LL

CERN-MT-95-14-ESH

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

see 8620

CERN LIBRARIES, GENEVA

CERN-MT-95-14

CERN MT/95-14 (ESH)
LHC Note 363**A Composite Vacuum Barrier for the LHC Short Straight Section**

B. Jenny, P. Rohmig, J.-M. Uriarte*

The lattice of the CERN Large Hadron Collider (LHC) will contain 384 Short Straight Section (SSS) units, one in every 53 m half-cell. The SSS is composed of a twin aperture high-field superconducting quadrupole and of two combined-function corrector magnets operating in pressurized helium at 1.9 K. The SSS cryostat contains also a barrier for sectorisation of the insulation vacuum. The vacuum barrier is mounted between the helium vessel and the vacuum enclosure. Its functions are to limit the extent of eventual helium leaks and to facilitate the leak detection and the pumping-down from atmospheric pressure. During installation of the LHC, the vacuum barrier permits independent testing of the half-cells, thus enabling higher installation rates. In parallel to a conventional barrier made out of austenitic stainless steel, a barrier of composite material was developed, taking advantage of the lower thermal conductivity of glass fibre reinforced epoxy resin, and with the aim of reducing costs for LHC. The thermo-mechanical design together with the conception and the moulding techniques used for the manufacture of the prototype are described. Bonding techniques for the leak tight stainless steel composite interfaces are presented and test results shown. Results on the mechanical performance and on the helium tests carried out on the prototype are given.

Cryogenic Engineering Conference and International Cryogenic Materials Conference,
July 17-21 1995, Columbus - Ohio, USA

Geneva, Switzerland
6 November 1995

* FIBERTECNIC, 01013 Vitoria-Gasteiz, Spain

A COMPOSITE VACUUM BARRIER FOR THE LHC SHORT STRAIGHT SECTION

B. Jenny¹, P. Rohmig¹, J.-M. Uriarte²

¹CERN, 1211 Geneva 23, Switzerland

²FIBERTECNIC, 01013 Vitoria-Gasteiz, Spain

ABSTRACT

The lattice of the CERN Large Hadron Collider (LHC) will contain 384 Short Straight Section (SSS) units, one in every 53 m half-cell. The SSS is composed of a twin aperture high-field superconducting quadrupole and of two combined-function corrector magnets operating in pressurized helium at 1.9 K. The SSS cryostat contains also a barrier for sectorisation of the insulation vacuum. The vacuum barrier is mounted between the helium vessel and the vacuum enclosure. Its functions are to limit the extent of eventual helium leaks and to facilitate the leak detection and the pumping-down from atmospheric pressure. During installation of the LHC, the vacuum barrier permits independent testing of the half-cells, thus enabling higher installation rates. In parallel to a conventional barrier made out of austenitic stainless steel, a barrier of composite material was developed, taking advantage of the lower thermal conductivity of glass fibre reinforced epoxy resin, and with the aim of reducing costs for LHC. The thermo-mechanical design together with the conception and the moulding techniques used for the manufacture of the prototype are described. Bonding techniques for the leak tight stainless steel composite interfaces are presented and test results shown. Results on the mechanical performance and on the helium tests carried out on the prototype are given.

INTRODUCTION

CERN is currently undertaking design studies and prototype development work leading towards the construction of the Large Hadron Collider (LHC)¹. This multi-TeV range collider will consist of a ring of twin aperture superconducting magnets, operating in a pressurized superfluid helium bath at temperatures below 2 K and housed in vacuum enclosures.

The LHC of a total circumference of about 27 km, is subdivided in eight standard arcs, each about 3.2 km in length. The insulation vacuum of the helium enclosures of each standard arc is sectorized by vacuum barriers. The functions of these barriers are to limit the propagation of eventual helium leaks and to facilitate leak detection. During installation of the LHC, they enable independent testing of the half cells, and promote high installation rates.

Placed within the Short Straight Sections (SSS)² they sectorize the insulation vacuum every 53 m (Fig. 1).

These vacuum barriers must present a high thermal impedance to limit the thermal load to the 1.9 K helium bath, while retaining the high mechanical strength necessary to sustain atmospheric pressure loads and thermal stresses.

The barriers must also be leak tight to helium, have a low helium permeation rate, and they must present a low outgassing rate under vacuum.

A prototype vacuum barrier made out of corrugated stainless steel tubes separated by a thermalized eccentric disk (Fig. 2) is installed in a so-called test string³. This string, composed of a series of prototype superconducting magnets, is dedicated to testing and validating choices concerning essential functions (cryogenics, powering, quench protection etc.) of the future LHC.

In parallel, a vacuum barrier made out of composite material has been developed with industry, taking advantage of the high resistance and low heat conductivity of this material. Another aim is to achieve low cost series production for the LHC.

Pre-impregnated fibre glass epoxy resin segments, forming the membrane, are placed in a mould and polymerised in a furnace together with stainless steel tube interfaces. Designed to fit in the prototype Short Straight Section, a prototype was built and mechanically tested (Fig. 3).

CERN is currently mounting this composite vacuum barrier into the test string to simulate cryogenic cycling and to verify its thermo-mechanical behaviour.

Figure 1. Longitudinal section of the LHC Short Straight Section

Figure 2. Vacuum barrier made out of stainless steel

Figure 3. Vacuum barrier made out of composite

THERMO-MECHANICAL DESIGN

Several load cases influence the design of the vacuum barrier. During installation atmospheric pressure may act in either direction, while vacuum is maintained for leak detection on the opposing side. During normal operation there is no pressure difference, but thermal contraction during cooldown results in a displacement of the inner flange fixation by 0.5 mm vertically and about 3 mm longitudinally. Various tubes at working temperatures between 4.5 and 75 K pass through and are connected to the vacuum barrier.

The geometry consists mainly of a flat membrane with spherical reinforcements to improve buckling resistance and a large undulation which increases the thermal conduction path and provides the necessary flexibility for the thermal contraction displacements. To intercept heat from the 300 K flange, a copper ring is integrated in the inner part of the contraction wave and is thermally connected to the 50 K line.

The structure was designed and optimized on the basis of acceptable mechanical and thermal stresses calculated with Finite Element Method (FEM)⁴. The maximum Von Mises equivalent stresses and failure criteria "TSAI-WU"¹⁾ are shown in Table 1 and 2.

Figure 4. FEM mesh of composite vacuum barrier

Figure 5. Result of FEM buckling calculations

Table 1. Von Mises maximum mechanical stresses and TSAI-WU criteria

	Lower Ply	Intermediate Ply	Upper Ply
Von Mises (MPa)	254	54	303
TSAI-WU (< 1)	0.55	0.04	0.84

Table 2. Von Mises maximum thermal stresses and TSAI-WU criteria

	Lower Ply	Intermediate Ply	Upper Ply
Von Mises (MPa)	81	69	127
TSAI-WU (< 1)	0.2	0.08	0.2

Table 3. Thermal losses [Watts]

		Calculated	Specified
Thermalization	(50 K)	4.61	10.8
He - enclosure	(1.9 K)	0.44	0.33
Cryogenic tube	4 (5 K)	0.07	0.13
	5 (5 K)	0.19	0.13
	6 (50 K)	- 0.09	—
	7 (50 K)	- 0.08	—
	8 (1.9 K)	0.15	0.09
	9 (2.2 K)	0.06	0.04

¹⁾ Extension of the Von Mises criterion to a quadratic one, based on scalar products of stress components

The highest stresses occur in the vicinity of the junctions with the 50 K tubes, and a maximum displacement of 6 mm is located next to the spherical reinforcement. The buckling resistance was calculated and after optimization of the membrane a safety factor of 5 was achieved. Thermal losses were also calculated with FEM (Table 3) and results conform to the values stipulated in the specifications. To meet the stringent thermal requirements a pre-impregnated E-glass fibre/epoxy resin was chosen for the barrier, taking a tensile strength of 420 MPa and thermal properties of G-10 CR laminate as reference.

MANUFACTURING TECHNIQUES

Multi-Layer Design

For manufacture a two dimensional anisotropic (monolithic) structure formed by the superposition of composite layers was selected. These layers are formed from fabric, consisting of two perpendicular thread systems, the warp and weft, previously impregnated by epoxy resin "prepreg". A satin weave was chosen for its better drapability. This fulfils best the mechanical strength requirements through addition of the strengths of the different single layers and the multi-directionality of the layer fibres.

The "prepreg" concept favours an homogeneous and constant resin impregnation of the fibres. At the same time it permits an accurate orientation and alignment of the fibre tissue.

Moulding Technique

The moulding process was performed in a fully air-conditioned clean room where the relative humidity was kept at $50\% \pm 3$ and the temperature at $21^\circ\text{C} \pm 1$ to avoid water contamination of the "prepreg" material. The precise directional alignment of the fibres, required in particular in the complicated parts of the mould (corners), imposed the adoption of a manual process, called "hand lay up". This process was also necessary to permit introduction of the metallic parts between the plies.

In order to obtain a correct compactness between the plies, and avoid porosity (air bubbles), the barrier was vacuum pumped twice for periods of 30 minutes during layer assembly.

After the build up of all plies in the mould a vacuum bag (Fig. 6) was made, composed of :

- a release agent film; to separate the plies from the mould,
- a breather; to facilitate air pumping during polymerization,
- a thermocouple; to measure continuously the temperature and to control the process,
- a vacuum film; to close the bag with a sealant zinc chromate tape,
- a vacuum connection; to allow a controlled pump down to be carried out.

Figure 6. Schematic layout of the moulding technique

Curing Process

The curing of the vacuum barrier was carried out in an autoclave. An external pressure was applied while vacuum pumping of the mould with the barrier and holding the polymerisation temperature (Fig. 7). Constant process provides a maximum compactness between the fibres thereby yielding optimum mechanical properties.

During the thermal process the viscosity was controlled. The most critical part of the cycle is reached when the viscosity is minimum. At this point of the curing cycle, the pressure applied defines the final location of each fibre and thus fixes the final compactness and consequently the mechanical properties of the vacuum barrier.

Prototype manufacturing tests

The manufacturing of the prototype was preceded and followed by test programs ensuring the optimum choice of materials and technologies.

Helium permeation tests⁵ on 2.5 mm thick samples confirmed that outgassing values of $8 \times 10^{-14} \text{ m}^2 \text{ s}^{-1}$ at 300 K can be obtained without special surface coatings.

The leak tight connections of the composite membrane with the stainless steel tubes represent critical areas of the vacuum barrier. Results of tension and shearing tests of flat samples with different adhesion are shown in Table 4.

Subsequent thermal cycling on model tube composite connections, from 300 K to 77 K (LN_2), showed good results concerning leak tightness, but also revealed the sensitivity to rapid thermal shocks. In this cases cracks in the composite bounding occurred.

A hydraulic pressure test of a test barrier showed good agreement with the calculated estimates of failure. Final reception tests at 300 K of the vacuum barrier confirmed the leak tightness under atmospheric pressure and a background signal of $1 \times 10^{-8} \text{ mbar l s}^{-1}$.

Figure 7. Curing set-up scheme

Table 4. Results of sample tests

	T (K)	Shear (MPa)	Tensile (MPa)	Contraction (//) % (293 - 77 K)
Adhesive only (FM 73M Cytec)	293	23.78	48.10	1.1
	77	18.52	97.36	
"Prepreg" only (MXB ICI Fiberite)	293	33.34	63.69	0.24
	77	36.99	114.44	
Adhesive + "Prepreg" + Adhesive	293	28.26	51.25	
	77	28.10	87.08	

CONCLUSIONS

The vacuum barrier made out of composite material (GFRER) while presenting similar heat loads and mechanical properties as the stainless steel version, is considerably lighter (25 kg against 260 kg) and more compact (150 mm against 750 mm in length). The reduced weight enables easy handling during assembly. The moulding technique opens the way for semi-automatic series production. Further studies on the bonding technique for the composite to stainless steel interfaces are required to improve the reliability of these junctions. This in particular in view of a fully welded link to the vacuum and helium enclosures.

The future LHC string test program foresees integration of a composite vacuum barrier to gain information units on the cryogenic behaviour.

ACKNOWLEDGEMENTS

This project was carried out in the framework of a collaboration contract between CERN and FIBERTECNIC, initiated and financially supported by the Centre for the Development of Industrial Technology (CDTI), Madrid, Spain.

The authors wish to thank the teams involved in the design, the calculation and the manufacture of the prototype vacuum barrier at CERN and at FIBERTECNIC. Special thanks to P.-E. Faugeras for his support, A. Mathewson for the fruitful discussions concerning the vacuum requirements and A. Toukhtarov for his design work on the string test set up.

REFERENCES

1. The LHC Study Group, Design Study of the Large Hadron Collider (LHC), CERN 91-03, May (1991).
2. W. Cameron, B. Jenny, G. Riddone, P. Rohmig, R. van Weelden, "Design and Construction of the Prototype Cryostat for the Short Straight Sections (SSS) of the CERN LHC", CERN MT/93-04 (ESH), Presented at the Cryogenic Engineering Conf., Albuquerque, July (1993).
3. P.-E. Faugeras for the LHC String Team, "Assembly and Commissioning of the LHC Test String" Geneva, May (1995).
4. Design Calculations FIBERTECNIC / INASMET, Spain, July (1993).
5. V. Baglin, A. Grillot, "Test de Perméation à l'Hélium d'Echantillons pour une Barrière à Vide en Composite", Note Technique 94-05, Février (1994).