Plasma Chamber Design and Fabrication Activities

Ignitor Project

B. Parodi, A. Bianchi, *Ansaldo-Ricerche, Genova, Italy*
A. Cucchiaro, A. Coletti, P. Frosi, A. Pizzuto, G. Mazzone, G. Ramogida,
ENEA, Frascati, Italy
F. Lucca, A. Marin, *LTCalcoli, Lucca, Italy*
B. Coppi, MIT, *Cambridge, MA*

ANSALDO RICERCHE

ENEA Fusion Technologies FUS-TEC

Abstract

The upgraded design of the Plasma Chamber (PC) and of the First Wall (FW) system consider the updated scenarios for IGNITOR [1] vertical plasma disruption (VDE). The electromagnetic (EM) loads are so large to require a dynamic elastic-plastic structural analysis of the PC. A 360° PC torus has been modeled to take into account the toroidal asymmetry of the halo current as well as the lateral EM loads. The PC wall thickness reduces the displacements within the clearance with toroidal coil. The PC low-cycle fatigue analysis results in a lifetime longer than the number of disruption events at the maximum performance.

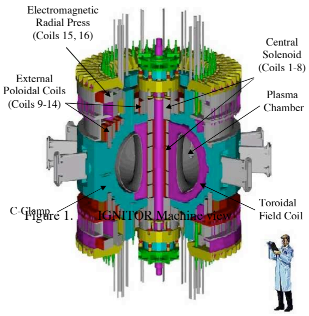

Figure 1. IGNITOR Machine view

Introduction

IGNITOR (Fig. 1) Plasma Chamber is made up of 12 D-shaped toroidal sectors of Inconel 625 welded together to make up a torus by automatic remote equipment (Fig. 2). The whole inner surface of the PC is protected by TZM (Molybdenum) tiles to offer the maximum possible area for spreading the plasma heat load. The fast transient behavior and high values of the E.M. loads produce plastic strain in the PC structure. The first wall withstand the heat and the electromagnetic loads in normal operating conditions and plasma disruptions.
Complying with the new E.M. loads the wall thickness has been increased (from 26 mm to a 26/36/52 mm) in proper PC areas.

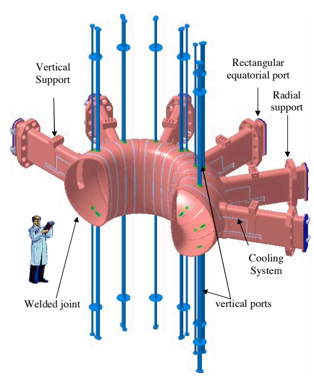

Figure 2. IGNITOR Plasma Chamber view.

Plasma chamber prototype

Two full scale plasma chamber sector were realized by hot forming plates. A sector was constructed by welding two half shells and milling them to assure the design tolerance.
Know how and definition of the adequate tooling and process parameters for moulding under high load a very tough material, without deterioration of the original properties, have already been successfully developed.

Figure 3. Dimensional inspection of the assembled sectors

Welding of PC assembly.

The PC sector is jointed to the adjacent sector by a laser butt welding which assure the achievement of the vacuum tightness. Once the torus is completed the welding groove is then filled up by TIG-NG (Narrow Gap) which strengthen the joint.

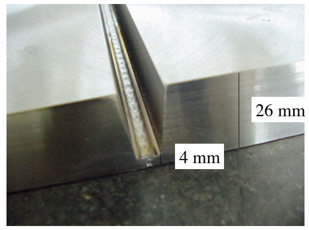

Figure 4. Laser butt welding test.

Numerical simulations, based on ABAQUS code, required a trial validation of metallurgical data obtained with a simple plate model (100x160 in mm; 26 mm thick) welded with the same procedure as above. The main goal is to assess by numerical evaluation the residual stresses and deformations due shrinkage (of ~0.1÷0.3 mm cross welding) which are crucial for the definition of the PC manufacturing accuracy.
This activity has also highlighted the allowable mismatch between sector edges (Max. gap 0.2 mm with 2 kW) (Fig. 4).

Electromagnetic Loads

The EM loads of the plasma disruptions have been obtained from the MAXFEA 2D code. The reference plasma disruption is a VDE of the plasma column with a slowly decreasing current, followed by the appearance of halo currents when the safety factor q_{95} decreases below 2. The thermal quench and the fast current decay occur when q_{95} falls below 1.5 (Fig. 5). A 3D Finite Element Model of 30° sector has been used to calculate the eddy current and the related E.M. forces during the VDE. The 360° model of EM loads due to eddy currents has been obtained by repeating in turn the acting force calculated for each sector.
The EM loads toroidal distribution due to halo currents is evaluated from MAXFEA output and distributed toroidally as the law (1+cos α), where α is the toroidal angle. A peaking factor equal to 2 has been assumed.
This asymmetry has important design implications, since lateral displacement of the JET vacuum vessel has been observed in JET disruption. Lateral loads has been measured for a 3.5 MA JET VDE to be in the order of 2 MN. An IpBtR scaling of this value to IGNITOR yields lateral loads of ~ 10 MN.
The asymmetry in the plasma toroidal current induces the source/sink of the vessel asymmetric current resulting in a net horizontal force.
The above total force is distributed in the toroidal direction as the law (sin α) and in the poloidal direction according to the picture below.

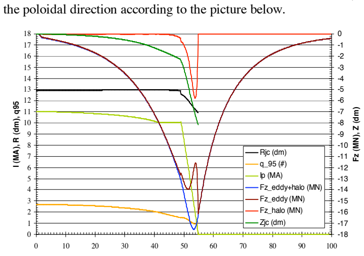

Figure 5. Main VDE parameters and vertical (Fz) and hoop (Fr) EM force.

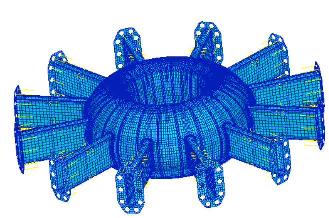

Figure 6. -360° Plasma Chamber Finite Element Model.

Finite Element Model

The PC finite element model mesh (Fig. 6) consists of shell elements. Vertical and lateral supports are modeled with spring elements. Port is fixed in radial direction with truss elements reacting in all directions. The dynamic analysis with elasto-plastic material has been carried out by means of ABAQUS code.
On the 3D model (Fig.6) of the most EM loaded tile carrier, structural analysis, applying Eddy and Halo forces as well as thermal loads, has been performed.

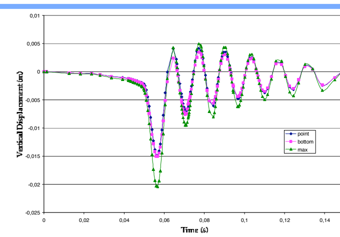

Figure 7. - Vertical displacement versus time.

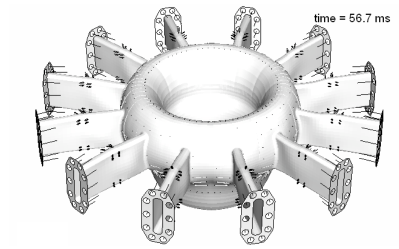

Figure 8. - Maximum vertical displacement at t=56.7 ms.

Plasma Chamber non linear transient analysis

Non linear transient analyses [3] [4] have been performed using Abaqus code on 26/36/52 mm PC configurations under Eddy, Halo and net horizontal loads condition (Fig. 7, Fig. 8).
The maximum Von Mises stresses result at 56.7 ms from VDE starting. These stresses raise a plastic deformation in the PC Top/Bottom area and on the port attachments (Fig. 9). The peak residual plastic deformation located in a discrete area of the welding zone is 0.83 %. The maximum residual plastic deformation located in the plate wall is 0.23 %.
Limits for inelastic strains, according to ASME – Boiler and Pressure Vessel Code [5] are satisfied.
A complete load cycle has been analyzed, finding for each element the strain difference between a reference instant ("when conditions are at an extreme for the cycle") and any other time. To predict the low-cycle fatigue lifetime the cycle effective or equivalent strain is calculated using the ASME code equation.
Maximum plastic strain component values are achieved close to the weld regions at Top/Bottom zone, it results an equivalent maximum strain range of D emax = 0.00546. Entering this value on the design fatigue strain range curve [4] it turns out that the low-cycle fatigue lifetime close to the weld region is equal to a few thousand cycles.

Plasma chamber radial support

Radial supports are acting in both versus (centripetal and centrifugal) with high stiffness. The end of radial ports are connected to the C-Clamp structure. This connection will be free to allow for thermal movement; only during the pulse the connection will be locked by clamping sleeves hydraulically operated. Each clamping sleeve has been tested up to 0.35 MN.

Testing set up

Conclusions

The most severe plasma disruptions among those envisioned which induce higher EM loads in the IGNITOR Load Assembly components has been dealt with. The stiffness of the concerned components has been reviewed to comply with the new loads. A viable mechanical solution for the Plasma Chamber has been developed.

References

[1] B. Coppi, IGNITOR project Group-Engineering Design Description- Ignitor Programm-RLE Reportn° PTP 96/03, December 96.
[2] A. Bianchi, B. Parodi "Camera a vuoto–PROGETTO IGNITOR" IGN.CAV.P.5101-Ansaldo Ricerche, Genoa (Italy), Aprile2003.;
[3] G. Mazzone, A. Pizzuto "Ignitor Plasma Chamber Structural Analysis" ERG-FUS-TECN-MEC IGNITOR 96/CV/002 & 96/CV/003;
[4] A. Cucchiaro, B. Coppi, A. Pizzuto et. al. "Ignitor Plasma Chamber Structural Design with dynamic loads due to Plasma Disruption Event" Soft, Venice (Italy), September 2004.
[5] ASME, Boiler and Pressure Vessels Code, Section III, Division 1, Code case N-47-29.
[6] A. Pizzuto, A. Cucchiaro, B. Coppi, "First Wall System and Plasma Chamber in Ignitor", *Bull. Am. Phys. Soc.* **49 (8),** 80 (2004) –DPP04 CP1 44

* Sponsored in part by ENEA of Italy and by the U.S. DOE

48th Annual Meeting of the Division of Plasma Physics
October 30-November 3, 2006 Philadelphia, Pennsylvania