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EXPERIENCE WITH A PRE-SERIES SUPERFLUID HELIUM TEST BENCH FOR LHC MAGNETS

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Abstract

The Large Hadron Collider (LHC) under construction at CERN is based on the use of high-field superconducting magnets operating in superfluid helium. For the validation of the machine dipoles and quadrupoles, a magnet test plant is under construction requiring 12 so-called Cryogenic Feeder Units (CFU). Based on experience done at CERN, two pre-series CFUs were designed and built by industry and are currently in use prior to final series delivery. This presentation describes the features of a CFU, its typical characteristics and the experience acquired with the first units.

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Experience with a Pre-Series Superfluid Helium Test Bench for LHC Magnets

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1 INTRODUCTION

The main magnetic system of LHC will consist of about 1200 twin-aperture, high-field superconducting dipoles and 400 twin-aperture, high-gradient superconducting quadrupoles operating in pressurized superfluid helium below 1.9 K [1]. All these magnets will be tested at CERN before their final installation in the accelerator tunnel.

In 1994 the first magnet test bench for LHC magnet prototypes was designed and built by CERN [2]. It was used to test 10 magnet prototypes before its dismantling in 1999. On the basis of the experience done with this first bench, two pre-series CFUs for testing of LHC pre-series magnets were designed and built by Oxford Instruments Ltd, installed and tested at CERN.

The functions of the CFU are to control the cool down and warm up of a magnet, to maintain a magnet in saturated liquid helium at 4.5 K or in pressurized superfluid helium at 1.9 K for magnetic measurements and quench training, to recover as much liquid helium as possible after a quench and to automatically cool down the magnet again. The CFU also contains all the current leads for the main coil and for the auxiliary magnets.

2 PRINCIPLE OF OPERATION

The magnet under test is fixed to three support posts, which are anchored to the concrete floor of the test hall. Cryogenic and electric feeding is done through the magnet feed box of the CFU, connected to one end of the magnet, the opposite end of the CFU being closed by a magnet return box. As the magnetic measurement equipment only operates at ambient temperature, both magnet apertures are equipped with warm bore inserts, which bring a heat load of 25 W into the superfluid helium bath.

The process flow diagram is presented in Figure 1. The main operation modes are as follows:

2.1 Magnet pre-cooling (300 K to 90 K)

When all electric and hydraulic CFU/magnet connections are completed and tested, the vacuum space of CFU/magnet is pumped down and globally leak tested. As the cold mass is about 35 tonnes, the cool-down from 300 to 90 K is done by helium gas pre-cooled with liquid nitrogen in a dedicated heat exchanger, which is not part of the CFU.

The cold helium gas at 10 bar enters the system at interface L1, passes through the phase separator and control valve FV165 before flowing through the magnet from the far end. The cold helium gas passes the magnet before flowing through FV149 into the decanter, then the flow is split into two. The main flow goes through FCV177 while the rest passes through the CFU and the magnet thermal shields. Both flows join again and leave the CFU through interface L2 at about 2 bar. This flow splitting is controlled such as to pass the maximum possible flow through the thermal shield without limiting the required flow for a simultaneous coldmass cool-down. The maximum mass flow during the pre-cooling phase is 80 g/s; the maximum temperature difference between cooling gas and cold mass is 60 K.

2.2 Magnet cooling (90 K to 1.9 K)

When the cold mass reaches 90 K, the helium gas cooling is stopped and the cooling continues with liquid helium through the same circuit. Liquid helium enters the system at interface L3 and leaves CFU through interface L4.

Whenever a cold mass is filled with saturated liquid helium at 1.3 bar, the level in the phase separator and in all the current lead vessels is kept at the required value. In this phase a magnet can be operated at 4.5 K or it can be cooled further down to its working temperature of 1.9 K. For this purpose the CFU is equipped with a low-pressure circuit connected to a liquid/liquid heat exchanger (LLHX) built inside the magnet. Saturated helium at 1.3 bar passes through TCV145 which is the main impedance in this circuit and which controls the helium level inside the LLHX. The liquid helium is pre-cooled in a liquid/gas heat exchanger with cold low pressure gas which is pumped via PCV144 controlling the pressure in the LLHX. The pre-cooling liquid continues through an internal pipe to the opposite end of the LLHX, thermally coupled to the cold mass. The cold low-pressure gas leaves the CFU, passes the Very Low Pressure Heater [3] before entering the Warm Pumping Unit [4]. The maximum flow capacity of this circuit is 6 g/s at 10 mbar. The gas/liquid heat exchanger is of the perforated plate type [5].

2.3 Magnet warm-up

After the magnetic measurement campaign, the magnet is quenched and the heaters inside the decanter and in the phase separator will boil off the liquid helium. Any remaining liquid helium is evaporated by a small flow of gaseous helium.

Once the liquid helium is evaporated, the magnet is warmed up to room temperature with a large (80g/s) flow of warm helium gas using the same circuit (via L1 and L2) as during the pre-cooling phase.

2.4 Magnet powering

In order to power all magnet coils, the CFU is equipped with one pair of main 13 kA current leads, two pairs of 1 kA and two pairs of 0.6 kA auxiliary current leads. In order to minimize the number of cryogenic valves, flowmeters, control loops etc., the 4 pairs of auxiliary current leads are built as twins.

The cold terminals of the main current leads are connected to terminals of the main coil by a double superconducting cable, partially stabilized with copper. This double cable is soldered to the cold current lead terminal and mechanically clamped to a magnet coil terminal. Cold terminals of the auxiliary current leads are connected to auxiliary coils via a copper stabilized superconducting cable soldered at both ends. Each current lead and bus-bar is designed to withstand 2 kV with resistance to ground better than $10^9\Omega$ in pure gaseous helium at 1 bar and ambient temperature. In addition, the main current leads withstand 5 kV with resistance to ground better than $10^9\Omega$ under cold conditions, when a cold mass is filled with liquid helium.

The magnet coils are operating in pressurized superfluid helium at 1.9 K and 1 bar and all current leads are operating at saturated liquid helium at 4.5 K. Hence the two helium circuits are separated by so-called lambda plates. The key component of the lambda plate is the ceramic feedthrough that was specially developed for this purpose [6].

2.5 Magnetic measurements and magnet training

In order to validate the required maximum magnetic field, each magnet must pass magnetic measurements and “quench training” [7]. “Quench” is a transient mode of a superconducting coil when it looses its superconducting state, because of poor cooling or high current/magnetic field. During the quench the liquid helium around the coil vaporises and the pressure increases rapidly. A mixture of gas and liquid helium passes through a “quench” discharge valve (FV149) into a decanter of about 400 litres volume. The gas leaves partially through the recovery line and partially through the low-pressure line (interface L4). The liquid helium remaining in the decanter is used for recooling the cold mass, which may have warmed up to 35 K during the “quench”.

3 CONTROL AND INSTRUMENTATION

The CFU is fitted with 12 pressure and vacuum transmitters, 23 temperature sensors and 3 cold flow meters. Also each current lead incorporate 3 temperature sensors and a dedicated flow sensor with control valve.

The complete CFU is controlled by an industrial PLC with remote input/output units using a Profibus interface. The PLC monitors all parameters and devices. The software is written such that the CFU can be operated with minimum operator interaction. Once a magnet has been connected and leak tested the control system will perform all warm tasks, like pumping and purging of helium and vacuum circuits, cooling down of the magnet through its 3 phases (pre-cooling, 4.5 K and 1.9 K cooling), automatic quench recovery and warm-up. The interface with the operator is using a separate SCADA software package called PCVUE ™.

4 TEST RESULTS

The first CFU has been in operation for testing of two 15 m dipole magnet prototypes for 7 months. The system has handled more than 150 quenches. The second CFU has been commissioned and successfully tested at the end of 1999.

The duration of a typical magnet test cycle with the CFU is at present as follows:

Magnet installation: 5 days ; Vacuum pump down: 8 hours ; Cool-down: 30 hours at m = 80 g/s and dT = 60 K ; Magnetic measurements: about one month ; Quench recovery: 3 hours ; Warm-up: 50 hours at m = 80 g/s and dT = 60 K ; Dismantling: 5 days. In future the CFU/magnet interfaces will be modified and the gas flow and temperature difference between gas and magnet will be increased in order to shorten the global time of a magnet test.

The total heat loads of CFU in a dummy configuration (without magnet) are shown in Table 1.

Temperature level (K)	Heat load at I = 0A (W)	Heat load at I = 13kA (W)
1.9	9.1	~ 10
4.3	27	~ 45
50	48	48

Table 1 CFU Heat Loads

™ : PCVUE is a registered Trade Mark of ARC Informatique – France.

REFERENCES

1. Lebrun, Ph., Superfluid Helium Cryogenics for the Large Hadron Collider Project at CERN, Cryogenics (1994) 34 1-8
2. Benda, V. et al, Cryogenic Benches for Superfluid Helium Testing of Full-Scale Prototype Superconducting Magnets for the CERN LHC Project, Cryogenics (1994) 34 733-736
3. Benda, V. et al, Electrical heater for very-low pressure helium gas, Proceedings, 4th International Conference Cryogenocs ’96 (1996), Praha, Czech Republic, pp. 40-43.
4. Benda, V. et al, Cryogenic infrastructure for superfluid helium testing of LHC prototype superconducting magnets CEC, ICMC (1993), Albuquerque, USA.
5. Viargues, F. et al, Construction and Preliminary Testing of Perforated Plate Heat Exchanger for Use in Helium II Refrigerators, Cryogenics (1994),.34, ICEC Supplement, 325-328.
6. Benda, V. et al, Current feedthroughs for superconducting magnets operating below 2K, ICEC 17 (1998), pp.739-742.
7. Billan, J. et al, Manufacturing features and performances of long models and first prototype for the LHC project, EPAC 98 (1998), Stockholm, Sweden

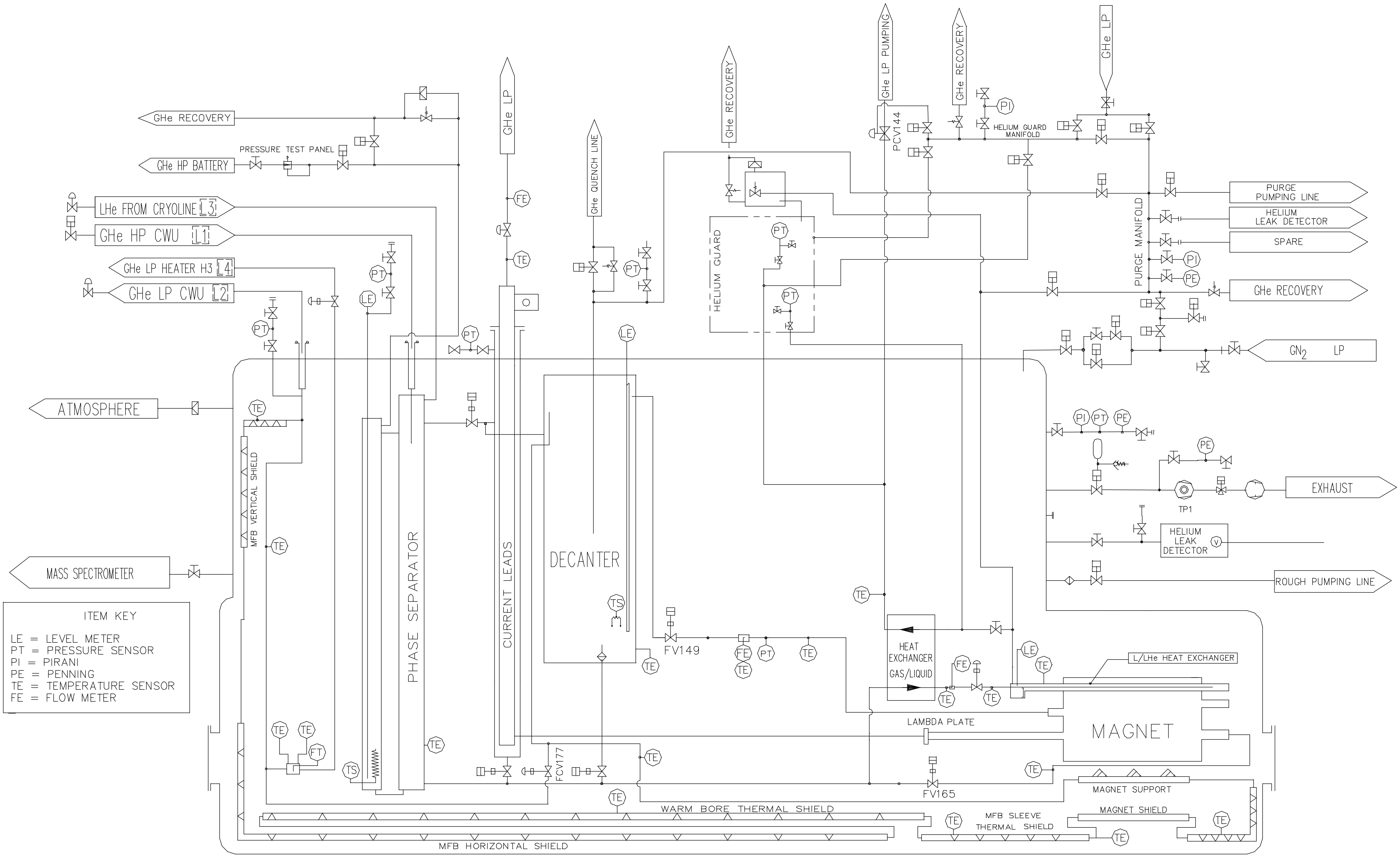

Figure 1 The process flow diagram