18. SUPPORT SYSTEM

18.1 INTRODUCTION

The support system has to ensure the precise and rigid suspension of the cold mass inside the vacuum tank. The loads to be supported are the 220 tonnes weight of the cold mass and the magnetic forces due to the decentring and misalignment of the coil with respect to the return yoke. The design must also take into consideration the shrinking of the coil during cooling and its deformation under magnetic forces. The system has been analysed at Saclay [18-1] and FNAL [18-2].

18.2 DESCRIPTION

The support system consists of a set of rods made out of titanium alloy (see Fig. 18.1) and the photograph of a mock-up in Fig. 18.5, p. C-44. The longitudinal forces are taken by the pre-stressed antagonist pulling rods, called the longitudinal tie rods (see Chapt. 18.5). The weight and radial forces are taken by pre-stressed belts in two different sections of the solenoid, called "radial belts" (see Chapt. 18.6), they are grouped in sets of three. The studies of the support system are made for three different working conditions:

- Room temperature: 300 K;
- Cryogenic temperature and no field: 4 K, 0 T;
- With the solenoid energised: 4 K, 4 T.

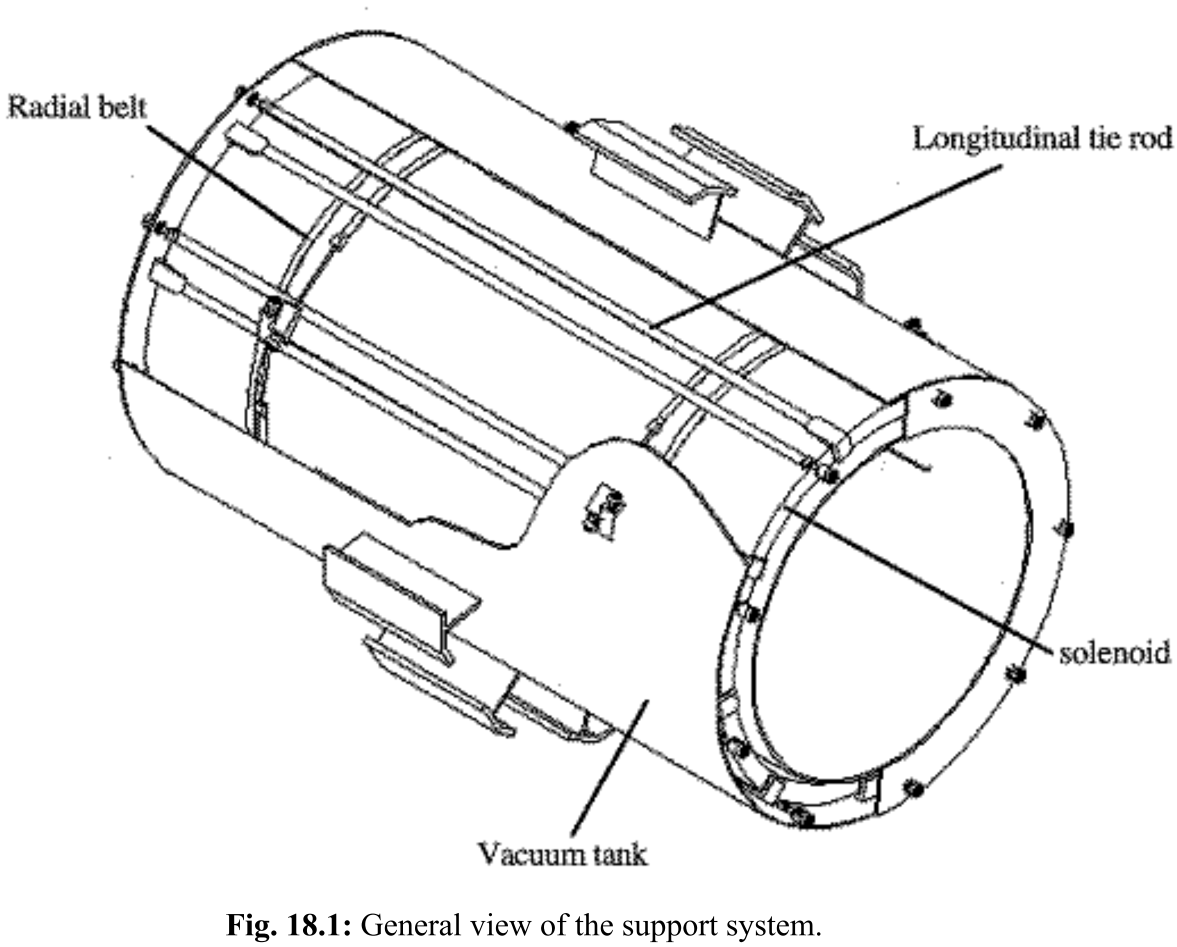

Fig. 18.1: General view of the support system.

18.3 LOADS AND DEFORMATIONS

18.3.1 Mechanical loads

Figure 18.2 shows the cold mass, its axis and the possible displacements caused by decentring and misalignment.

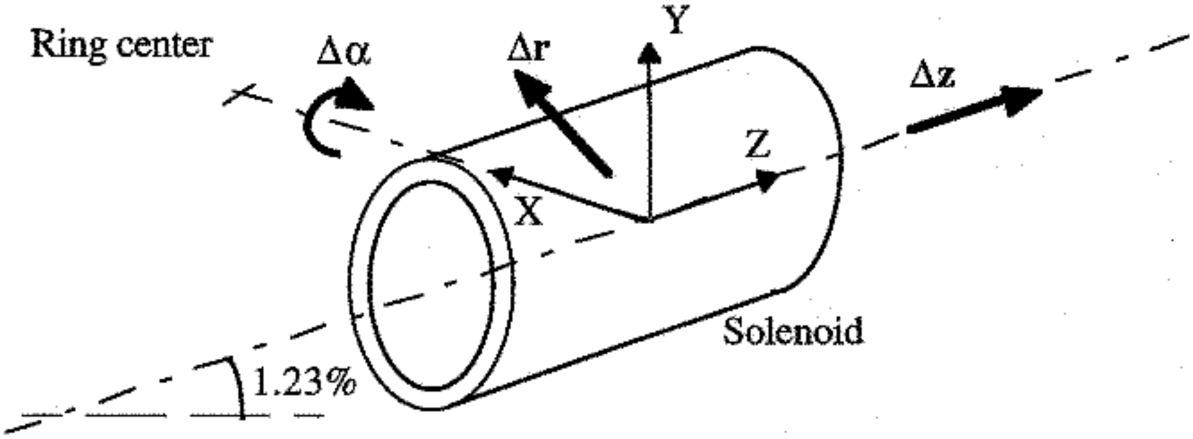

Fig. 18.2: Displacement components.

The loads acting on the suspension system are the following:

a) Weight of the solenoid (2200 kN):
The calculation also takes into account a 1.2 g acceleration during handling. This value is low because when the system is being moved, it will always be supported by the hydraulic dampers provided by the air pad system and its associated hydraulic jacks (see Chapt. 10 and 26).
b) Loads due to a magnetic misalignment:
As an hypothesis, the solenoid axis must lie within a 10 mm radius, centred around the magnetic axis, see Chapt. 18.8, where the alignment procedures during the first energisations are described.

The worst scenario loads, taking into account the results of Chap. 6-7, are indicated in Table 18.1.

Table 18.1
Solenoid misalignment and induced loads.

Solenoid misalignment	Corresponding loads
Dz = 10 mm	Fz = 1100 kN
Dr = 10 mm	Fr = 110 kN
Da = 5'	Mx = 2730 kN•m

where Dz, Dr, and Da are defined as follows:

- Dz : Displacement in Z direction,
- Dr : Displacement in the plane X, Y,
- Da: Rotation around X.

18.3.2 Coil shrinking and deformation under field

During cooling-down the coil diameter and its length are reduced in the same ratio:

DR / R (300 / 4 K) = DL / L (300 / 4 K) = - 4.15 10^{-3},

giving: DR_1 = - 14 mm, and DL_1 = - 50 mm.

During the energisation of the solenoid, the coil diameter increases and the length decreases by the following values:

DR / R (0 / 20 kA) = +1.5 10^{-3},

DL / L (0 / 20 kA) = - 8.22 10^{-4},

giving: DR_2 = + 5.5 mm, and DL_2 = - 11.4 mm.

18.4 REQUIREMENTS

The rigidity of the support system is designed to limit any additional misalignment to 2 mm in any direction from an original misalignment of 10 mm, thus preventing any large displacement of the coil position. The stress in the support system components must always be inferior to the allowable stress. The Titanium alloy chosen is TA6V which presents the following mechanical properties:

- Young's modulus: 110 GPa,
- $Rp_{0.2}$: 900 MPa,
- allowed stress: 600 MPa.

18.5 LONGITUDINAL TIE RODS

As explained in 18.2, the longitudinal tie rods are pulling in opposite directions. They are attached to the solenoid, at a temperature of 4.2 K on one side, and pulled from the vacuum tank flange at room temperature on the opposite side, and have a length of 12500 mm. Fig. 18.3 shows schematically how the solenoid is centred longitudinally inside the vacuum tank by the antagonist tie rods. A detail of the mock-up can be seen on the photograph of Fig. 18.6, p. C45.

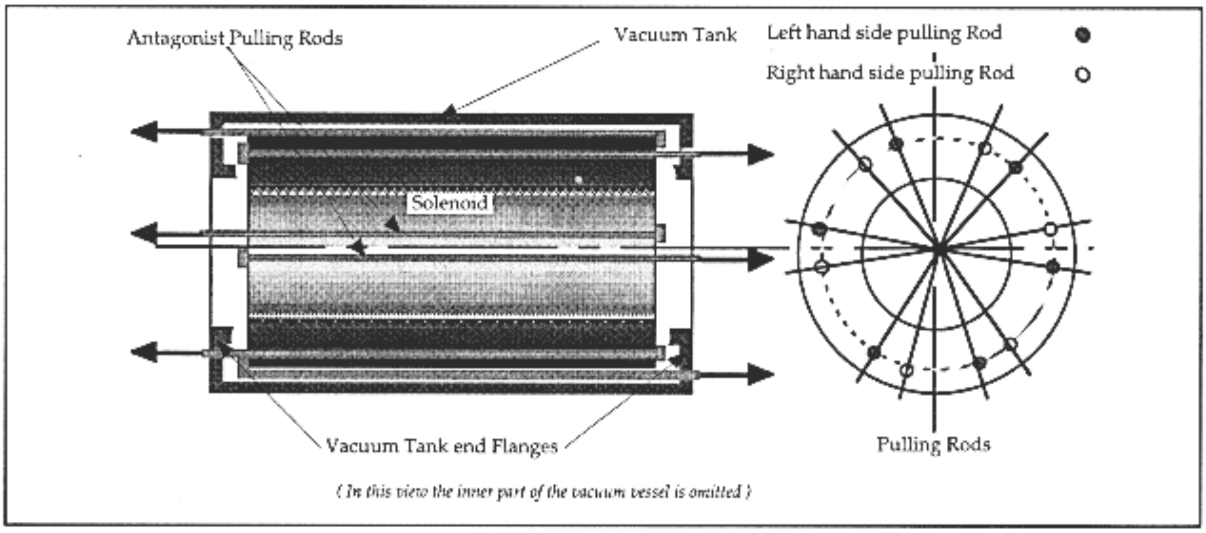

Fig. 18.3: Longitudinal positioning system of the solenoid.

The main mechanical parameters of the longitudinal tie rods are given in Table 18.2.

Table 18.2
Main mechanical characteristics of the longitudinal tie rods.

Material	TA6V
Number of tie rods	Two sets of 9
Cross sectional area	3 600 mm^2 (200 mm x18 mm)
Pre-stress	196 MPa
Maximum axial displacement	2 mm

The stress in the longitudinal tie rods varies with the loading conditions. The maximum values are indicated in Table 18.3.

Table 18.3
Maximum stress in the longitudinal tie rods.

Working conditions	300 K	4 K, 0 T	4 K, 4 T
Maximum stress (MPa)	197	86	53

The thermal loss from 300 to 4 K, per longitudinal tie rod, is found to be 0.4 W, without taking into account any intermediate heat interception.

18.6 RADIAL BELTS

Two sets of three "U" shaped radial belts distributed at 120° are attached to the solenoid at 4.2 K on one side, and pulled from the outer shell of the vacuum tank at room temperature on the other side. Fig. 18.4 shows schematically how the solenoid is centred radially in the vacuum tank by antagonist radial belts every 120

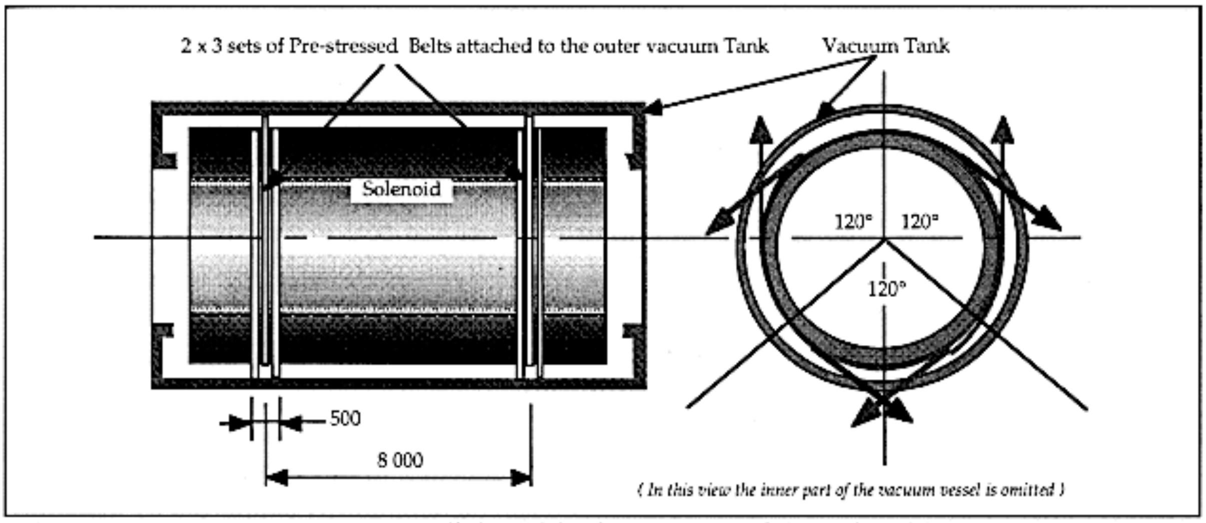

Fig. 18.4: Radial positioning system of the solenoid.

The main mechanical parameters of the radial belt system are given in Table 18.4.

Table 18.4
Main mechanical characteristics of the radial belt system.

Material	TA6V
Number of tie rods	two sets of 3
Cross sectional area	2 700 mm^2 for 60 mm dia.
Pre-stress	510 kN
Maximum radial displacement	2 mm

The stress in the radial belt system varies with the loading conditions. The maximum values are indicated in Table 18.5.

Table 18.5
Maximum stress in the radial belt system.

Working conditions	300 K	4 K, 0 T	4 K, 4 T
Maximum stress (MPa)	450	280	410

The thermal loss from 300 to 4 K, per radial tie rod, is found to be 2.4 W, without taking into account any intermediate heat interception.

18.7 INDUCED STRESSES ON THE COIL

A first study has shown that the stresses induced on and in the coil by the supporting system are acceptable. A full 3-D finite element analysis will be carried out to check the result in detail and to properly design the attachment points.

18.8 ADJUSTMENT PROCEDURE

In order to accurately centre the solenoid it is necessary to measure the unbalanced forces by applying a small current to the coil and then make a step by step adjustment of the coil position. Using the pre-stressing equipment of the tie rods it will be possible to move the coil inside the vacuum tank and obtain, when the magnet is at full field, the same force in corresponding tie rods. Strain gauges will be attached to the support system to obtain these measurements which will be carried out during a test of the coil in the surface hall. This adjustment procedure will be performed with the two hadronic barrels HB inserted, to have the final deformations of the vacuum tank.

To gain access to perform the radial adjustment of the coil inside the vacuum tank both endcaps and the two outer rings YB/2 and YB/-2 will need to be moved. The axial adjustment however will only require moving the two endcaps (see Fig. 4.3, p. C-5). All tie-rods are equipped with bellows to ensure air tightness when connecting to the vacuum tank. In case a leak occurs in the bellows of a radial tie rod, the coil can be temporarily supported by installing a second tie rod system from the cold mass belt system during the repair or replacement of the bellows.