[International Journal of Mechanical and Industrial Engineering](https://www.interscience.in/ijmie)

Volume 2 | Issue 1 Article 9

July 2012

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Recommended Citation

Kodarkar, Nakul M.; Gore, Abhay S.; Bhatt, S. B.; and Rodge, M. K. (2012) "Analysis of Limiters for ADITYA Tokamak," *International Journal of Mechanical and Industrial Engineering*: Vol. 2 : Iss. 1 , Article 9.
DOI: 10.47893/IJMIE.2012.1064
Available at: https://www.interscience.in/ijmie/vol2/iss1/9

Analysis of Limiters for ADITYA Tokamak

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Abstract - ADITYA Tokamak is a medium size ohmically heated tokamak. The hot plasma interacts with the vacuum vessel wall introducing impurities in the plasma and also damages the vacuum vessel wall. Limiter is used to reduce plasma - wall interaction and protect the vacuum vessel wall as well as inside components. It also controls impurity generation. ADITYA has a set of two types of limiters (i) Safety limiter (ii) a Poloidal limiter.

Formally all the limiters are made of shaped graphite tiles fixed on stainless steel base plates. But graphite tiles are responsible for low Z impurities in plasma. To avoid these low Z impurities Molybdenum tiles are suggested. In this paper, we are going to present ansys analysis of surface temperature rise of molybdenum tiles compared to graphite tiles when used as Poloidal Limiter during plasma discharges in Aditya tokamak. The analysis is carried by ANSYS 11.0 software using Transient Thermal Analysis module. The results are compared with experimental results for graphite tiles. The graphite and molybdenum tiles are analyzed under same conditions.

Keywords - *ADITYA Tokamak, Limiter, Molybdenum, Transient Thermal Analysis.*

I. INTRODUCTION

ADITYA is the first indigenously built medium size of non-superconducting tokamak, designed, fabricated, erected and commissioned at Institute for Plasma Research, Bhat, Gandhinagar (IPR) [1]. It is a moderate field tokamak capable of producing 250 kA of plasma current with 300 ms of flattop duration. The working fuel gas is hydrogen is kept at pressure 8 x 10^{-5} torr to 1 x 10^{-4} torr. The peak electron density is of the order of 2 x 10^{13}cm^{-3} and a peak electron temperature of about 5 million degrees. The device has been operational since September 1989. To study the important physics aspects, various experiments including the plasma parameters fluctuation studies with gas-puff, Lithiumization, molecular beam injection, movable limiter, limiter biasing, ICRH heating experiment, error field compensation and pre-ionization have been carried out. The breakdown occurs at a peak loop voltage of ~18 -24 V and loop voltage during flattop is ≈ 2 - 3 V with better wall conditioning.

In a tokamak, the limiter defines the hot plasma boundary [2]. It is the first material surface to come in contact with the hot plasma and hence the heat and the particle fluxes per unit area falling on the limiter surface far exceed that falling on any part of the wall of tokamak. Hence the basic requirement of a limiter is to withstand the intense heat and particle fluxes falling on it without undergoing severe damage by evaporation, melting or cracking. The limiter material must not generate significant impurities by thermal/particle induced desorption or by sputtering. These factors put a severe restraint on the choice of the limiter material. The limiter must also protect the vessel wall and other components/systems inside the vacuum vessel from the damages caused by normal and disruptive discharge as revealed by post-mortem analysis of the limiters of many machines. The limiter must take most of the energy contained in the particles diffusing to the wall during normal discharges as well as during the occurrence of MARFE, runaway and disruptive phenomena. The limiter configuration plays a significant role in the edge plasma phenomena and to some extent on the core plasma characteristics. Many different modes of tokamak plasma are not well understood in terms of edge plasma characteristics. It would be advantageous if the limiter design incorporated within itself certain features which would lead to the possibility of measuring the effects due to plasma-limiter interaction to good details

II. DESIGN EVALUATIONS

The investigation of interaction between plasma and limiter is a matter of continuing studies in many experiments. However, for the purpose of design, a conventional model is envisaged whose assumptions have been tested to be reasonably true in a number of independent experiments.

A. The Plasma-Limiter Interaction Model [3]

The particle and heat removal from the plasma by solid material limiters occur basically in the following way. From the hot plasma core, the particles and heat are transported radially across the magnetic field into the edge plasma where it is removed by radiation due to impurities, charge exchange neutrals and transport into the limiter scrape off layer. Within the limiter scrape off layer, the particles and heat are transported via conduction and convection parallel to the magnetic field lines to the limiter surfaces where they are mostly absorbed. Thus, the particle and heat flux fall on the limiter surfaces perpendicular to the magnetic field.

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The maximum heat flux (Q_o) for various values of density and plasma electron temperature can be calculated using the following formula.

$$Q_o = n_o v_o T_c$$

$$= 1.8 * 10^{-18} * n * T_e^{3/2} \ (W/m^2)$$

Where n_o is the density at the edge (in m^3), V_o is the velocity of the particle (in m/s) and *Te* is the temperature at the edge (in eV)

B. Limiter heating

Four type of shapes for ADITYA limiter were considered [3]

1. Straight edge limiter - Limiter surface perpendicular to the toroidal magnetic field lines.
2. Wedge shaped limiter - Limiter surface inclined to toroidal field lines at an angle.
3. Semicircular shaped limiter - Limiter surface is shaped semi circularly.
4. Edge profiled limiter - Limiter edge is profiled such that the heat flux deposited on the surface is uniform.

Out of these four shapes, semicircular shaped tiles for ADITYA limiter were chosen. [3].

The surface temperature of the limiter will rise because of deposition of energy on its surface. The rise in temperature for Aditya limiter is estimated for 150 KJ energy deposition over limiter per discharge.

a) Bulk Temperature Rise:

The estimated rise in bulk temperature of carbon tiles and support structure is 12.5K and for molybdenum tiles 10.42K.

b) Surface Temperature Rise:

Since the bulk temperature can be maintained, we use the following formula to evaluate the temperature at a time t as T (0, t) [4].

$$T = \frac{2W}{(kc\rho)^{1/2}} t^{1/2}$$

Where K= Thermal conductivity

C= Specific Heat

□= Density

W= Heat load

t= Plasma time

Simplifying this equation,

$$\Delta T = \frac{2W}{K} \sqrt{\frac{t}{\pi}}$$

This gives the temperature rise of limiter surface.

The graphite used as ADITYA limiters has thermal conductivity 90 W/mK, density 1850 Kg/m^3, specific heat 837 J/KgK, thermal diffusivity 5.8X10^{-5} m^2/sec. The molybdenum has properties as thermal conductivity 138 W/mK, density 10200 Kg/m^3, specific heat 254 J/KgK.

The power deposited on a limiter tile is calculated at time instant t, considering poloidal symmetry from plasma position, total power falling on poloidal limiter belt is calculated. This is done by a special technique Infrared (IR) Thermography [5]. Transient Thermal Analysis is carried out for shot no. 12438 and 12453 with different plasma parameters. Temporal profile of surface temperature over ADITYA limiter is shown in the figure 1. The table 1 shows values of temperature rise for two different shots.

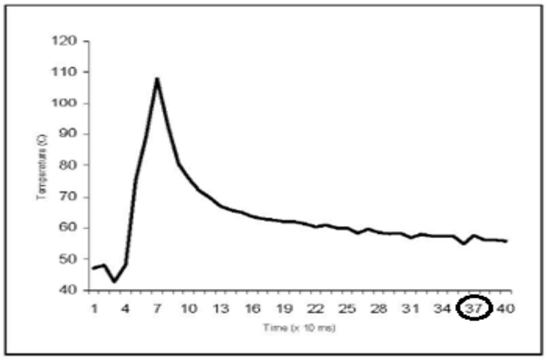

Fig. 1: Temporal profile of surface temperature over ADITYA limiter

III. ANSYS ANALYSIS

For analysis ANSYS Mechanical is used. Element type used is 10NODE Tetra SOLID 87, fine meshing is carried out. Material used for ring is SS 304L and for tiles it is graphite and molybdenum. The comparision in surface temperature rise of the graphite tiles obtained by thermography and ANSYS are shown in table 1. The table 2 shows the comparision in surface temperature rise of the graphite and molybdenum tiles obtained by ANSYS analysis. The ANSYS analysis for Graphite and Molybdenum for t=57 shot no. 12438 is shown in figure 2.

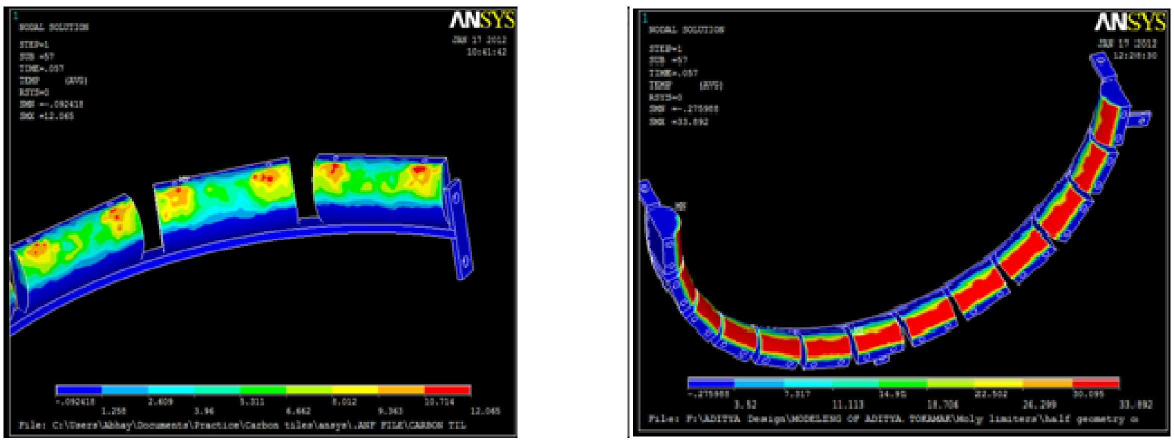

Fig. 2 : The ANSYS analysis for Graphite and Molybdenum for t=57 shot no. 12438

Table1. Comparison of Temp rise between Thermography and ANSYS for Graphite

Shot Number	Time (ms)	Loop Voltage (Volts)	Plasma Current (KA)	Total input power (KW)	Surface Temp. Rise (ΔT^oC) By Thermography	Power falling on limiter (KW)	Heat flux on Limiter (MW/m^2)	Surface Temp. Rise (ΔT^oC) By ANSYS
12438	t= 37	4.35	^{6}2.60	272.31	19.75	105.2	3.005714	17.57
	t = 57	3.50	75.30	263.55	11.85	57.30	1.6371428	12.065
12453	t= 37	4.10	56.30	230.83	14.5	77.25	2.2071428	13.65
	t = 57	3.20	67.57	216.22	6.5	33.00	5.7894736	5.26

Table 2 : Comparison between Graphite and Molybdenum Tiles

Surface Temp. Rise (ΔT^oC) for Graphite	SurfaceTemp. Rise (ΔT^oC) for Molybdenum
17.57	50.64
12.065	33.89
13.65	37.19
5.26	19.51

IV. SCOPE OF LIMITER DESIGN

1. The design of a limiter should allow itself to position symmetrically with respect to the plasma shape to enable the distribution of heat/particle load. The limiter should be movable whenever it is necessary to enable experiments with varying plasma radius.

2. The heat and particle loads falling on the limiter should be below the critical load to minimize melting and evaporation during normal discharges. This shall be achieved by appropriate shaping of the limiter.

3. During runaway and disruption, heat and particle fluxes may be beyond tolerable limit of the limiter material which would cause a certain amount of damage to the limiter. The limiter surface should not release high *Z* elements.

4. The design must take into account the practical considerations of ADITYA tokamak and its subsystems for the limiter mounting, aligning and testing.

V. CONCLUSION

Results are compared for Thermography and ANSYS. The comparison is done for temperature rise of graphite and molybdenum tiles. The Molybdenum limiter is 30-35% efficient than Graphite limiter. Also simulation by ANSYS is another reliable technique to find surface temperature rise.

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