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Large Hadron Collider Project

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ULTRA-HIGH VACUUM SEALS OPERATING UNDER PRESSURE AND AT 1.8 K

J.C. Brunet, A. Jacquemod

Abstract

The Large Hadron Collider (LHC) project will be the next major high energy physics facility at CERN. Superconducting magnets operating at a magnetic field of 8.4 Tesla in a superfluid helium bath at 1.8 K are required to guide the high energy beams of protons on their trajectory. As part of the magnet qualification tests, magnetic measurements are made using a special device where demountable seals are required. The seals must be leak tight to vacuum and must be able to resist for short periods to pressure bursts up to 20 bar during resistive transitions (quench). Two types of seals have been qualified. Maximum leak rates were in the range 6.10^{-10} to 1.10^{-9} mbar.l.s^{-1}, in the worst conditions (20 bar, superfluid helium at 1.8 K).

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1. INTRODUCTION

The Large Hadron Collider (LHC) project, approved by the CERN Council in December 1994, will be a major research facility in high energy physics. Based on a ring of high field, twin aperture superconducting magnets operating in super fluid helium below 2 K, to be installed in the 26.7 km circumference existing LEP tunnel, it will provide proton-proton collisions with a centre of mass energy of 14 TeV.

The superconducting magnets are cryogenic pressure vessels, which must be connected to cryogenic feed boxes via demountable flanges for magnetic testing purposes. Once installed in the machine, all interconnections of the magnets with adjacent components will use weld and cut technology.

Under specific conditions, the superconducting magnets can undergo a resistive transition (quench). This can induce a pressure increase in the helium vessel of up to 20 bar. Since a quench can occur during magnetic measurements when the cryomagnets are connected via demountable joints, the seal must mechanically resist this pressure, and remain sufficiently leak tight.

CERN has therefore engaged in 1993 Research & Development studies aimed at assessing leak thickness at high pressure superfluid helium of commercially available joints [1]. This paper presents the latest results obtained.

2. OPERATING CRITERIA

The seals need to meet the following operating criteria:

- lowest possible leak rate (close to the detector's sensitivity limit of 10^{-10} [mbar.l.s^{-1}])
- resistance to repeated pressurisation at P = 20 bar during quenches, at 1.9 K
- resistance to a qualification pressure test at 25 bar at room temperature.

3. CHOICE OF THE SEALS TO BE TESTED

Operating conditions combining ultra-high vacuum, high pressures of 20 bar, superfluid helium II and temperatures ranging from 300 K to 1.8 K are not common. In space applications, the pressure are higher but the operating temperature is 20 K (liquid hydrogen). In the RF cavities of LEP, the temperature is 4.2 K (liquid helium I) but the pressures to be handled by the seals are low. That is also the case for the HERA accelerator in Germany and the RHIC accelerator in the USA. Tests performed for the KEK project in Japan have given encouraging results that now needed to be completed [2]. The project therefore consisted in resuming tests with some of the most promising seals, following a preliminary survey of existing technologies. A list of potentially suitable seals was drawn up; tests were then limited to the Helicoflex^{TM} and to solid aluminium seals using a sharp shaped sealing surface.

4. DESCRIPTION OF THE TEST EQUIPMENT

The test equipment is shown in Fig. 1, and is further described in ref. 1. To ensure improved tightness during the pressure and temperature variations, double seals were used (Fig. 2). The outer part is immersed in superfluid helium.

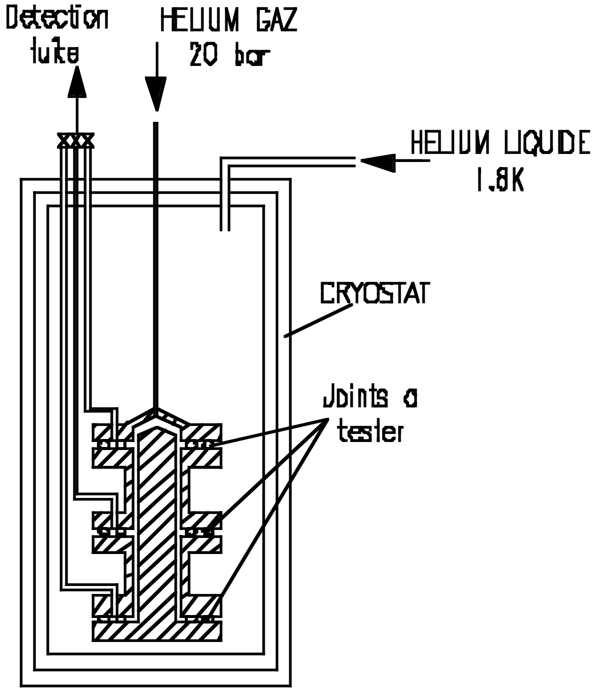

Figure 1: General view

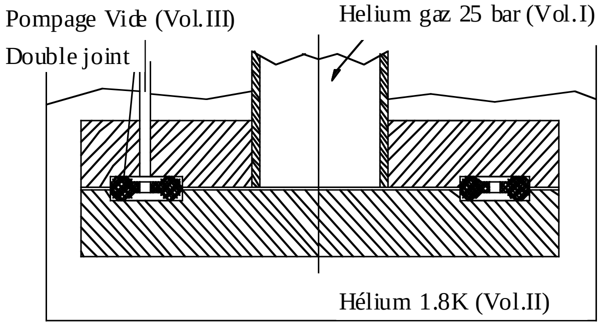

Figure 2: Double seal technique

Should a leak appear during magnetic measurements, the intermediate pumping technique allows the origin of the leak to be detected. If the leak occurs in the vacuum system itself, the magnetic measurements on the magnet can continue.

All the mechanical parts immersed in liquid helium were made of stainless steel (grade AISI 316LN). In addition, the flanges receiving the seals to be tested were designed to withstand pressures of up to 30 bar, and were machined according to UHV requirements (surface quality, tolerances, hardness, flatness, etc.).

Other tests were also performed with a variety of bolts used to assemble the flanges, and for different tightening torques.

The test apparatus was installed in a cryogenics laboratory where the air was permanently contaminated with helium gas. This "pollution" of the atmosphere was due to emissions and leaks that occur during liquid helium transfer to the various experiments taking place in the laboratory. To limit any harmful effect on the environment due to the presence of helium, all parts of the test equipment were designed with a minimum number of sensitive connections, which were fitted with metal seals.

5. TEST PROGRAMME

Seals cannot be approved in isolation, since overall tightness is provided by three components: the seal, the flange and the tightening device. So the seal approval test also involved testing separately the applied tightening torque values and the screws.

For each type of seal, the test programme comprised the following sequences with the leak detector always connected:

- leak test at room temperature with $\Delta p = 1$ bar to check the set-up,
- leak test during and after thermal shock at the temperature of liquid nitrogen (77 K) and Dp = 1 bar. Ten cycles of pressurisation-depressurisation,
- leak test during and after thermal shock at the temperature of liquid nitrogen (77 K) and helium pressure of Dp = 30 bar in volume I, with the leak detector connected to Volume III. 10 cycles of pressurisation-depressurisation,
- leak test during and after thermal shock at the temperature of superfluid helium (1.8 K) and helium pressure of Dp = 25 bar in Volume I. Ten cycles of pressurisation-depressurisation,
- test by helium accumulation during 2 hours.

6. RESULTS

6.1. Massive aluminium seals

The seals tested are depicted on Fig. 3A. This type of seal has two major advantages: its price is relatively low and its behaviour is known because it has been used for many years in various accelerators in the UHV field. In particular it was installed in the CERN-LEP machine using an aluminium light alloy (0.5% magnesium). A double version was also used for inter-seal pumping and leak detection at HERA.

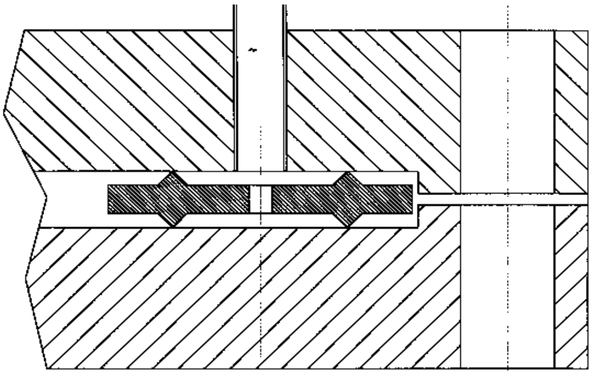

Figure 3A: Aluminium massive seal

The seal knife angle was fixed at 90˚. In the first phase of testing attention immediately focused on the manufacturing tolerances and, after analysis of the measured values, it was possible to double the tolerance of the flat part of the seal face from ± 0.05 to ± 0.1 mm and to increase the roughness from Ra = 0.8 to Ra = 1.6 µm.

The materials used were the aluminium alloy with 0.5% magnesium and a 2219 alloy (with copper additive), machined by two industrial collaborations.

Nine groups of tests were carried out with 29 seals tested. 21 of these were validated. The reasons for failure of the remaining 8 seals pertain to the difficulties encountered in ensuring proper manufacturing and mounting conditions.

	Min. leak [mbar.l.s^{-1}]	Max. leak [mbar.l.s^{-1}]
Aluminium Mg 0.5	$1.5.10^{-9}$	3.10^{-9}
Aluminium Copper (2219)	6.10^{-10}	6.10^{-10}

Table 1: Main results on massive aluminium seals. Leak rates at 20 bar, 1.8 K

6.2. Helicofex™ seals

The manufacturer Celifac (le Carbone Lorraine, F) offers various types of Helicofex™ seals.
A preliminary research suggested the use of the classical ring seal, and of the delta type covered with Aluminium or Silver.

The tests were then limited to the classical ring seal with Aluminium plating (Fig. 3B). Four groups of tests were carried out with 13 seals tested. Nine of these seals were validated. The remaining 4 seals failed.

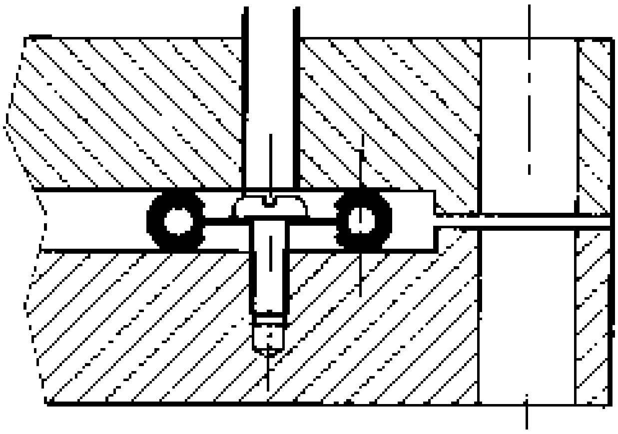

Figure 3B: Helicoflex seal

The main resulted are shown in table 2.

	Min. leak [mbar.l.s^{-1}]	Max. leak [mbar.l.s^{-1}]
Helicoflex™	1.6.10^{-9}	9.10^{-9}

Table 2: Main results on Helicoflex™ seals.
Leak rates at 20 bar, 1.8 K

7. COMMENTS AND CONCLUSIONS

The tests done so far allow two types of seals to be accepted, the massive aluminium seal and the Helicoflex. Their sealing performance under pressure of 20 bar at 1.8 K is equivalent to a leak rate in the range from 6.10^{-10} to 1.10^{-9} mbar.l.s^{-1}. The Helicoflex seal with aluminium plating is expensive; however it is insensitive to the quality of the mating surfaces of the flanges when several assembly and disassembly operations are required. The mounting of these seals is straightforward if the standard conditions are respected.

The massive aluminium seal is cheap but due to high pressures developed with the necessary mounting forces, the aluminium may tend to cold weld to the rough surface of the flanges. To overcome this, the flange surfaces can be cleaned with acid. This technique however is not applicable in some installations.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

[1] J.C. Brunet, A. Poncet, Ph. Trilhe, "Leak Tightness assessment of demountable joints for the Superfluid Helium System of the LHC", CERN-MT/93-03 (ESH)

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