Structural Assessment of the Central Solenoid of Ignitor

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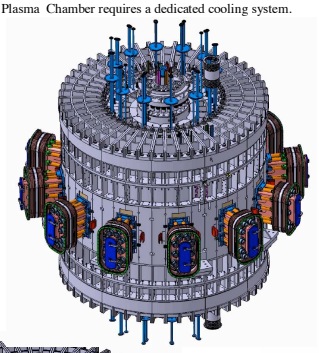
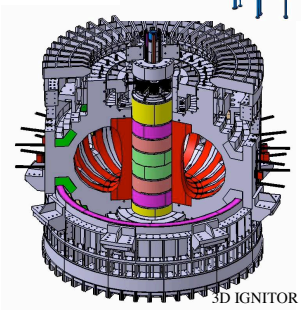
Introduction

IGNITOR, has a pulsed, resistive Toroidal Field (TF) and Poloidal Field (PF) magnets which are at cryogenic temperatures (30 K) and adiabatically heated during the plasma pulse. The magnet structure must withstand:
-Central Solenoid (CS) centrifugal forces,
-TF inner leg centripetal forces,
- coil turns bursting loads,
- the twisting moment resulting from the interaction of toroidal field coil currents and the poloidal field.
The PF coils are placed outside of the TF coils. The CS is segmented to allow greater plasma shaping. Helium gas is used for cooling the poloidal field coils and the toroidal field magnet. The inter-pulse cooling time is about 4 hours. The cooling of the rest of the machine is assured by the good thermal contacts between the major components. Plasma Chamber requires a dedicated cooling system.

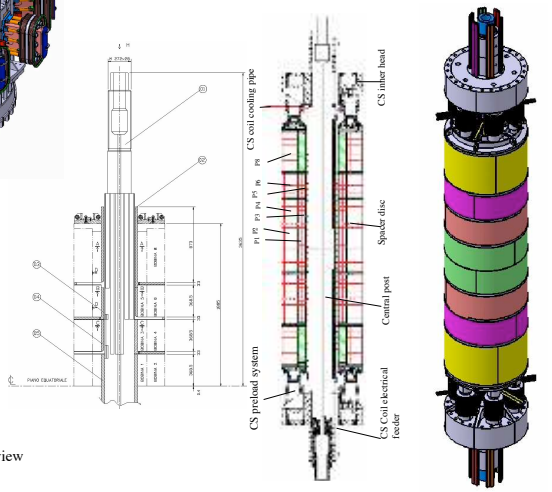




3D IGNITOR Machine view

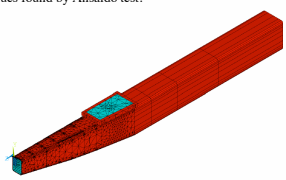
Central Solenoid Coils

The CS coils are mounted around the central steel post of the machine. In order to keep the bending stresses on the radial feeders (electrical and hydraulic) within acceptable values, specially machined pieces are brazed to the coil conductor in the connection region. The adopted mechanical design solution allow for:
- an easy assembling and disassembling of the central solenoid and their related components.
- a proper arrangement of the electrical and hydraulic lines ensuring suitable constraints.
The CS coils (upper and lower) are maintained under compression by means of two heads. The heads have two spring washer systems: the first to preload all the coils and the second to set the position of the central solenoid with respect to the magnetic system.
The first preloading system withstand the repulsive electromagnetic force of P5 and P6 coils arising during the pulse operation. This system allow for the relative thermal expansion preventing any relative movement among the coils, central post and the electro-hydraulic conductors.
The second preloading system enables the vertical setting of the central solenoid with respect to the equatorial plane, (during the first assembly at room temperature) and applies a certain compressive force on the toroidal magnet structure to support and keep in position the central solenoid.



Central Solenoid feeder connection structural assessment

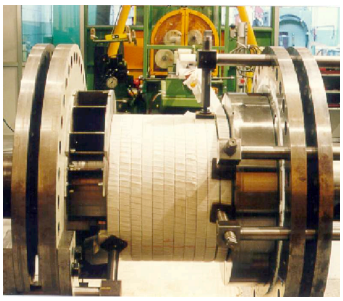
Thermal mechanical analysis is carried out using ANSYS code based on a linear 3D Finite Element model (Fig. 8). The model takes into account the insulation layer and the epoxy resin filling to restore the coil winding shape. The assessment considers the transient condition at the starting of the pulse (heating) and during the cooling phase. This transients which causes high shear stresses on the insulation material has brought to optimize the feeder connection. The results in the most critical condition (start up) are within the allowable values found by Ansaldo test.



Linear Model of the Central Solenoid feeder.

Prototypes-PFC

One full-scale prototype CS coil has been manufactured by ABB. The dimensions of the coil are: outer radius 322 mm, inner radius 215.5 mm, height 370 mm (4 layers, 11 turns). The conductor is a OFHC copper insulated by a glass epoxy and kapton tape compound. A large (24x32 mm²) conductor cross section, with an inner cooling channel of ∅=8 mm, was adopted.
The process to wind the prototype includes brazing, hardening of the conductor after brazing, surface treatment, priming and insulating, overbending for the "S" shaped inter turn transitions, winding of the conductor in the coil, and final impregnation.
A final complete test program, including physical test of selected materials, leak tests on brazed joints, dimensional test under and after the winding process, voltage test of the inter turn insulation, AC voltage test to ground, flow measurements etc. has been performed with fully satisfactory results.

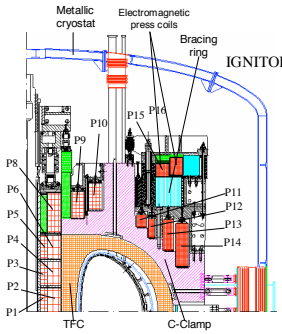


Poloidal Field Coil (P1) Winding

Poloidal field coil (P1) prototype

Poloidal Field Coils

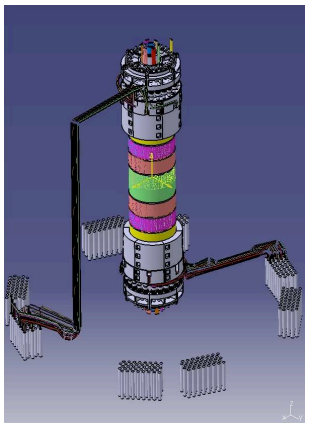
The IGNITOR poloidal field is generated by an optimised system of 13+13 coils.
These are symmetrically located relative to the machine equatorial plane. The main components are the Central Solenoid (CS) (7 coils), the External Coil Assembly (ECA) (6 coils) and Press Coils (2 coils). Hollow conductors are used for cooling with a bore 8 mm. The conductor are wrapped with glass fabric and kapton tapes and vacuum impregnated with epoxy resin. The coil temperatures have been calculated taking into account the magneto-resistive effect. The magneto-resistive effect plays an important role in the coil pairs 2 and 4 where the magnetic field gradient can produce a significant temperature gradient.
The same mechanical structure (C-Clamp) supports either the vacuum chamber or the TFC and the Poloidal Field Coil PFCs ensuring their relative position.
The primary function of the CS is to produce most of the magnetic flux variation needed to drive the plasma current according to prescribed scenarios. The radial splitting of the CS into two concentric coils has been adopted to maximise the magnetic flux variation while keeping the coils within their thermal and mechanical limits. The axial four groups of coils is required to match the plasma shape with the first wall profile and to easy the manufacture.
All coils are layer winding type and have an even number of layer for having the electrical leads located on the same side of the coil.



IGNITOR Poloidal Coils Layout

Optimization of the IGNITOR poloidal field coils system

The central solenoid includes seven coil pairs and is a critical component of the machine because of its temperature gradient and its contributions to the overall mechanical bucking of the toroidal magnet. In order to reduce the temperature gradient and the EM forces between coils of the central solenoid, an increased grading of the current density distribution between the turns of the coils has been adopted in the current design, obtaining so an increased uniformity of the temperature into the coils.
In the previous design, the external coils P9, P12 and P13 were subjected to very large forces during the machine operation; to withstand these stresses, it was foreseen to manufacture them using dispersion strengthened copper (DSC), a high purity copper with 0.3% aluminium oxide. This material shows enhanced mechanical properties but its manufacturing is hard and expensive for the size of these coils. To avoid its use, the currents on these coils have been decreased, increasing the currents on the less solicited ones. This redistribution of currents among coils involved a decreasing of the available flux swing that was partially recovered with the grading of P8 and P9 coils.



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