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CRYOGENIC FACILITIES AT 1.9 K FOR THE RECEPTION OF THE SUPERCONDUCTING WIRES AND CABLES OF THE LHC DIPOLES MAGNETS

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Abstract

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Cryogenic Facilities at 1.9 K for The Reception of the Superconducting Wires And Cables of the LHC Dipoles Magnets

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1 INTRODUCTION

The LHC accelerator ring will house about 1600 high-field superconducting magnets operating at 1.9 K. About 6400 km of Nb-Ti cables will be necessary to construct these magnets. The cable itself is composed of superconducting wires of 1.065 mm or 0.825 mm diameter. Almost 200 000 km of wires will be purchased. To conduct statistical reception tests for these Nb-Ti elementary wires and cables, CERN has installed a new cryogenic test facility [1] composed of a helium liquefier, a cryogenic distribution line and pumps with fully automatic control system. The scope of the tests is to verify the value of the critical current, the magnetisation current, the RRR of individual wires on one hand, and on the other hand, to carry out a measurement of the critical current of whole cable samples. It is foreseen to perform 200 tests a year with the cable test facility, and 1500 tests per year for the wire test facilities, starting from the end of year 1999 to the final completion of the construction of magnets (year 2003 - 2004).

2 CRYOGENIC INFRASTRUCTURE

2.1 General layout (see Figure 1)

The required pace of the testing program has determined the necessity of a fast succession of tests. To comply with this requirement, the choice for the general layout of the cryogenic installation has been to multiply the number of test benches, and to maximise the use of each test-bench. Seven small test benches work in parallel, independently from one another, with a complete cool-down and warm-up cycle per day, each cycle lasting 8 hours. The remaining test bench (FRESCA, test facility for cables, fully described in [2]) consists of two independent cryostats, one of which is cycled once a day, while the other one is always kept cold.

The helium liquefier TCF50, boosted with LN2 and equipped with an internal phase separator liquefies approximately 6.2 $g.s^{-1}$ at 4.5 K. The cycle compressor is a KAESER screw compressor providing a gaseous helium mass-flow of 80 $g.s^{-1}$. The liquefier supplies liquid helium via a 35 m transfer line to a dewar of 6000 litres. Along the line, seven liquid helium control valves provide a maximum flow of 2 g.s^{-1} to each of the seven small cryostats. The liquid phase of the dewar is connected to a valve box supplying the FRESCA facility through 2 transfer lines.

In this way, three cryostats can be fed at the same time, while the excess production is stored in the dewar to supply FRESCA. The operating cycles of the seven small test-benches are delayed to ensure one complete cycle per cryostat per day.

From the dewar (@ 0.135 MPa), a cold gas line is connected to the liquefier to recover the gas created by residual thermal losses of the liquid distribution system and by the expansion of the liquid.

The cold gas produced during cooling down, test process and warming up of the seven cryostats is locally warmed up at a maximum flow of 2 g.s^{-1} per cryostat and sent to the helium gas recovery system for purification. The cold gas produced by FRESCA is warmed up and sent to the warm suction side of the cycle compressor. The quality of this flow is continuously monitored by an oxygen-meter. If the quality is not satisfying, a three-way valve sends the gas to the recovery system. The return mass-flow is limited to 10 g.s^{-1}.

Refrigeration below 4.3 K is achieved by pumping. The pumping system for the FRESCA test bench is composed of one roots pump (2000 Nm3.h-1) in series with two primary pumps. The maximum mass flow acceptable is 1.45 g.s^{-1} with an inlet pressure of 1500 Pa. Five other primary pumps are connected respectively to 5 of the small cryostats (from C1 to C5). Each pump provides a mass-flow of 0.14 g.s^{-1} with an inlet pressure of 1000 Pa.

It is apparent that the sum of LHe maximum consumptions for all cryostats exceeds the capacity of the liquefier. The integrated weekly consumption is therefore matched to the available liquid production rate by sequential cycling. In addition to this, the daily cycle required for every test bench has to be guaranteed. These sequences are optimised, according to priorities predefined, by the fully automatic control system, composed of two PLC's (ABB).

The operator in charge simply has to change the samples, re-install the sample holder and signal to the control system that the bench is ready for cool-down. Once the measuring sequence is completed and the measured data stored, the operator signals to the control system that the cryostat is ready for warm-up. Each helium flow is constantly monitored and controlled according to the status of the cryostat (Cool-down, measurement or warming up phase).

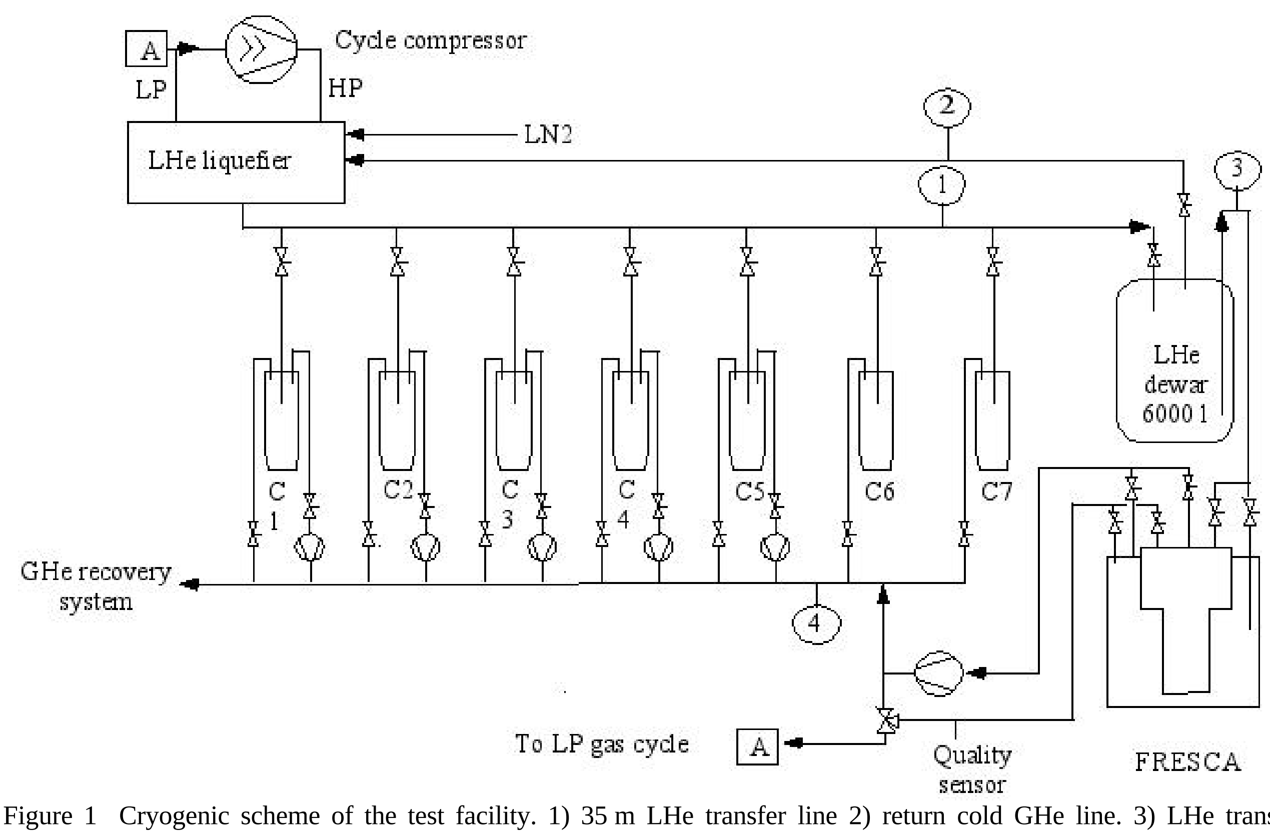

Figure 1 Cryogenic scheme of the test facility. 1) 35 m LHe transfer line 2) return cold GHe line. 3) LHe transfer line. 4) warm GHe recovery line to be purified

All the cryostats have been designed and commissioned by the LHC Main Magnet and superconductors group, responsible for the superconducting cables procurement and acceptance test.

Typical cycles of a test facility for wires and for FRESCA are detailed into the followings chapters.

2.2 Test facilities for wires

About 200 000 km of superconducting wires have been ordered. To assess the quality conformity of these wires, four kinds of test-benches are used.

Four test-benches (C1 to C4, Figure 2) measure the value of the critical current under a magnetic field. The upper bath of the cryostats operates with saturated helium at 4.3 K. The lower bath, hosting the test magnet, works with helium at 1.9 K and 0.11 MPa, sub-cooled through a saturated helium heat exchanger. The sample holder can accommodate up to 10 wire samples. A typical cycle of 8 hours consists in installing the sample holder, cool down to 4.3 K, perform a critical current measurement, then cool down to 1.9 K and again measure the critical current, and finally warm up the cryostat. The cool-down to 4.3 K takes three hours. Then, the heat exchanger is pumped down to reach 1.9 K in one hour time. The He mass flow during test at 1.9 K is 0.6 $g.s^{-1}$ from the upper bath and to 0.3 $g.s^{-1}$ from the heat exchanger cooling the lower bath. Warming up to 300 K takes approximately 3 hours.

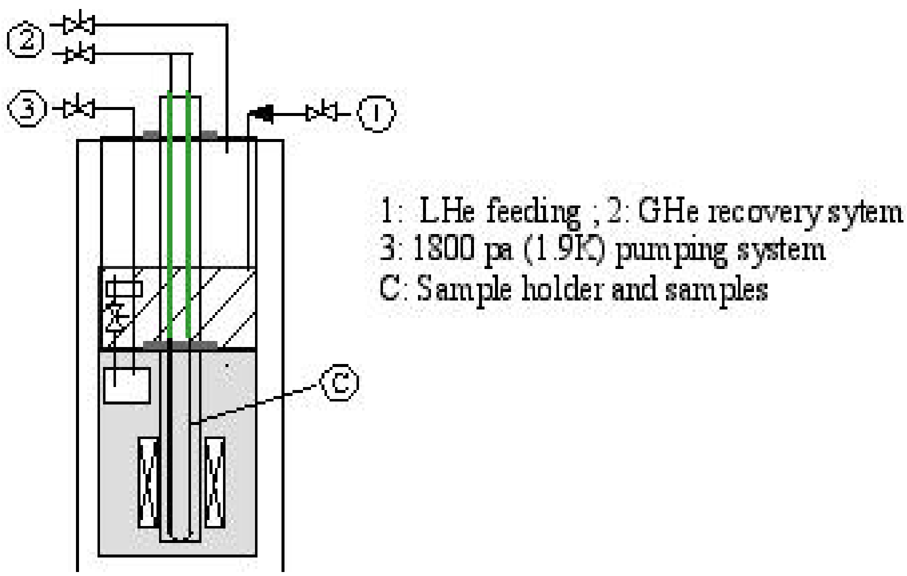

Figure 2 Cryostat for measuring the value of wire critical current under magnetic field

Test-bench C5 is dedicated to measuring the magnetisation current of the wire under a magnetic field, produced by an external resistive dipole. Multiple samples are measured in one single test cycle, lasting 8 hours. The cryostat works between 4.3 K and 1.9 K with a saturated bath.

Test-benches C6 and C7 operate both in saturated helium at 4.3 K. C6 is dedicated to measuring the residual resistivity of the wire at 10 K. The measurement is done in cold gas during warming up. C7 is dedicated to the measurement of the contact resistance between wires on the whole cable.

2.3 Test facility for cables (FRESCA), reference [2]

It consists of an outer cryostat containing a superconducting dipole magnet and an inner cryostat housing the samples, which penetrates through the bore of the magnet. This construction permits to change samples while keeping the magnet cold. The facility is used to measure the critical current of whole cable samples. The daily cycle is shown in Figure 3.

The outer cryostat is composed of 2 baths of liquid helium separated by a so-called lambda-plate. The upper bath is a saturated bath of helium at 4.3 K. The lower bath is a sub-cooled helium bath at 1.9 K and 0.11 MPa. Due to the large cold mass of the magnet (4800 kg) this cryostat is kept cold during the complete period of tests (up to 10 months). In a typical testing cycle, the lower bath is cooled down at 1.9 K, then the current (13 kA) is established into the magnet. When the test on the cable is finished, the current is ramped down, then the pumping valve is closed. The temperature of bath increases slowly from

1.9 to 2.3 K during a night. The 16 kA current leads use 0.6 to 1.2 $g.s^{-1}$ of He, depending on the current. Static thermal losses of this cryostat give a gaseous helium flow of 0.35 $g.s^{-1}$.

The inner cryostat is composed of 2 baths of liquid helium separated by a lambda-plate. The upper bath is a saturated bath of helium at 4.3 K. The lower bath is a sub-cooled helium bath at 1.9 K and 0.11 MPa. During a typical testing cycle, the sample holder is installed, then the cryostat is cooled down in 4 hours and filled with saturated helium at 4.3 K. The mass flow consumed for cooling down and warming up is 4 $g.s^{-1}$. A cycle of measurement is done at 4.3 K, then the lower bath heat exchanger is pumped down to reach 1.9 K, to perform a second cycle of measurement. Cool-down from 4.3 K to 1.9 K takes 2 hours. The pumping mass flow during this phase reaches 1.0 $g.s^{-1}$. Warming up to 300 K takes approximately 4 hours. The sample is powered via a pair of 32 kA current leads. Each current lead uses 1.0 to 1.5 $g.s^{-1}$ depending on the current value. Static thermal losses of the inner cryostat give a gaseous helium flow of 0.4 $g.s^{-1}$.

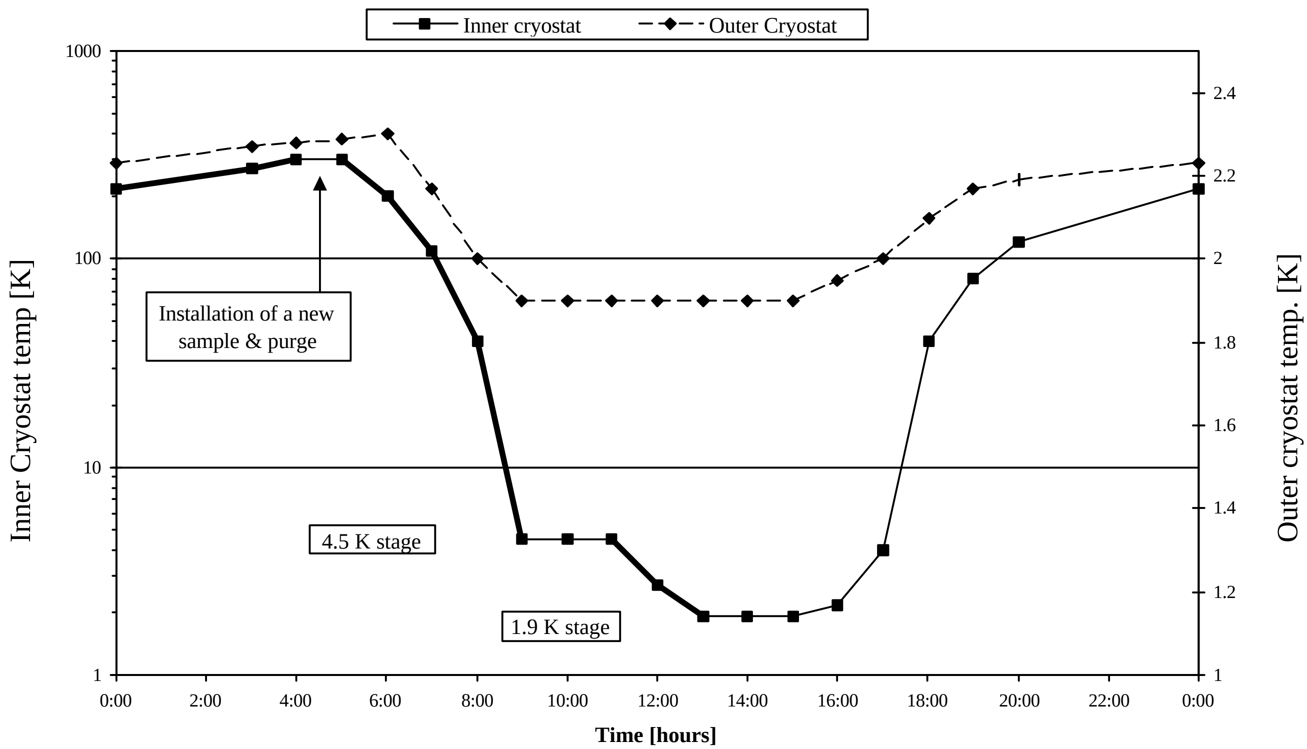

Figure 3 Typical thermal cycle for FRESCA, 24 hours

3 CONCLUSION

The cryogenic installation has been operating continuously for 8 months. During this period, no major interruption was recorded due to failure of the cryogenic facilities or the control system.

With the implementation of the new cryogenic facilities for reception tests, the rate of testing superconducting wires and cables at 1.9 K has drastically increased at CERN. This new facility can process automatically roughly 1500 different tests-cycles each year. Such a rate will allow performing acceptance test according to the schedule foreseen for the LHC project.

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