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TORE-SUPRA : DESIGN OF THERMAL RADIATION SHIELD AT 80 K

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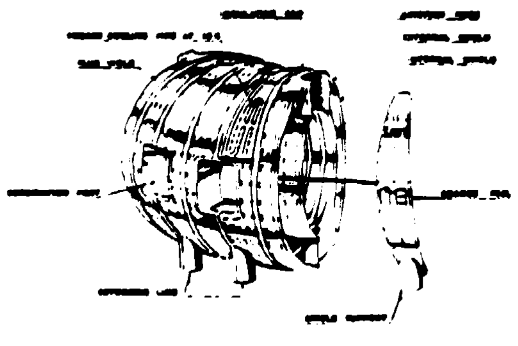
ABSTRACT

The TORE-SUPRA superconducting toroidal magnet /1/ operating at liquid helium temperature, must be protected against thermal radiation from the vessels. For this purpose, stainless steel heat shields, cooled at 80 K, are positioned between coil casings at 4.5 K and the vessels, and constitute a double stiff toroid which completely surrounds the magnet. Mockups have been manufactured to study their design and operating problems. Calculations have also been made to analyse the mechanical behaviour of these shields.

1. DESCRIPTION OF HEAT SHIELDS (see Fig.1)

1.1 Mechanical structure :



ONE MODULE OF THE 80 K RADIATION SHIELD SYSTEM

Fig.1

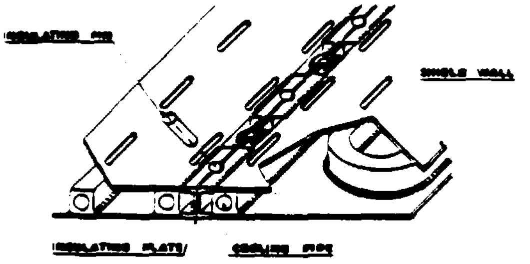
One shield is built from six modules bolted together. One module is composed of three welded sectors. Inner and outer shields are also held together by means of vertical and horizontal sleeves. This structure gives a high mechanical rigidity to assembly and requires six supports only.

The supports are composed of tubes concentric to the toroidal magnetic field coil bearing legs, and are welded to these legs.

The shield sectors are two frusta of a cylinder, with an opening angle of 10°, connected together by an insulating cut-off. The diameter of each cylinder is respectivly 3,03 m for external shield and 2,1 m for internal shield. Each 10° cylinder sector element is constituted by two 3 mm stainless steel 304 L sheets braced by the cooling system tube. This tube has a 24 mm square section and a 18 mm dia.cylindrical hole. The tubes are continuously welded onto the shield inner sheet and plug welded on the outer sheet. Such a structure gives a correct mechanical inertia to the shields.

1.2 Insulating cut-offs :

An insulating cut-off (Fig.2) has been introduced on each of the 18 inner and outer shield sectors. These cut-offs allow the penetration of the poloidal magnetic field. Their number has been selected to limit shearing efforts related to plasma breaks, acting on the edges. The cut-offs consist of an epoxy-glass ring on which adjacent shield sectors are bolted. Shearing efforts, 25 T per cut-off, are supported by epoxy-glass pins distributed over the insulating cut-off length.



SKETCH OF SHIELD WALLS

Fig.2

1.3 Cooling circuit :

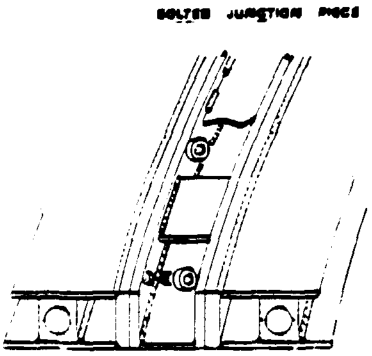
The cooling of the shields at 80 K is provided by gaseous helium flowing at a rate of 200 gs^{-1}, under a pressure of 1,5 MPa in the tubes welded between the shield sheets. The length of tube constituting the cooling circuit of the shields is 2 km. Many welds are required to manufacture this circuit. The pipe routing has been designed considering two requirements :

- to locate the welds between tubes in easy access zones, in order to allow eventual repairs with a minimum disassembly of Tokomak.
- to set the maximum distance between tubes at 20 cm in order to limit thermal gradients during operation and to provide a correct mechanical rigidity over the complete shield area.

1.4 Assembly :

The junction between an inner sector and an outer shield sector is located at the vertical and horizontal sleeves. This junction is achieved by a thick plate (7 mm) fitted and welded on installation.

The junction between two inner shield sectors or two outer shield sectors is provided by an intermediate part. This part, (Fig.3) bolted on adjacent shield sector shall be fitted on installation in order to ensure a high assembling flexibility on the system.



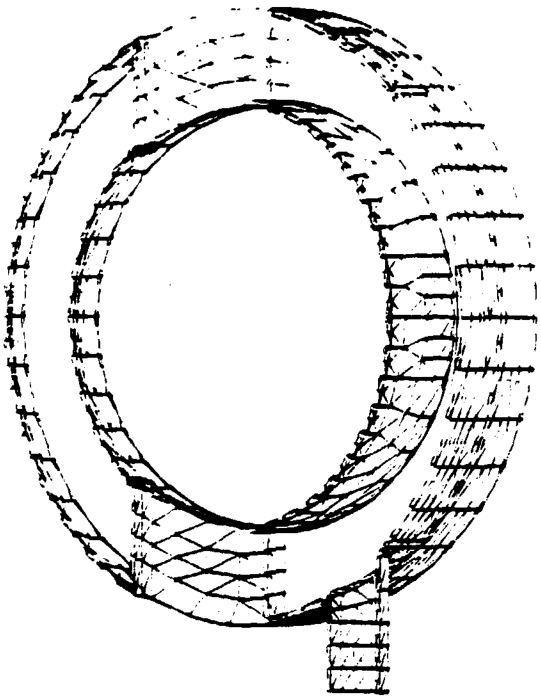
SHIELD JUNCTION SYSTEM

Fig.3

2.. CALCULATION

The analysis of shield elastic behaviour has been carried out by means of a numerical code using the finite element method (CEA-CASTEM System). Two types of charge have been studied : - static charge of dead weight,

- cooling or baking of shields.



MESH OF HALF A JONCTION SECTOR

Fig.4

2.1 Mesh pattern :

The structure symmetry allows modelling of a half sector only (10° sector). The meshing uses 3-node shell elements (Fig.4).

2.2 Boundary conditions :

Three types exit :

. symmetry of the junction plane between shield sectors

. displacement of support leg. Only radial displacement related to temperature conditions is permissible

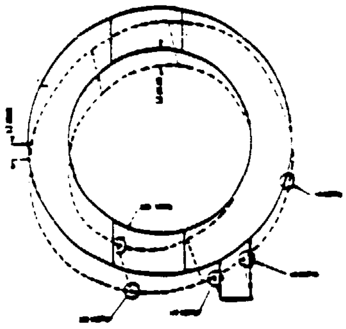
. The nodes representing insulating cut-off pins must remain in the same plane.

2.3 Loads and results :

The shields are supported in six locations, hence, the areas located around the rests are submitted to buckling and bending efforts. The resulting stresses and distortions depend on the rigidity of shield assembly.

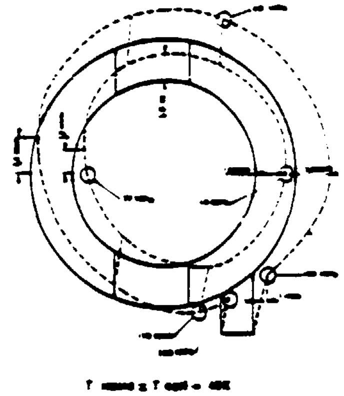
Calculation has demonstrated that the outer shield must be stiffened by addition of pins in the plane of its insulating cut-off, to limit their deflection under their own weight. Thus, this deflection has been reduced to 7 mm, when the inner shield is pinned, and to 1.7 mm when both shields are pinned in the plane of their insulating cut-off. The influence of shield stiffening on the level of stresses encountered is very slight (Fig.5)

During several operating regimes of the machine, thermal loads bring on important stresses. For instance when baking to desorb water before cooling, the high stresses located in the support leg have lead us to limit the thermal gradient between the toroidal coils and the shields (Fig.6).



DEFORMATION UNDER DEAD WEIGHT

Fig.5



DEFORMATION UNDER BAKING

Fig.6

3. MODELS

3.1 Mock-up of a sector :

Realized to qualify the mechanical solution, this stainless steel part reproduces one shield sector in actual size. This model has allowed us to verify the feasibility of the selected shield manufacturing and to develop the construction engineering.

3.2 Emissivity measurement model :

The shield cooling by gaseous helium flow does not allow to dissipate heat flux greater than 30 kW.

Hence, it has been necessary to study on models the surface preparation of the various TORE-SUPRA vessels, in order to limit the heat radiation exchange between the vacuum chambers and the shields.

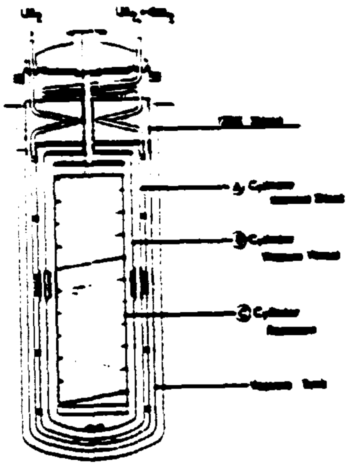
During some operations, the temperature of inner vacuum chamber reaches 550 K for an approximate area of 100 m^2. According to surface condition of sheet material, the heat exchange between vessels and shields could exceed 30 kW.

3.2.1 Equipment (Fig.7) :

Concentric cylinders are introduced into a cylindrical vacuum vessel at liquid nitrogen temperature :

. a cylinder A, cooled by liquid nitrogen flow at 80 K, simulates the TORE-SUPRA thermal shields

. a cylindar B, which temperature varies between 300 and 550 K, simulates vacuum vessels, and is heated by the thermal radiation of an other cylinder (C) baked to high temperature by an electric resistor.



THERMAL EXCHANGE MEASUREMENTS

Fig.7

The measurement of electric power required to maintain cylinder B at temperature T, represents practically the thermal power radiated by vessel at temperature T to corresponding shield at a temperature of 80 K.

In this model, the exchanges by conduction have been limited to a value lower than 5 % of radiated power.

3.2.2 <u>Results</u> :

The results are given in Fig.8.

Fig.8a shows the influence of the material on heat exchange. The cylinder A is made of steel 304 L and its temperature is 80 K. The cylinder B is made of stainless steel 304 L (a), plated with (d) silver (electrolytic deposition), (c) aluminium (vacuum deposition), (b) nickel (Kanigen process deposition annealed at 620 K).

Fig.8b shows polishing effect on heat exchange between the cylinder B which surface roughness is 0.2 µm and the cylinder A which surface roughness obtained by mechanical polishing is lower than 0,1 µm (a) ; 0,2 µm (b) ; 0,4 µm (c) and 0,9 µm (d).

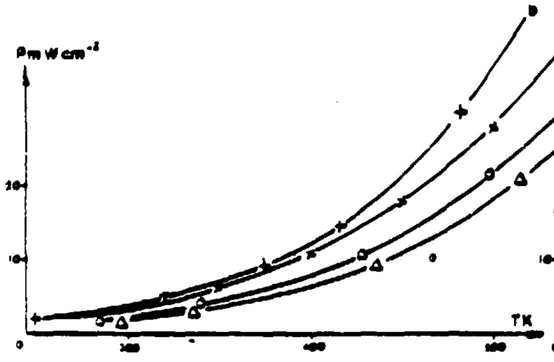


Fig.8a

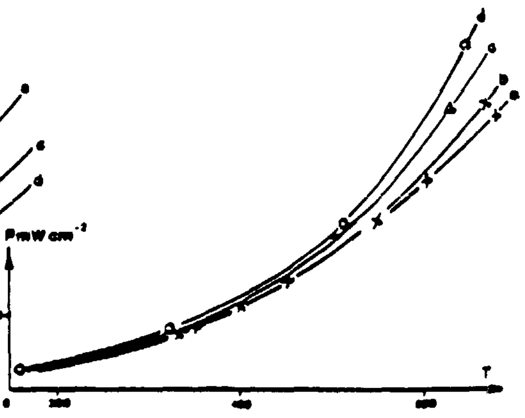


Fig.8b

3.2.3 Conclusion :

In order to limit heat exchange to an admissible value, we had to polish the stainless steel surfaces of the vessels to 0.2 μm roughness on the walls where temperature exceeds room temperature ; to 0,4 μm for other walls.

On the other hand, it has been necessary to add, between inner vacuum vessel and inner shield, which is not cooled, attached on the vacuum vessel, polished to 0.2 μm roughness and aluminium (or silver) plated.

The thermal power to be dissipated on the radiation shields at 80 K, should thus be limited to 10 kW.

REFERENCE

/1/ TORE-SUPRA Basic Design Tokomak system EUR-CEA-FC-1068 (October 1980).