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**Cryogenic Benches for Superfluid Helium Testing
of Full-Scale Prototype Superconducting Magnets
for the CERN LHC Project**

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The Large Hadron Collider (LHC) project at CERN will make massive use of high-field superconducting magnets, operating below 1.9 K in pressurized superfluid helium. Reception testing of these magnets requires dedicated cryogenic facilities, consisting of an array of single-magnet test benches fed from a common large-capacity refrigeration system. Following installation and commissioning of general cryogenic infrastructure, we have designed and constructed two such cryogenic benches, and are operating the first one for tests of 10-m long LHC prototype dipole cryomagnets supplied by European industry. We describe system architecture, cryogenic process and constructional features of these benches in the following, and report on test results in a companion paper.

INTRODUCTION

The main magnetic system of the Large Hadron Collider (LHC) project at CERN will consist of about 1300 twin-aperture, high-field superconducting dipoles and 400 twin-aperture, high-gradient superconducting quadrupoles, operating in pressurized superfluid helium below 1.9 K [1,2]. These magnets, together with their cryostats, will be series-produced by European industry and delivered to CERN for reception testing prior to installation. Reception tests include complex procedures such as controlled cooldown and warmup, powering to nominal current and possible training, magnetic measurements in the apertures, leaktightness and thermal checks of the cryostat. Although starting to operate on a few prototypes, the test station must ultimately handle the series magnet delivery rates, with minimum use of resources in manpower, equipment and utilities. These conflicting requirements guided the design of the cryogenic system and magnet test benches, described in the following.

SYSTEM ARCHITECTURE

The basic idea is to compromise between modularity, which preserves operational flexibility of each test bench and expandability of the system, and sharing of common, powerful resources, which allows to benefit from economy of scale and redundancy. The LHC magnet test station, eventually composed of some 20 benches, will be installed in a 7200 m² floor-space hall, where we have installed and are operating a cryogenic infrastructure [3] providing large refrigeration capacity at 80 K (50 000-litre liquid nitrogen storage), 4.5 K (6 kW helium refrigerator) and 1.8 K (6 g/s @ 1 kPa helium pumping unit WPU, being upgraded to 18 g/s). In view of the operating schedule and relative duration of the different phases of a magnet test, the test benches are grouped in clusters of four, each served by a 120 kW cooldown and warmup unit (CWU) and a 17 kA electrical power supply. Two adjacent clusters (i.e. eight benches) are connected to a branch of the liquid nitrogen distribution, very low-pressure helium and quench recovery networks, as well as to a liquid helium feed box (LFB), where the liquid transferred from the main 25 000-litre storage is decanted. Thus only basic, local cryogenic functions are performed in each bench. The architecture of the system is schematized in figure 1.

The magnet under test rests on a long, rigid beam, which also supports and aligns the long shaft and rotating coil of the magnetic measurement system [4]. Cryogenic and electrical feed is done through a magnet feed box (MFB), connected to one end of the magnet, while a magnet return box (MRB) closes the opposite end. Since the magnetic measurement equipment only operates at ambient temperature, the magnet apertures are equipped with warm bore inserts [5], which significantly increase the heat load on the superfluid helium bath. The general flow-scheme and overall view of the first bench appear in figures 2 and 3, respectively.

The cryogenic process of the bench, inspired from the CEN-Saclay test station [6], is such as to create adequate operating conditions for the cryomagnet under test, while keeping to a minimum the required connections to the cryogenic pipework. As a consequence, the cryostat will not function on the test bench exactly as it is designed to operate in the LHC. In particular, the helium II heat exchanger tube, which acts as a distributed heat sink in the LHC magnet cooling scheme, is not used here. Instead, the heat load to the superfluid helium bath is transported by conduction along the magnet length, at the cost of a 0.1 K temperature gradient, to a lumped cold source inside the MFB, with a nominal capacity of 50 W at 1.8 K. This source consists of a hollow-finger heat exchanger, made of DHP copper with a developed area of 1 m², fed with liquid helium drawn from the bottom of the 4.5 K bath and later subcooled in a copper mesh heat exchanger before Joule-Thomson expansion to saturation at 1.35 kPa. The low saturation pressure on the source is controlled by a cold DN50 valve on the local branch of the VLP line to the WPU. The 4.5 K saturated helium bath, which intercepts residual heat at the lower end of the 18 kA vapour-cooled current leads, is thermally and hydraulically separated from the pressurized helium II enclosure by two small-diameter "lambda plates", made of an epoxy-glass composite, which allow feedthrough of the superconducting current bus and instrumentation wiring. An electro-pneumatically actuated, spring-relieved "respirator" valve located at the bottom of the 4.5 K bath allows liquid filling and pressure compensation of the pressurized helium II enclosure upon density changes between 4.5 and 1.8 K. Emergency pressure relief and helium discharge after a resistive transition is performed through a DN50 electro-pneumatically-actuated, industrial-type, cold valve, with an opening time of 120 ms, discharging into the 4.5 K vessel where the two-phase mixture is finally decanted. In order to limit helium loss to the recovery line and gas bags, the 4.5 K vessel has an ullage volume of 300 litres and is protected by a discharge valve opening at 0.19 MPa. Ultimate protection of the pressurized helium enclosure, which has a design pressure of 2 MPa, relies on a DN50 nickel rupture disc, operating at 1.8 K and connected to an evacuated pipe discharging to atmosphere.

INSTRUMENTATION AND PROCESS CONTROL

The bench is comprehensively instrumented with cold sensors for measuring temperatures (thin film platinum and carbon resistors), pressures (Siemens KPY and Validyne sensors) and levels (superconducting wire gauges), to allow monitoring and control of the cryogenic process. In addition, several phases of operation, such as controlled cooldown and warmup, make use of signals from sensors mounted on the cryomagnet under test. The quench discharge line is equipped with a cryogenic flow indicator using a Pitot tube located on the axis of the pipe. The discharge valve, which opens on pressure rise, quench trigger or utility failure, features a linear displacement transducer to monitor the travel of the stem.

All benches and main components of the cryogenic system are controlled by embedded industrial-type programmable logic controllers, supervised by a central, workstation-based supervision package through a standard communication network. This flexible, powerful system has permitted gradual commissioning of the different components and swift startup of operation.

TESTING AND OPERATION

The first cryogenic bench has started to operate for tests of the first industry-made, 10-m long prototype superconducting dipole, in the spring of 1994. Results are presented in a companion paper [7].

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Figure 1 Architecture of the cryogenic test station

Figure 2 Process flow-scheme of cryogenic test bench

Figure 3 Overall view of cryogenic test bench