MECHANICAL BEHAVIOUR OF THE LHC CRYODIPOLES

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Abstract

The LHC cryodipoles are slender and heavy objects more than 15-m long. The major components of the cryodipole assembly are the 28-tonne cold mass, supported on its three Glass-Fibre-Reinforced-Epoxy support posts and the 4-tonne vacuum vessel. The performance of the LHC depends very much upon the accurate positioning of the dipoles and the beam tubes, in particular to maximise the useful beam apertures. The cryodipoles will be conditioned and measured in surface assembly buildings, then handled and transported to their positions in the tunnel and, finally, aligned.

This paper presents the static and dynamic studies of the cryodipole in different configurations. The tests and analyses carried out have led to a thorough understanding of the mechanical behaviour of the cryodipoles.

From the static analysis, an hyperstatic supporting system is proposed in order to minimise the systematic deflections and the effects due to changing temperature conditions in the tunnel.

The dynamic analysis has shown that the cryodipole resonates at a series of very low natural frequencies and, moreover, shows a low damping value. Since the dynamic loads during transport and handling are in the low frequency range, the cryodipole components are potentially susceptible to damage. Simulations have included the truck suspension for road transport and the lifting device for handling with a crane. Solutions coping with the transport and handling conditions are presented.

1 INTRODUCTION

An LHC cryodipole is a superconducting dipole magnet ("dipole cold mass") housed inside a cryostat. The dipole cold mass consists of two dipole coils, a common non-magnetic, force-retaining laminated structure made up of stainless steel, a laminated iron yoke, all surrounded by a shrinking cylinder, made up of two stainless steel half-cylinders welded together. The cryostat of the dipole magnet consists of three Glass-Fibre-Reinforced-Epoxy (GFRE) support posts to position the cold mass, a multilayer radiation screen and an aluminium thermal shield with its multilayer super-insulation, all situated inside a low carbon steel vacuum vessel [1] (Figure 1).

A three-dimensional (3D) finite element model (Figure 2) of the cryodipole assembly was developed using ANSYS™ and validated with experimental data.

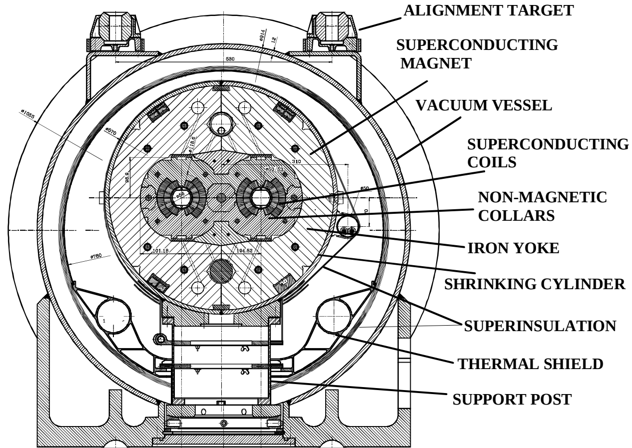


Figure 1: Cross-section of the LHC cryodipole

The finite element model included the dipole cold mass (3D elements), the GFRE support posts (shell elements) and the vacuum vessel (shell elements). An equivalent material concept was used to model the stiffness and weight of the cold mass collars and yoke laminations.

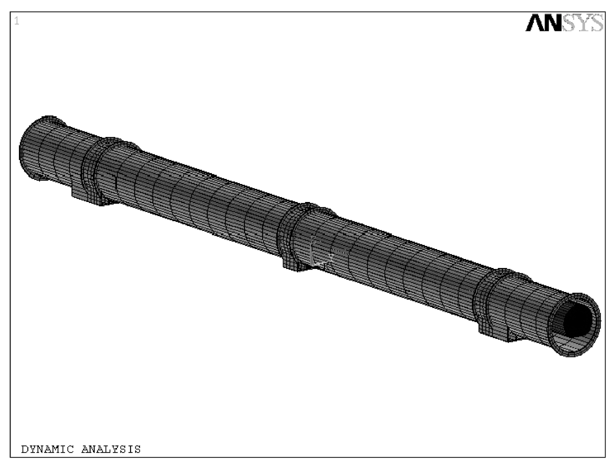


Figure 2: Finite element model of the LHC cryodipole

2 STATIC ANALYSIS

This analysis concerns the supporting system of the LHC cryodipoles in the tunnel. They will be situated on top of mechanical jacks that will allow the alignment of the LHC machine with respect to targets situated on the vacuum vessel outer wall. The accuracy and long-term stability of the positioning of dipoles and the beam tubes depends on the supporting system of the cryodipoles. Three different configurations have been studied and are presented schematically in Figure 3.

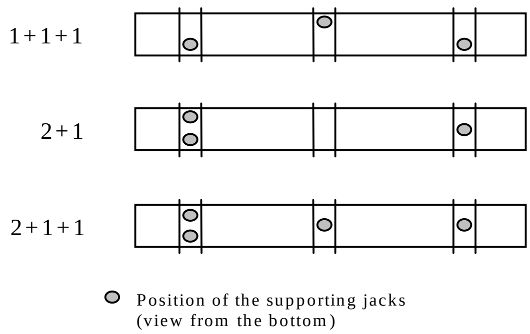


Figure 3: Supporting system configurations

A comparison of tilts and displacements due to self-weight loading for the three supporting configurations is given in Table 1.

Table 1: Effect of self-weight loading (computations)

Supporting system	**Tilts of supporting sections (mrad)**	**Vacuum Vessel mid-length vert. displacement (mm)**	**Displacements of the cold mass extremities (mm)**	
			Lateral	Vert.
1+1+1	3.2 1.8 3.2	+0.5	+1.7	+2.1
2+1	No	-4.5	No	+1.6
2+1+1	No	No	No	+0.4

Increments of tilts and displacements due to thermal conditions in the tunnel are given in Table 2. A thermal gradient between top and bottom of the vacuum vessel due to powering racks in the tunnel was considered.

Table 2: Effect of temperature conditions in the tunnel (variations with respect to reference position of Table 1)

Supporting system	**Thermal gradient**	**Tilts of supporting sections (mrad)**	**V.V. mid-length deflection (mm)**	**Displacements of the cold mass extremities (mm)**	
				Lateral	Vert.
1+1+1	4°	-2.2* -2.2* -2.2*	-0.5*	-1.3*	-1.2*
2+1	10°	No	-1.1* -1.4	No	+0.6* +1.1
2+1+1	7°	No	-0.4* No	No	+0.3* +0.1

* Measurements

The displacements of the alignment targets when pumping insulating vacuum, taking into account the manufacturing imperfections of the vacuum vessel, were also computed and values were below 0.1 mm.

The 1+1+1 supporting system leads to a non-symmetric deformation of the cryodipole and a torsion in both the cold mass and the vacuum vessel. Moreover, it shows large sensitivity to changing temperatures in the tunnel. The 2+1 supporting system induces symmetric deformations. However, it leads to a large mid-length vertical deflection that depends on temperatures in the tunnel. Finally, the 2+1+1 supporting system, with a central support limiting exclusively the mid-length vertical displacements, has symmetric deformation of the cryodipole and very small sensitivity to changing temperatures in the tunnel. Reinforcing the bottom plate of the vacuum vessel central supporting cradle also helps.

3 DYNAMIC ANALYSIS

The LHC cryodipoles will be transported and handled from the surface assembly buildings to their final position in the tunnel. Therefore they will be subjected to dynamic loads that could damage the dipole cold masses and cryostat components. Previous dynamic analyses on transport of the LHC cryodipoles can be found in [2].

The present analysis concerns the dynamic behaviour of the LHC cryodipoles when transported on a hydraulic suspension truck. The effect of transport restraints was also assessed.

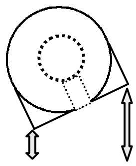
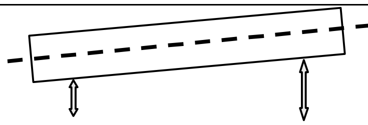
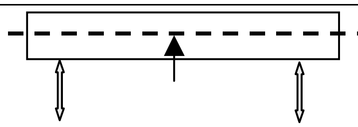
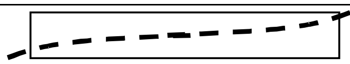
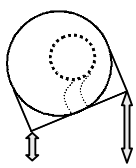
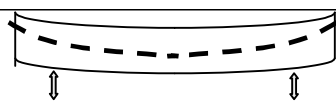
The dynamic behaviour of a system (natural modes and frequencies) depends on all assembled components and boundary conditions. Therefore, the hydraulic suspension system of the truck, the truck bed frame and the transport restraints were included in the finite element model.

The natural modes and frequencies of the cryodipole on a hydraulic suspension truck are given in Table 3. Four cases where considered: no transport restraints, only end restraints, end restraints and reinforcement on the central GFRE support post, and end restraints and reinforcements on all GFRE support posts.

Natural modes in the low frequency range were found. Dynamics loads observed during transport are also of low frequency and therefore the natural modes of the cryodipole can be excited (resonance).

The first three modes are truck suspension modes and do not change if the cryodipole has transport restraints or not. The fourth mode is a lateral movement of the cold mass extremities and when adding the end restraints the mode is shifted from the low frequency range. The fifth mode is a lateral bending of the GFRE support posts. Adding the end reinforcements shifts the natural frequency to values over 20 Hz.

Table 3: Dynamic behaviour of the LHC cryodipole on a hydraulic suspension truck with and without transport restraints (finite element computations). First natural modes.

Natural modes	**Natural frequencies (Hz)**			
	No transport restraints	**End restraints**	**End + central support restraints**	**End + all support posts restraints**
	1.0	1.0	1.0	1.0
	1.9	1.9	1.9	1.9
	2.9	2.9	2.9	2.9
	8.4	No	No	No
	8.7	21.1	21.3	23.0
	9.1	9.1	9.3	9.4

The sixth mode is a vertical displacement of the cryodipole mid-length section. Neither the end reinforcements nor the reinforcements on the GRFE support posts change significantly the natural frequency of this mode.

The dynamic loads that the GFRE support posts can withstand and the maximum admissible dynamic bending stresses in the cold mass shrinking cylinder will limit the maximum admissible accelerations during transport. Work is currently going on to establish the maximum admissible accelerations during transport and handling.

4 CONCLUSIONS

The 2+1+1 supporting system is chosen for positioning the LHC cryodipoles in the tunnel. This supporting system has symmetric and small static deflections due to self-weight loading. Also the effect of changing temperatures in the tunnel is minor, and can be improved by reinforcing the bottom plate of the central cradle.

For the cryodipole on a truck, natural modes in the low frequency range were found and are potentially excited during transport (resonance). Reinforcements at both ends of the cryodipole are proposed. The fact of adding reinforcements to the GFRE support posts does not change significantly the frequencies of the first natural modes. However, in order to protect the GFRE support posts the central support reinforcement may be needed during road transport of the LHC cryodipoles.

REFERENCES

[1] JC Brunet et al, “Design of the second series of LHC prototype dipole magnet cryostat”, CEC/ICMC, Portland U.S.A., 1997.

[2] A.Buenaventura et al, “Dynamic analysis of the LHC 15-m cryodipole under transport and handling conditions”, CERN, LHC Project Note 204, Geneva, October 1999.