance, is absorbed in a special component, the "first wall" which, as its name illustrates, is the first material element encountered by the plasma. The energy, which appears in the form of kinetic energy in neutrons, is, for its part, converted into heat in the breeding blanket (4): which is the element beyond the first wall, but nevertheless inside the vacuum chamber. The vacuum chamber itself is the component enclosing the area where the fusion reaction takes place. The first wall, blanket and vacuum chamber are obviously cooled down by a heat extraction system. The heat is used to produce steam and supply a conventional turbine and alternator electricity producing system (5).

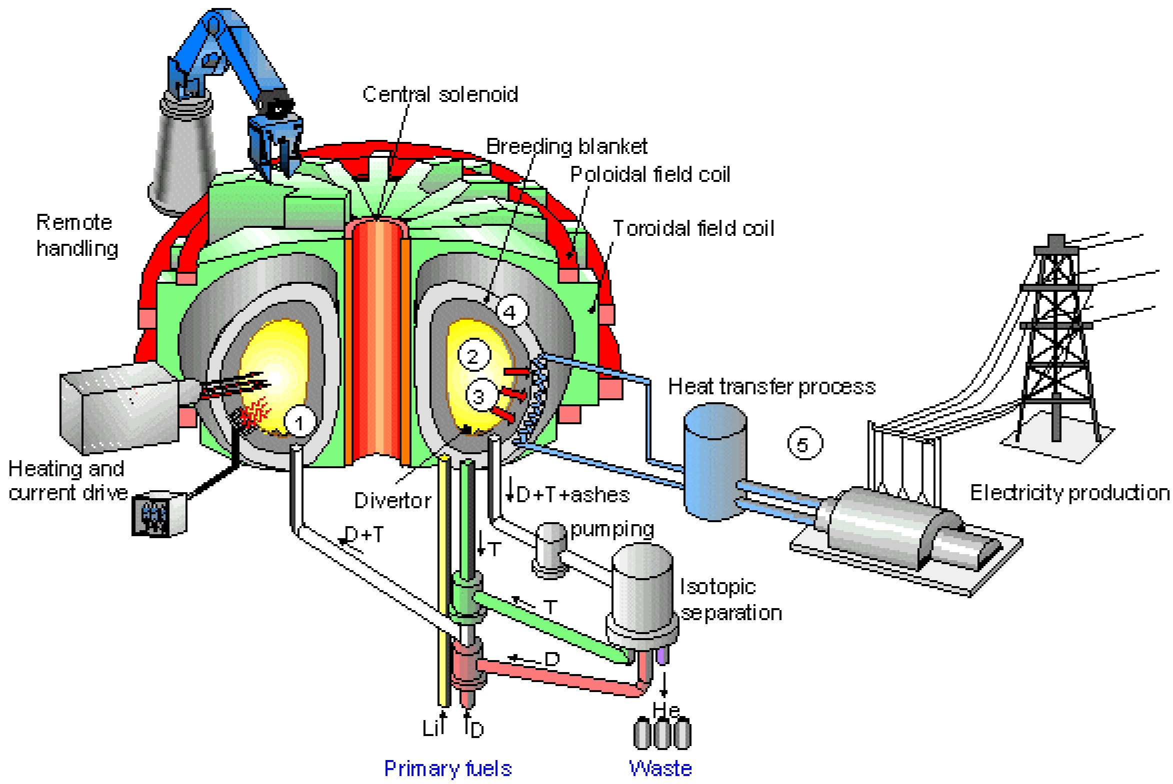


Fig 1.2 Principle of Fusion reactor for generating electricity

1.4. Research on Tokamak

The present generation of the TOKAMAKS is concentrating their research on some major factor describe in following paragraphs.

1.4.1. Confinement

By studying how matter and heat are transported through the magnetic field, scientists can analyze and describe the plasma particle and energy confinement. This means surveying a large number of parameters (magnetic field, current, density, temperature, etc.) and measuring the space-time profiles of numerous characteristics of the plasma.

1.4.2. Plasma-purity

Impurities released by wall-plasma interactions increase radiation losses and dilute the fuel. By operating with a magnetic limiting device, the plasma can be kept away from the material components with which it would otherwise come into contact. Coating the wall with low atomic number materials (B, Be, C) helps to reduce plasma contamination due to release of heavier metal atoms from the confining structures (as SS).

1.4.3. Steady-state or virtually steady-state operation

A transformer can induce a current in the plasma for only a short time. However, if the current is generated by non-inductive methods (such as a neutral beam or radiofrequency waves) it can be maintained.

1.4.4. Disruptions

Tokamaks operate within a limited parameter range. Outside this range sudden losses of energy confinement can occur. These, known as disruptions, cause major thermal and mechanical stresses to the structure and walls If the early warning signs of such D-disruptions can be identified, preventive measures will be possible in future devices

1.4.5. International Thermal Experimental Research (ITER)

Scientists and engineers from China, Europe, Japan, Korea, Russia, and the United States are working in an unprecedented international collaboration on the next major step for the development of fusion - ITER (which means "the way" in Latin).

ITER's mission is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. To do this, ITER will demonstrate moderate power multiplication, demonstrate essential fusion energy technologies in a system integrating the appropriate physics and technology, and test key elements required to use fusion as a practical energy source.

ITER will be the first fusion device to produce thermal energy at the level of an electricity-producing power station. It will provide the next major step for the advancement of fusion science and technology, and is the key element in the strategy to reach the following demonstration electricity-generating power plant (DEMO) in a single experimental step.

ITER is an experimental fusion reactor based on the "tokamak" concept - a toroidal (doughnut-shaped) magnetic configuration in which to create and maintain the conditions for controlled fusion reactions. The overall ITER plant comprises the tokamak, its auxiliaries, and supporting plant facilities.

In ITER, superconducting magnet coils around a toroidal vessel confine and control a mix of charged particles - the "plasma" - and induce an electrical current through it. Fusion reactions take place when the plasma is hot enough, dense enough, and contained for long enough for the atomic nuclei in the plasma to start fusing together.

The tokamak concept was first developed in Russia and has since been brought to a high level of development in all the major fusion programs of the world.

To meet its objectives, ITER will be much bigger (twice linear dimensions) than the largest existing tokamak and its expected fusion performance will be many times greater. These extrapolations in size and physics performance provide the major challenges to the design of ITER.

The ITER experiment (ITER means "the way") is designed to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. Following on from today's largest fusion experiments worldwide, ITER aims to provide the know-how to build subsequently the first electricity-generating power station based on magnetic confinement of high temperature plasma - in other words, to capture and use the power of the sun on earth.

ITER will test all the main new features needed for that device - high-temperature-tolerant components, large-scale reliable superconducting magnets, fuel-breeding blankets using high temperature coolants suitable for efficient electricity generation, and safe remote handling and disposal of all irradiated components. ITER's operating conditions are close to those that will be experienced in a power reactor, and will show how they can be optimized, and how hardware design margins can be reduced to control cost.

ITER began in 1985 as collaboration between the then Soviet Union, the USA, Europe (through EURATOM) and Japan. Conceptual and engineering design phases led to an acceptable detailed design in 2001, underpinned by $650M worth of research and development by the "ITER Parties" to establish its practical feasibility. These (with the Russian Federation replacing the Soviet Union and with the USA opting out of the project between 1999 and 2003) have been since joined in negotiations on the future construction, operation and decommissioning of ITER by Canada (who terminated their participation at the end of 2003), the People's Republic of China and the Republic of Korea. The project is expected cost ~$10 billion over its complete life. Constructing and operating ITER is the essential step to determining whether magnetic confinement of plasma can be usefully employed by humankind for centralised electricity generation in the latter half of this century, and this dream will be brought much closer to reality by the choice of its site. [2].

1.5. Tokamak Economics:

The aim of tokamak research is to build a reliable power producing system. As this goal is approached economic question will become more insistent. The cost of an electricity power has two basic components. The first part is the heat producer, which is different for the different fuels. The second part is that which transform the heat into electricity and consists basically of turbines and generators. In the case of a tokamak fusion station the cost of the reactor itself will dominate that of the convential plant, John Wesson [1].

1.6. Steady State Superconducting Tokamak (SST-1)

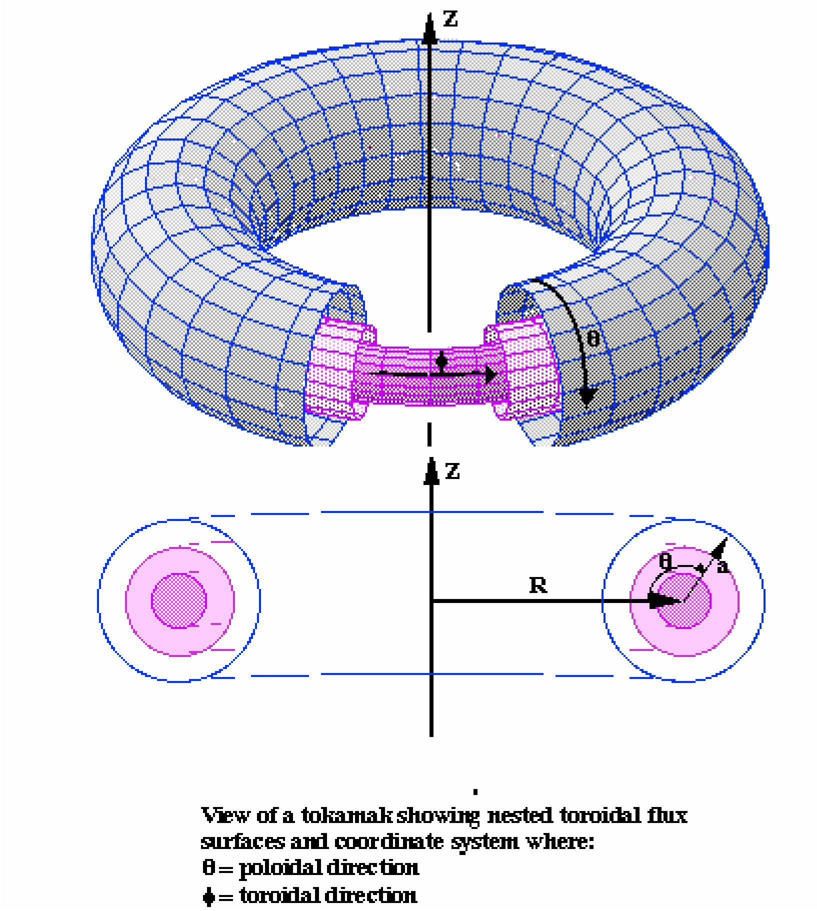


Fig 1.3 View of a tokamak showing nested toroidal flux

The word tokamak means "toroidal chamber" in Russian. It is a magnetic fusion device that is in a shape of a torus (e.g. a doughnut), and which depends on external windings for generating a strong toroidal magnetic field (i.e. in the direction along the doughnut). Poloidal magnetic fields (in the direction of the doughnut's cross-section) are created primarily by a toroidal current inside the plasma itself and then are processed. This combination of toroidal and Poloidal magnetic fields generates an overall nested helical structure which is necessary to keep the plasma stable. (See the image on above) The tokamak is presently the leading candidate design for a future "working" magnetic fusion device.

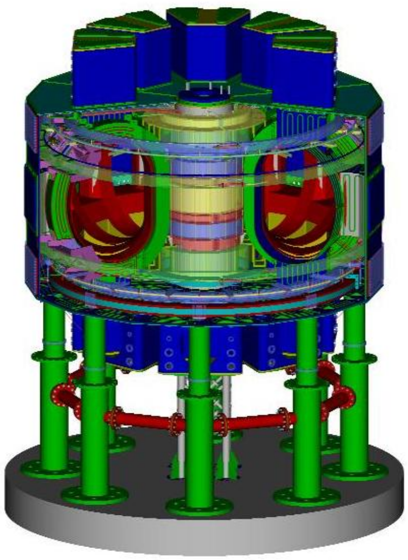
Tokamak is an installation for hot plasma creation and for researches on nuclear fusion. Tokamak consists of a doughnut (a toroidal vacuum chamber), which surrounds a core of a great transformer. The chamber is filled with an ionized gas (deuterium or deuterium and tritium). The transformer causes magnetic field. The field induces electric current. The current causes gas discharges and the ionization and the heating of the gas increases. Finally hot plasma is created. It is held in a compact column inside the ring thanks to the strong magnetic field. First tokamak was built in 1950 in Moscow. In Great Britain there is a great tokamak called JET. On November the 9th 1991 an experiment was held in JET. The reaction was held for about two hours and produced the power of about 1 megawatt. Other great Tokamaks are TFTR-Princeton (USA) and JT-60 (Japan).

The Steady state Superconducting Tokamak (SST-1) is being designed and built at the Institute for Plasma Research, Gandhinagar (Gujarat). The goal of present day Tokamak research is to ultimately develop a “Fusion Reactor” which is the source of unlimited amount of useful energy and is safe also .this project is unique in the sense that, unlike most of the existing Tokamak in the world, it is aimed at developing a Tokamak that can be operated in steady state mode.

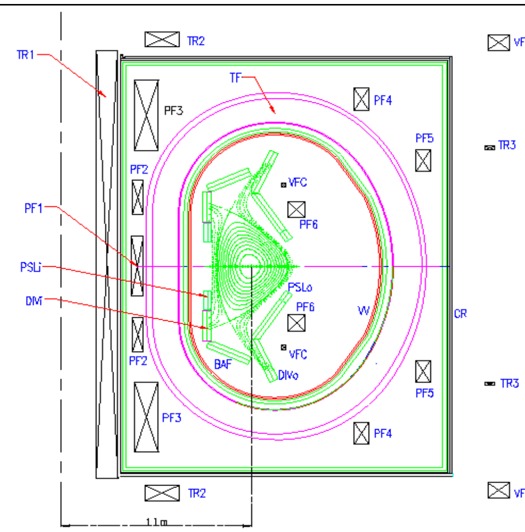
1.6.1. SST-1 Tokamak at Institute for Plasma Research

In India Institute For Plasma Research is working for the development of the fusion technology .The Institute for Plasma Research (IPR) is located in a peaceful and green campus on the bank of the Sabarmati River near Gandhinagar, Gujarat. It was established in 1986 with a mandate to pursue research in Plasma Science, especially on magnetically confined (Tokamak) plasmas, to promote industrial applications of plasma based technologies and to simulate plasma research in Indian Universities. Having built India’s first Tokamak, ADITYA, which has been in operation since 1990, IPR is erecting a new machine- the Steady-state Superconducting Tokamak (SST-1). IPR has also set up a Facilitation Center for Industrial Plasma Technologies (FCIPT) which is engaged in plasma based projects of interest to Indian industries. The term ‘Plasma’ refers to an ionized state of matter. The production, confinement and the diagnosis of plasmas being truly multi-disciplinary activities, the IPR faculty consists of scientists and engineers from a wide range of disciplines engaged in research in:

- Electrical discharge phenomena
- Plasma confinement, waves & instabilities
- Plasma surface interactions
- Particle and energy transport in plasmas
- Non-neutral, dusty and quark-gluon and such ‘exotic’ plasmas
- Plasma heating by high power RF radiation and fast neutral beams
- Pulsed power technology
- Novel plasma diagnostic techniques



3D model of SST-1



Sectional view

Fig.-1.4. SST Assembly

Elongation improves the current carrying capacity of the plasma. The choice of the parameters is dictated by the technological and physics goals

1.6.2 Machine Parameters

A list of various plasma parameters for SST 1 is given below. [3]

Table 1.1 Plasma Parameters

1.	MAJOR RADIUS	1.1m
2.	MINOR RADIUS	0.2 m
3.	ASPECT RATIO	5.5
4.	ELONGATION	1.7-2
5.	TRIANGULARITY	0.4-0.7
6.	TOROIDAL FIELD	3T
7.	PLASMA CURRENT	220 kA
8.	AVERAGE DENSITY	1X 1013cm^{-3}
9.	AVERAGE TEMP.	1.5 keV
10.	PLASMA SPECIES	HYDROGEN
11.	PULSE LENGTH	1000S
12.	CONFIGURATION	DOUBLE NULL POLOIDAL DIVERTOR
13.	HEATING & CURRENT DRIVE	LOWER HYBRID
14.	AUXILIARY HEATING	ICRH, ECRH & NBI

1.6.3. Major subsystems of SST-1

Some of the major subsystems are as follows:

- Vacuum Vessel
- Vacuum Pumping Systems
- Super Conducting Magnets
- Cryogenics
- High Power RF sources
- Large Power Supply Systems
- Neutral Beam Injector
- Plasma Facing Components
- Plasma Diagnostics Systems
- Data acquisition and control systems

1.6.4. Aditya Tokamak

ADITYA is the first indigenously designed and built tokamak of the country. It was commissioned in 1989. ADITYA, a medium size Tokamak, is being operated for over a decade. It has a major radius of 0.75m and minor radius of the plasma is 0.25 m. A maximum of 1.2 T toroidal magnetic field is generated with the help of 20 toroidal field coils spaced symmetrically in the toroidal direction. The major subsystems and parameters of the machine have been described elsewhere.

ADITYA is regularly being operated with the transformer-converter power system. 100 msec 80 - 100 kA plasma discharges at toroidal field of 8.0 kG are being regularly studied. During this period experiments on edge plasma fluctuations, turbulence and other related works have been conducted.

In 1990, annual per capita primary energy consumption was 2.2e11 Joules or 5.1 toe (Tones of oil equivalent) in the industrialized countries –ten times more than in developing countries. In 2050, world primary energy consumption could be anything from two to three times its current level, depending on which energy demand scenario is chosen (see the table below). Most of this demand will have to be met by:

- Fossil fuels (mainly coal, because crude oil and natural gas reserves will be greatly depleted).
- Nuclear energy: fission and fusion.
- Renewable energy resources: hydroelectric, solar, wind, wave, tidal, geothermal, biomass, etc.

Table 2.1 Annual consumption & demand

Group of countries	Per capita (toe/year)			Global demand (toe/year)		
	1988	2050		1988	2050	
		Standard	Low		Standard	Low
OECD	5.2	5.2	2.6	4.0	4.6	2.3
Central & Eastern European countries	4.4	4.4	2.2	1.9	2.1	1.1
Developing countries	0.5	1.5	1.0	2.0	13.8	9.2
World (total)	1.5	2.0	1.2	7.9	20.5	12.6

Even though renewable resources will probably be able to meet a greater proportion of the world's energy requirements than they do at present, experts agree that they will not be able to satisfy the total demand. New energy options must therefore be developed systems which are optimally safe, environment-friendly and economical. Controlled thermonuclear fusion is one of these rare options.

2.1. Fusion

Fusion is simply combining the nuclei of light elements to form a heavier element. This nuclear reaction results in the release of large amounts of energy – typically a million times more energy than can be obtained by combining atoms chemically (such as burning coal).

In a fusion reaction, the total mass of the resultant nuclei is slightly less than the total mass of the original particles. This difference is converted to energy as described by Einstein's famous equation:

$E = mc^2$

2.1.1. Fusion Reaction

First-generation fusion reactors will use deuterium and tritium, isotopes of hydrogen, for fuel. Deuterium occurs naturally in nature - about one part in 6000 is found in ordinary water. Tritium can be produced from lithium. Reactions of Primary Interest for Fusion are given in Table 2.1

Table 2.2 Reactions of Primary Interest for Fusion

Reaction	Energy Released	Energy Threshold
D + T → 4He + n (14.1 MeV)	17.4 MeV	4 KeV (4.5×107 °K)
D + D → T + p D + D → 3He + n (2.5 MeV)	4.0 MeV 3.25 MeV	35 KeV (4.0×108 °K)
D + 3He → 4He + p	18.2 MeV	30 KeV (3.5×108 °K)

In order or fusion reaction to occur, the particle must be hot enough (temperature), in sufficient no. (Density) and well contained (confinement time) these simulation condition represented by a fourth state of matter known as plasma, electron are stripped from their nuclei. Plasma is therefore consisting of charged particles, ions and electron. There are three principle mechanism for confining these hot plasma – magnetic, inertial and gravity

2.2. Plasma

The history of plasma physics parallels the development of electricity and magnetism. In fact, plasma physics today can trace its origin to the merging of two distinct paths of physics: gaseous discharge and ionosphere/astrophysics studies.

Fig 2.1 Plasma Physics

Plasma is by far the most common form of matter. Plasma in the stars and in the tenuous space between them makes up over 99% of the visible universe and perhaps most of that which is not visible. On earth we live upon an island of "ordinary" matter. The different states of matter generally found on earth are solid, liquid, and gas. We have learned to work, play, and rest using these familiar states of matter. Sir William Crooke's, an English physicist, identified a fourth state of matter, now called plasma, in 1879.

Plasma temperatures and densities range from relatively cool and tenuous (like aurora) to very hot and dense (like the central core of a star) Ordinary solids, liquids, and gases are both electrically neutral and too cool or dense to be in a plasma state. The word "PLASMA" was first applied to ionized gas by Dr. Irving Longmuir, an American chemist and physicist, in 1929. Plasma consists of a collection of free-moving electrons and ions - atoms that have lost electrons. Energy is needed to strip electrons from atoms to make plasma. The energy can be of various origins: thermal, electrical, or light (ultraviolet light or intense visible light from a laser). With insufficient sustaining power, plasmas recombine into neutral gas. Plasma can be accelerated and steered by electric and magnetic fields, which allows it to be controlled and applied. Plasma research is yielding a greater understanding of the universe. It also provides many practical uses, new manufacturing techniques, consumer products, and the prospect of abundant energy.

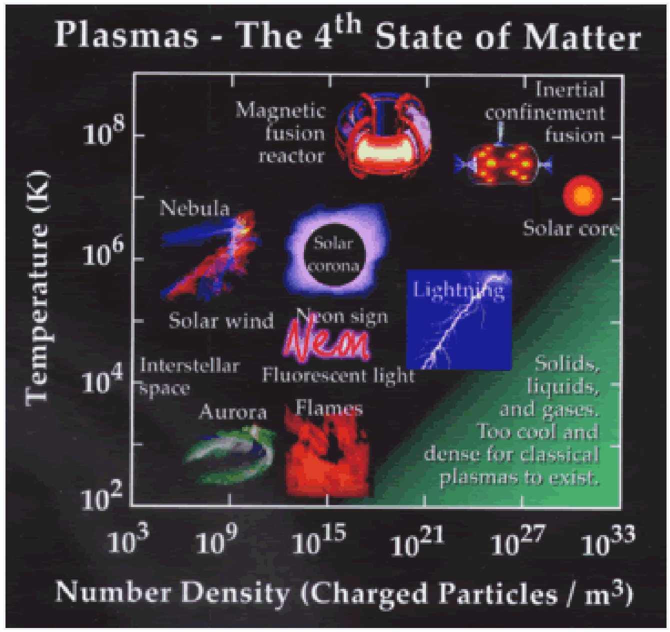


Fig 2.2 Characteristics of Plasma

Plasma consists of freely moving charged particles, i.e. electron and irons. Formed at high temperature when electrons are stripped from the natural atoms Plasma is common in nature. Plasma are a “forth state of matter” because of their unique physical properties, distinct form solids, liquids, and gases. Plasma densities and temperature vary widely.

Each matter in the universe is bounded in three states: Solid, liquid and gases. The plasma state is the fourth state of matter. Heating solid makes liquid, heating liquid makes gas and heating a gas makes plasma. When gas heated particles gain energy some gas particles get ionized.

Plasma is a mixture of gaseous molecules, atoms, ions and electrons that exhibit collective behavior plasma contains a significant fraction and of charged particles in which potential energy of a typical particle due to its nearest neighbor is much smaller than its kinetic energy. Local imbalances of negatively and positively charged particles give rise to electrical fields motion of charge creates a current that produces a magnetic field. The electrical magnetic fields can affect motion of the particle at large distance particle motion that depends not only on local condition but also on remote condition is called collective behaviors. It is this collective behavior that sets plasma apart other states of matter.

Plasma is often called the "Fourth State of Matter," the other three being solid, liquid and gas. A Plasma is an ionized gas .When fully ionized it is composed entirely of ions and electrons. These components have many of the properties of the normal gas. For example they can be described by their particle density and temperature. However, a plasma has two characteristic properties, Firstly the electric charge density of the two species is so large that any substantial separation would lead to a very large restoring force, and as consequences the ion and electron densities in plasma are almost equal. The second property is the ability to carry a current as result of a relative drift between the ions and electrons .Plasma is a distinct state of matter containing a significant number of electrically charged particles, a number sufficient to affect its electrical properties and behavior. In addition to being important in many aspects of our daily lives, plasmas are estimated to constitute more than 99 percent of the visible universe.

Plasma consists of a collection of free-moving electrons and ions- atoms that have lost electrons. Energy is needed to strip electrons from atoms to make plasma. The energy can be of various origins: thermal, electrical, or light (ultraviolet light or intense visible light from a laser). With insufficient sustaining power, plasmas recombine into neutral gas, [4].

2.3 Plasma confinement by magnetic field

Plasma like a gas will occupy all geometrical space available, because of collision between the particles. Magnetic field can confine plasma, because the ions & electrons of which it consists will follow helical paths around the magnetic field lines.

If a vessel containing plasma is pleased in a rectilinear magnetic field the particle of plasma cannot reach the side wall, but they will strike the ends of vessel. To prevent particles from coming in contact with the material walls in this way, two type of configuration have been studied:

Linear configurations in which the intensity of the magnetic field increased at the ends of container so that particle are reflected by the magnetic mirror before they can come into contact with any material. Unfortunately particle collision effect renders the system liable to high particle losses at the mirror point and such systems are no longer being considered as potential rectors.

Toroidal configuration in which the risk of losses is removed by curving the magnetic lines around to form a closed loop Theoretical study of particle trajectories shows that, if the particles are to be confined, the toroidial field must have superimposed upon it a field component perpendicular to it (i.e. a poloidal field). The force line of the total field thus become spiral (helical) paths along and around which the plasma particles are guided The PF Coil system is comprised of nine SC coils (PF1 to PF5) and two normal copper coils (PF6). The PF6 coils are placed in the bore of the TF coils inside the vacuum vessel. They are required to obtain plasma shapes with high triangular. In the absence of PF6 coils, large numbers of ampere turns are required in the external PF coils to obtain similar triangularity. The PF coils allow for a wide range of elongation and triangularity and support wide range of plasma equilibrium

2.4. Plasma Heating:

The most efficient way to heat tokamak plasma is by passing through it a current induced by the primary coil. This coil is the primary circuit of a transformer in which the plasma ring constitutes the secondary circuit. It works like an electric heater, the amount of heat generated depending on the current and the resistance of the plasma. Unfortunately, the plasma resistivity decreases as the temperature rises and the heating process becomes less effective. The maximum temperature that can be achieved in tokamaks by the resistive heating (or ohmic heating) method is about 3×10^7 K, twice the temperature in the center of the sun but less than needed to startup a reactor, about 10^8 K. In tokamak experiments auxiliary heating is used to reach temperatures currently as high as 5×10^8 K (more than 30 times the temperature at the sun-center). The two main methods of additional heating is by the injection of high-energy neutral particle beams and radiofrequency waves of various types. Ref [4]

2.5. Plasma Facing Components:

The in-vessel components, which are in direct vicinity of the plasma, are called the Plasma Facing Components (PFC) or First Wall Components (FWC) (shown in figure 2.1 & 2.2). PFC or the first wall of a tokamak is expected to receive high heat and particles fluxes during normal and off load operations. They are also subjected to large electromagnetic forces induced by plasma disruption and halo currents.

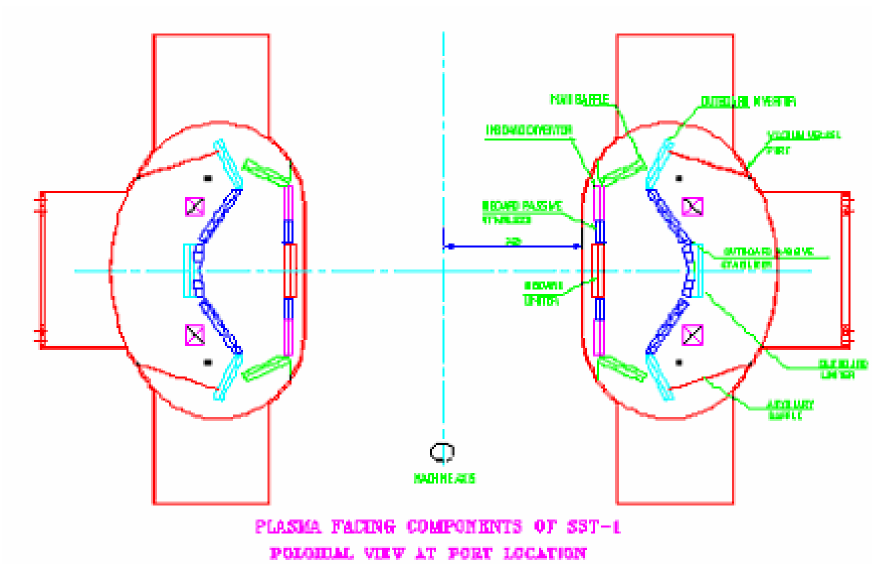


Fig 2.3 Cross-sectional view of SST-1

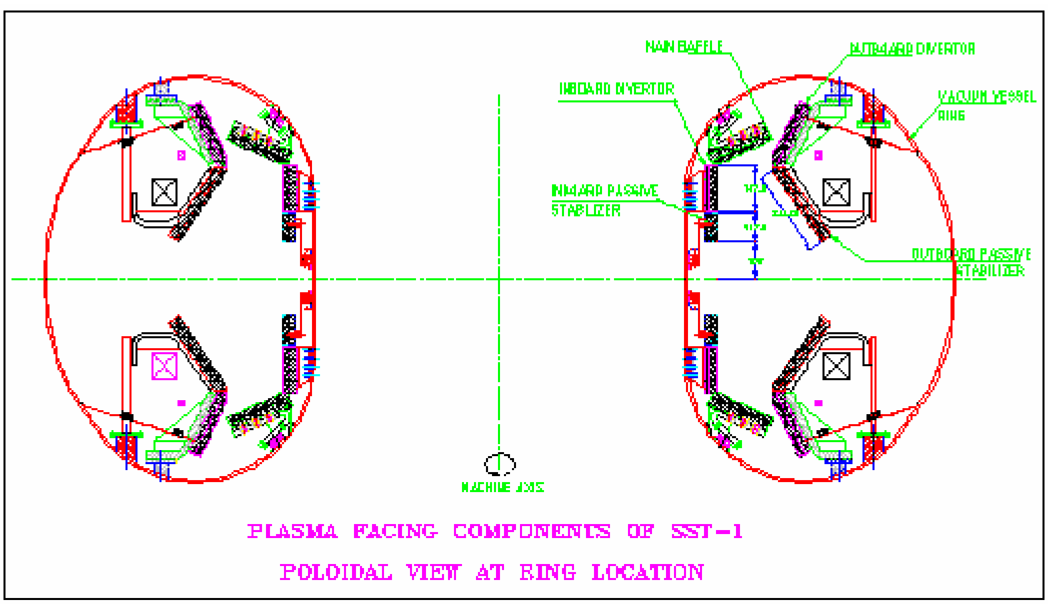


Fig 2.4 Poloidal view of SST

The support which holds these components should be designed to withstand these loads. In case of a failure, the first wall components and the support design should allow an easy replacement of the damaged parts. [7].

Following are the Major Plasma Facing Component:

- Divertor
- Baffles
- Limiters
- Passive Stabilizer

2.5.1. Divertor:

A component of a toroidal fusion device used to shape the Magnetic field near the plasma edge so that particles at the edge are diverted away from the rest of the plasma. These particles are swept into a separate chamber where they strike barrier, become neutralized, and are pumped away. In this way, energetic particles near the plasma edge are captured before they can strike the walls of the main discharge chamber and generate secondary particles that would contaminate and cool the plasma.

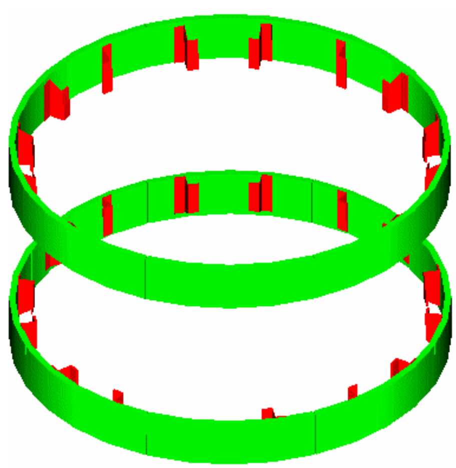


Fig 2.5 Inner Divertor Plate

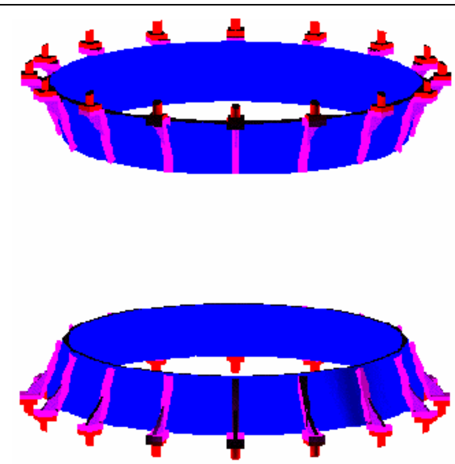


Fig 2.6 Outer Divertor Plate

In SST-1 tokamak, there are four diverters viz, (IDP-Top), (IDP-Bottom), (ODP-Top), (ODP-Bottom). The inboard divertor (Fig 2.3) divided into eight modules along the toroidal direction. The Outboard (Top & Bottom) (Fig 2.4) divertors are conical shaped and divided into sixteen modules along the toroidal direction. Each module of the inboard divertor is supported on inboard side of vacuum vessel using two supports whereas each module of the outboard divertor is supported on the outboard side of vacuum vessel using one support. During plasma operation supplying water through the coolant tube brazed/welded to it actively cools all divertor modules.

2.5.2. Baffle (main & auxiliary):

It helps in reducing heat flux on divertor. Neutral particles and their flow in the vacuum vessel play a major role in the performance of Tokamak plasma. Control over flow of neutral particles is very essential for controlling plasma parameters in core as well as edge region. The size shape of the baffles is optimized to control back flow of neutral particles from plasma edge region and to increase neutral particles in divertor region In SST-1 tokamak there are mainly two Baffle consist of Top main Baffle (BAF-Top) and (OABAF-BOT) (Fig 2.5).The main baffle Top & Bottom are conical shaped and divided into sixteen module along toroidal direction. The Auxiliary Baffles is provided to control neutral particle transport in the back side of plasma facing components and it does not receive thermal as well as mechanical loads and hence it is not actively cooled.

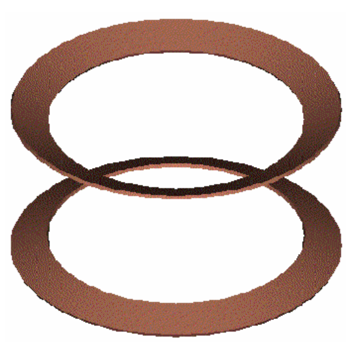


Fig 2.7 Main Baffle

2.5.3. Limiter:

Device placed inside the plasma chamber to intercept particles at the edge of plasma called Limiter. The cross-sectional view is shown in figure 2.1 & 2.2. By “scraping off” these particles from the plasma edge, the limiter defines the size of the plasma.

2.5.4. Passive Stabilizer

Passive Stabilizer is another most important plasma facing component used for plasma facing component used for plasma stabilization. This component is in saddle configuration forms an electrically conducting loop around the toroidal plasma. The elongated plasmas generally unstable to vertical shift away from its equilibrium position. Any such vertical movement of the plasma induces stabilizing current in the saddle loop formed by these components, since functioning of these components is totally based on induced currents and no external electrical power is supplied to it, is called Passive Stabilizer. In SST-1 tokamak, there are four types of passive stabilizer viz.(IPS-TOP),(IPS-BOT),(OPS-TOP),(OPS-BOT). Its location is very near to the plasma therefore it receives heat energy in the form of particles Kinetic energy as well as radiation, Therefore all passive stabilizer are actively cooled by supplying water through the coolant tubes brazed/welded to them[9]

2.6 PFC support structure:

Calculation of the Stress due to the Electromagnetic loads Supports are required to keep the modules rigidly in their positions during baking operation and capable to deflect to allow for the toroidal expansion of the modules. The supports are allowed to withstand the halo and eddy current electromagnetic loads. The supports are made of Inconel X750. IPS is a toroidally continuous ring with one break. One end of the supports are attached to bracket welded on the vessel and other end attached to the components. For this support structure we have to calculate the stress for the worst case scenario of the electromagnetic loads arising due to a VDE followed by the Halo current by N.Ravi Prakash et.al [7].

The design requirements for the support structure of the Plasma Facing Components can be listed as follows. [4]

1. To attach the first wall components to the vacuum vessel.
2. To hold the first wall components in their position precisely within the vessel.
3. Should withstand the loads due to static (dead) weights of the PFCs and impulsive electro-magnetic forces due to disruptions and halo currents.
4. Should deflect in order to allow thermal expansion of the components during baking to limit the thermal stresses
5. Should allow differential expansion of the vacuum vessel and the PFCs
6. Should be of smaller size to occupy less space inside the vessel.
7. It should allow easy assembly and disassembly of the PFCs
8. The material for the support structure should be UHV compatible and also should be bake bale to high temperatures.
9. Should be easily fabric able and weld able.
10. Should have high strength at elevated temperatures.
11. Should be easily available.

As the thermal impact load is acting on the PFC, the transient dynamic analysis is required to check its stability and strength criteria under time fluctuating load.

From the support structure point of view, three different scenarios can be discussed in details; namely

1. Baking
2. Normal operation
3. off - normal operation

These three scenarios are characterized by different loads and operating condition on the supports.

1. Baking:

During backing the PFCs will expand and the support should be flexible enough to allow this expansion. The baking temperature will be as high as 350ºc for the first wall components and hence thermal expansion of these components will be significant. When the vacuum vessel is baked and the PFCS are baked by the conduction and radiation from the vessel, there will be a time lag in the temperature rise of the PFCs. In this case the vessel will be at a higher temperature than the PFCs till equilibrium is reached. When the PFCs are baked to 350ºc and the vessel is limited to 150ºc which will be maintained throughout the period of baking. In this case the vessel will be at a lower temperature than the PFCs. The supports are to be designed keeping in view that there will be at a temperature difference of about 200ºc between the PFCs and vessel. The design should be compatible for both conditions, namely: [12]

(a) PFCs are at a higher temperature than the vessel temperature and

(b) Vacuum vessel at a higher temperature than the PFCs.

2. Normal operation:

During normal operations, the first wall components will be subjected to gravity forces, heating due to conducted and radiated heat from plasma, and differential thermal expansion due to temperature difference between the vessel and in - vessel components. The forces due to eddy currents or induced currents on all the PFCs during normal operation are expected to be much smaller than those existing in the off - normal conditions. Therefore, the design considers mainly the loads arising during off normal operation. [12]

3. off - normal operation:

The induced currents during a disruption and the halo currents will result in large forces on the PFCs. This is due to the interaction of disruption and the halo currents with the ambient magnetic field present during these events. Halo currents which have both toroidal and poloidal components normally close through the structures supporting the PFCs. Because of these currents in the structures, there will be additional loads have to be considered while designing the supports. [12]

2.6.1 Material for Support Structure:

The structure material for first wall components should maintain its mechanical integrity and dimensional stability for adequate life-times under the severe thermal and stress condition supposed in the tokamak environment. The candidate material must be capable of elevated temperature operation. In addition, the structure material should have adequate resources and readily fabric able [7].

1. Selection criteria for structural material

a) A low thermal expansion

b) A high thermal conductance

c) A low elastic modulus

d) High strength

2. Candidate structural material

A number of potential structural material have been surveyed for all first wall components of SST-1.six classes of material have been considered in some detail include

a) Austenitic Stainless Steel

b) Ferritic Stainless Steel

c) Nickel alloys

d) Titanium alloys and

e) Vanadium alloys

f) Niobium alloys

Aluminum alloys are not considered because of their low operating temperatures and Molybdenum alloys for difficulty in fabrication.

Nickel alloys can be selected as the primary candidate structural material for all the PFCs of SST-1 Alloy used for steady state operation and high temperature baking properties are Inconel 625, Inconel X750 [7]

2.7 Material for the Plasma Facing Component:

Plasma facing component will be operated in an environment which comprises incident particles and heat flux from the plasma .The surface of the plasma facing material is subjected to erosion by energetic ions and neutral atoms escaping from the plasma. Experiments with high Z-materials (Z is the atomic number) have been carried out in the ASDEX Upgrade Tokamak, since the erosion of this material under normal operation conditions is considerably lower than the plasma induced erosion of low Z-materials like carbon (C) or Beryllium (Be).The disadvantage of high Z-material, however is the far lower tolerable impurity concentration within the plasma which poses strong demand on plasma control. Neutron damage can lead to the degradation of the mechanical properties and in some cases to a decrease of the thermal conductivity and dimensional changes of the PFMs. There is also progress of R&D work on Plasma surface interaction with high Z-materials, especially tungsten (W**),** by H.Bolt et.al. [3]

All the PFCs are made up of copper alloys (CuCrZr and CuZr) on which the graphite tiles are mechanically attached .These copper alloy are actively cooled with water flowing in the channels grooved on them with the main consideration in the design of the PFCs as the steady state heat removal of about 1.0MW/m^2 .PFCs are also designed to be compatible for baking at 350 deg centigrade, by N.Ravi Prakash et.al [7]

2.8. Vacuum vessel

SST1 vacuum vessel consists of a toroidal chamber and port extensions. There is large number of in-vessel components for different applications.

The vacuum vessel of SST1 is an all welded continuous structure made of SS 304 L materials; requirements of material selection for vacuum vessel (VV) are in section 2.2.2. Since there are sixteen toroidal magnetic field coils positioned at an angle of 22.5^0 in the toroidal direction, the vacuum vessel is also divided into sixteen vessel modules. Each vessel module is made up of one wedge shaped sector along with ports (describe in section 2.2.1), a radial port and two (top and bottom) vertical ports and one vessel ring. So, there are sixteen wedge shaped sectors and sixteen vessel rings which are welded to form a complete torus. The dimensions of wedged sectors are such that they can be radially taken out after cutting the weld joints without distributing the TF coils. This is required to repair TF coil or vessel in case of any failure. The poloidal c/s of vessel (Fig 2.2) will be closed to 'D' shape. Each wedge sector has a pair of vertical ports and a radial port. The wall thickness of vessel is 10 mm. The top, bottom and radial ports in each sector are extended up to cryostat. These ports are welded to the cryostat wall which provides mechanical support to vacuum vessel.

The vacuum vessel is designed for ultra high vacuum (≤10-8 torr) operation and it can be baked up to 525K. [10].

2.8.1. Port

All the ports structure is single - wall welded construction with the same leak tightness criteria as the vacuum vessel.

The ports are mainly for diagnostics

- Diagnostics
- Electrical feed through
- Plasma observations
- Energy import
- Vessel illumination
- Limiters feed through viewing
- Human access to the inside of the vacuum vessel.

Other factors considered in the port design were mechanical stresses due to temperature gradients during baking and plasma operations and the best possible access to the inside of the vessel for the installation of various components and their maintenance.

Each wedge sector of vessel contains two vertical (top and bottom) ports which are triangular in shape and one radial port which is rectangular in shape. Since there are sixteen wedged sectors of vessel, there are 16 top and 16 bottom triangular ports and 16 rectangular ports. The wall thickness of all the ports is 6 mm. these ports are designated as T1, R1 and B1 for top, radial and bottom port respectively on wedge sectors of the vessel. Out of sixteen radial ports, one radial port is specially designed for neutral beam injection which is marked as NBI port (port1). The rest of other fifteen radial ports are identical and marked as standard radial ports. [10]

2.8.2. Material Selection for vessel:

The material and the wall thickness of the vacuum vessel have been chosen on the basis of the following conditions:

1. The material should be non magnetic so as not to shield or distort the externally applied magnetic fields.
2. The resistivity should be such that the eddy currents generated by the time varying magnetic fields would dissipate in times far smaller than the characteristic

rise times.

3. The material should be machine able to high finish; it should have good weld ability, resistant to corrosion and oxide formation and should be compatible to UHV standards.

4. The wall thickness should be chosen such that it can withstand the atmospheric pressure load, electromagnetic forces during plasma initiation and disruptions and thermal stresses during baking and normal operation.

Based on these requirements it was found that Austenitic Stainless Steel of AISI series 300 offers favorable properties for use in Ultra High Vacuum systems. The chromium - nickel composition of these steel (18-8 %) helps the formation of a thin protective layer of chromium oxide which is impermeable to and insoluble in most corrosive media. Nickel improves corrosion resistance, weld ability and ductility as well as maintaining austenitic structure. In the 300 series the most commonly used stainless steels are 304L and 316L both of which have low carbon (0.03%) content which reduces carbide precipitation during welding. Considering all these specifications SS 304L can satisfy most of the vessel design requirements. The mechanical, elastic and electrical properties of SS 304L are as follows. [11]

Yield strength = 200 MN/m^2

Young's modulus = $1.941*10^{10}$ Kg/m^2

Poisson ratio = 0.305

Resistivity = $72*10^{-8}$ Ohm-m

2.9. Baking Analyses for PFC for SST-1

PFC are structurally continuous in the Toroidal direction. As SST-1 is designed to run double null divertor plasmas, these components are having Up-down symmetry. the passive stabilizer are located close to the plasma to provide stability against the vertical instability of the elongated plasma The purpose of high temperature bake out is to clean the PFC and Vacuum vessel to limit the out gassing during plasma operation. During the initial phase of operation of SST-1 it is planned to bake the VV at 250 deg centigrade by flowing hot nitrogen gas through the channels welded on its inner wall and all the PFC will be baked by radiation from heated VV wall. In Later phase of operation of SST-1,if required the PFC will be baked independently at 350 deg centigrade by flowing hot nitrogen gas while maintaining the VV at 150 deg or 200 deg centigrade.[7].

2.10. Electro-magnetic Force for Disruption Scenarios in SST-1 Tokamak

In Tokamak fusion Research and Development, the transient electromagnetic problem is one of the most important ones from the standpoint of structural design against an intensive electromagnetic loading on device components as well as from the stand point of control analysis of plasma current, plasma position and plasma shape. As a practical problem, it is difficult to carry out a reliable evaluation of the eddy currents in a tokamak system, because of the complexities in machine geometry and electrical characteristics. Moreover the eddy current problem of a multicomponent system must be solved for all components simultaneously, since each component is magnetically coupled with each other, [14].

The calculation of electro-magnetic loads is important for the SST-1 tokamak from the point of view of mechanical design of its various subsystems. The SST-1 tokamak will operate plasmas of elliptical or more precisely a D-shaped cross-section. Such plasmas arc inherently unstable for motion along the axial direction (i.e. along the Z-axis or the axis of symmetry). To a good approximation, the plasma can simply be regarded as a coil with a certain major radius, minor radius and the height Z_p at which it is placed above the nominal mid-plane. Since the plasma is inductively coupled to the surrounding conducting structures, the movement of the plasma or the alterations in the plasma current cause eddy currents to be induced in these structures. It is the interaction of these currents and magnetic fields which generates significant electro-magnetic loads on the SST-1 tokamak. In experiments with shaped plasmas, it has been usually observed that the disruptive termination of the plasma-current is preceded by a vertical displacement event (VDE), [9].

2.10.1. Plasma Disruption:

Electro-magnetic loads arise due to the interaction of currents and the magnetic field acting on the current carrying structures. In a tokamak, the plasma which carries a large toroidal current is surrounded by electrically conducting structures. Therefore, movement of the plasma or alterations in its current can lead to induction of currents in the surrounding structures. In tokamaks with a shaped cross-section, like SST-1, the plasma can experience a vertical instability. Usually it is overcome by the combined influence of passive stabilizers and an active feedback coil, but there can be episodes of 'loss of control'. In such cases, the plasma undergoes an uncontrolled vertical displacement (either upwards or downwards) which ends up in a disruption. A disruption means rapid decay of plasma current. One calls the former event as VDE (vertical displacement event) which is then invariably followed by a disruption.

The SST-1 tokamak will have auxiliary heating systems to heat the plasma and non-inductive current-drive for achieving a steady-state operation. In such plasmas, the energy confinement time increases with increasing plasma current. Therefore, one would like to pin as much current as one can safely, given the major radius, minor radius and the toroidal magnetic field. This is achieved by elongating the plasma cross-section, which is as if the plasma is sandwiched in a an "effective" up-down symmetric pair of coils, which are trying to pull it from above and below. Any push, either upwards or downwards can take the plasma further upwards or downwards as the pull becomes asymmetric. The conducting structures which surround the plasma tend to suppress this movement, however, they themselves experience a force in this process. Furthermore, the currents induced in these structures decay due to finite resistivity, so the unstable movement of the plasma never really stops, it continue at a rate decided by a certain fraction of the overall L/R time constant of the stabilizing structures. As the plasma moves vertically, its shape deforms, it loses its elongation, its MHD safety factor 'q' drops and it becomes vulnerable to the disruptive instability. As the plasma finally comes into contact with the structures, it begins to loose current at a rapid rate. For SST-1 sized tokamak, this decay time may be of the order of 1-2 milliseconds. As a result of this, two crucial phenomena arise: (1) generation of additional Emf due to decay of plasma current and (2) development of poloidal halo-current in the surrounding structures. It should be noted that the induced currents due to vertical motion arise so as to oppose the motion, which, in a structure closer to the plasma, would flow in an opposite direction to that of the plasma current. However, the disruption induced Emf would try to preserve the flux linked with the structures, thereby creating a current which flows in the same direction as the plasma current. Thus the VDE and disruption induced currents can be subtractive or additive depending upon the distance of the structure from the plasma, [6].

2.11. Project work

Dissertation Topic

Structural Analysis of Divertor & Baffle of Steady State Tokamak (**SST-1**) for Electromagnetic and Thermal loads using ANSYS software.

0bjective:-

The objective of project is the detailed study on the Structural analysis for thermal and electromagnetic loads at transient conditions for divertor and baffles is needs to carry out. The eddy currents are produced on the stabilizer cage surrounding the plasma in SST-1 due to the change in position of plasma due to instabilities. The resulting electromagnetic forces on components due to the induced currents have to be analyzed for the components. The divertor and baffle plates are designed indigenously and final design has been completed and the component is under fabrication. The actual geometry of stabilizers has been modified with bolt holes and other requirements in the tokamak. The vacuum vessel of sst-1 machine will be baked to a temperature of 200 0 C and component will be at 350 0 C. There will be induced thermal loads on the components due to differential thermal expansion during the baking process & the induced stresses have to be analyzed.

The project work has to evaluate the exact currents that will be induced on the components with the actual modeling of geometry and with a mapped meshing. The works also involves the theoretical back for the complete mechanism to compare the analysis results.

Significance

In Tokamak fusion Research and Development, the transient electromagnetic problem is one of the most important ones from the standpoint of structural design against an intensive electromagnetic loading on device components as well as from the stand point of control analysis of plasma current, plasma position and plasma shape. As a practical problem, it is difficult to carry out a reliable evaluation of the eddy currents in a tokamak system, because of the complexities in machine geometry and electrical characteristics. Moreover the eddy current problem of a multicomponent system must be solved for all components simultaneously, since each component is magnetically coupled with each other, [6].

The calculation of electro-magnetic loads is important for the SST-1 tokamak from the point of view of mechanical design of its various subsystems. The SST-1 tokamak will operate plasmas of elliptical or more precisely a D-shaped cross-section. Such plasmas arc inherently unstable for motion along the axial direction (i.e. along the Z-axis or the axis of symmetry) To a good approximation, the plasma can simply be regarded as a coil with a certain major radius, minor radius and the height Z_p at which it is placed above the nominal mid-plane. Since the plasma is inductively coupled to the surrounding conducting structures, the movement of the plasma or the alterations in the plasma current cause eddy currents to be induced in these structures. It is the interaction of these currents and magnetic fields which generates significant electro-magnetic loads on the SST-1 tokamak. In experiments with shaped plasmas, it has been usually observed that the disruptive termination of the plasma-current is preceded by a vertical displacement event (VDE), [6].

2.11.1 Loading Conditions:

Loading conditions & degree of freedom (DOF) Constraints which are applied for different analysis are summarized in table 2.3.

Table 2.3 Loading condition & DOF Constraints for analysis

Analysis	Loading Conditions	Degree of Freedoms
Electromagnetic Analysis	Steady state Current Density (J = I/A) is applied on 16 TF, 11 PF and transient Current Density is applied on Plasma	Flux Parallel applied on All outer area of outer air region & vector potential applied on a node.
Structural analysis for Electromagnetic loads	Electromagnetic forces are transferred from electromagnetic analysis for structural analysis.	Fixed all deformation (U_x, U_y, U_z) on area ,attached to VV
Baking Analysis	Temperature is applied on PFC.	Symmetry Boundary conditions on base & side area, which are in the plane of symmetry.

2.11.2 Methodology:

Analysis of components for such conditions is couple field analysis. coupled field analysis is an analysis that takes into account the interaction (coupling) between two or more discipline. Electromagnetic forces are calculated at different time steps in electromagnetic Transient analysis by applying varying current density on plasma coil at different time steps, and these forces are transferred from electromagnetic analysis to Structural Analysis by sequential coupling.

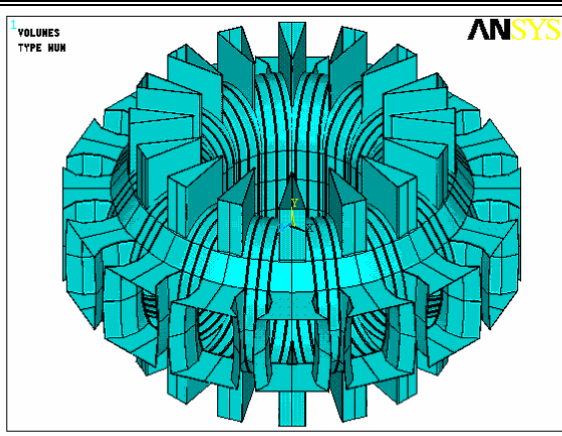
The methodology of analyzing the components for such condition is in following steps.

1 Modeling the components for electromagnetic & structural model using actual dimension in ANSYS.
2. Meshing the electromagnetic model using solid 97.
3. Apply electromagnetic Load on Model for transient analysis.
4. Switching electromagnetic model to structural model by sequential coupling..
5. Applying structural load (electromagnetic forces) and solve for each steps.
6. Viewing results.
7. Comparing results

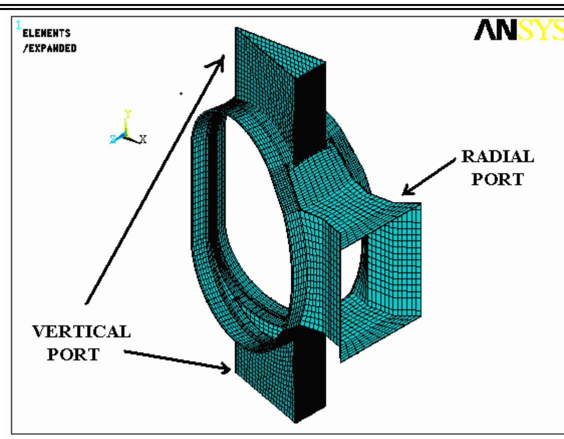
Modeling of the Divertor (IDP, ODP), baffle with support structure & Electro-magnetic model of these components of the SST-1 Tokamak was done on the ANSYS software. The PF coil, TF coil and Plasma also include in Electromagnetic model. Description of location & position of the components are given below.

3.1. Vacuum vessel (V.V):

Vacuum vessel (V.V) is divided into sixteen vessel modules, each of 22.5^o. Each vessel module is made up of one wedge shaped sector along with a radial port and two (top and bottom) vertical ports and one vessel ring. So, there are sixteen wedge shaped sectors and sixteen vessel rings which are welded to form a complete torus. The poloidal c/s of vessel will be closed to 'D' shape. Each wedge sector has a pair of vertical ports and a radial port. The wall thickness of vessel is 10 mm. The top, bottom and radial ports in each sector are extended up to cryostat. These ports are welded to the cryostat wall which provides mechanical support to vacuum vessel (V.V).



Full isometric view of SST-1 Vacuum Vessel (V.V)



One sector

Fig 3.1 Solid and FE Model of Vacuum vessel (V.V)

3.2. Divertor

The Outer Divertor (Top & Bottom) on the outer board side are conical shaped sixteen modules along the toroidal direction each module are 22.2^0 with the machine axis, & inner divertor (top & bottom) are eight modules along the toroidal direction & each module are 44.3^0 with the machine axis, details like poloidal length toroidal length, angle with mid plane are given in Table 3.1 & modeling of ODP & IDP for electromagnetic & structural analysis are shown in Figure 3.2 & 3.3 respectively

3.3. Baffle

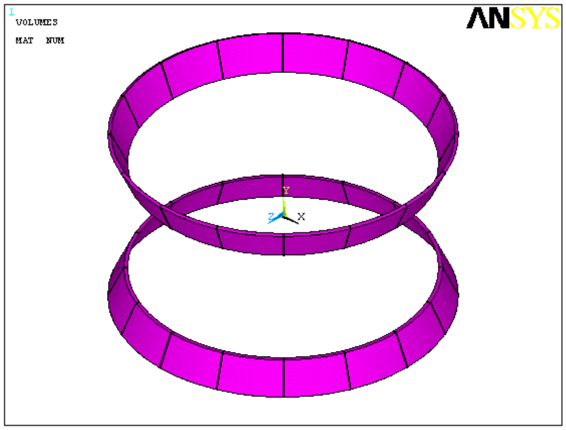
The main baffle Top & Bottom is conical shaped sixteen modules along toroidal direction each module are 22.3^0 with the machine axis , details like poloidal length toroidal length ,angle with mid plane are given in Table 3.1 modeling of baffle plate for electromagnetic & structural analysis are shown in Figure.

Table 3.1 Details of Divertor & Baffle

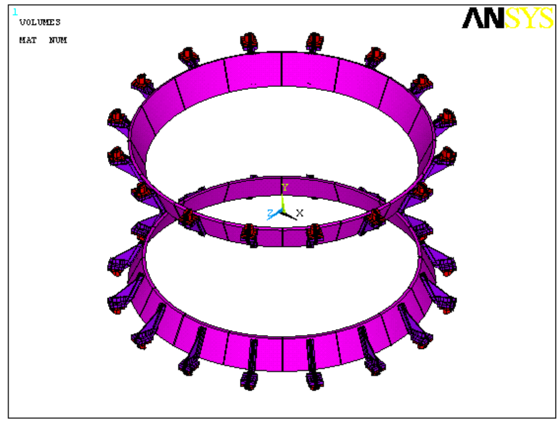
	Posit -ion	**Shape**	**Thick- ness (mm)**	**R max (mm)**	**L_{max} (Toroidal) (mm)**	**L (Poloidal)**	**Angle with mid plane (deg.)**
Divertor	In board	Thin cylinders	25	870	640	190	90
	Out board	Hollow frustum	25	1246.8	430	280	65
Main Baffle		Hollow frustum	25	1085.3	420	260	23.4

3.4. Solid Model

Three dimensional modeling of all components (ODP, IDP, and BAF) with & without support structure for electromagnetic & structural analysis are done using ANSYS .The following figures showing different 3-D solid model views.

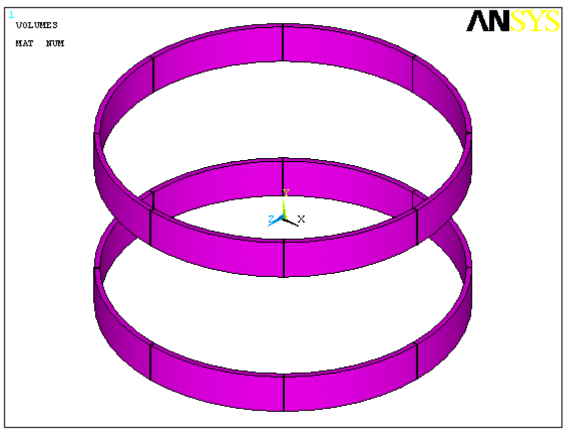


(A) Solid model of ODP

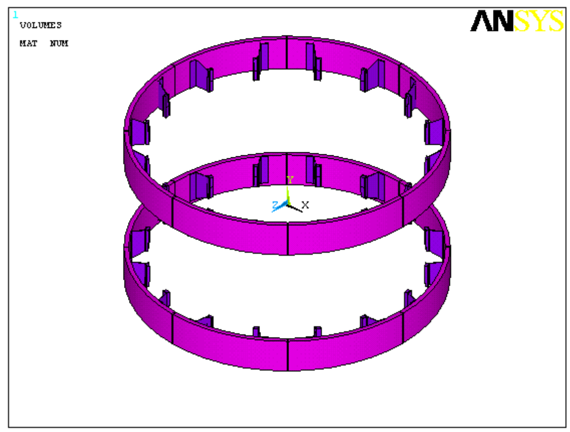


(B) Solid model ODP with Support structure

Fig 3.2 (A, B) Solid model of ODP

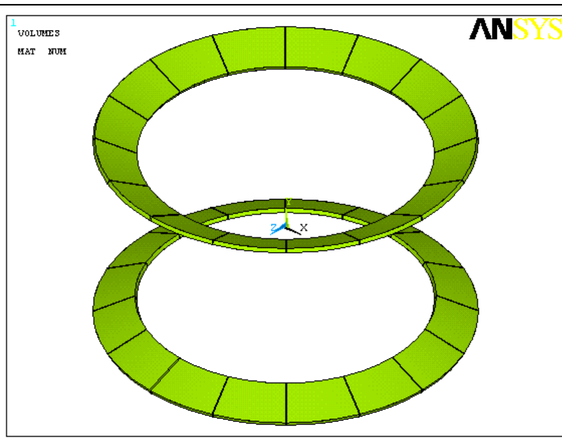


(A) Solid model of IDP

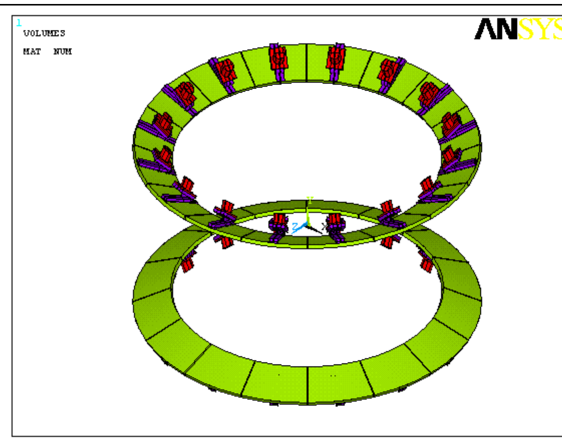


(B) Solid model IDP with Support structure

Fig 3.3 (A, B) Solid Model of IDP



(A) Solid model of Baffle plate



(B) Solid model Baffle with Support structure

Fig 3.4 (A, B) Solid Model of Baffle plate

3.5 FE Model

The following figures (fig 3.5 – 3.7) showing different views of FEA model of outer divertor (top & Bottom), inner divertor (top & Bottom) & main baffle (top & Bottom) using element Solid 95. [15]

Hex/Sweep meshing are done in Divertor (IDP, ODP) in all cases which include using global set with objective of element control & computational time for simulating whole model during transient conditions.

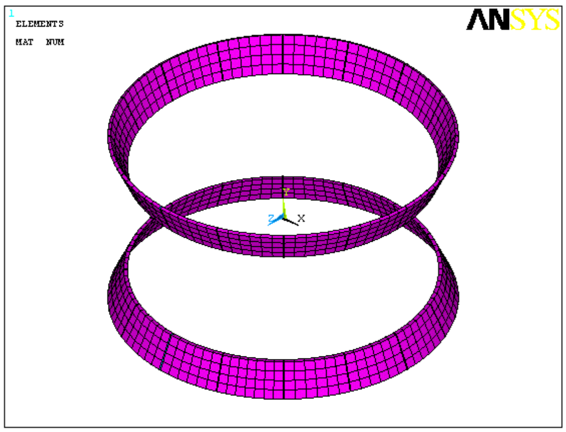
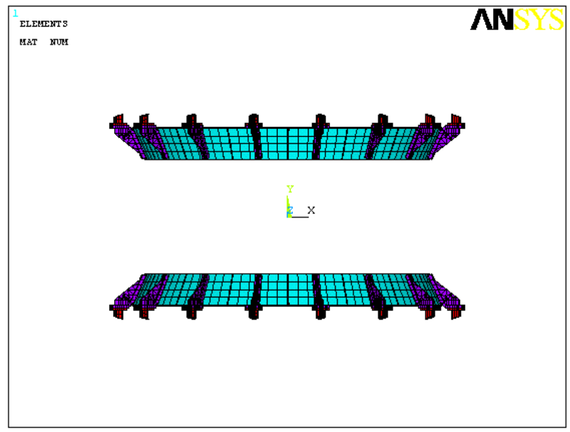
	
A. FE model of ODP	FE model of ODP with Support structure

Fig 3.5 (A, B) FE model ODP

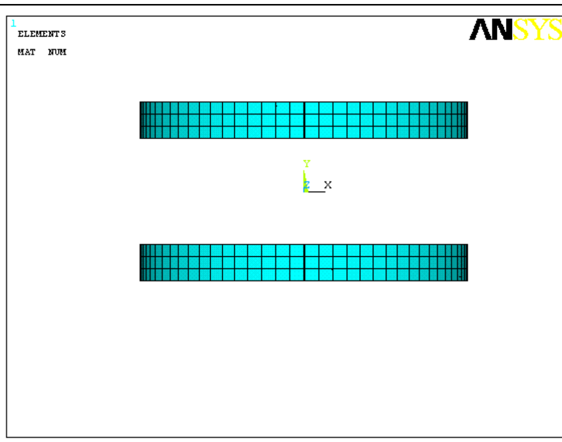
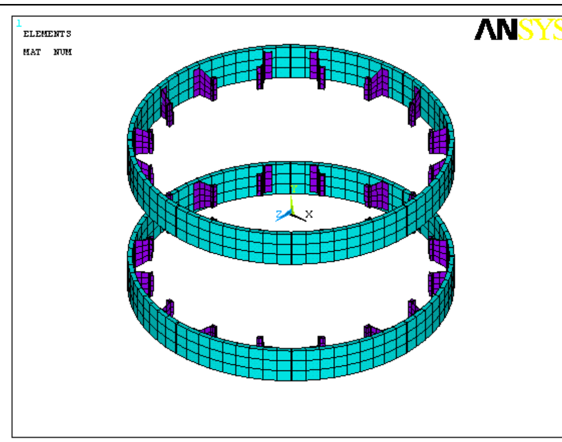
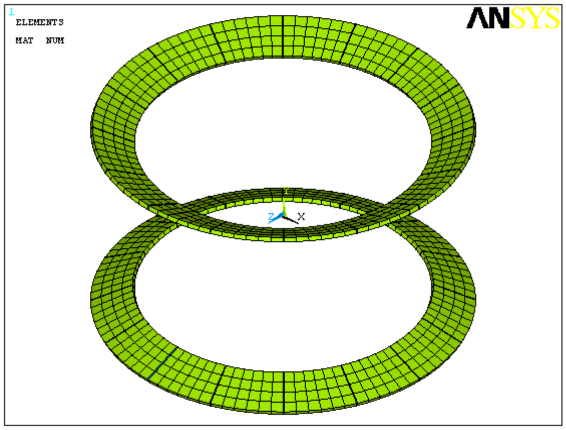
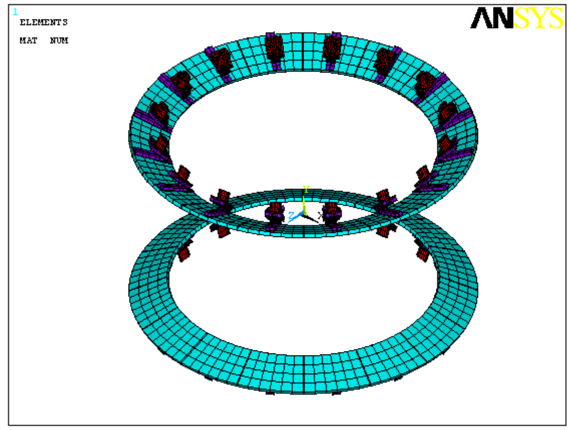
	
A. FE model of IDP	B. FE model of ODP with Support structure

Fig 3.6 (A, B) FE Model of IDP



A. FE model of Baffle



B. FE model of Baffle with Support structure

Fig 3.7 (A, B) FE Model of Baffle plate

3.6. Plasma Coil

Plasma is modeled as a single turn coil with a dimension of 100 x 100 mm^2 and is located at a radius of 1100 mm at the mid plane of the machine. In order to accommodate the condition of disruption of dislocated plasma at Z = +250 mm, one more coil of plasma is modeled at the location Z = +250 mm. [16].

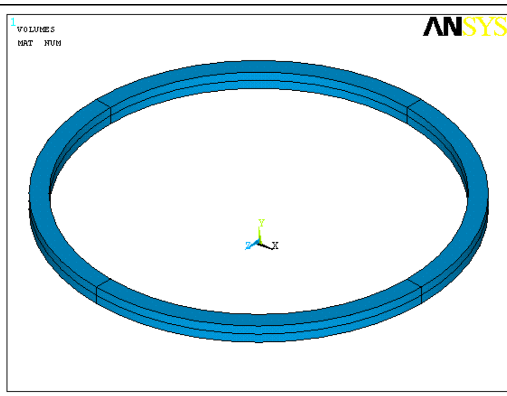


Fig 3.8 Solid Model of Plasma coil

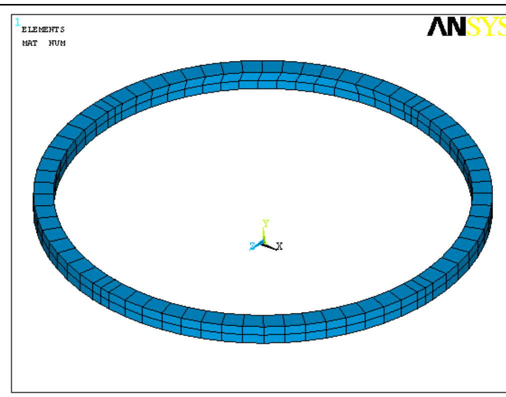


Fig 3.9 FE Model of Plasma coil

3.7 TF Coil

All 16 TF coils which are placed at angle 22.5^0 form each other & carries current in toroidal direction which is very difficult to apply in FEA package of ANSYS. All 16 TF coil have D-shape cross-section & hence, in order to provide current in exact toroidal direction total 5 co-ordinate system is defined for each coil in center of curve. All 16 TF coil carries current in proper toroidal direction with total 80 co-ordinate system which takes considerable time in modeling of total geometry. Hex/Sweep meshing is provided in all 16 TF coil using global set option in FEA package of ANSYS. [15]

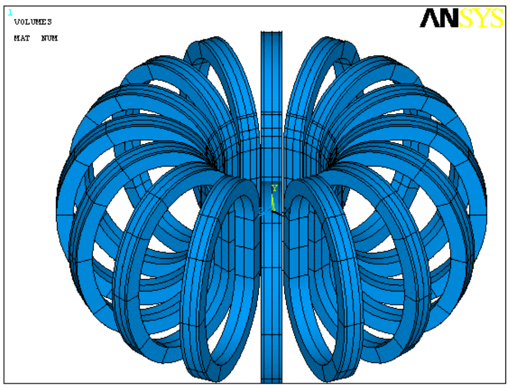


Fig 3.10 Solid Model of TF coil

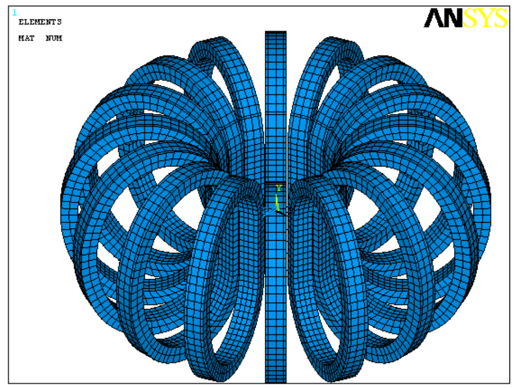


Fig 3.11 FEM model of TF coil

3.8. PF Coil

All 11 PF coil which carries current in theta direction which is in the same direction of plasma coil. In order to flow current in theta direction one extra co-ordinate system is also defined. Dimensions, No. of turns, current in each turn & cross-sectional area of each coil is shown in below table. Hex/Sweep meshing is provided in all 11 PF coil using global set option in FEA package of ANSYS. The details of pf coil are in table 3.2. [16]

Table 3.2 Details of PF coil

PF No.	**X (m)**	**Y (m)**	**Dx (m)**	**Dy (m)**	**Area (m^2)**
1	450E-3	0	71 E-3	320 E-3	22720E-6
2 u/l	450 E-3	425 E-3	71 E-3	163 E-3	11573 E-6
3 u/l	500 E-3	930 E-3	135 E-3	383 E-3	51705 E-6
4 u/l	1720 E-3	1030 E-3	85 E-3	135 E-3	11475 E-6
5 u/l	207 E-30	650 E-3	85 E-3	135 E-3	11475 E-6
6 u/l	1350 E-3	350 E-3	100 E-3	100 E-3	10000 E-6

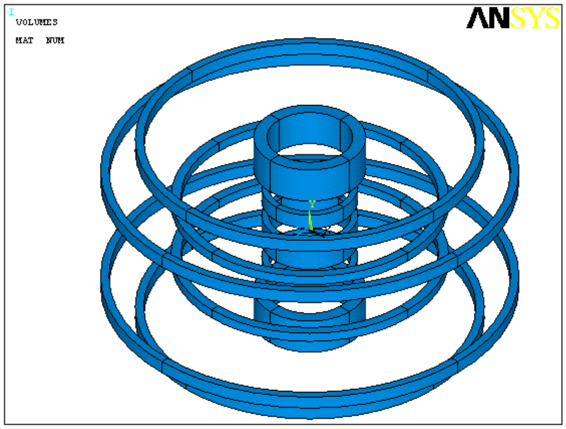


Fig 3.12 Solid Model of PF coil

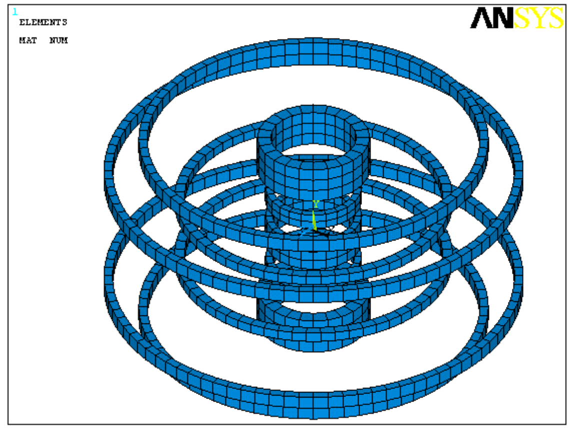


Fig 3.13 FE model of PF coil

3.9. Air region

For Magnetic Analysis in FEA package of ANSYS it is always require finite air region to simulate the analysis & to obtain the better results. In our all cases finite air region is modeled to get accurate results & it is always difficult to obtain hex/sweep meshing in air region because it has where irregular shape and sharp edges, solid & FE model of components with air region is in fig 3.14 & 3.15 respectively. [15]

3.10. Model for Electromagnetic Analysis:

For Analysis of Electromagnetic complete model with all PFC's, TF coil, PF coil and Plasma was done**.** The entire component were enclosed in the air region, this is done in order for the generation of Flux shown in following figure 3.14. [15]

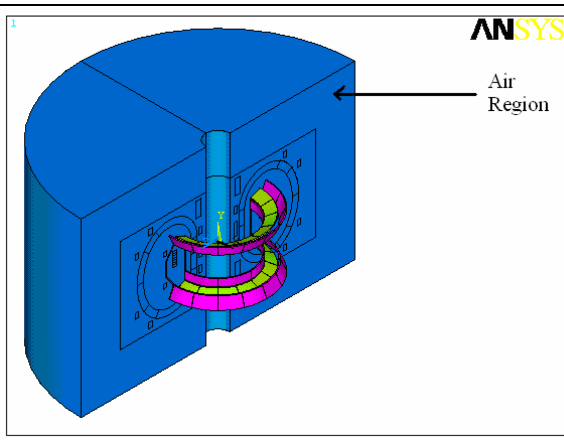


Fig 3.14 Solid Model of all component

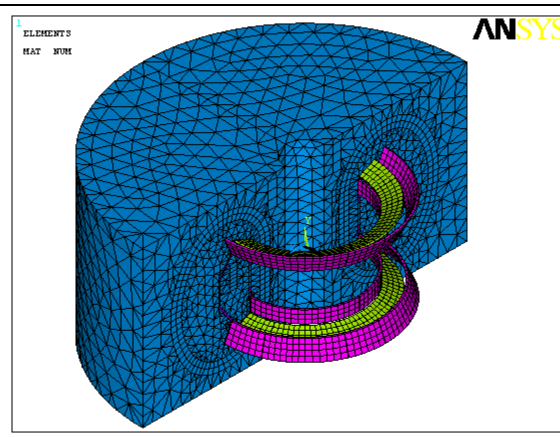


Fig 3.15 FEM model of all component

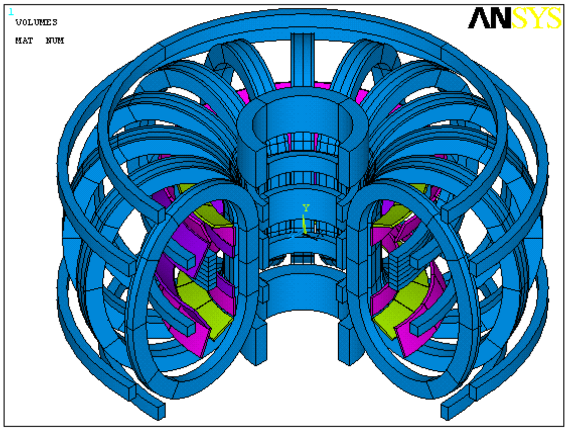


Fig 3.16 Solid Model of all components with coils

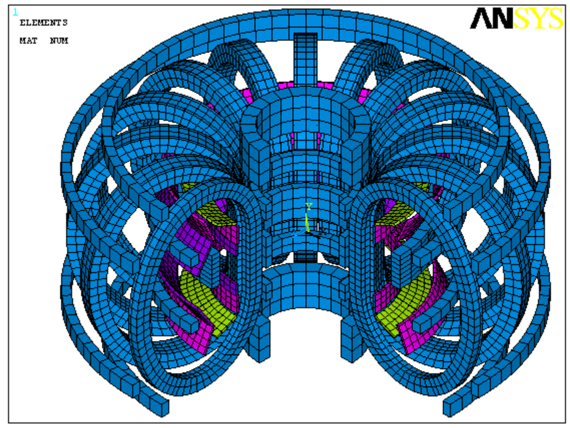


Fig 3.17 FE Model of all components with coils

3.11 Modeling of the component for backing analysis:

As outer divertor, baffle & vacuum vessel (V.V) are sixteen modules in complete 360^0, & inner divertor are eight module in 360^0, each inner divertor covers one full sector & two half sector, one on each side of full sector, therefore we can modeled the component in one full sector two half sector on each side of full sector for apply the symmetric boundary condition, because the model is symmetric after considering this. Ref [16]

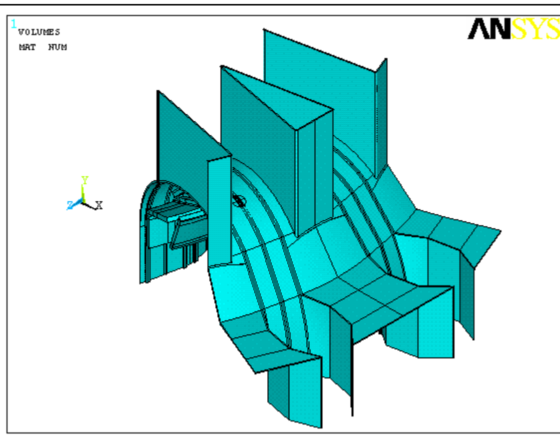


Fig 3.18 Solid Model of All Components

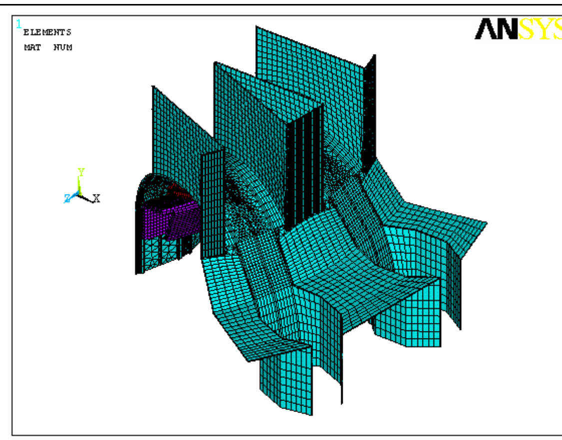
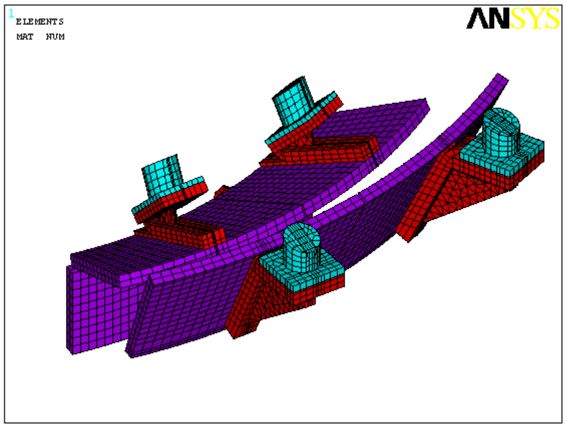
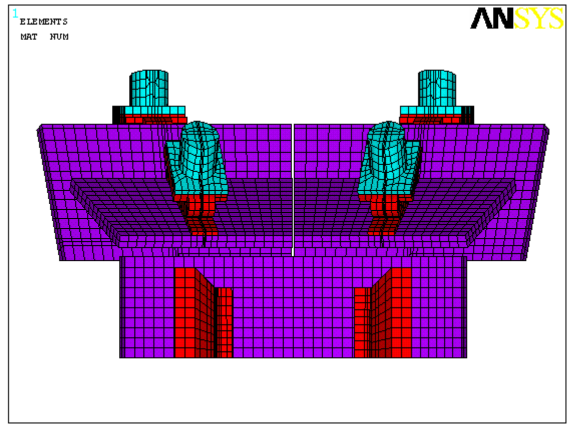


Fig 3.19 FE model of All Components (with vessel)



Isometric View of assembly



Left side View of assembly

Fig 3.20 FE Model with IDP, ODP and Baffle assembly

Fig 3.18 & 3.19 shows the assembled view of IDP, ODP & baffle with support structure & vacuum vessel.

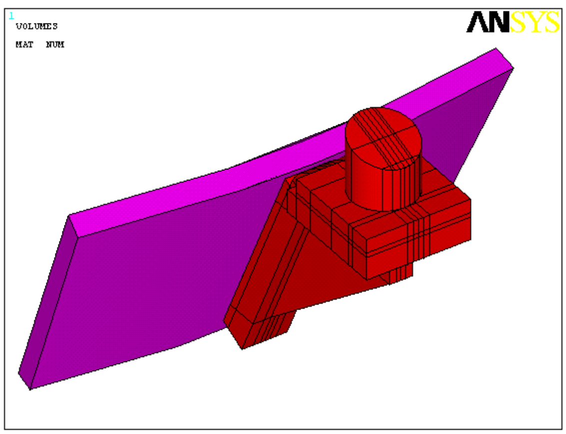


Fig 3.21. Solid Model Of ODP with Support Structure

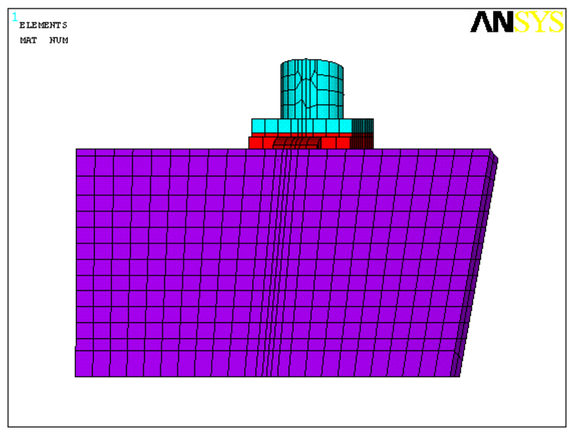


Fig 3.22 FEA Model of ODP with Support Structure

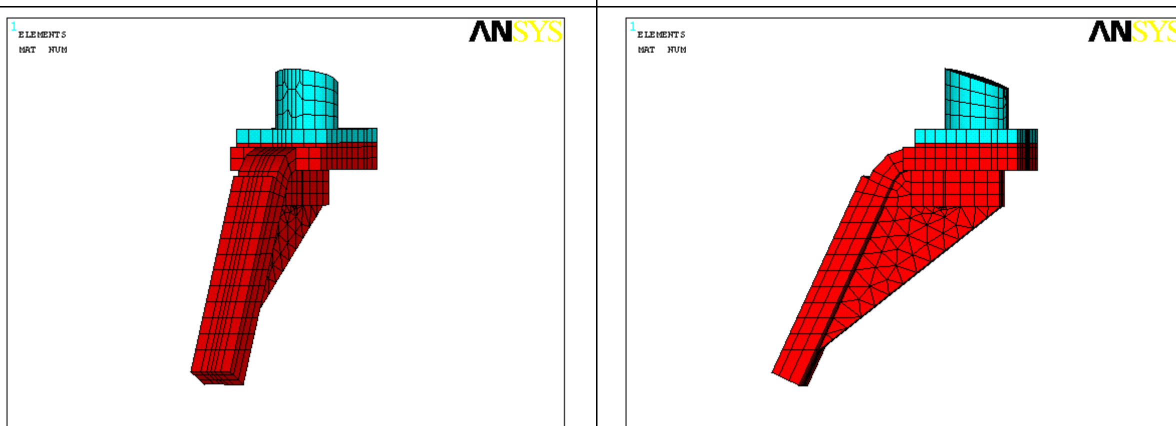


Fig 3.23. FEA Model of ODP support structure

Fig 3.21- 3.23 shows the solid & FE model of Outer divertor with support structure .

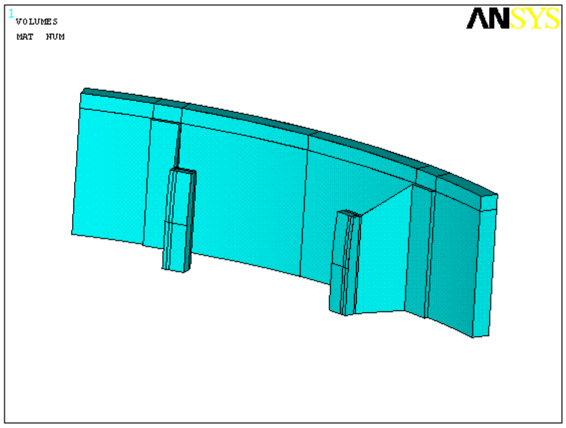


Fig 3.24. Solid Model Of IDP with Support Structure

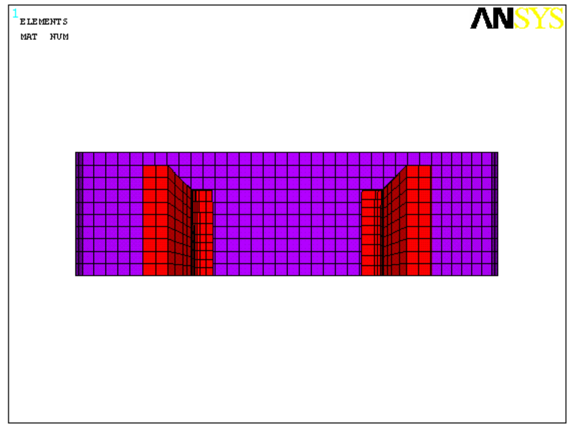


Fig 3.25. FEA Model of IDP with Support Structure

Fig 3.24 & 3.25 shows Solid model & FE model of Inner divertor with support structure

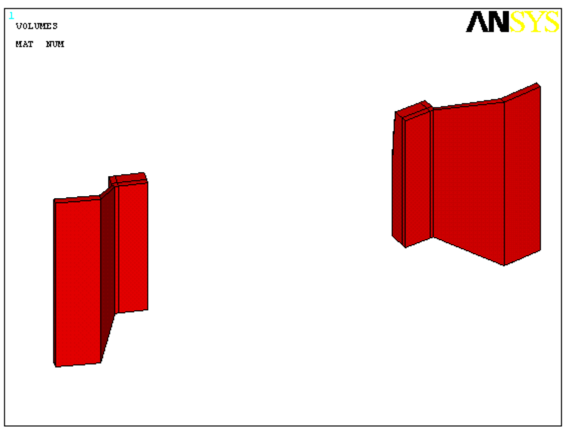


Fig 3.26. Solid Model Of IDP Support Structure

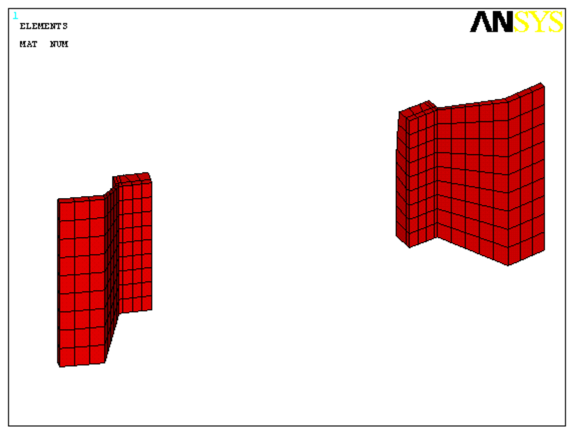


Fig 3.27. FEA Model of IDP Support Structure

Fig 3.26 & 3.27 shows Solid model & FE model of Inner divertor support structure

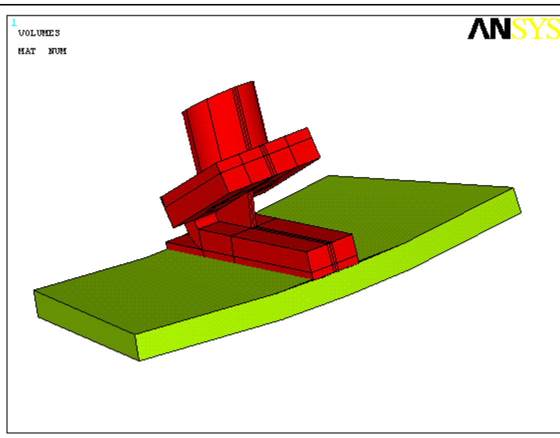


Fig 3.28. Solid Model Of Baffle with Support Structure

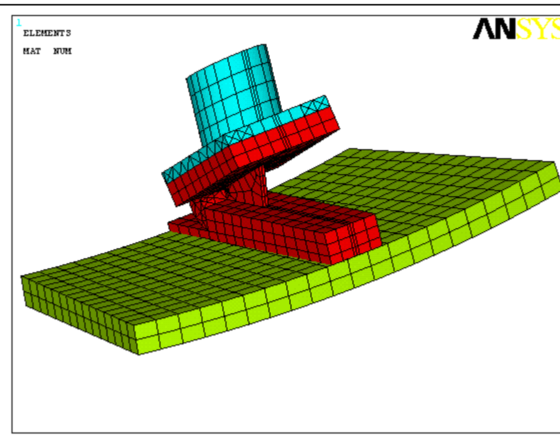


Fig 3.29. FEA Model of Baffle with Support Structure

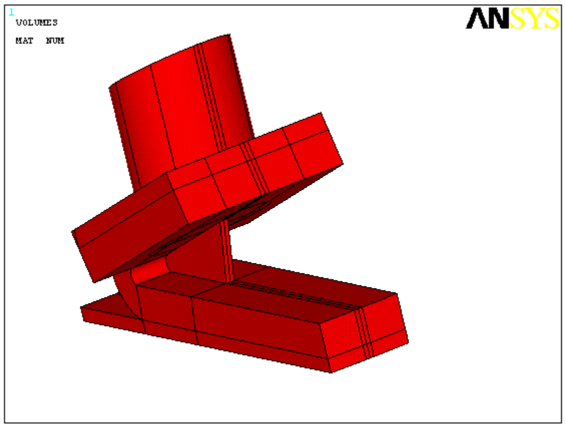
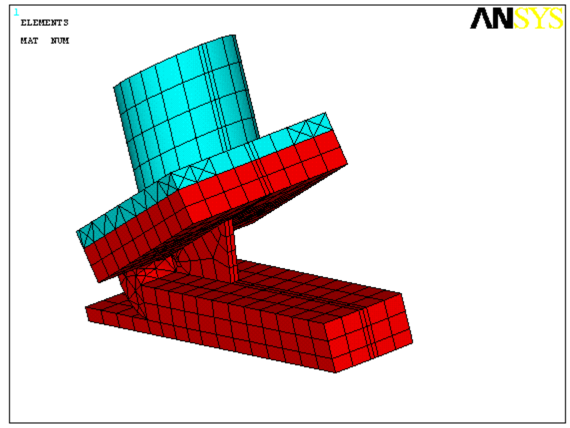
	

Fig 3.30. Solid Model Of Baffle Support Structure	Fig 3.31. FEA Model of Baffle Support Structure

Fig 3.28 – 3.31 shows Solid model & FE model of Main Baffle with support structure

This chapter covers the loading & boundary conditions, analysis methodology for solving electromagnetic & structural analysis & results from these analyses for outer divertor (Top & Bottom), inner divertor (Top & Bottom) & main baffle (Top & Bottom).

4.1 Analysis of Components (Divertor & Baffles) from Electromagnetic Loads:

The sudden disappearance of electrical current during a plasma disruption in the Tokamak induces large transient eddy currents in the surrounding PFC's. These eddy currents interact with the background magnetic fields to produce significant mechanical loads. In addition to the high heat loads, the large electromagnetic(EM) force acts on the first wall(F/W) and shield block at the plasma disruption by the interaction effect between toroidal and poloidal magnetic fields and induced eddy current in the toroidal direction. The high stresses are induced on the PFC's module due to the EM forces mentioned above, especially on the module attachments by the shearing force acting on the module side surfaces The reduction of the EM load acting on the PFC's module, therefore, is one of the key design issues to ensure the structural reliability of the support structure.

The tokamak shaped plasma column is inherently unstable to vertical displacements because of negative equilibrium index. There are requirements to have a stabilization of this motion and active and passive elements are used to stabilize it. The vertical stabilization of elongated plasma imposes severe requirements on the system since the stabilizing magnetic field increment must be initially imposed on the time scale of the plasma displacement. It is usually not possible to accomplish this with an active coil system alone because of the excessive peak power which would be required; consequently stability using passive coils has been under evaluations. The desired role of passive structure is to reduce the vertical stability growth rate so as to make active control feasible.

The general approach is to allow the rapid plasma displacement to generate eddy currents in passive elements and produce an associated induced magnetic field which will reduce the rate of displacement. The active coil can then control the plasma motion on a longer time scale thereby limiting peak power requirements to reasonable levels.

Plasma current in SST-1 is disrupted in time step and due to this disruption the behavior of components (Divertor & baffle) is analyzed for actual Electromagnetic Force when it is subjected to operate in the combined magnetic field which includes Plasma, all 16 TF & all 11 PF.

4.2 Analysis Methodology Overview

The methodology use for analysis is as follows

4.2.1 Electromagnetic analysis

The Electromagnetic analysis includes modeling, meshing, boundary condition & Solution in FEA package of ANSYS. The Simulation is carried out in five different ways to observe different conditions for eddy current & electromagnetic force during Disruption of Plasma. SOLID97 is used in FEA package of ANSYS with option vector magnetic potential (AX, AY, AZ) & time-integrated electric potential (VOLT). VOLT degree of freedom must be applied on the regions of eddy current induction which is components (divertor & baffle) in our case.

4.2.2. Structural analysis

The Electromagnetic force obtained in the step is transferred to the Structural analysis by switching the element from electromagnetic to the structural analysis. Solid 97 is converted to the Solid 95. As the electromagnetic analysis of the PFC's were performed without the support structure in order to reduce the element, because if the No of element increases then the result file (**.rst** file) exceeds the limit and ANSYS quits from the solution, therefore the supports are modeled separately and after the electromagnetic analysis, they are coupled with the PFC's for structural analysis and the loads from the electromagnetic analysis are read from the electromagnetic result file (**. rmg**).

4.2.3. Considerations of analysis

Disruption of plasma is transient condition so the structural analysis of components (divertor & baffle) due to the disruption of plasma current is transient analysis. This analysis is to be done in the Transient Analysis by coupling the Electro magnetic loads to the structural loads.

4.2.3.1. Solution Technique:

1. We have to find the electromagnetic forces from the Electromagnetic analysis and then we have to transfer these loads to the Structural analysis by coupling.
2. For Electromagnetic Analysis all PFC's, TF and PF coil were taken and they are enclosed in the air region and then the current is induced in the coil.
3. Flux Parallel is applied at all the areas of the air region and vector potential is applied at one node.

A Boundary condition for Electromagnetic analysis:

Disruption includes three boundary conditions. The boundary conditions are

1. Flux parallel is applied on all areas of the air region,
2. Vector potential is applied on one node of the air region.

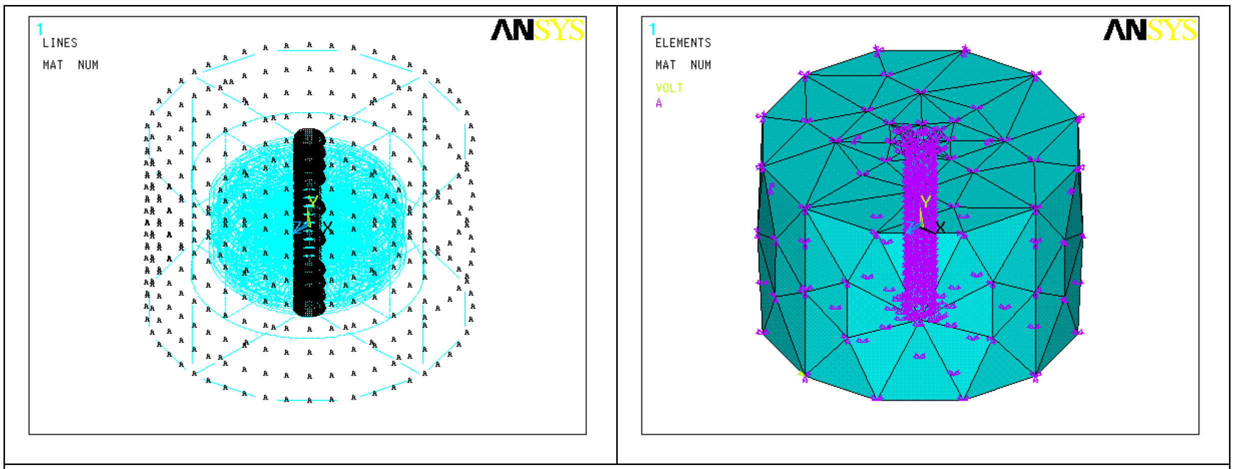


Fig 4.1 Boundary condition for electromagnetic analysis

Proper boundary conditions like flux parallel, flux normal, time varying current density on the plasma coil are applied and then solved for the induced currents & electromagnetic force on the structures.

B. Element Used:

Element Selected: SOLID 97 (For Electromagnetic Analysis).[15]

SOLID 95 (For Structural Analysis). [15]

C. Material Property for Electromagnetic Analysis:

The material properties of components (ODP, IDP, and BAFF) for electromagnetic analysis are in Table 4.1.

Table 4.1 Material properties of components for electromagnetic analysis

Module	Material	Material Properties	
		Resistivity	Permeability
Outer Divertor	CuZr	2.87E-08	1
Inner Divertor	CuZr	2.87E-08	1
Baffle	CuZr	2.87E-08	1
Plasma	-------	------	1
Air	-------	------	1

D. Loading conditions for magnetic analysis:-

1. Current density on Plasma is ramped from 220 KA to 0.00117 KA from 0.028 sec to 0.0399 sec. Current density is applied toroidaly on Plasma. The details are given in Table 4.2.

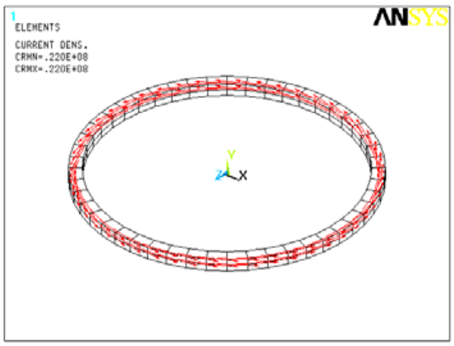
Table 4.2 Disruption Scenario of Plasma

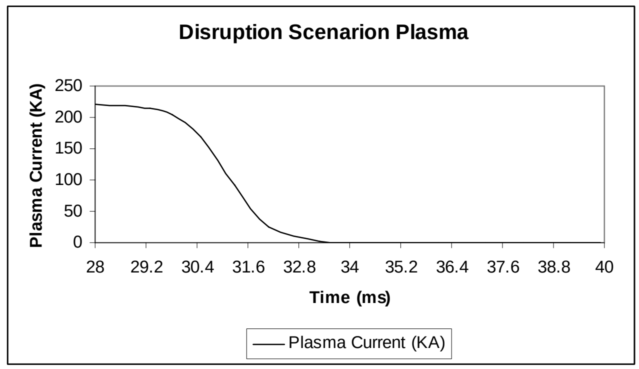
Sr. No.	Time (ms)	Plasma Current (KA)
1	28.00	220
2	29.30	214
3	29.80	205
4	30.50	168
5	31.30	90.7
6	32.10	25.8
7	33.30	3.01
8	34.20	0.47
9	35.10	0.071
10	36.10	0.0104
11	37.20	0.00117
12	38.10	0.000172
13	39.20	0.0000221
14	39.90	0.0000048

For Electromagnetic analysis Plasma is disrupted in six steps (Table4.3) due to the limitation of the workstation, as the no of elements increases and this leads to the increase in the size of the Result file (.rst) and the software quits from the solution. a vector plot of current density applied on plasma & profile of current during disruption are shown in Fig. 4.2.

Table 4.3 Disruption Profile of Plasma

Time (sec.)	0.028	0.0298	0.0313	0.0333	0.0351	0.0399
Plasma Current (KA)	220	205	90.7	3.01	0.071	0.00117





Profile of Plasma during disruption

Fig 4.2 Loading condition on Plasma

2. Current density is applied on all PF coils applied toroidal , detail are in Table 4.4 & vector plots on all PF coil are shown in Fig 4.3.

Table 4.4 Details of PF Coil Loading

PF No	**No. of turns**	**Current per turn (Amp.)**	**Appear Turns (AT)**	**Area (m^2)**	**Current density ($Amp./m^2$)**
1	80	10000	800000	2.27E-02	3.52E+07
2 u/l	40	10000	400000	1.16E-02	3.46E+07
3 u/l	192	10000	1920000	5.17E-02	3.71E+07
4 u/l	40	10000	400000	1.15E-02	3.49E+07
5 u/l	40	10000	400000	1.15E-02	3.49E+07
6 u/l	16	10000	160000	1.00E-02	1.60E+07

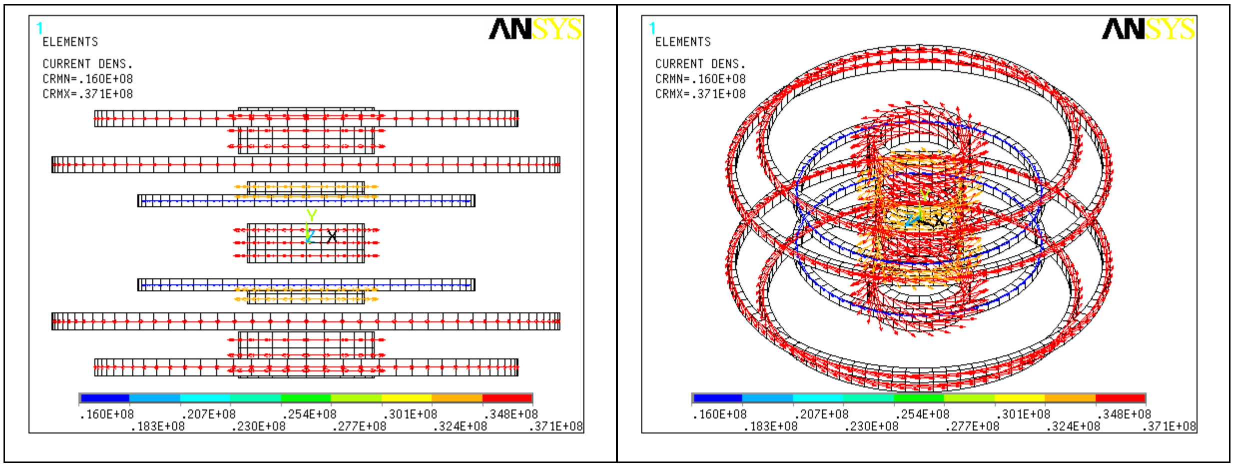


Fig 4.3 Loading condition on PF coils

3. Current density (J = I/A) of 33.2E+06 ampere/m^2 is applied on all TF coils in poloidal direction, the vector plot of this current density are shown in figure 4.4.

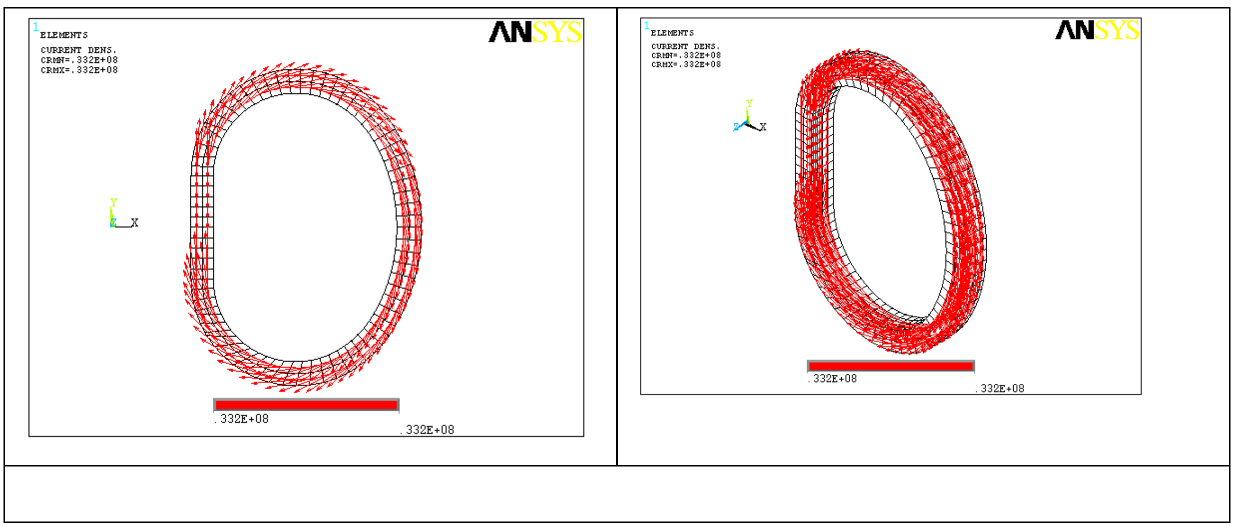
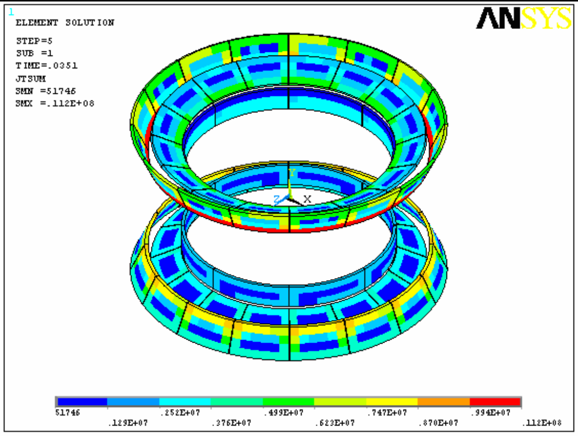


Fig 4.4 Loading condition on TF coil

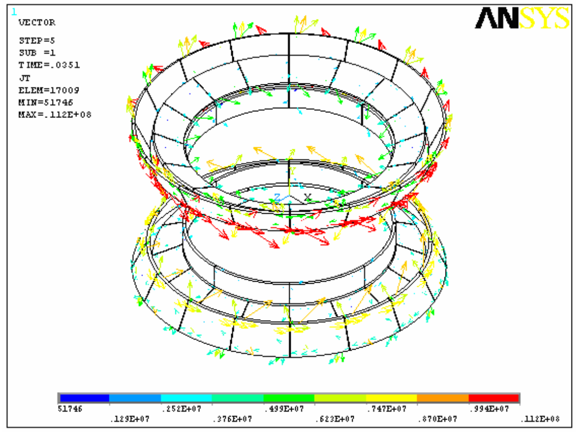
4.3 Results of Electromagnetic analysis:

Details of Induced Current & magnetic force in components from electromagnetic analysis are given as follows.

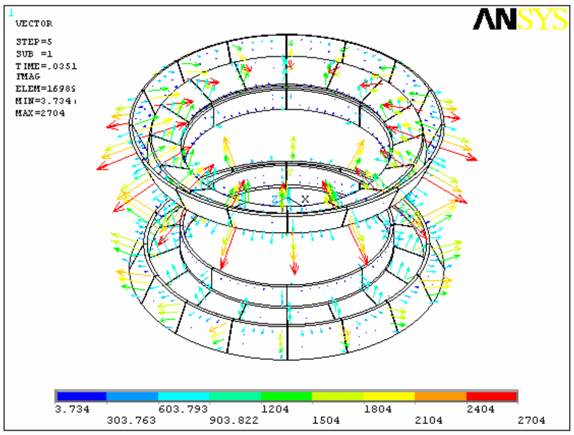
The counters & vector of current density & magnetic forces at each step are same, as shown in figure at step 4, but values of induced current & magnetic force are different. The values of induced current (current density x elemental area) & magnetic force are tabulated in table 4.5 & 4.6 for ODP, table 4.7 & 4.8 for IDP, table 4.9 & 4.10 for Baffle respectively.



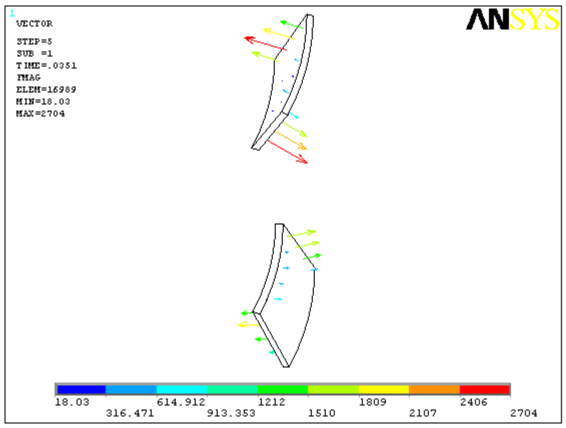
A. Counter Plot Of current Density



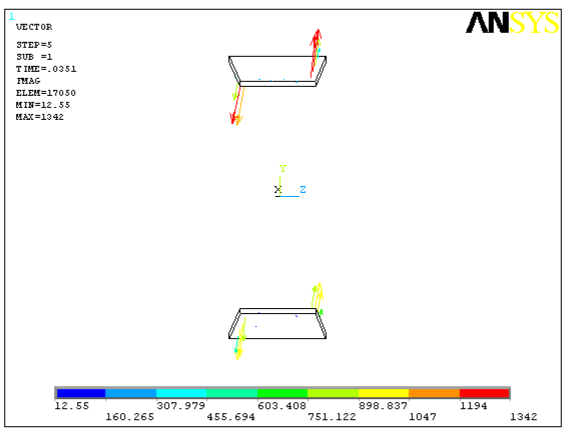
B. Vector plot of Current density in ODP, IDP & BAFFLE



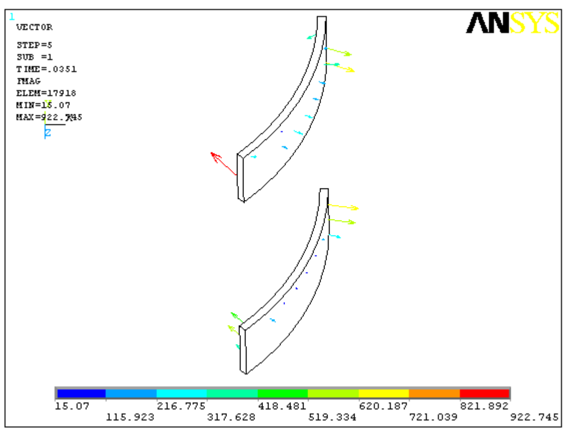
C. Vector plot of Magnetic Forces in ODP, IDP & BAFF



D. Vector plot of Magnetic Forces in ODP one module



E. Vector plot of Magnetic Forces in Baffle one module



F. Vector plot of Magnetic Forces in, IDP one module

Fig.4.5 (A, B, C, D, E) Results from Electromagnetic Analysis

Fig. 4.5 (A, B, C, D, E) shows profile of induced current density (JT) & its vector for step 5. Result of Disruption Induced Current Density & magnetic forces are listed in Table 4.5 to 4.10.

A. Induced current & Magnetic forces in Outer Divertor Plate (ODP)

Detail of induced current & magnetic force in ODP (Top & Bottom) for each steps of electromagnetic analysis are in Table 4.5 & 4.6 respectively & profile of these current and magnetic force are shown in figure 4.6.

Induced current in Outer Divertor Plate

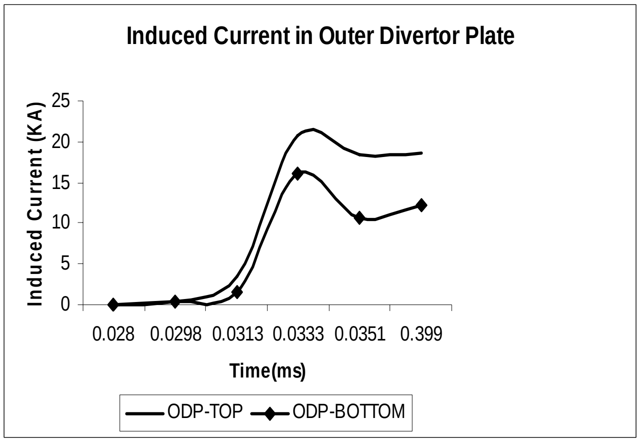
Table 4.5 Details of Induced current in ODP

Sr. No.	Time (Sec)	Induced current in ODP (KA)	
		ODP Top	ODP Bottom
1	0.028	0	0
2	0.0298	0.345	0.3164
3	0.0313	3.4	1.62516
4	0.0333	20.817	16.0349
5	0.0351	18.42446	10.7548
6	0.399	18.6329	12.2476

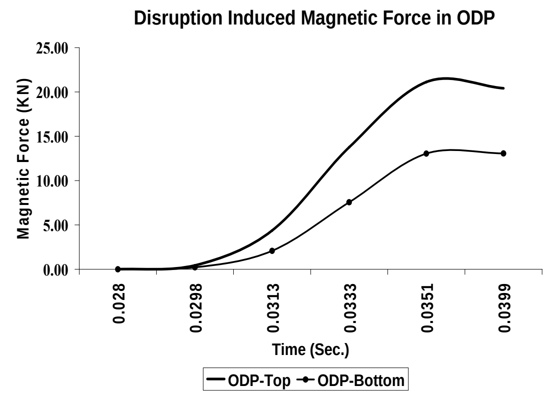
Details of the Magnetic forces in ODP Module

Table 4.6 Magnetic force in ODP Module

S. No.	Time (Sec)	Magnetic force in ODP Fmag Sum (KN)	
		ODP Top	ODP Bottom
1	0.028	0.00	0.00
2	0.0298	0.44	0.21
3	0.0313	4.36	2.08
4	0.0333	13.77	7.56
5	0.0351	21.13	13.05
6	0.0399	20.42	13.06



A. Profile of induced current in ODP



B. Profile of Magnetic Force in ODP

Fig. 4.6 (A, B) Profile of induced current & magnetic Force in ODP

B. Induced current & Magnetic forces in Inner Divertor Plate

Detail of induced current & magnetic force in IDP (Top & Bottom) for each steps of electromagnetic analysis are in Table 4.7 & 4.8 respectively & profile of these current and magnetic force are shown in figure 4.7.

Induced current in Inner Divertor Plate

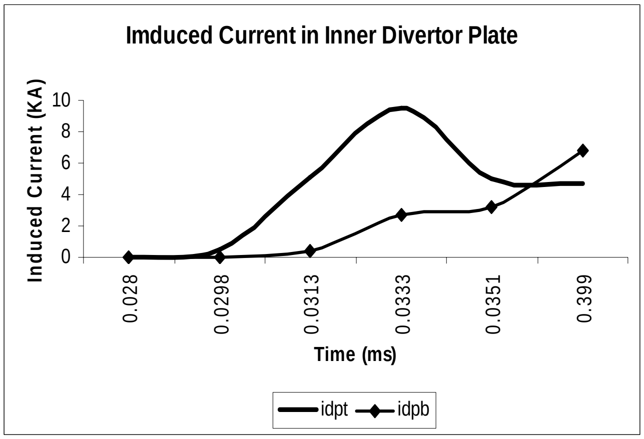
Table 4.7 Details of Induced current in IDP

Sr. No.	Time (Sec)	Induced current in IDP (KA)	
		IDP Top	IDP Bottom
1	0.028	0	0
2	0.0298	0.53906	0.04178
3	0.0313	5.119	0.37406
4	0.0333	9.4536	2.692
5	0.0351	4.95009	3.206689
6	0.399	4.663565	6.783

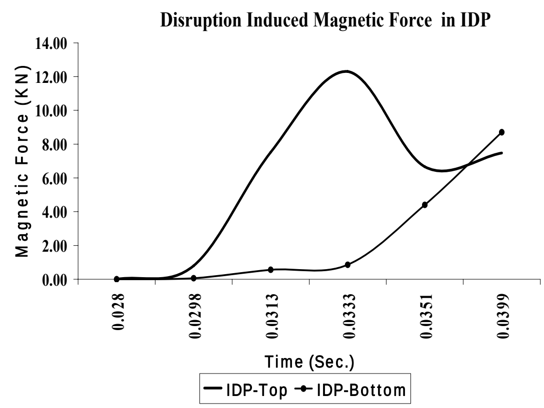
Details of the Magnetic forces in IDP Module

Table 4.8 Magnetic force in IDP Module

S. N0.	Time (Sec)	Magnetic force in IDP Fmag Sum (KN)	
		IDP Top	IDP Bottom
1	0.028	0.00	0.00
2	0.0298	0.80	0.06
3	0.0313	7.52	0.56
4	0.0333	12.3	0.86
5	0.0351	6.66	4.40
6	0.0399	7.47	8.71



A. Profile of induced current in IDP



B.Profile of Magnetic Force in IDP

Fig. 4.7 (A, B) Profile of induced current & magnetic Force in IDP

C. Induced current& Magnetic forces in Baffle Plate

Detail of induced current & magnetic force in Baffle (Top & Bottom) for each steps of electromagnetic analysis are in Table 4.9 & 4.10 respectively & profile of these current and magnetic force are shown in figure 4.8.

Induced current in Baffle Plate

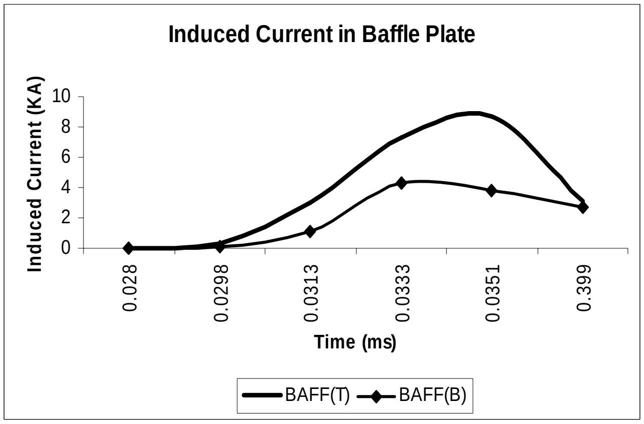
Table 4.9 Details of Induced current in Baffle

Sr. No.	Time (Sec)	Induced current in Baffle (KA)	
		Baffle Top	Baffle Bottom
1	0.028	0	0
2	0.0298	0.3188	0.113
3	0.0313	2.9945	1.1187
4	0.0333	7.265	4.30019
5	0.0351	8.7271	3.75085
6	0.399	3.101	2.6975

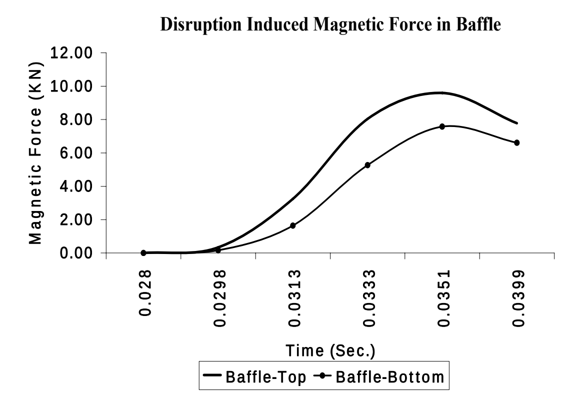
Details of the Magnetic forces in Baffle Module

Table 4.10 Magnetic force in Baffle Module

S. N0.	Time (Sec)	Magnetic force in Baffle Fmag Sum (KN)	
		IDP Top	IDP Bottom
1	0.028	0.00	0.00
2	0.0298	0.34	0.17
3	0.0313	3.24	1.64
4	0.0333	8.04	5.27
5	0.0351	9.60	7.58
6	0.0399	7.78	6.61



A. Profile of induced current in Baffle Plate



B. Profile of Magnetic Force in Baffle Plate

Fig. 4.8 (A, B) Profile of induced current & magnetic Force in Baffle

It is observed that the induced current is maximum at the 0.0333 sec in outer divertor (Top & Bottom), Baffle (Top & Bottom) & inner divertor top but it is maximum at 0.0399 sec in inner divertor bottom and therefore the Magnetic force is also be maximum at these time because F = J x B, where F is the Magnetic Force, J is the Current Density (kilo Ampere/meter^2) and B is the Magnetic Flux.

The magnetic force on each side of top & bottom board side of divertor (IDP & ODP) & baffle plate act in opposite direction because induced current are moved in a close loop & in these plates due to this nature current are reversed on each side (Fig4.9) & force is the vector product of current & magnetic field.

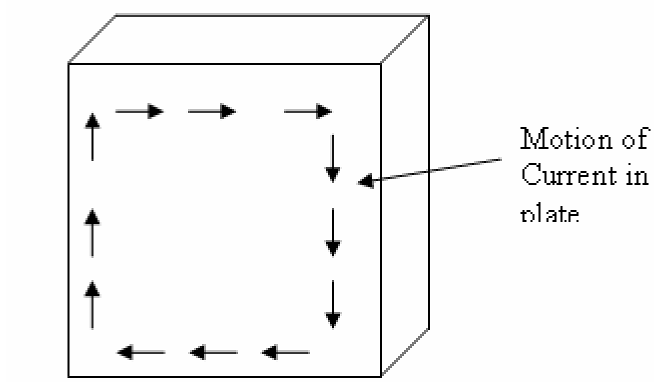


Fig. 4.9 Motion of induced current in Plates

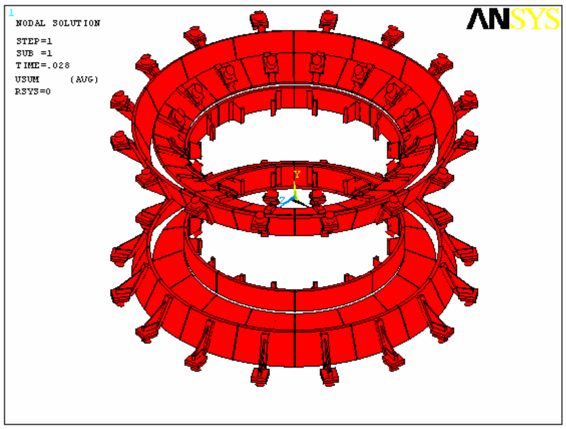
The magnetic forces on same side of top & bottom module are also in reverse direction because the motions of induced current in top & bottom modules of plate are of opposite nature.

4.4. Results from Structural Analysis due to Electromagnetic Load

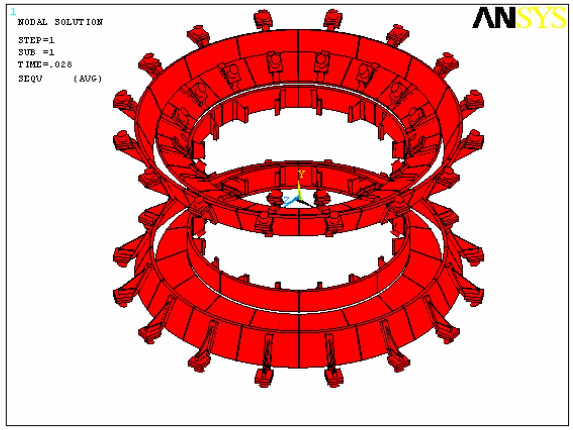
Results from Structural Analysis due to Electromagnetic Load at each step are in following section

4.4.1 Result of Deformation and Stress at Time step 0.028 sec

Deformation & stress results of assembly due to electromagnetic force at time step 0.028 are shown in following fig.4.10 (A, B). No stress & deformation at this time step because in electromagnetic analysis no current induced in all components in this step.



A. Deformation Results in assembly

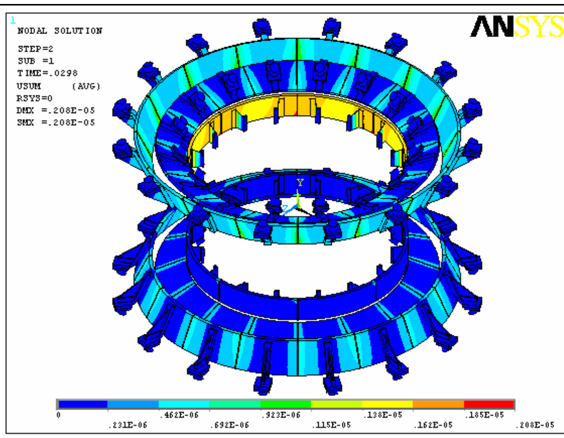


B. Stress (vonmisses) Results in assembly

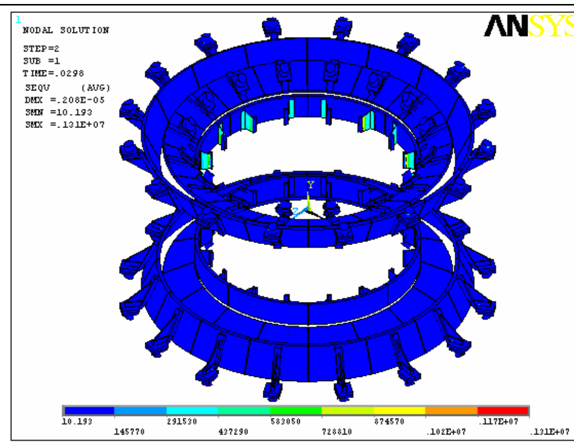
Fig 4.10 (A, B) Deformation & stress results in assembly at time step 0.028

4.4.2. Result of Deformation and Stress at Time step 0.0298 sec

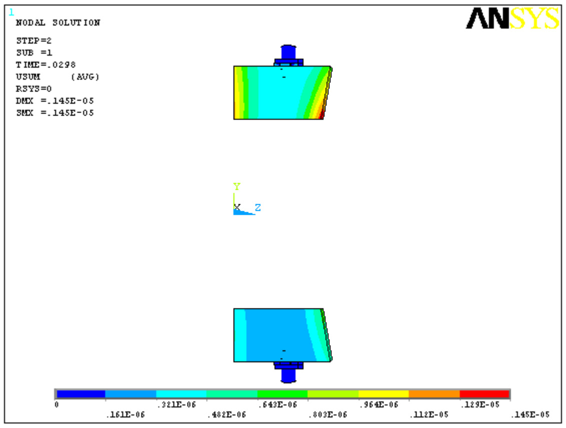
Deformation & stress results of assembly due to electromagnetic force at time step 0.0298 sec are shown in following figure, Fig 4.11 (A, B, C, D, E, F, G, H).



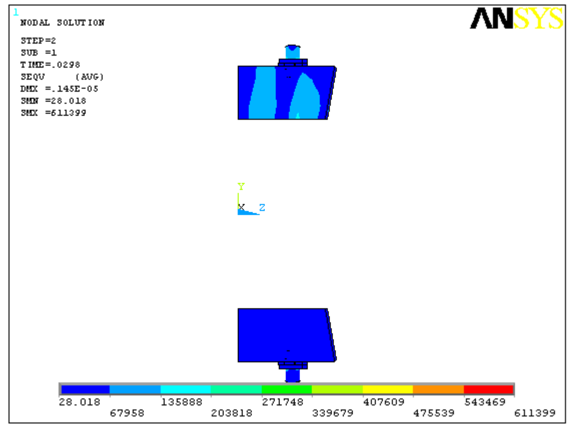
A. Deformation Results in assembly



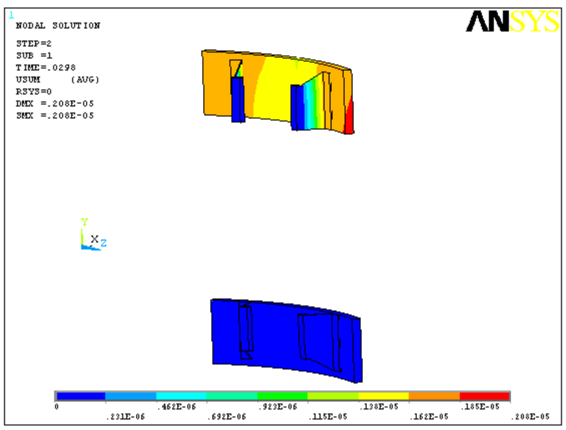
B. Stress (vonmisses) Results in assembly



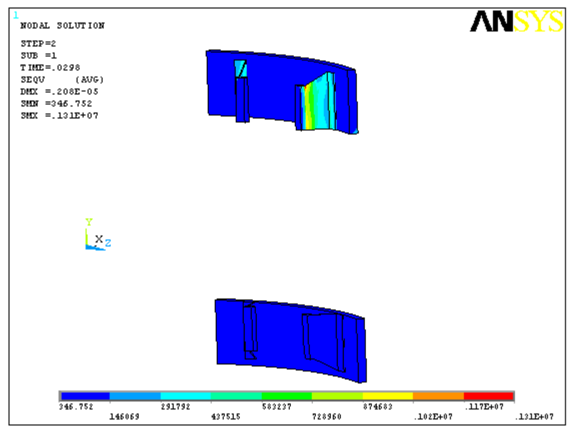
C. Deformation Result in ODP Module



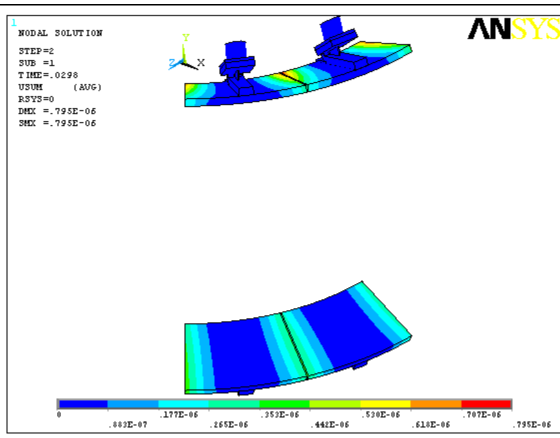
D. Stresses (vonmisses) Result in ODP Module



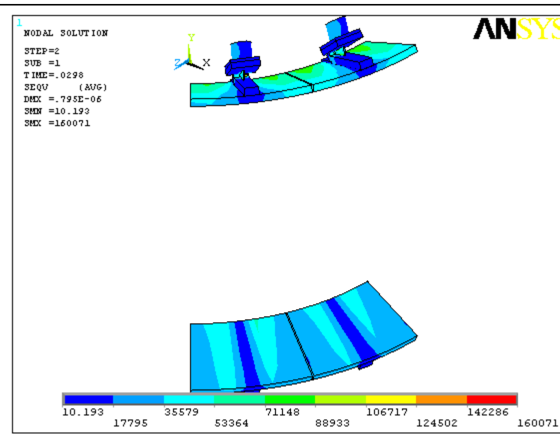
E. Deformation Result in IDP Module



F. Stresses (vonmisses) Result in IDP Module



G. Deformation Result in Baffle Module

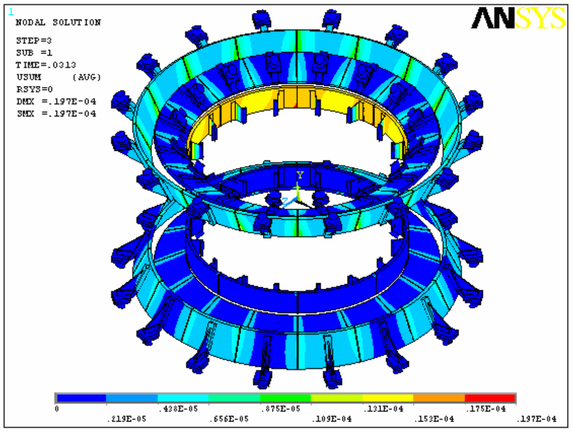


H. Stresses (vonmisses) Result in Baffle Module

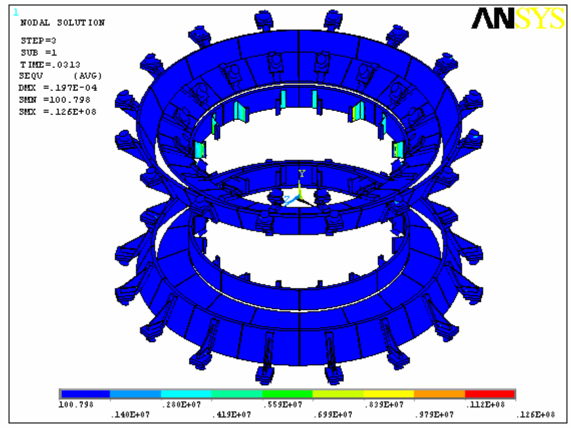
Fig 4.11 Deformation & stress results in assembly at time step 0.0298 sec

4.4.3. Result of Deformation and Stress at Time step 0.0313 sec

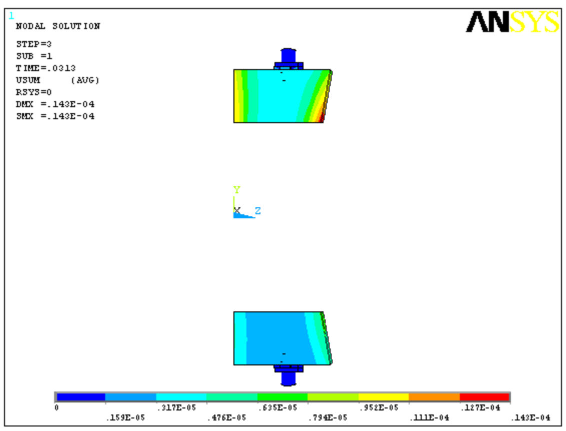
Deformation & stress results of assembly due to electromagnetic force at time step 0.0313 sec are shown in following figures, Fig 4.12 (A, B, C, D, E, F, G, H).



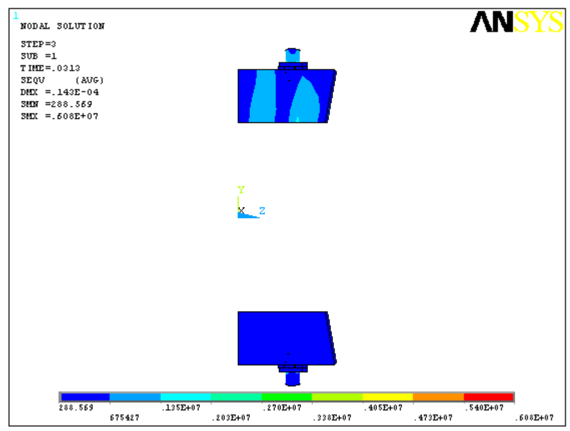
A. Deformation Results in assembly



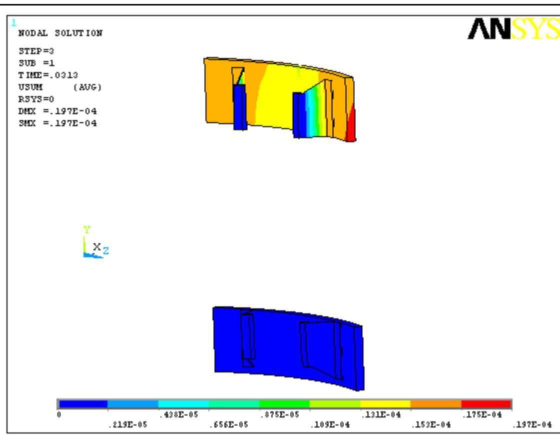
B. Stress (vonmisses) Results in assembly



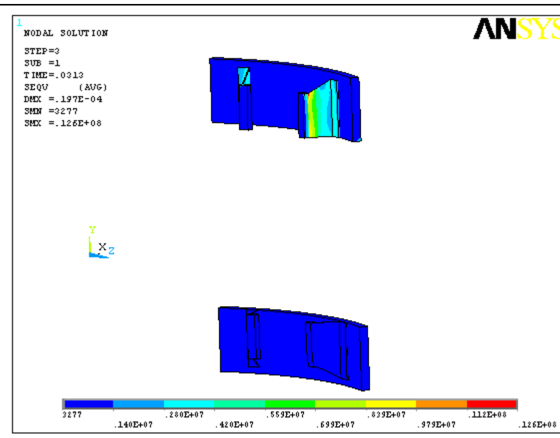
C. Deformation Result in ODP Module



D.Stresses (vonmisses) Result in ODP Module



E. Deformation Result in IDP Module



F. Stresses (vonmisses) Result in IDP Module

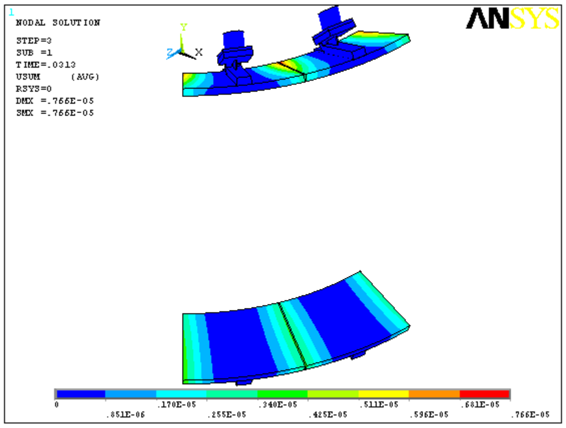
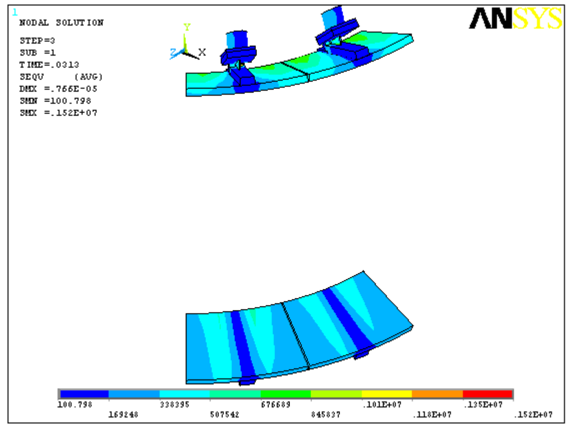
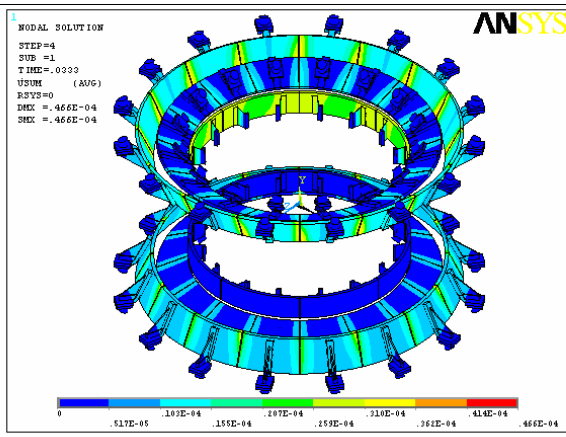
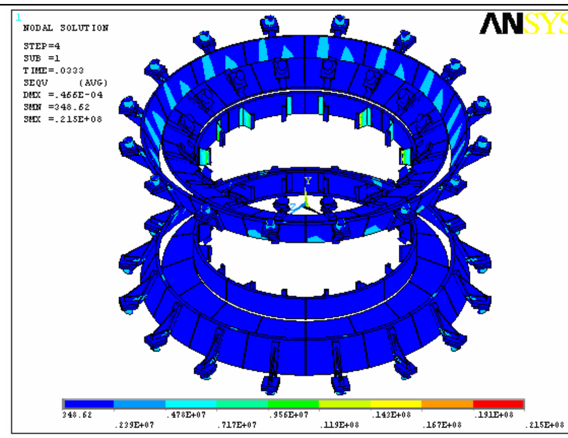
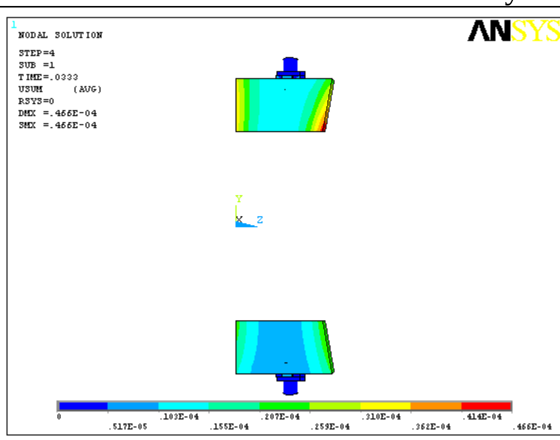
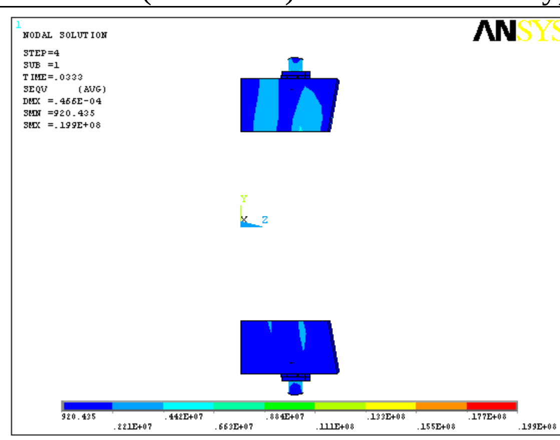
	
G. Deformation Result in Baffle Module	H. Stresses (vonmisses) Result in Baffle

Fig 4.12 Deformation & stress results in assembly at time step 0.0313 sec

4.4.4. Result of Deformation and Stress at Time step 0.0333 sec

Deformation & stress results of assembly due to electromagnetic force at time step 0.0333 sec are shown in following figures, Fig 4.13 (A, B, C, D, E, F, G, H).

	
A. Deformation Results in assembly	B. Stress (vonmisses) Results in assembly)
	
C. Deformation Result in ODP Module	D. Stresses (vonmisses) Result in ODP Module

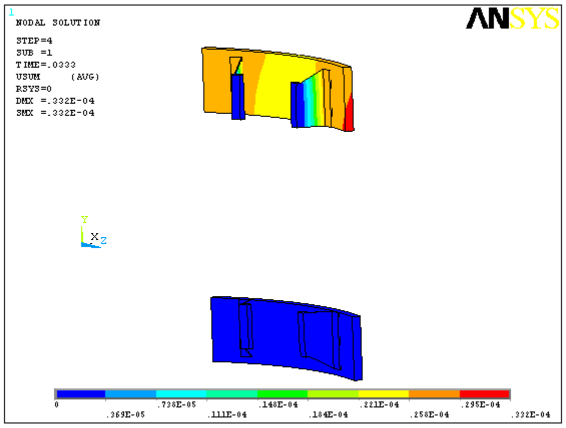
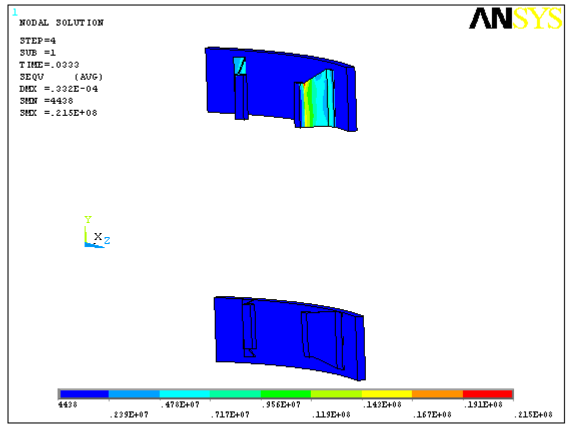
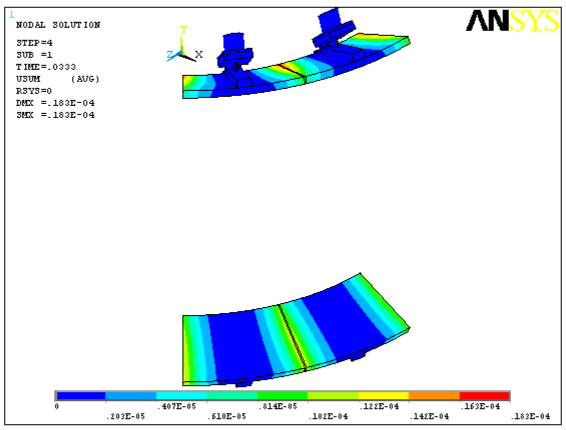
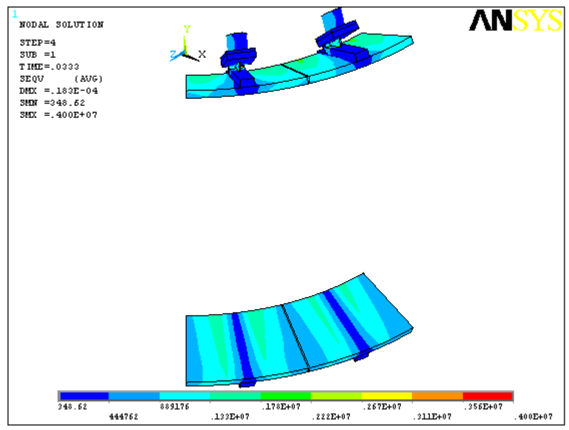
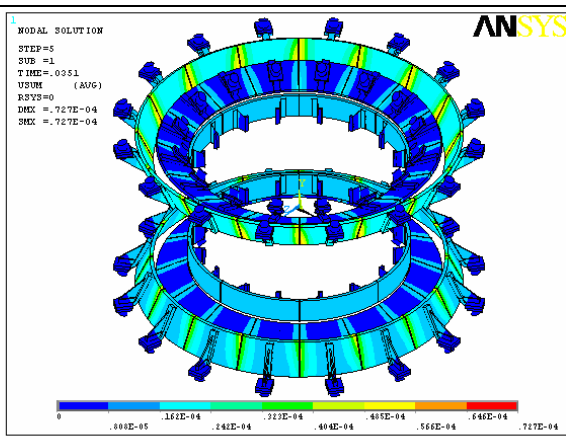
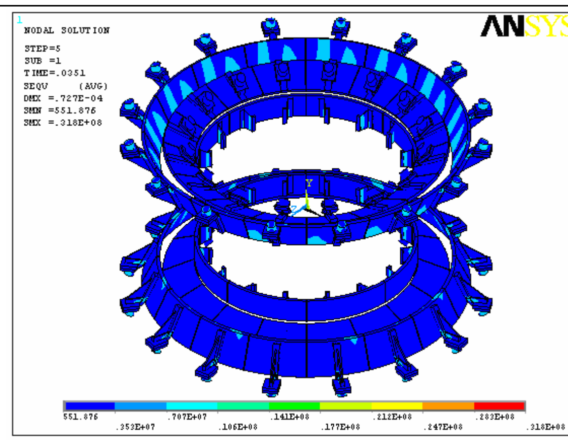
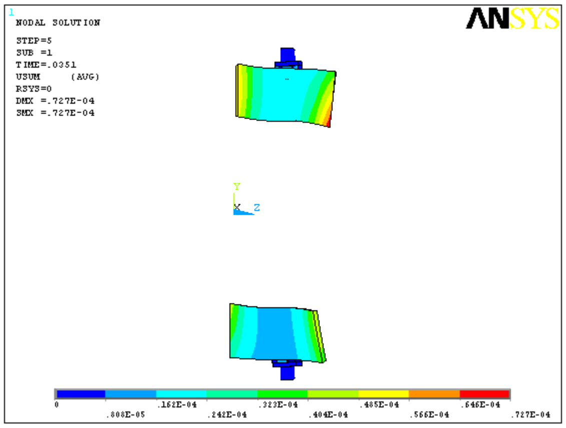
	
E. Deformation Result in IDP Module	F. Stresses (vonmisses) Result in IDP Module
	
G. Deformation Result in Baffle Module	H. Stresses (vonmisses) Result in Baffle Module

Fig 4.13 Deformation & stress results in assembly at time step 0.0333 sec

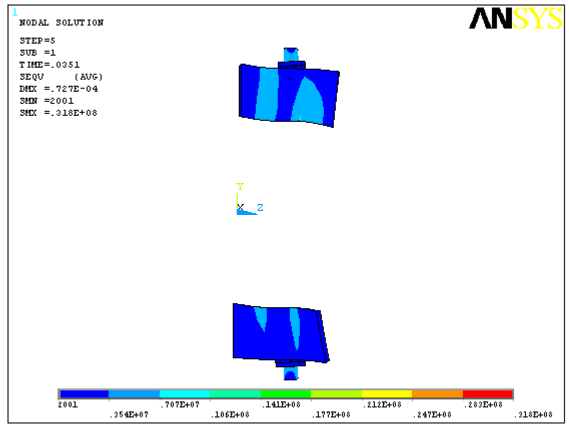
4.4.5. Result of Deformation and Stress at Time step 0.0351 sec

Deformation & stress results of assembly due to electromagnetic force at time step 0.0351 sec are shown in following figures, Fig 4.14 (A, B, C, D, E, F, G, H).

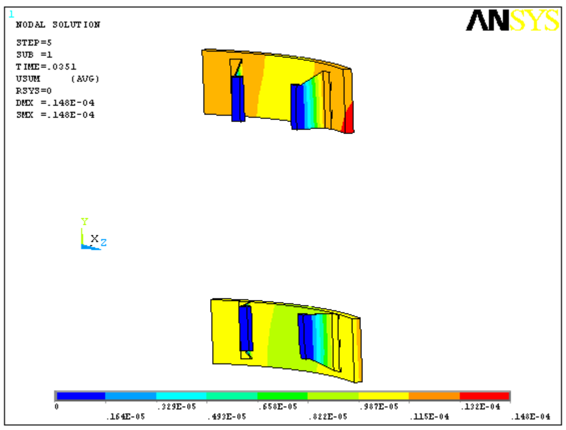
	
A. Deformation Results in assembly	B. Stress (vonmisses) Results in assembly



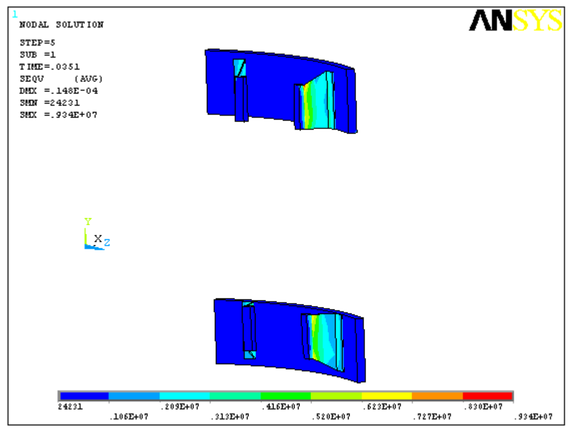
C. Deformation Result in ODP Module



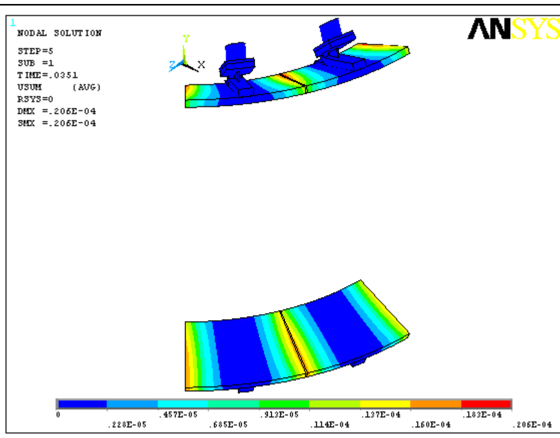
D. Stresses (vonmisses) Result in ODP Module



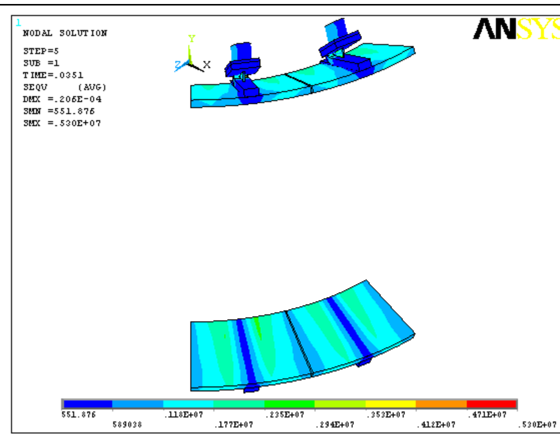
E. Deformation Result in IDP Module



F. Stresses (vonmisses) Result in IDP Module



G. Deformation Result in Baffle Module

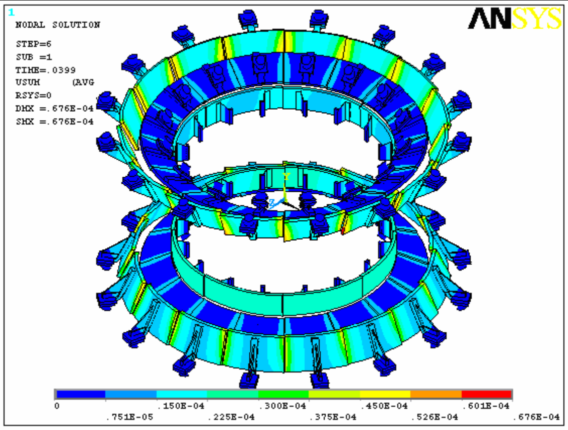


H. Stresses (vonmisses) Result in Baffle Module

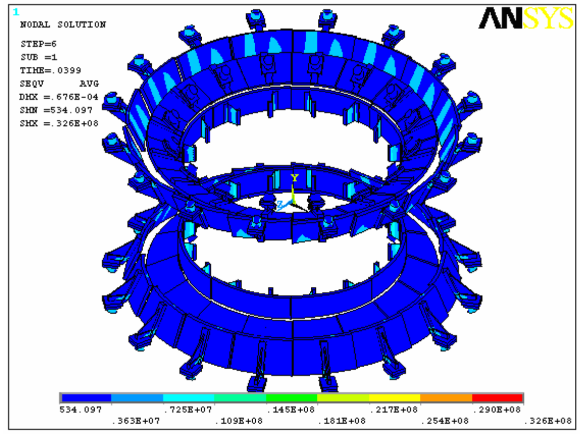
Fig 4.14 Deformation & stress results in assembly at time step 0.0351 sec

4.4.6. Result of Deformation and Stress at Time step 0.0399 sec

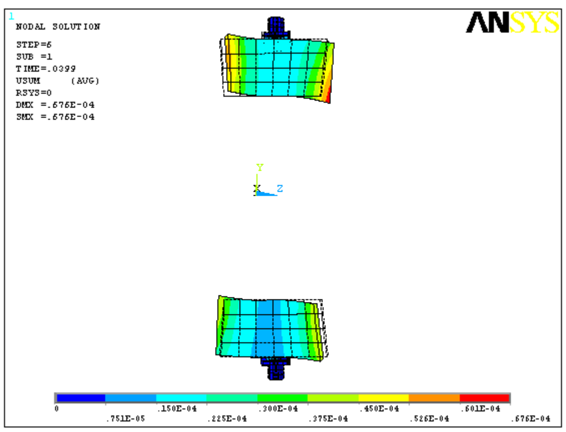
Deformation & stress results of assembly due to electromagnetic force at time step 0.0399 sec are shown in following figures, Fig 4.15 (A, B, C, D, E, F, G, H).



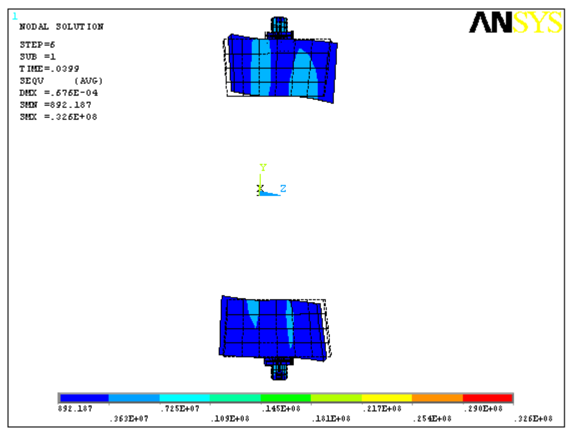
A. Deformation Results in assembly



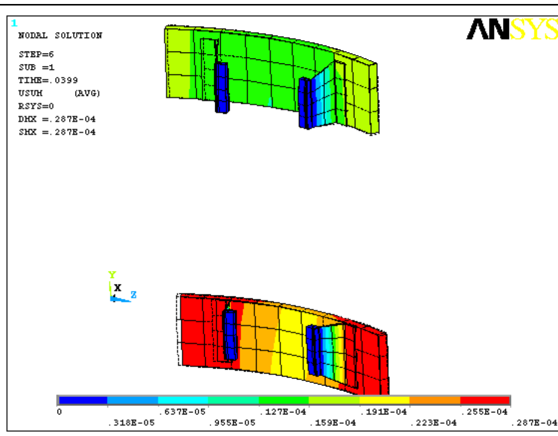
B. Stress (vonmisses) Results in assembly



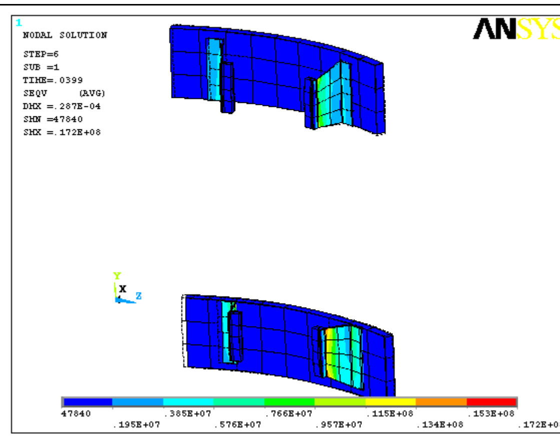
C. Deformation Result in ODP Module



D. Stresses (vonmisses) Result in ODP Module



E. Deformation Result in IDP Module



F. Stresses (vonmisses) Result in IDP Module

Fig 4.15 Deformation & stress results in assembly at time step 0.0399 sec

4.4.7 Maximum Stress & Deformation in Outer Divertor

Simulation results, deformation & stress (vonmisses), of all the steps for ODP (Top & Bottom) module are summarized in Table 4.11.

Table 4.11 Maximum Deformation & Stresses (vonmisses) in ODP module

ODP				
	TOP		BOTTOM	
TIME	U_{sum} (m)	S_{max} (N/m^2)	U_{sum} (m)	S_{max} (N/m^2)
0.028	0	0	0	0
0.0298	1.45E-06	611399	6.72E-07	303512
0.0313	4.30E-05	6.08E+06	6.71E-06	3.04E+06
0.0333	4.66E-05	1.99E+07	6.71E-06	1.23E+07
0.0351	7.27E-05	3.18E+07	4.59E-05	2.22E+07
0.0399	6.76E-05	3.26E+07	4.53E-05	2.35E+07

4.4.8 Maximum Deformation & stress in IDP module

Simulation results, deformation & stress (vonmisses), of all the six steps for Baffle (Top & Bottom) module are summarized in Table 4.12.

Table 4.12 Maximum Deformation & Stresses (vonmisses) in IDP module

IDP				
	TOP		BOTTOM	
TIME	U_{sum} (m)	S_{max} (N/m^2)	U_{sum} (m)	S_{max} (N/m^2)
0.028	0	0	0	0
0.0298	2.08E-06	1.31E+06	2.61E-07	1.44E+05
0.0313	1.97E-05	1.26E+07	2.40E-06	1.33E+06
0.0333	3.32E-05	2.15E+07	7.97E-07	8.36E+05
0.0351	1.48E-05	9.34E+06	1.19E-05	7.58E+06
0.0399	1.85E-05	1.20E+07	2.87E-05	1.72E+07

4.4.9 Maximum Deformation & stress in Baffle modules

Simulation results, deformation & stress (vonmisses), of all the six steps for Baffle (Top & Bottom) module are summarized in Table 4.13.

Table 4.13 Maximum Deformation & stress in Baffle module

BAFFLE				
	TOP		BOTTOM	
TIME	U_{sum} (m)	S_{max} (N/m^2)	U_{sum} (m)	S_{max} (N/m^2)
0.028	0	0	0	0
0.0298	2.08E-06	1.31E+06	2.61E-07	1.44E+05
0.0313	1.97E-05	1.26E+07	2.40E-06	1.33E+06
0.0333	3.32E-05	2.15E+07	7.97E-07	8.36E+05
0.0351	1.48E-05	9.34E+06	1.19E-05	7.58E+06
0.0399	1.85E-05	1.20E+07	2.87E-05	1.72E+07

4.5 Structural Analysis of components (Divertors & Baffle) Assembly due to baking:

4.5.1. Baking of PFC's:

All the PFCs are baked at 150 deg centigrade and due to this there is thermal expansion of the plates. During baking the PFCs will expand and the support should be flexible enough to allow this expansion. The baking temperature will be as high as 350º C for the first wall components and hence thermal expansion of these components will be significant and the supports of these components should be flexible enough to allow the full expansion of the Plates. Therefore the design requirement of the support plate should be seriously considered.

4.5.2. Consideration

To analyze the support structure when the PFCs are baked at 150 deg centigrade .The support structure should be capable enough to allow the full expansion of the plate.

A. Solution Technique:

1. Applying symmetric boundary condition at the cut section of the Vessel as shown in model of baking analysis.
2. Applying the temperature of 150^0 centigrade on the Divertor plates (IDP, ODP) & Baffle.
3. Constrained all degree of freedom of both Ports, vertical and radial.

B. Element Used: SOLID 95[16]

C. Boundary Condition:

Assembled model of components and Vacuum vessel of 45 deg sector one full and two half sector one half on each side of full sector are taken, symmetry boundary condition is applied on all the cut section of the vessel ,as shown in fig 4.16, and the ports are constrained to all degree of freedom.

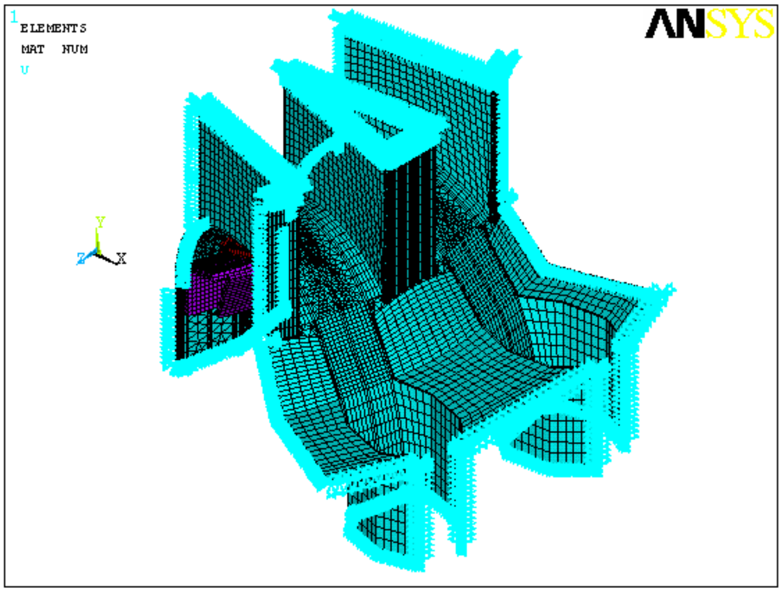


Fig 4.16 Boundary condition on the Assembly

D. Materials for the Assembly:

Material properties for ODP, IDP & Baffle for baking analysis are in Table 4.14, 4.15 & 4.16 respectively.

Table 4.14 Materials of different parts of ODP

Sr. No.	Part	Material	Young's Modulus, E (GPa)	Thermal Expansion, α	Poisson Ratio, ν	Tensile Strength
1	ODP Plates	Cu-Cr-Zr	118	15.8 e^{-6}	0.311	470Mpa
2	Support Base	SS 304	193	17.2 e^{-6}	0.29	515 Mpa
3.	Splice Plate	Inconel X-750	208	12.1 e^{-6}	0.304	1120@ 20 deg 965@ 540 deg
4	Spacer1	Inconel X-750	208	12.1 e^{-6}	0.304	1120@ 20 deg 965@ 540 deg
5	Spacer2	Inconel X-750	208	12.1 e^{-6}	0.304	1120@ 20 deg 965@ 540 deg
6	Bracket	SS 304	193	17.2 e^{-6}	0.29	515 Mpa

Table 4.15 Materials of different parts of IDP

Sr. No.	Part	Material	Young's Modulus, E (GPa)	Thermal Expansion, α	Poisson Ratio, ν	Tensile Strength
1	IDP Plates	Cu-Cr-Zr	118	15.8 e^{-6}	0.311	470Mpa
2	Support Structure	Inconel X-750	208	12.1 e^{-6}	0.304	1120@ 20 deg 965@ 540 deg

Table 4.16 Materials of different parts of Baffle

Sr. No.	Part	Material	Young's Modulus, E (GPa)	Thermal Expansion, α	Poisson Ratio, ν	Tensile Strength
1	Baffle Plates	Cu-Cr-Zr	118	15.8 e^{-6}	0.311	470Mpa
2	Base Plate	SS 304	193	17.2 e^{-6}	0.29	515 Mpa
3.	Bracket & Gusset Plate	Inconel X-750	208	12.1 e^{-6}	0.304	1120@ 20 deg 965@ 540 deg
4	Spacer	Inconel X-750	208	12.1 e^{-6}	0.304	1120@ 20 deg 965@ 540 deg
5	Spacer2	Inconel X-750	208	12.1 e^{-6}	0.304	1120@ 20 deg 965@ 540 deg
6	Rod of Base plate	SS 304	193	17.2 e^{-6}	0.29	515 Mpa

4.5.3 Results of the assembly & components due to baking:

Simulation results, deformation & stress (vonmisses), of assembly and all components from baking analysis are shown in following figures. Fig 4.17 – 4.30.

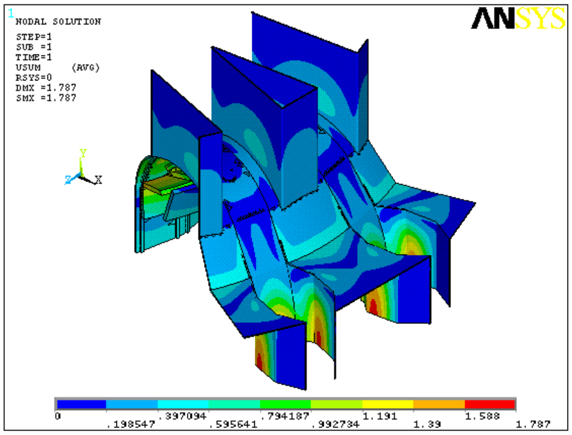


Fig 4.17. Deformation Result in assembly

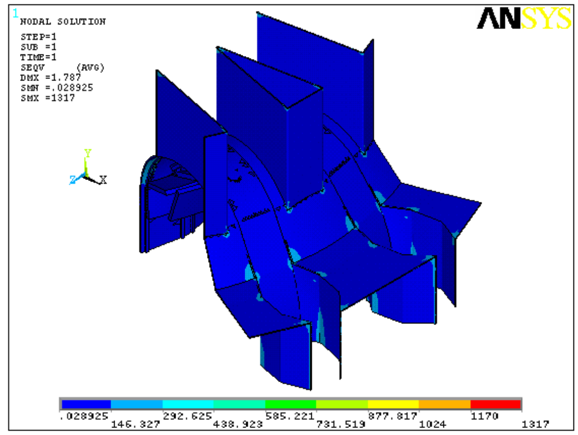
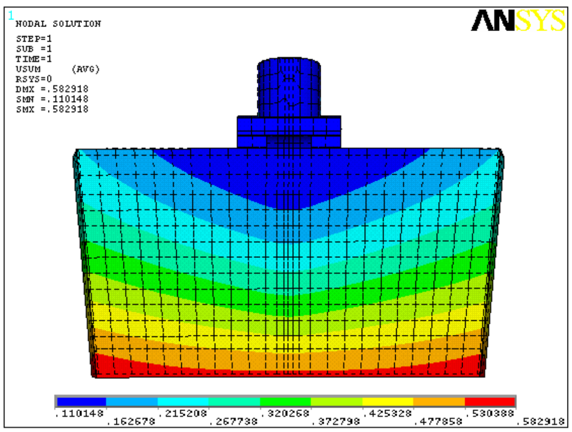


Fig 4.18 Stresses (vonmisses) Result in assembly



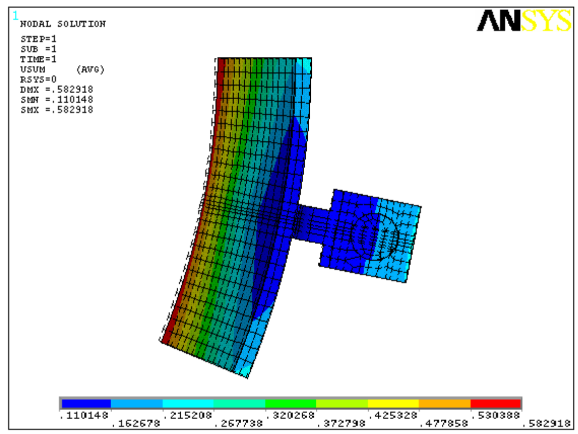
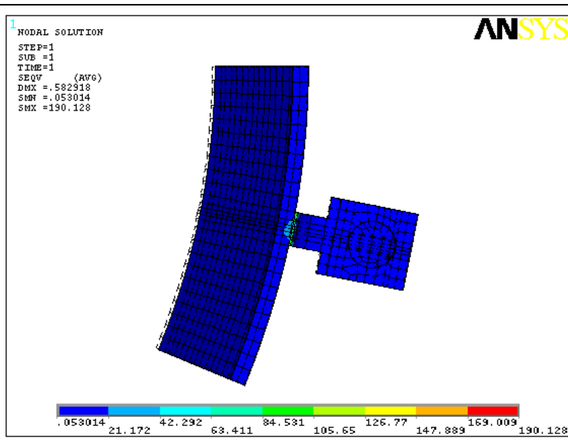


Fig 4.19 Deformation result of ODP



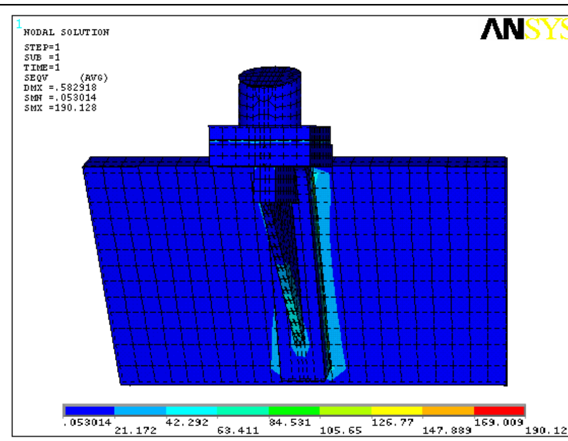


Fig 4.20. Stresses (vonmisses) result of ODP

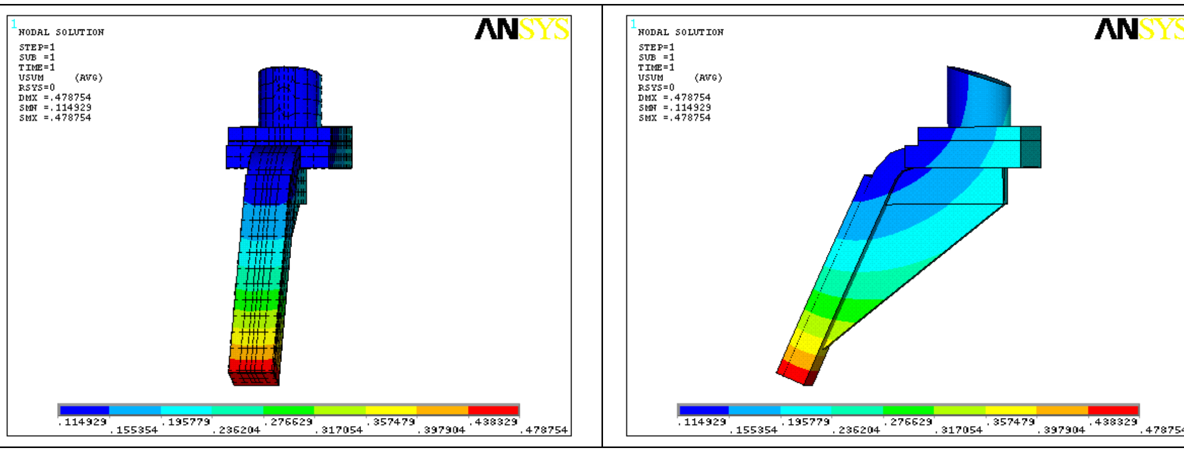


Fig 4.21. Deformation result of ODP support structure

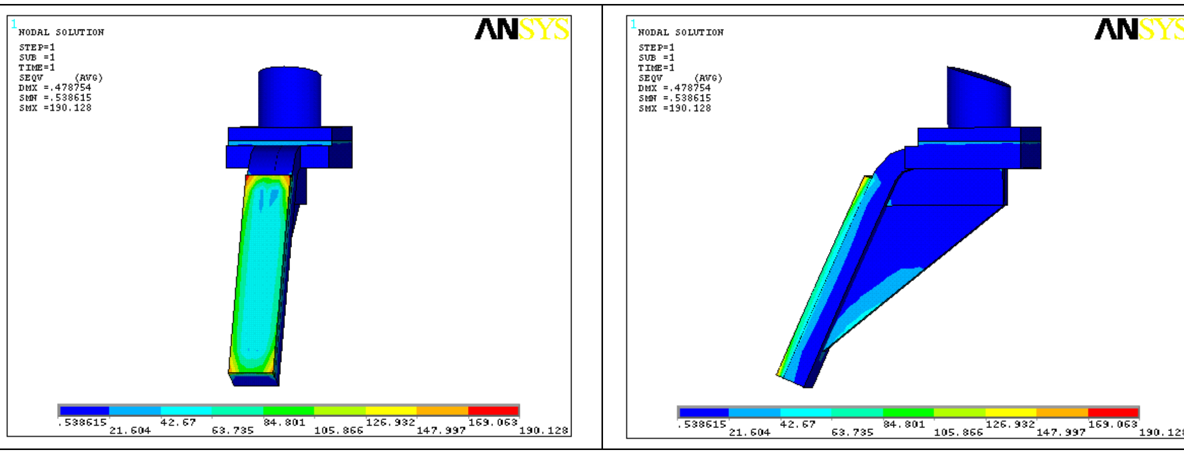


Fig 4.22 Stresses (vonmisses) result of ODP support structure

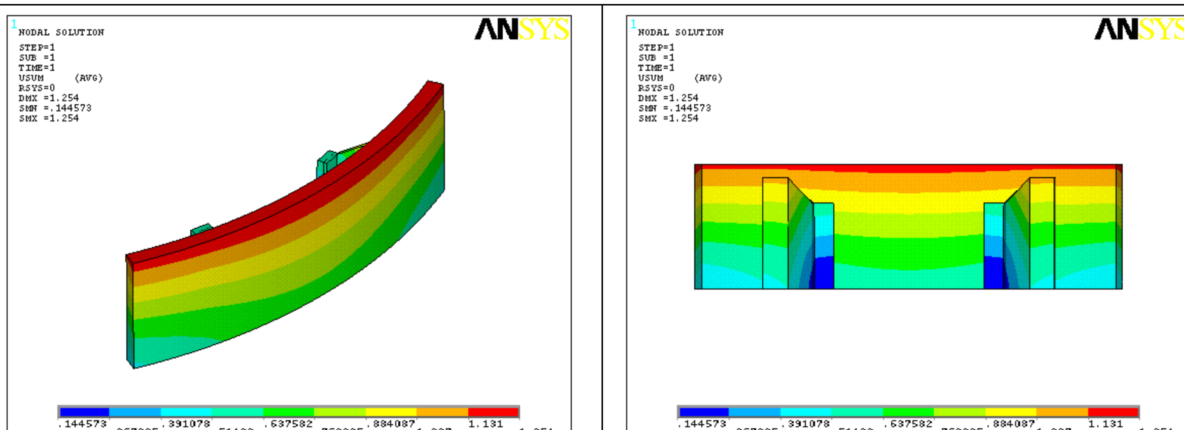
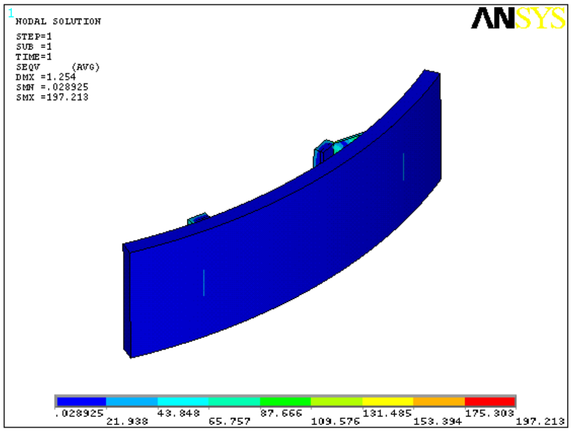


Fig 4.23. Deformation result of IDP



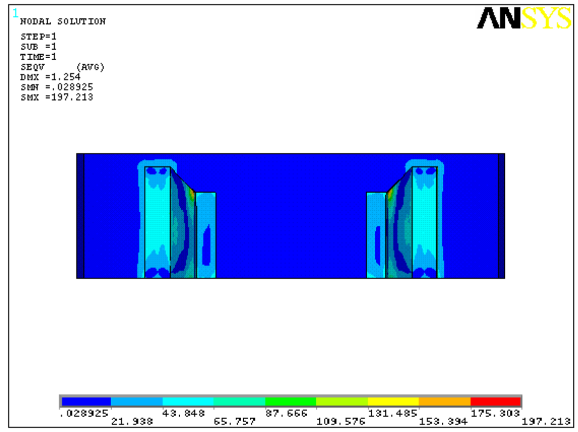


Fig 4.24. Stresses (vonmisses) result of IDP

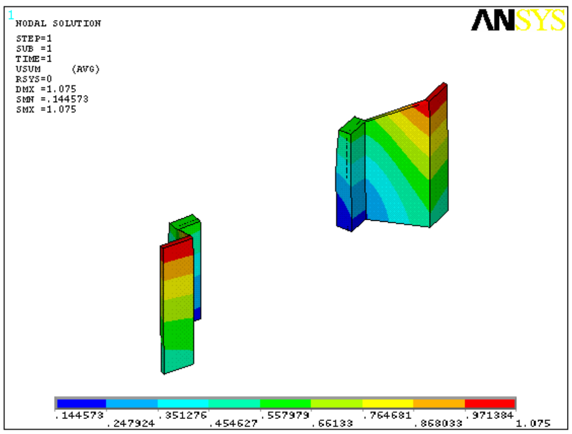


Fig 4.25. Deformation result of IDP support structure

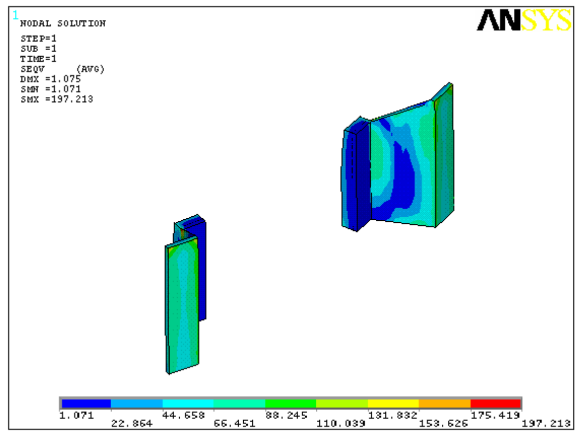
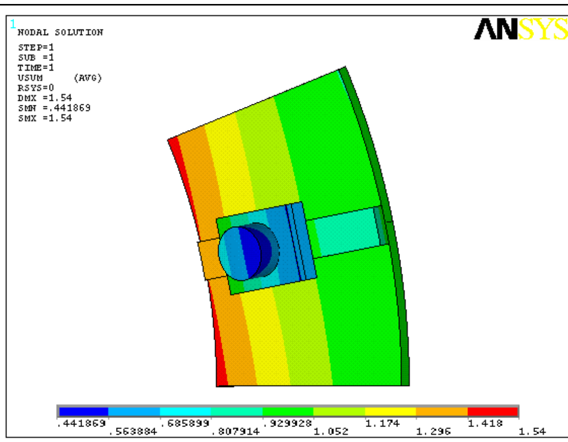


Fig 4.26. Stresses (vonmisses) result of IDP support structure



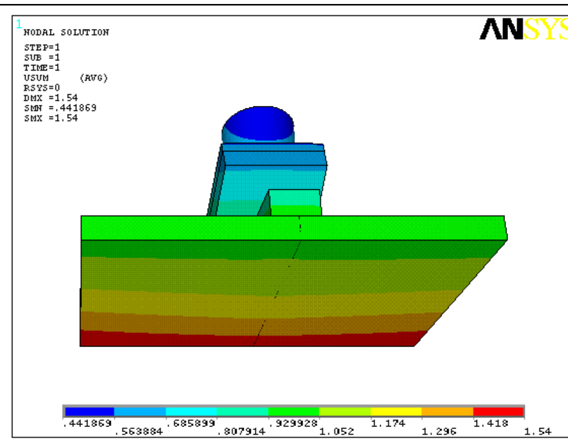
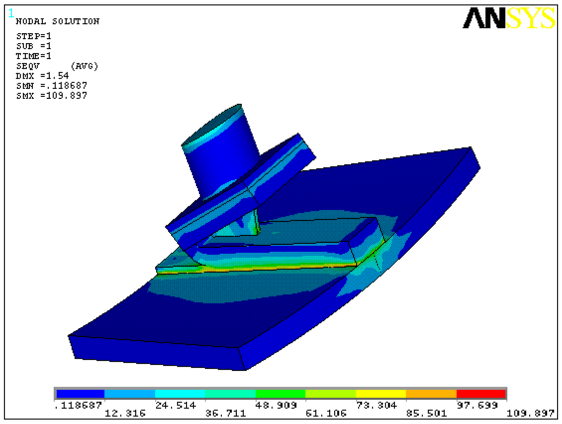


Fig 4.27. Deformation result of Baffle with Support structure



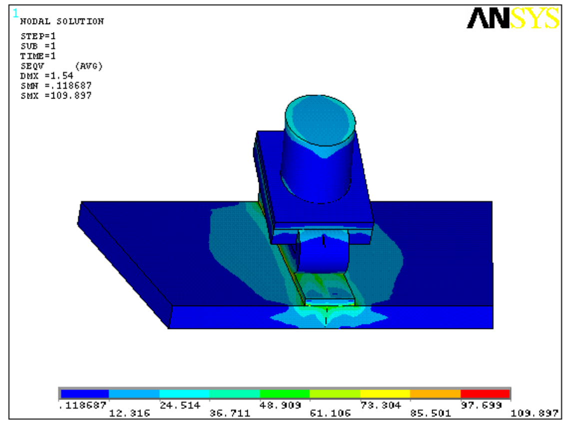


Fig 4.28. Stresses (vonmisses) result of Baffle with support structure

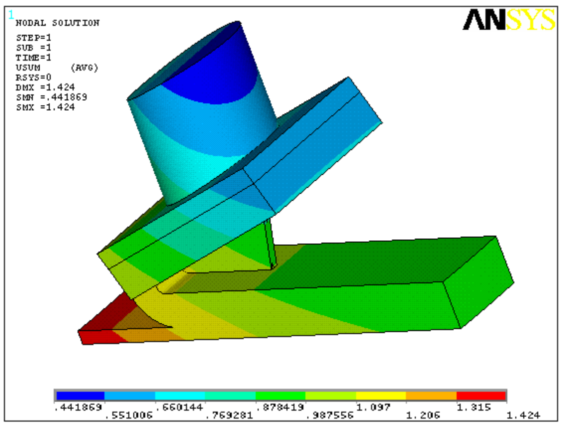


Fig 4.29. Deformation result of Baffle support structure

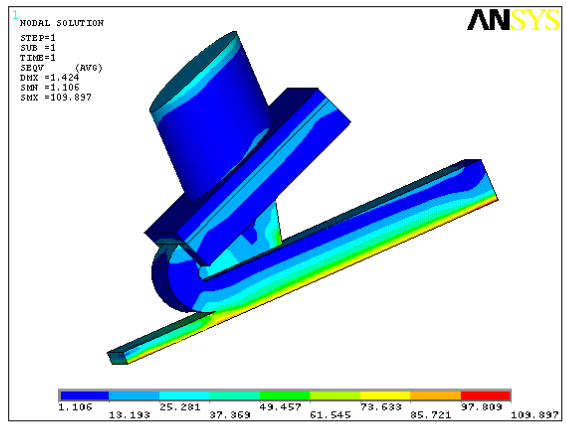


Fig 4.30. Stresses (vonmisses) result of baffle support structure

Electromagnetic and Structural analysis of Divertors (IDP, ODP) and Baffle of SST-I using ANSYS software has been carried out successfully for disruption and baking condition The project work cover most of the typical Electromagnetic and structural problems and the problem related to fields should be easily attempted and solved by any one while using the Module of ANSYS Package.

The report enables the user to go through the Finite Element Analysis work in ANSYS for any sort of Electromagnetic and structural problems.

The project work brings out all the details to perform Electromagnetic Force Calculations for Divertor & Baffles and hence can be extended to an analysis in more details in future for all other components of SST-I such as TF coil & PF Coil . It is quite possible to include the analysis for the Magnetic Force Calculation in all 16 TF & all 11 PF coils and also the structural analysis of support structure for the TF and PF coils which will be of great importance to the design and safe operation point of the SST-1 machine. Present project work has taken into the consideration of the real dimensions and locations of the components like Inner Divertor Outer Divertor, Baffle, and PF Coil & TF coil for the analysis of Electromagnetic and structural. The analyzed values are very near to the filament coding values.

The analyzed values are under safe limits of material (Table 4.14) so components are safe at these electromagnetic loads.

In this project there is a model is prepared through ANSYS software with some minor changes such as holes, by considering these the size of result file (.rst file) is increased and ansys quit without any saving data base because number of elements are increase due to holes, these changes can be considered in model for analysis.

Because of limitation of workstation two models (electromagnetic & structural models) are prepared after doing electromagnetic analysis structural model import in this model and then structural analysis is done by coupling the nodes. These two models can be prepared together for analysis can be considered as future work.

The electromagnetic analysis is done for disruption of Plasma but there is also another condition of vertical displacement event (VDE) of the plasma and also the VDE followed by the disruption and from there one can perform the structural analysis

.

For transient analysis the total time are divided in six steps because of limitation of work station for more accurate analysis the total time steps can be increased

There is a vacuum pump is installed on each support for creating vacuum. This individual vacuum pump creates oscillation on each support. The combined dynamic effect of the total oscillation of vacuum pump can be introduced in future.

APPANDIX-A

Verification of Symmetry Boundary condition

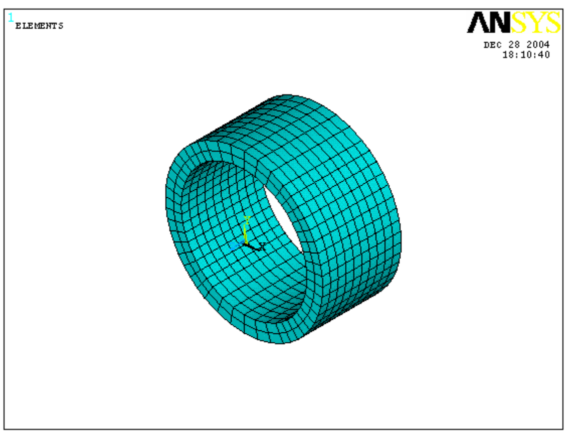
Hollow cylinder of Internal radius 8mm and external radius of 10 mm is taken and is constrained from both the faces and internal pressure of 100 Mpa is applied and the result of deflection is observed.

Cylinder is divided into Six equal sectors of 60 degree and the results were observed by applying the Symmetry boundary conditions on the sector model.One full sector model is also constrained from both faces and the symmetry boundary condition were applied at both cut portions and the result were taken.

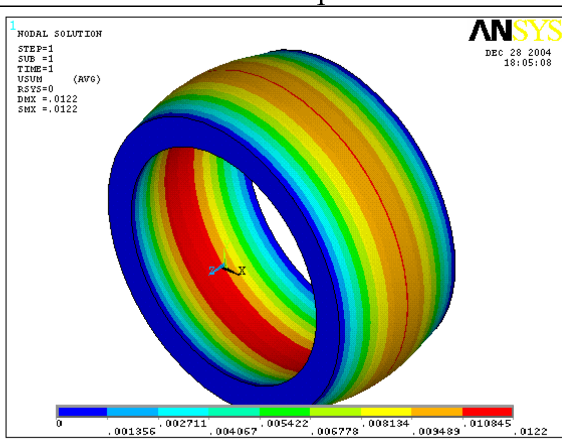
Also one sector was cut into two portion and the symmetry boundary condition were applied at the three cut portion and the result were taken.

Result Comparision:

Full Model

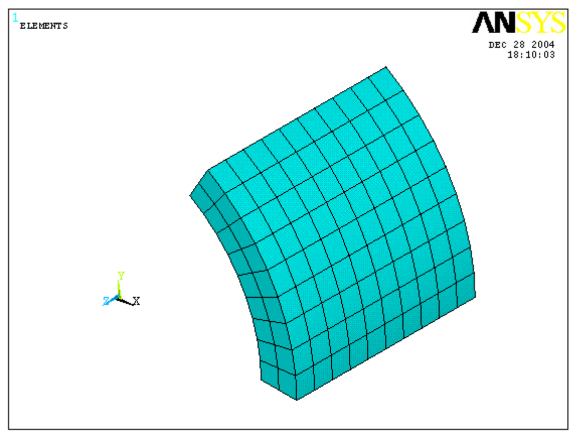


Element Sweep Meshed

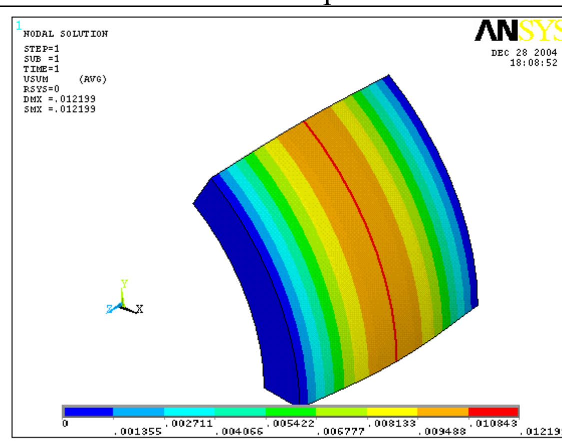


Displacement

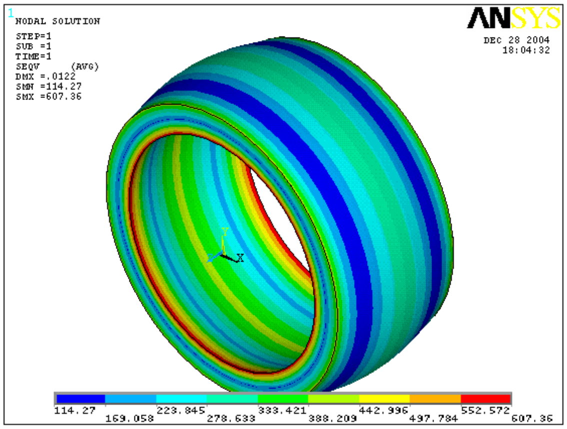
One Sector



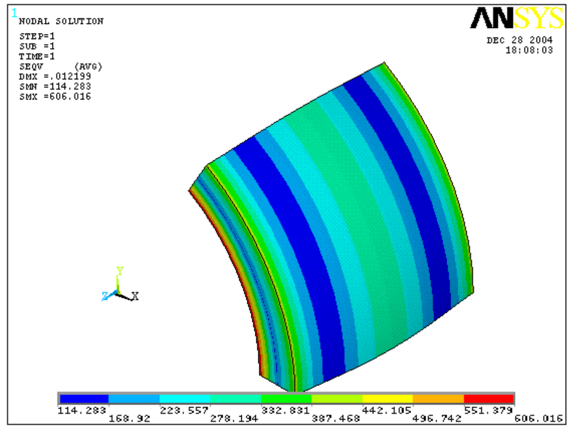
Element Sweep Meshed



Displacement, Symmetry B.C applied at the Cut Portions

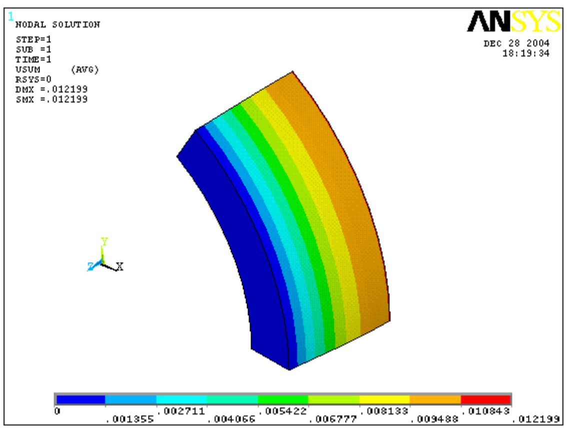


Stress

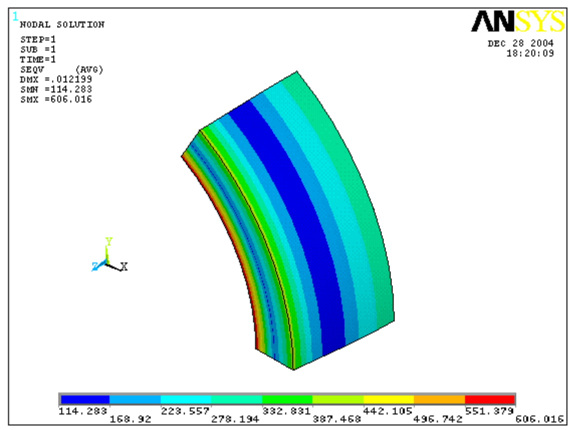


Stress, Symmetry B.C applied at the Cut Portions

Half Sector



Displacement ,Symmetry B.C at the Cut portion



Stress, Symmetry B.C at the cut Portion

Result	Full Model	Sector Model	Comparison Ratio
Deflection	0.00197 mm	0.00197 mm	1.00
Stress	255.184 N/mm^2	254.701 N/mm^2	1.001

Comparison ratio justifies this boundary condition.

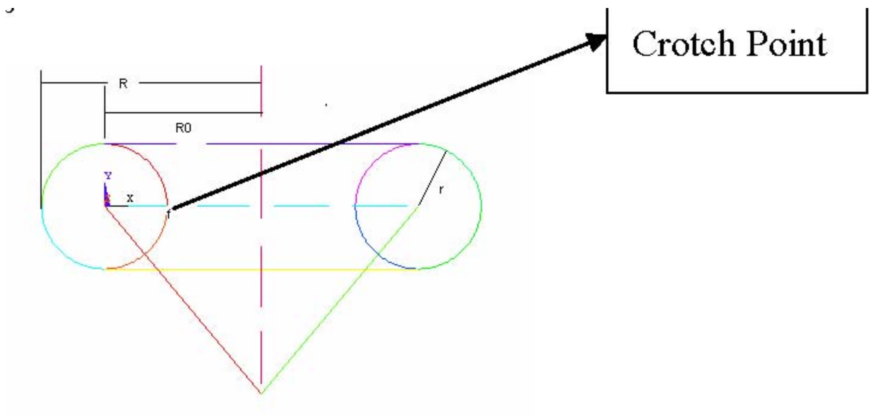
APPANDIX-B

Torus Under Internal Pressure

Torus subjected to the internal Pressure P. Hoop Stress will be given by the relation

$\sigma_2 = P[(R_0 + r \sin\theta)^2 – R_0] / [2h(R_0 + r \sin\theta) \sin\theta]$………… (1)

R_0 is the radius of centerline R is radius at any point h is the thickness of the torus



From (1) equation reduces to

$\sigma_2 = [(P * r * 2 * R_0 + r \sin\theta) / (2h * (R_0 + r \sin\theta))]$…..(2)

Minimum Hoop stress occur at the outside of the Torus on an axial plane of symmetry and is given by

$\sigma_2 = [(P * r * 2 * R_0 + r) / (2h * R_0 + r)]$………………..(3)

Maximum Hoop stress occur at the Crotch point ,f and is given by

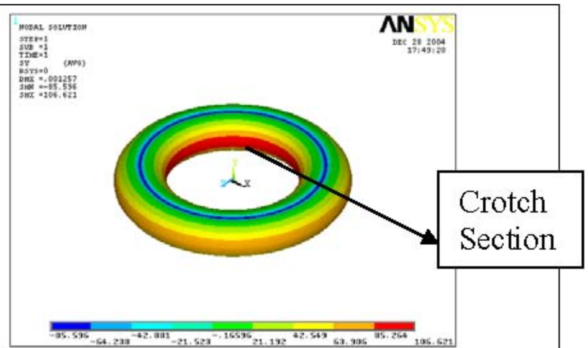
$\sigma_2 = [(P * r * 2 * R_0 - r) / (2h * R_0 - r)]$……………………………..(4)

Reference: Theory and Design Of pressure vessel, by John F Harvey.

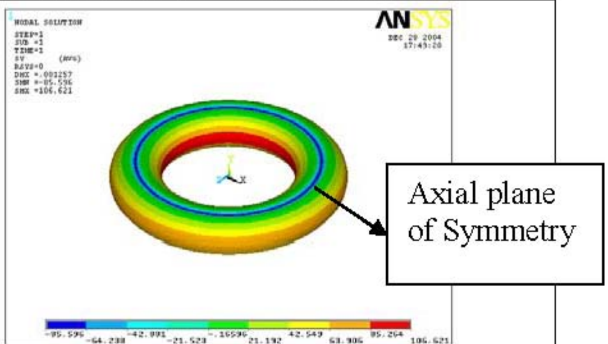
Dimension of the torus,

R_0 = 10mm r = 1 mm h = 1 mm P = 100 MPa

Hoop stress at the Crotch section will be given by σ_2 = 105.21 MPa using equation (4)



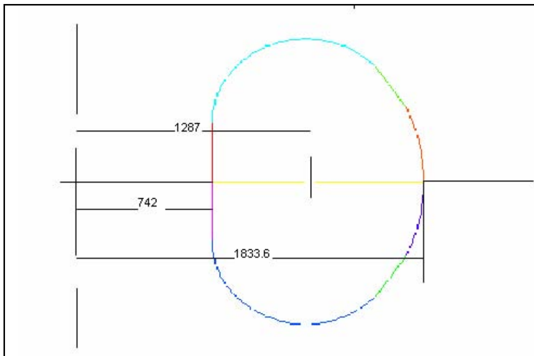
Maximum at the Crotch section

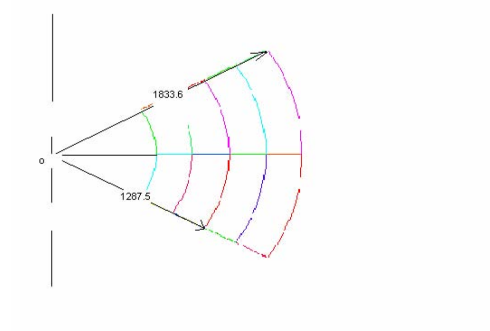


Stress minimum at Axial Plane of Symmetry

Stress in the Vacuum Vessel:

As the Vacuum vessel is also in the toroidal shape therefore when the pressure is applied from the inside it also should have the maximum stress at the bend portion and minimum at the axial plane of the symmetry. It is observed from the analysis that the maximum stress in the vessel is coming at the bend section only and the minimum at the axial plane of the symmetry.





Geometry of the D shaped Toroidal Vessel

Dimension of the D Shaped Torus are

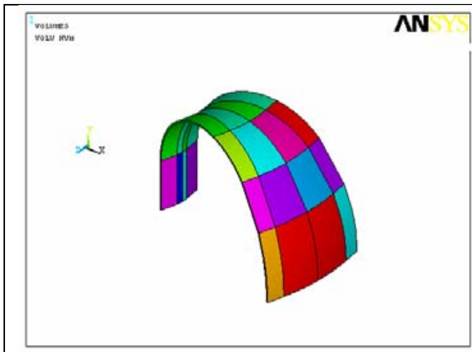
Ro (radius of the axial plane of symmetry)= 1287.5 mm r (radius of the torus) = 545.5 mm h (thickness of the torus)= 10 mm R (radius at the outer surface of the torus) = 1833.6 mm Pressure, P =100 MPa

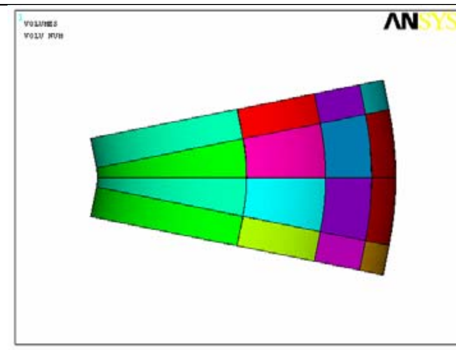
Using equation (1) at R = 1833.6 mm Stress σ_2 = 23823.72 MPa

at R=742 mm Stress σ_2 = -38239.67 MPa

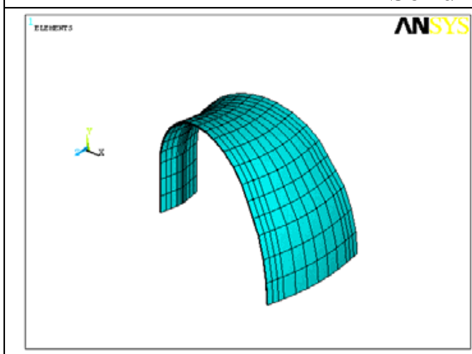
Element Selected : Solid 95 Meshing : Sweep Meshed

ANSYS Result

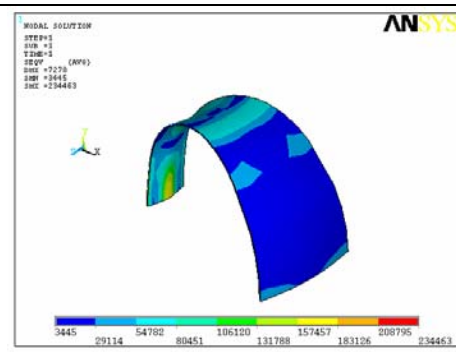




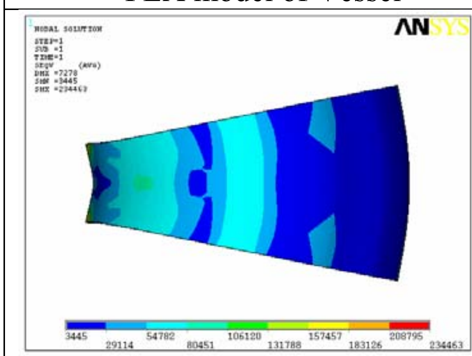
Solid model of vessel



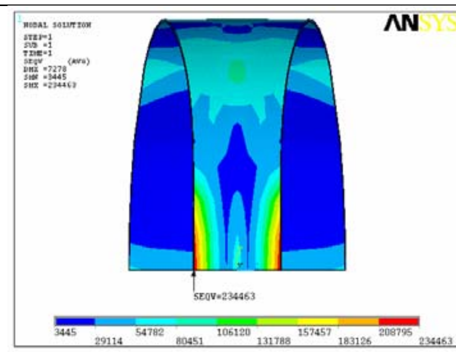
FEA model of Vessel



Stress in vessel



Top view



Left side view

Stress result in vessel

Appendix C

Verification of boundary condition for coupling nodes

A compressive load of 500 MPa is applied on one end of cylindrical bar while the other end is fixed and the same loading condition is applied on the other two cases, which is modeled in such a way that the total length is same as that of earlier and having same diameter, material properties & element type , are given as

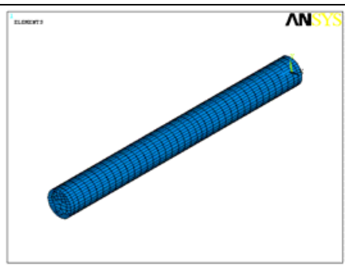
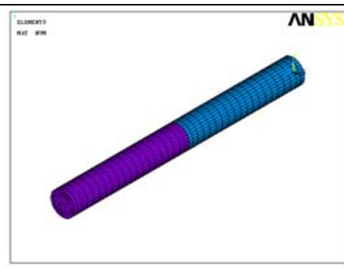
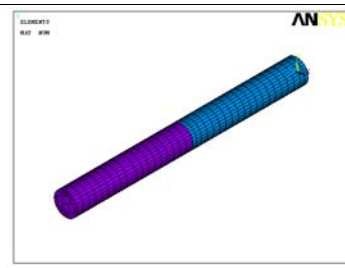
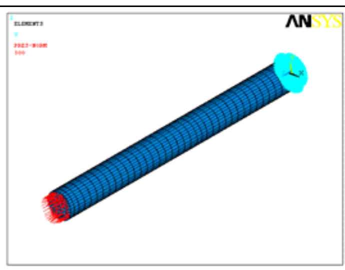
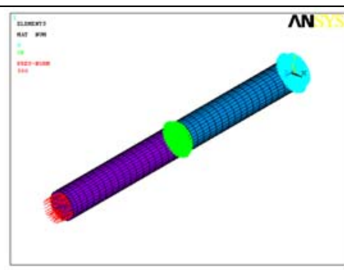
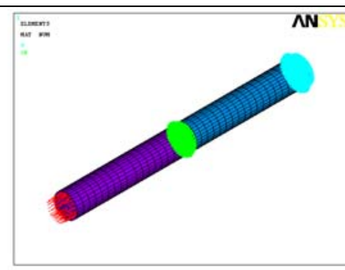
Case1- single bar of length L & diameter D

Case2- Two bar with equal length $\{L_1=(L/2)\}$ joint by use of coupling of nodes & the total length & diameters are equal of length & diameter of single bar as consider in case1 with same mesh density (smart size 3).

Case3- Two bar with equal length $\{L_1=(L/2)\}$ joint by use of coupling of nodes & the total length & diameters are equal of length & diameter of single bar as consider in case1with different mesh density (smart size 3 in first & 6 in second)

Dimension: Length = 100 mm, Radius 5 mm

Material Property: E = 200E+03 N/mm^2, Poisson ratio = 0.33

Case1	Case2	Case3
		
	FEA Model	
		
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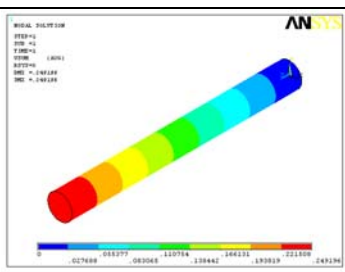
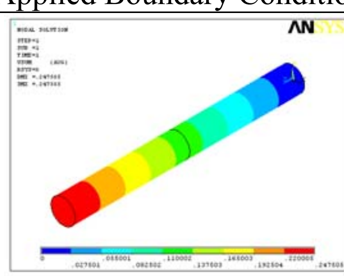
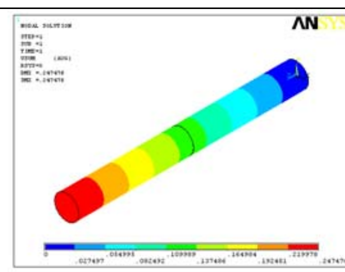
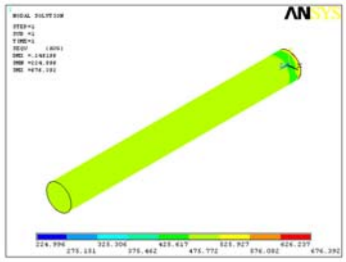
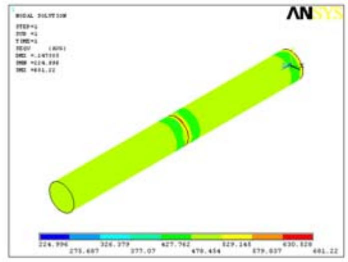
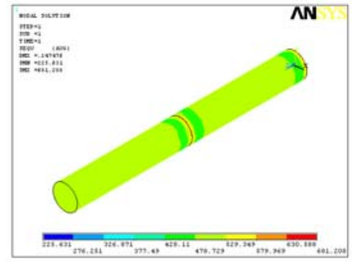
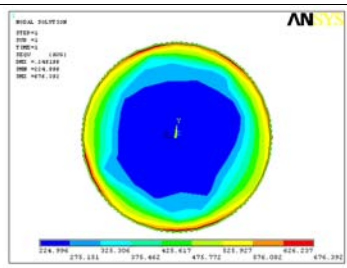
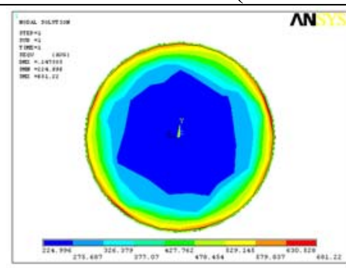
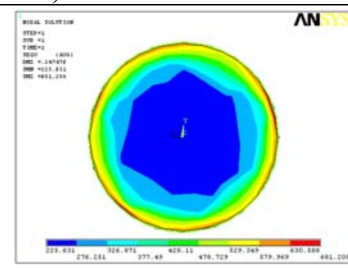
		
	Deformation results	

Von Mises Stress Result (Isometric View)

Von Mises Stress Result Back View

Analytical approach:

500 MPa of compressive load is acting on cross-sectional area of 4 mm2

Deflection of the bar is given by: $\partial l = {Fl}/{AE}$

From above relation deflection is 0.25 mm

	Case 1	**Case 2**	**Case 3**
Deformation (mm)	0.249196	0.247505	0.247476
Stress MPa	676.392	681.22	681.209

Results from analysis justify this boundary condition.

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