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CRYOGENIC INFRASTRUCTURE FOR SUPERFLUID HELIUM TESTING OF LHC PROTOTYPE SUPERCONDUCTING MAGNETS

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ABSTRACT

The Large Hadron Collider (LHC) project at CERN will require about 1800 high-field superconducting magnets, operating below 1.9 K in pressurized helium II. All magnets will be reception-tested before their installation in the 26.7 km circumference ring tunnel. For this purpose, we have installed large-capacity cryogenic facilities, beginning to operate for tests of full-scale prototype magnets produced by European industry. Based around a 6 kW@4.5 K helium refrigerator and a 25 m^3 liquid helium storage, the system includes a low-pressure, 6 to 18 g/s helium pumping unit for 1.8 K refrigeration, a set of magnet cooldown and warmup units delivering each up to 120 kW of refrigeration at precisely controlled temperature, and a network of cryogenic lines for transferring liquid nitrogen, liquid helium and cold gaseous helium. All components are controlled by embedded PLCs, connected to a general supervision system for operator interface. We present the system layout and describe the design and performance of the main components.

INTRODUCTION

CERN, the European Laboratory for Particle Physics, is conducting development and preparatory work in view of its next major research facility, the Large Hadron Collider (LHC). This machine[1], to be installed in the existing 26.7 km ring tunnel of the LEP collider, will accelerate and bring into collision intense, counter-rotating beams of high-energy protons and ions, thus enabling to probe the fine structure of matter on an unprecedentedly attained small scale. On the technological side, the project will require about 1800 high-field, twin-aperture superconducting magnets[2], operating in pressurized superfluid helium[3] at a temperature below 1.9 K. All magnets, to be produced by industry over a period of four to five years, will be reception-tested and measured at CERN before installation in the tunnel and connection to the LHC ring. Fulfilling this program will require the construction and operation of a dedicated multi-magnet test facility, with up to twenty benches eventually running in parallel, served by a large-capacity cryogenic system supplying refrigeration down to the 1.8 K level. A fully operational subset of this system has been designed, installed and is beginning to operate for tests of prototype LHC magnets. It will also serve the LHC test string, a full-scale working model of a 100-m long stretch of machine elements, presently under construction. Modularity in design and capacity upgrade will permit future expansion in order to match the onset and gradual startup of preseries and series magnet production.

SYSTEM LAYOUT

In view of the emerging requirements for series testing of superconducting acceleration cavities[4] and magnets at CERN in the early nineties, a 7200 m^2 floor-space hall, formerly devoted to LEP construction, has been converted into a large cryogenic test area, the overall layout of which appears in Figure 1. The basic building block is a 6 kW@4.5 K helium refrigerator[5], coupled to a 25 m^3 liquid helium storage serving the variety of users. Ancillaries include gaseous helium storage at 20 MPa and 2 MPa, 450 m^3 of gas bags for helium recovery, and two 100 m^3/h NTP off-line cryogenic purifiers operating at 20 MPa.

Since LHC magnet tests will require a mix of refrigeration duties at several levels of temperature, with strong time variations due to thermal transients ranging from cooldown and warmup to resistive transitions ("quenches"), maximum decoupling is required between the cryogenic plant and the users. This is achieved by operating mostly in liquefier mode, i.e. withdrawing liquid helium at 4.5 K as needed from the storage vessel, and returning the gas at ambient temperature to the suction side of the compressors. Very low-loss, vapour-shielded cryogenic lines of proven design[6] permanently transfer saturated helium across distances of up to 90 m, from the storage vessel to local distribution boxes where the liquid is decanted and fed to the local cluster of magnet test benches.

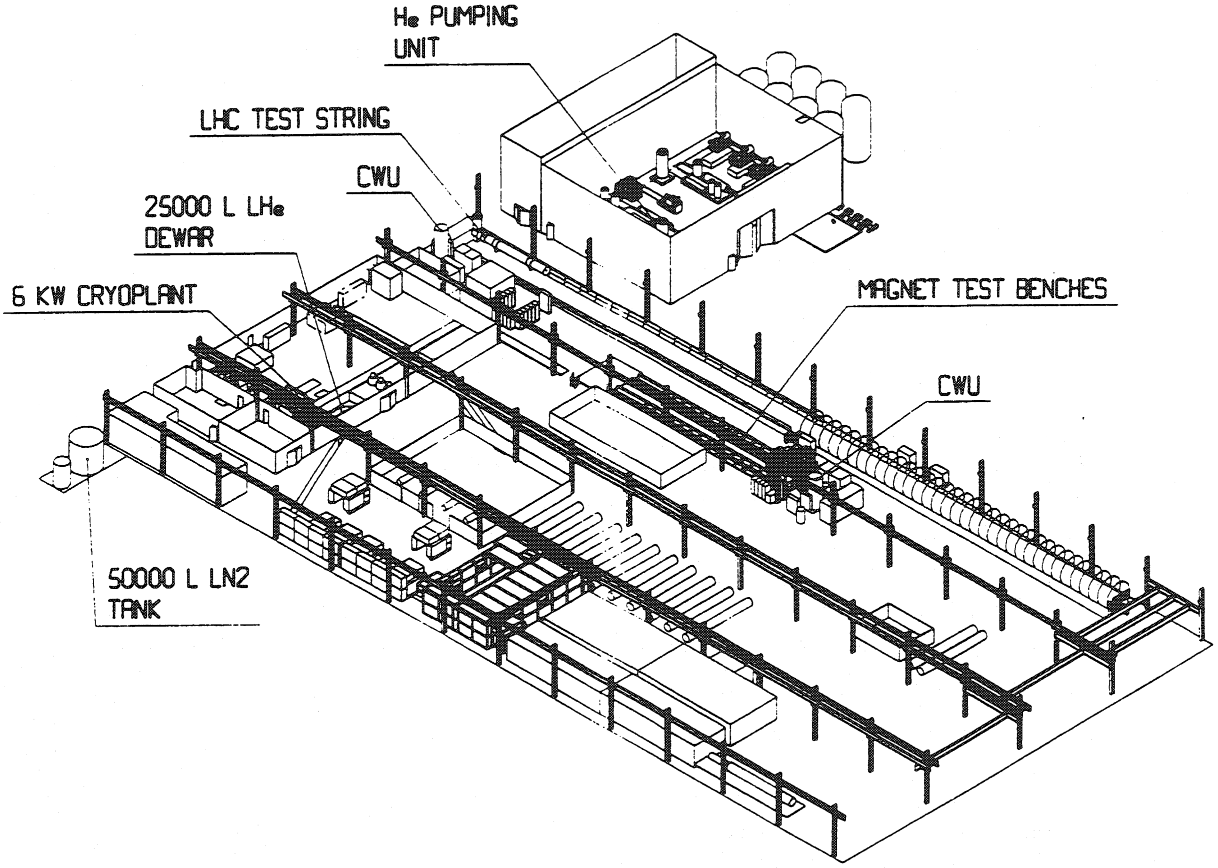

Figure 1. General layout of cryogenic facilities in test hall.

Although not normally required by the refrigeration cycle of the cryogenic plant, liquid nitrogen is heavily used as a large-power, readily available source of refrigeration for magnet cooldown and thermal shielding in steady operation. A 50 m^3 liquid nitrogen storage and a network of distribution lines make this utility widely available in the test hall.

LOW-PRESSURE HELIUM PUMPING UNIT

The heat deposited or generated in the superconducting magnets under test at 1.9 K will be transported by conduction in the pressurized helium II to cold sources in the test benches, where it will be absorbed quasi-isothermally by vaporization of saturated helium II. The saturation pressure on the 1.8 K baths is maintained by means of a low-pressure pumping unit operating at ambient temperature, with a specified capacity of 6 g/s at 1 kPa, thus allowing for head loss in the piping and gaseous helium heater. Following an initial survey of the available technologies, CERN issued a call for tenders based on a functional specification, leaving open the choice of the pumping system and machinery, and including the possibility of upgrade to 18 g/s at 3 kPa by adding a later stage of precompression. Other requirements included capacity adjustment over a range of 3 to 1, non-contamination of process helium and fully automatic operation.

The most economical solution was based on a combination of three stages of Roots blowers, backed by one stage of large rotary-vane pumps (Figures 2 and 3). The nominal working points of the different stages appear in Table 1. The low pressure ratio across the Roots blowers yields high volumetric efficiency and thus contributes to limit the size of the machinery, while the quasi-constant volumetric flow-rate characteristic of the rotary-vane pumps in the 10 kPa range enables them to adapt the interstage pressure in all working conditions.

Fine capacity adjustment is achieved by means of a variable impedance bypassing only the three stages of dry Roots blowers, and thus preventing any risk of oil backstreaming to the suction side. The full dynamic range is obtained by powering only selected machines in proper sequence, letting the others freewheeling. Detailed tests have permitted to measure the effective capacity and dynamic range of the pumping unit (Figure 4), which meet the specified requirements.

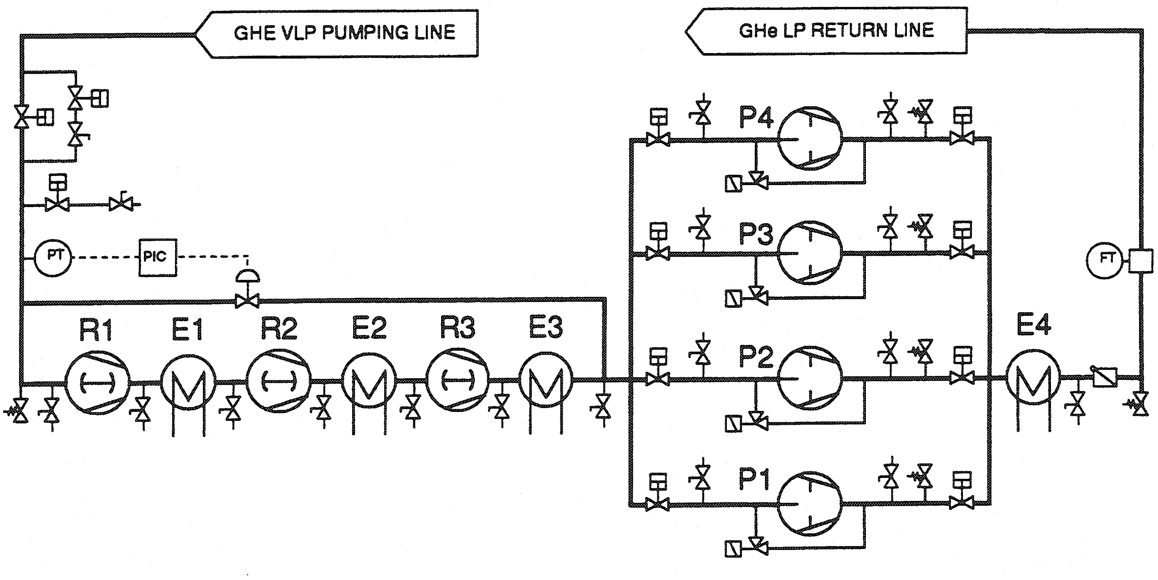

Figure 2. Simplified flow-scheme of the low-pressure helium pumping unit.

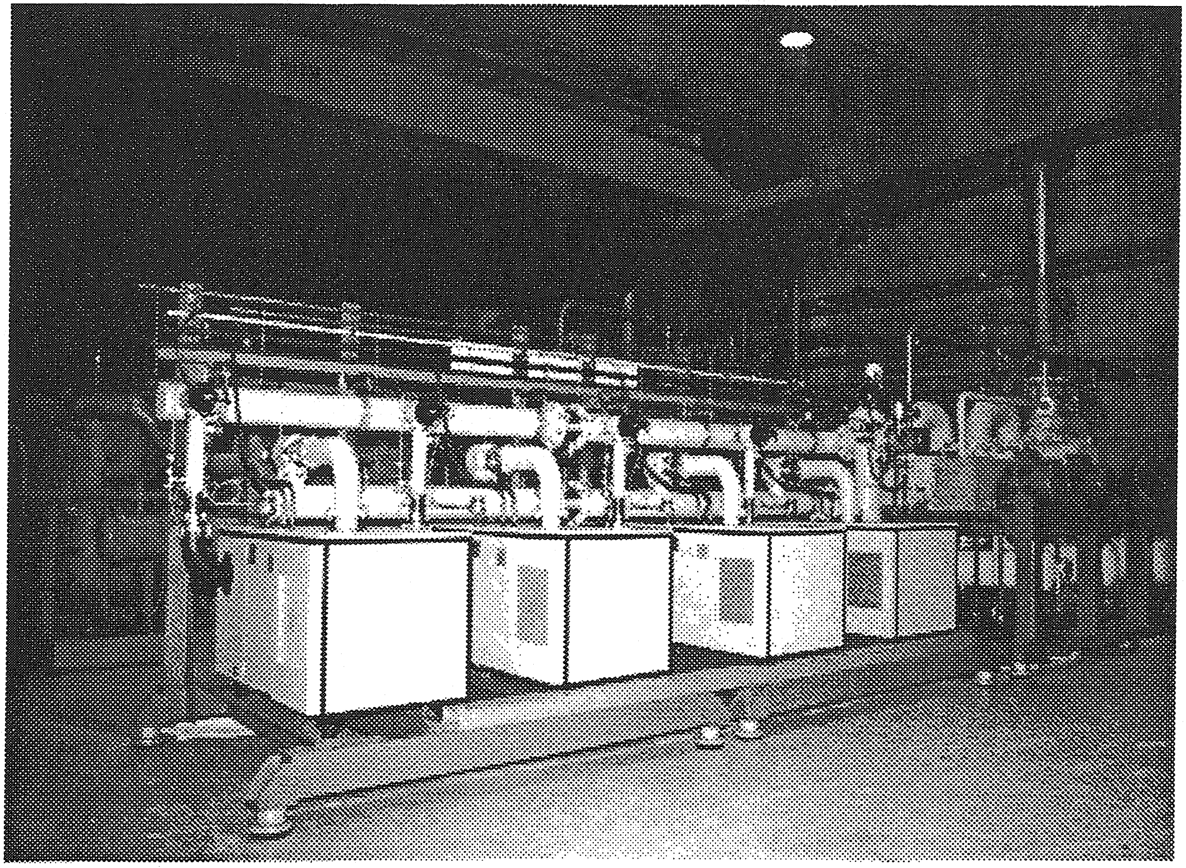

Figure 3. General view of the low-pressure helium pumping unit

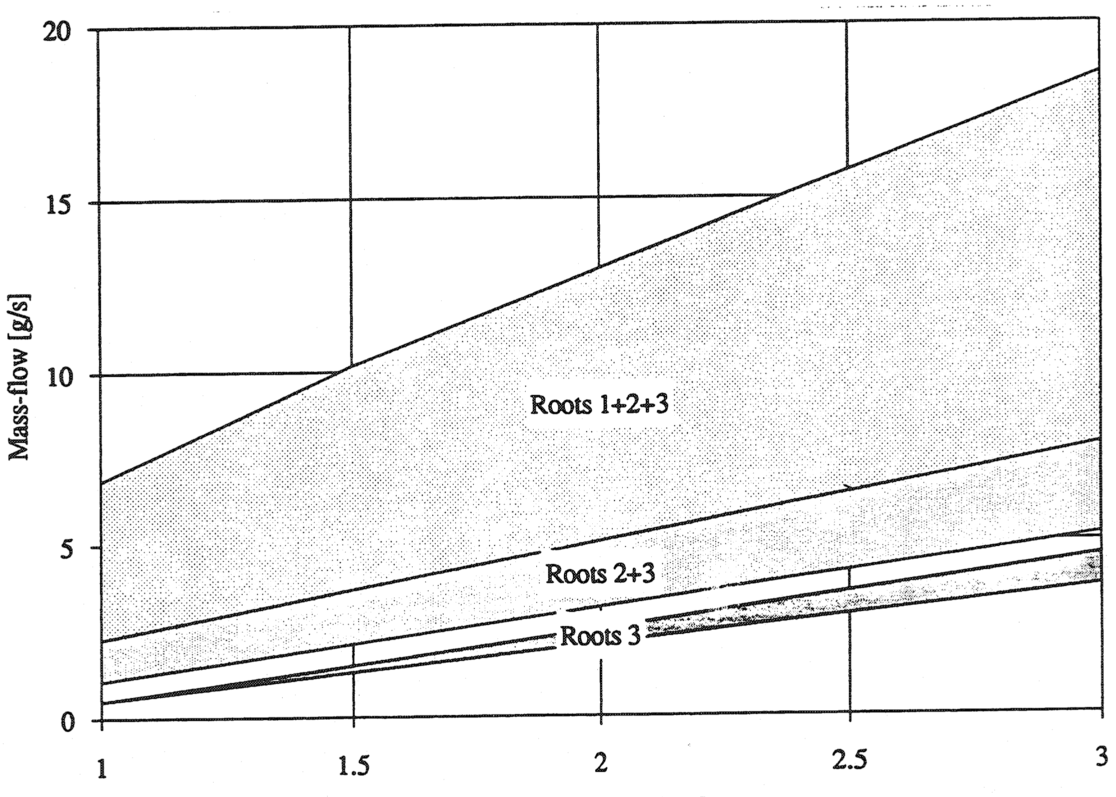

Figure 4. Measured working range of the low-pressure helium pumping unit.

Table 1. Nominal working points of the low-pressure helium pumping unit.

Mass flow-rate [g/s]	6	18
1st-stage Roots inlet pressure [kPa]	1.0	3.0
2nd-stage Roots inlet pressure [kPa]	1.9	5.7
3rd-stage Roots inlet pressure [kPa]	3.2	9.1
Rotary-vane pump inlet pressure [kPa]	5.9	15.5
Rotary-vane pump outlet pressure [kPa]	120	120

MAGNET COOLDOWN AND WARMUP UNITS

Magnet test bench occupancy will be largely determined by non-productive phases such as cooldown and warmup, which must therefore be kept minimum. Precooling a prototype dipole with a 17,000 kg cold mass down to 90 K in about 12 hours requires the extraction of up to 120 kW of heat at varying temperature, while thermal gradient limitations in the magnet structure impose moderate temperature difference and thus high flow-rate of gaseous helium. The latter can be tapped from the high-pressure side of the compressor station, but the required cooling power largely exceeds the capacity of the helium refrigerator, and therefore must be produced by vaporization of liquid nitrogen.

This is the basic function of the magnet cooldown and warmup units (CWU), operating on an economizer LN2/GHe cycle and built around a three-pass flat-plate heat exchanger (Figure 5). Thanks to a set of internal bypass, mixing and distribution valves, each CWU can circulate a flow-rate of up to 100 g/s gaseous helium at a precisely controlled temperature through any of the four magnet test benches in the cluster it serves. An internal buffer vessel of 0.31 m^3 capacity acts as a liquid nitrogen decanter and provides an autonomy of 15 minutes at full power in case of transfer interruption. Magnet warmup is achieved by means of an internal 25 kW heater located on the low-pressure side of the heat exchange line. All components are mounted in a vacuum-insulated coldbox, connected to the main utilities (Figure 6).

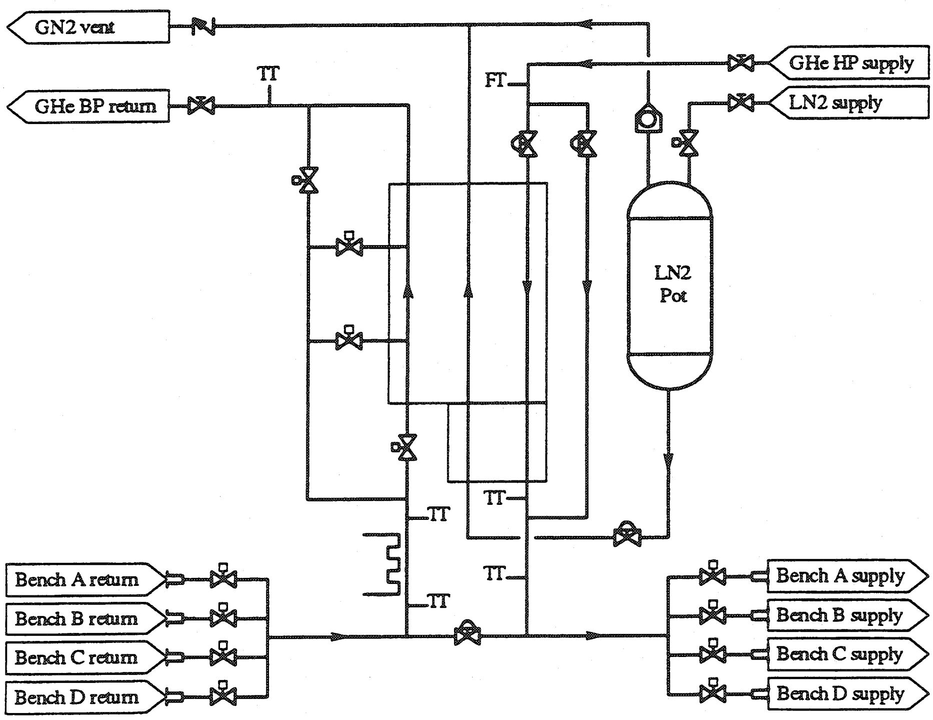

Figure 5. Simplified flow-scheme of the magnet cooldown and warmup unit.

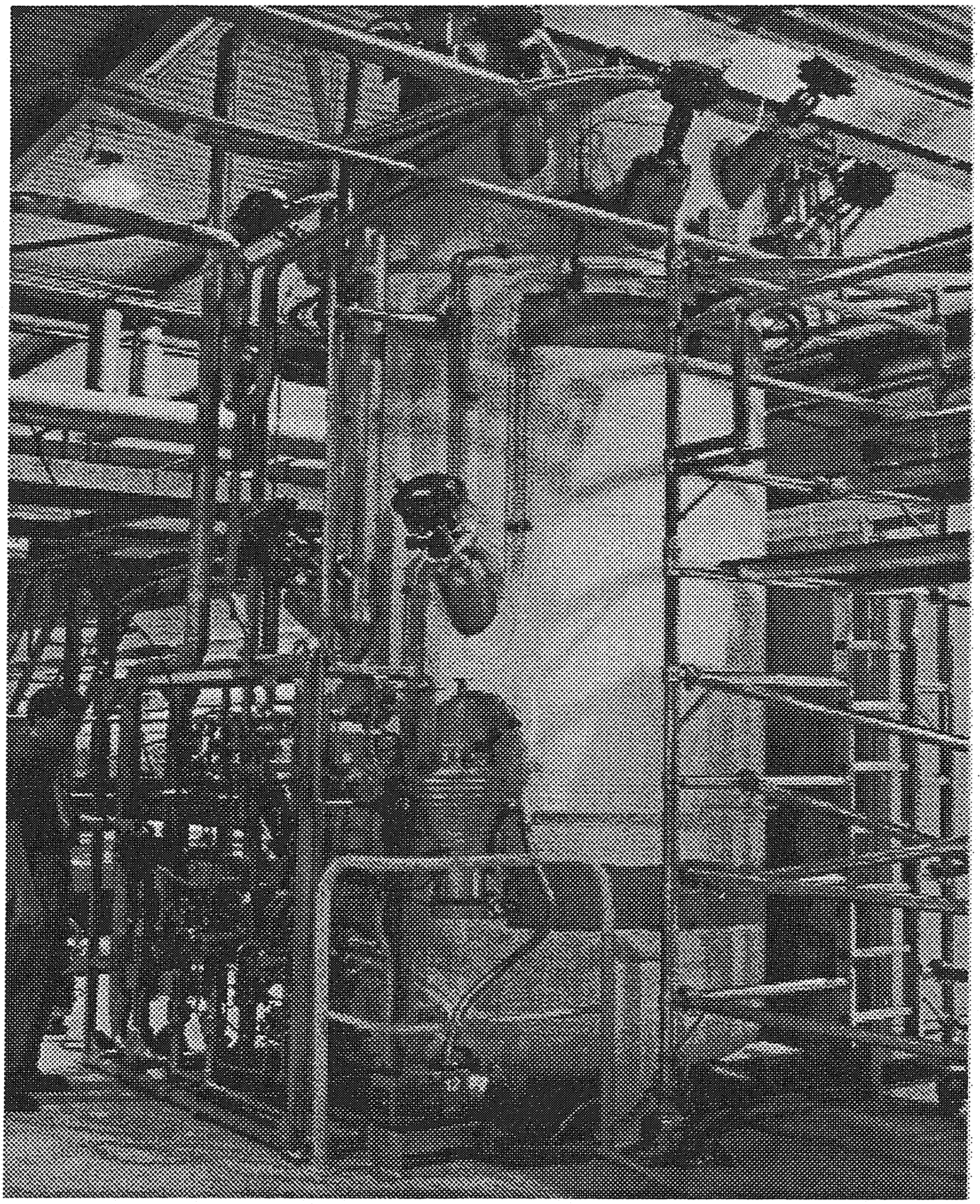

Figure 6. General view of the magnet cooldown and warmup unit.

CONTROL AND SUPERVISION

Early in the project, it was decided to control all the equipment of the cryogenic infrastructure using commercially available industrial control system components. This decision was applied at all three levels of process control, communications and supervision system, as illustrated in Figure 7.

The specifications for the major components included the requirement that industrial PLCs be included and their programming be part of the supply. The data structures for the exchange of information between operator and equipment were specified and agreed with the suppliers. As the usage of a particular brand of PLC was recommended, a plant network of the same brand was installed in the building hosting the cryogenic infrastructure. The applications for the supervision of the equipment were designed and developed in house using a workstation-based industrial supervision package.

Since the various levels of control are based on known and proven technology, their integration turned out to be an easy and straightforward process. The running-in of the supervision applications proceeds smoothly and matches the running-in of the equipment under control, while helping with its commissioning.

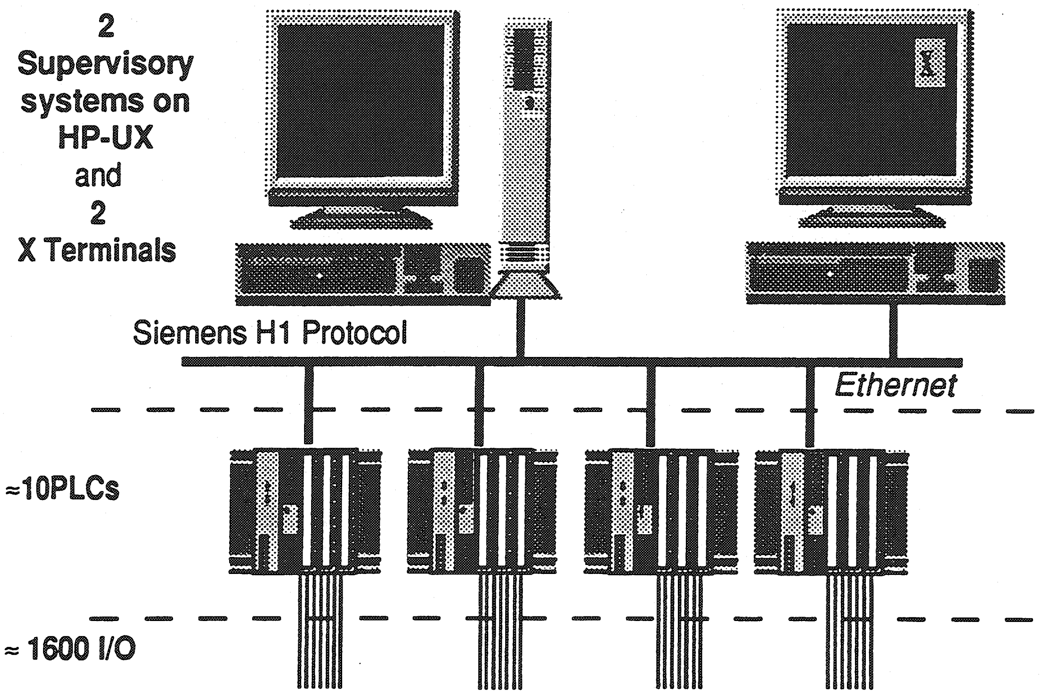

Figure 7. Architecture of the control and supervision system.

SYSTEM DEVELOPMENT AND UPGRADE

The present configuration of equipment is suitable for operating sequentially a cluster of up to four magnet test benches, as well as for running the LHC test string. Since all components on the low-pressure circuits have been sized for a maximum flow-rate of 18 g/s, the refrigeration capacity at 1.8 K, which presently exceeds 120 W, can be tripled by addition of a precompression stage using a cryogenic centrifugal compressor discharging at 3 kPa. Cryogen distribution equipment and magnet cooldown and warmup units will be added as required to serve other clusters of magnet test benches. Modular control and supervision systems will follow the expansion of the cryogenic infrastructure for magnet tests.

ACKNOWLEDGEMENTS

Most of the equipment described here was supplied by industry, in particular Air Liquide, France (helium refrigerator and CWUs), Linde, Germany (purifiers), Ruzchimmasch, Russia (gaseous helium storage), Alcatel Kabelmetal, Germany (liquid helium transfer lines), Leybold, Germany (low-pressure helium pumping unit), Demont, Italy (helium pipework), Siemens, Germany (PLCs), USData, USA (supervision package). The swift startup and commissioning of the system is a measure of the quality of their work, as well as of the dedication of many colleagues from these firms and from CERN.

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