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**LEAK-TIGHTNESS ASSESSMENT OF DEMOUNTABLE JOINTS FOR THE
SUPERFLUID HELIUM SYSTEM OF THE CERN LARGE HADRON
COLLIDER (LHC)**

J.C Brunet, A. Poncet, Ph. Trilhe

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LEAK-TIGHTNESS ASSESSMENT OF DEMOUNTABLE JOINTS FOR THE SUPER FLUID HELIUM SYSTEM OF THE CERN LARGE HADRON COLLIDER (LHC)

Jean-Claude Brunet, Alain Poncet, Philippe Trilhe

MT Division
CERN
1211 GENEVA 23
Switzerland

ABSTRACT

The future high energy accelerator LHC presently considered at CERN, will make heavy use of demountable cryogenic joints operating at superfluid helium temperatures (1.8 K). These joints will be required for connecting the cryomagnets to their feeding lines, helium safety valves to cold masses, both on their measuring benches and eventually in their final installation set-up. The very large size of the future machine and, consequently, the large number of cryogenic joints imply that their reliability in leak tightness be very high, in particular after extreme loading conditions such as the high helium pressures resulting from superconducting magnet quenches.

For these reasons, a test set-up has been especially built at CERN to reproduce these conditions, and to assess on the leak tightness reliability of commercially available joints. A description of the facility is presented, together with the first test results.

INTRODUCTION

The LHC project studied at CERN is currently in an intensive R & D phase. The machine being considered is a 7+7 TeV superconducting proton collider of 27km circumference, installed in the LEP tunnel. More than 1300 double aperture 13m long cryomagnets operating in super-fluid helium at 1.9 K and housed in a common cryostat will have to be built and tested before installation in the tunnel. In addition to the various magnets, the cryostats will have to accommodate all cryogenic transfer lines, safety valves, busbars and beam vacuum tubes (Figure 1).

The actual interconnection engineering design is based on weld and cut technology, for reasons of optimum leak tightness and reliability¹. However, before final installation in the tunnel, the cryomagnets and their cryogenic transfer lines and vacuum pipes will have to be thoroughly leak checked and connected to magnetic and cryogenic test stands as part of the overall quality plan.

¹ Interconnexion entre les composants magnétiques prototypes du LHC
(J.C. Brunet, M. Genet, C. Reytermier, Ph. Trilhe) - ref. CERN/MT/92-06 (ESH) - Note LHC 216

Fig. 1 : Overall view of the junction between two LHC dipoles.

Cryomagnets, their feeder lines and interconnections are cryogenic pressure vessels. During cooldown of the system, high pressure helium gas will be flowed through the various components. In addition, the magnets will be magnetically measured and tested at their maximum operating fields. They will thus undergo magnetic quenches, during which the helium pressure is expected to rise to a maximum value of 2 MPa (20 bars). The present technological note gives initial results of a test programme aimed at assessing the possibility of using easily demountable leak tight joints, capable of withstanding the high helium pressures quoted, and allowing quick and easy connection of the various cryogenic and vacuum pipes to the cryogenic feeding boxes of the test stands. In the actual design, the connecting flanges will be cut after testing and prior to installation.

FLANGES AND SEALS

Although the realm of leak-tightening devices (flanges and seals with UHV performance) against air, gas or fluids is extremely wide and rich, the published data are scarce on their applicability in cryogenic conditions, particularly for what concerns sealing against high pressure superfluid helium. It is planned to endeavour a systematic study of commercially available joints; however the initial attention of this test campaign has been oriented towards the rapid achievement of a satisfactory solution.

The scope of the study has therefore initially been reduced to classical combinations of thick bolted stainless steel flanges, able to withstand the high helium pressure with sub-micron deflections, and gaskets of already known ability to seal reliably to UHV standards against liquid helium, and having mechanical robustness². Stainless steel (AISI 316 LN) flanges of Conflat (CF) cross sectional dimensions, of Ø 152mm outer dimension and with a N6 (ISO) flat sealing surface machining, were initially chosen (Figure 2). This flange pair is designed to normally crush a copper conflat seal with a sealing force of 3.5×10^5 N per meter of sealing contact joint.

² H. Ishimaru and H. Yoshiki, "Sealing performance of gaskets and flanges against superfluid helium" p. 456 Cryogenics, Vol. 31, June 1991.

Fig. 2 Flanges and double seal test assembly

This represents a total bolt force of about 10^5 N, to be compared to an axial (flange separating) force of 2×10^4 N, when the 2.5 MPa (25 bars) helium pressure is applied to the whole active flange surface, as it can be the case in operating conditions and was applied in the test apparatus. The flanges are tightened with 16 M8 stainless steel ISO 3506-A4-100 bolts, having a rated tensile strength of 1000 MPa. The high hoop and torsional rigidity of the CF flange (compared for instance with other numerous conical flange designs with quick disconnect clamps) are also assets to prevent any sizeable motion of the sealing faces with application of high helium pressures. Concerning the gaskets tested, the initial choice has been for already proven seals in similar applications, presenting a minimum required sealing force compatible with the sealing force capability of the conflat flange ($\geq 3.5 \times 10^5 \text{ Nm}^{-1}$), with a double seal design as illustrated on figure 2. The purpose of the double seal design is twofold : to allow the possibility to leak check a mounted flange pair by pumping between the inter-seal space, and to give the higher safety of a double seal design. Double HelicoflexTM seals with soft Aluminium wraps rated at $1-1.5 \times 10^5 \text{ Nm}^{-1}$ linear sealing force have been tested. This type of seal has already been mentioned in the literature for its good sealing properties against superfluid helium³.

In addition to this, double diamond seals made of an Aluminium alloy with 0.5% magnesium and of high strength and ductile Aluminium-Copper alloy, type ASM 2219, chosen for their low cost and simplicity, were also tested in this first campaign (Figure 2).

³ J. Montuclard, M. Lefrançois, Ch. Romand "What joining Method for the New Generation of Accelerators (SSC and LHC)
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42029 ST-ETIENNE/CEDEX - FRANCE

TEST APPARATUS AND EXPERIMENTAL DETAILS

Figure 3 shows the test set up designed for testing 3 flange/seal combinations simultaneously. The test column is inserted in a superfluid helium dewar. High pressure helium gas can be introduced in the central volume of the test column to pressurize the superfluid helium against the inner seal. Stainless steel tubes welded on each flange and communicating with the volume comprised between the two seals are used for leak checking.

The helium flow scheme together with a typical test sequence (protocol) are represented on figure 4.

The leak detector used is a calibrated ULTRATEST M2 from Leybold-Heraeus, with a leak detection sensitivity of $2 \cdot 10^{-12} \text{ Pa m}^3 \text{ s}^{-1}$ ($2 \cdot 10^{-11} \text{ mbar L s}^{-1}$). Due to the high helium background of the cryogenic laboratory where these tests were made, the background signal read by the leak detector was within the range $10^{-10} \sim 10^{-11} \text{ Pa m}^3 \text{ s}^{-1}$, despite the precautions taken, such as the use of metal seals, careful leak detection and background reduction obtained with prolonged pumping times. Extensive precautions and controls were also systematically applied during the mounting of the seals :

- Visual inspection for scratches, dirt, etc.
- Geometrical control of the flange sealing faces (parallelism).
- Careful alcohol cleaning (degreasing) of the seals and flanges.
- Manipulation of seals and flanges with clean polyethylene gloves.

Lubricated flange bolts are tightened with a torque wrench at 20-25 Nm, progressively and symmetrically to maintain flange parallelism.

Fig. 3 Flange/Seal test column inserted in its cryostat

- ### Test at Ambient Temperature

1. Leak test (volume I at atmospheric pressure)
2. Pressurize volume I to 3×10^6 Pa (30 bars)

- Test at Liquid Nitrogen Temperature (77 K)**

3. Leak test (volume I at 2×10^5 Pa (2 bars) with helium gas
4. Pressurize volume I to 3×10^6 Pa (30 bars)

- Test at Liquid Helium
Temperature(4.2 K)

5. Leak test (volume I at 2×10^5 Pa (2 bars) with helium gas)

6. Pressurize volume I to 2.5×10^6 Pa (25 bars)

7. Pump volume II to 1.6×10^1 Pa (16 mbar) (1.8 K)

8. Leak test (volume I at 2×10^5 Pa (2 bars) with helium gas)

9. Pressurize volume I to 2.5×10^6 Pa (25 bars)

10. Repeating the last point 10 times

- ### Test at Ambient Temperature

11. Leak test (volume I at atmospheric pressure)

The leak detector is permanently connected to volume III.

Fig. 4 Helium and pumping flow scheme, and test procedure

TESTS

Several series of tests were made on the double Helicoflex and Aluminium seals according to the test procedure described in the preceding paragraph. The results are given in table 1.

The quoted values for the leak rates measured are given as below (<) the background level of 10^{-11} to 10^{-10} Pa m³ s⁻¹, when no net leak rate could be measured. This occurred when the signal with the detector valve opened did not exceed the signal with the leak detector valve closed (background level). As already said, the background level is usually high because of the large amount of helium gas in the laboratory, despite all the precautions taken.

To improve on leak sensitivity, accumulation tests were conducted on some seals (AA 2219). This was done by letting eventual leaking helium accumulate into the system with the detector valve closed for a few hours at 1.8 K. The temperature of the liquid helium bath was then raised to 10-15 K in order to release the eventual surface-adsorbed He gas into the gas phase. The valve to the detector was then opened, and the helium signal integrated versus time, to yield the average leak rate during the test. (Table 1)

Test Series	Seal type	(2) 300 K $\Delta p = 10^5$ Pa	(3) 77 K $\Delta p = 3 \times 10^6$ Pa	(4) 4.2 K $\Delta p = 2.6 \times 10^6$ Pa	(5) 1.8 K $\Delta p = 2.6 \times 10^6$ Pa
1	Helicoflex double tore - Alu plated	$< 10^{-10}$	3.2×10^{-9}	6.3×10^{-9}	3.7×10^{-9}
2	Double diamond AlMg 0.5	1.3×10^{-9}	2.1×10^{-9}	2.1×10^{-9}	2.4×10^{-9}
3	Double diamond AlCu 2219	$< 10^{-10}$	$< 10^{-10}$	1.5×10^{-9}	6.1×10^{-10}

Notes : (1) Test done according to protocol Fig. 4
(2) Test sequence 1-2
(3) Test sequence 3-4
(4) Test sequence 5-6
(5) Test sequence 8-10

Table 1 Average Leak Rates [10^{-1} Pa m³ s⁻¹ (1)] for 3 types of seals

A second series of tests was made to determine the minimum sealing force (or torque applied on the bolts) to obtain leak tightness (as defined above) on AA 2219 seals, at several temperatures (300 K, 77 K, 4.2 K, 1.8 K), and during and after Helium gas pressurization at 2.6 - 3 MPa for each of these temperatures. The results are given on table 2, together with the torques necessary to achieve leak tightness.

$\Delta p \ 10^5$ Pa (bar)								
daN.m	300 K (a)		77 k (b)		4.2 K (c)		1.8 K (d)	
	$\Delta p = 1$	$\Delta = 30$	$\Delta p = 2$	$\Delta p = 30$	$\Delta p = 2$	$\Delta p = 26$	$\Delta p = 2$	$\Delta p = 26$
Average (e)	17.6	18.8	18.3	21	21.3	21.3	21.3	21.8
Mini	15	15	15	18	19	19	19	20
Maxi	21	21	21	25	25	25	25	25

Notes : (a) Average leak rate $< 10^{-9}$ Pa m³ s⁻¹
(b) Average leak rate $< 10^{-9}$ Pa m³ s⁻¹
(c) Average leak rate $< 1.5 \times 10^{-9}$ Pa m³ s⁻¹
(d) Average leak rate $< 6 \times 10^{-9}$ Pa m³ s⁻¹
(e) Average values with 6 seals in 2 series.

Table 2 Determination of the sealing torque to obtain leak-tightness at different temperatures and pressures for the double diamond seal AA 2219

PRELIMINARY DISCUSSION

Despite the fact that some small leaks above background could be detected on all types of seals and under all tests conditions, they always remained small enough for an application where the cryomagnets are to be connected for a short time (a few weeks to several months) to a measuring test bench. This validates the possibility to use the designed flanges and seals with high helium gas pressures entailed by forced flow cooling or resulting from magnet quenches.

All seals tested performed satisfactorily. Notably, the good performance of the double diamond 2219 Aluminium seals has been demonstrated. Statistically and in the limit of the background, no leak could be detected during and after pressurization at 2.5 MPa in superfluid helium, provided the sealing torque applied on the bolt was at or above 23 N.m.

It remains to be understood whether the higher sealing force required for leak tightness at 1.8 K and 2.6 MPa, compared to the room temperature case, is due to the necessity to further plastically deform the seal, in order to prevent enhanced flow rate of the superfluid helium through an existing defect at the flange seal-interface. Another explanation could be that the torque to achieve tightness has to be higher than at room temperature, in order to prevent any relative motion of the flanges under the action of temperature stresses.

Tests are continuing, aiming at understanding the dependence of leak flow rates upon helium superfluidity, pressure, and at assessing further the reliability of various sealing gasket designs for the operating conditions of the cryogenic interconnections of the LHC.

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