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DESIGN, TEST AND PERFORMANCE OF THE LIQUID HELIUM CRYOSTATS FOR THE LEP SUPERCONDUCTING QUADRUPOLE MAGNETS

by

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The experimental areas of LEP, the high-energy electron-positron collider presently under construction at CERN, will be equipped with eight superconducting quadrupole magnets, housed in liquid helium cryostats embedded in the complex detector set-ups. To comply with transverse space restrictions, the 2.5 m-long slender cryostats feature a 130 mm diameter warm bore and a horizontally-oriented service funnel at one end, equipped with 2000 A current leads. The cryostats have been designed by CERN, manufactured and assembled by industry, and tested in the laboratory. Besides design principles and constructional features, results of tests and comparative performance data are presented.

INTRODUCTION

CERN, the European Laboratory for Particle Physics, is presently constructing a large electron-positron collider called LEP, housed in an annular underground tunnel of 26.7 km in circumference, on a 1.4% sloping plane [1]. Four large physics experiments are installed in underground caverns at the collision points of the counter-rotating particle beams; the interaction rate is enhanced by the use of strong focusing superconducting quadrupole magnets on either side of these points. The quadrupoles, housed in individual cryostats, are embedded into the experimental detectors, which imposes unusual design constraints [2]. Following good experience with a prototype [3], the eight series CERN-designed cryomagnets have been manufactured by industry and tested in the laboratory.

DESIGN AND CONSTRUCTION

The superconducting quadrupole magnets are cooled by saturated boiling helium at 4.3 K. The boil-off vapour is used to intercept heat inleaks to the helium bath by cooling the 2000 A current leads [4], the cryostat screen and service funnel housing all cryogenic and electrical connections to the magnet. As a consequence, no liquid nitrogen is used, and all boil-off helium is eventually recovered at ambient temperature, two simplifications of importance in view of the deep underground implantation and remoteness from refrigeration plants of the cryomagnets. In order to minimize geometric and magnetic interference with the experimental set-ups, the magnets are slender and ironless; as regards the cryostat, this constraint imposes a compact radial insulation system and a horizontally-oriented service funnel. Moreover, as LEP is a non-superconducting accelerator with the beam pipe at ambient temperature, the cryostats feature an insulated warm bore.

A transverse cross-section of the cryomagnet appears in Fig. 1, while Fig. 2 shows a completed unit under test. The magnet, enclosed in its helium vessel, is suspended by low-conduction supports from the reinforced vacuum vessel. In the evacuated space between the helium and vacuum vessels, thermal insulation is achieved by the use of a superinsulated vapour-cooled screen. As the space available around the warm bore is limited, only superinsulation is used there.

The mechanical design is such that all vessels can withstand the pressures occurring in the different modes encountered in the course of assembly, testing and operation of the cryomagnets. It also permits their sequential assembly around the magnet, allowing easy testing and repair of welded joints while still accessible.

The **helium vessel** consists of a corrugated cylindrical shell, closed by flat end covers, and by a cold bore tube inside the magnet aperture. The inner tube of the service funnel protrudes from the vessel at one end. The design pressure is 0.4 MPa (4 bar) and the helium enclosure is entirely welded. The **heat screen** is a double-walled pressure-formed cylindrical shell, incorporating a cooling circuit and conduction-cooled end-plates. The screen is wrapped with 30 layers of aluminized Mylar [5] **superinsulation.** Superinsulation is also used around the warm bore, but consists there of 45 layers of aluminized Kapton [5], in order to withstand the combined effects of ionizing radiation and heating during the 150 °C bakeout of the beam pipe [6]. The **vacuum enclosure** consists of three sections assembled by bolted flanges with elastomer O-ring seals. The central section concentrates all structural functions and alignment references on two precision-machined reinforcement rings. The magnet, which has a mass of 1050 kg, is suspended, via short axles at its quarter points, by **tension rods** to the reinforcement rings. In order to preserve alignment when the cryomagnet is tilted, the top axles are held in position with respect to the vacuum vessel by **pretensioned wires. A horizontal column** at the connections end fixes the longitudinal position of the magnet. For transportation, the "cold" assembly is supported by a set of withdrawable **blocking devices,** calculated to withstand accelerations of up to 2 g.

The basic material used for the cryostats is AISI 304L austenitic stainless steel. The cold bore is a centrifugally-cast AISI 304LN tube, while the warm bore tube is made of AISI 316LN steel: this guarantees a magnetic permeability of less than 1.025 under operating conditions. INCONEL 718 is used for the main suspension rods, and the longitudinal positioning column is made of glass-fibre epoxy composite.

It was not possible to take full advantage of thermal stratification for insulation of the horizontal **service funnel.** In order to (i) limit heat inleak to the helium bath and (ii) avoid excessive cooling of the terminal flange, which could result in condensation or icing, the final layout shown in Fig. 3 is used. This relies on a succession of low-emissivity baffles equipped with flexible Teflon [5] skirts at their periphery, and an insulating plug of epoxy-based foam [7]. The number and staging of the baffles and the routing of services inside the funnel, were optimized on a full-scale instrumented model, and checked on the prototype. The test revealed the heat penalty on the bath to be acceptable; of more concern however was the slight cooling of the terminal flange, which was coped for by careful adjustment of the baffles and installation of a small electrical heater onto the flange.

The breakdown of **heat inleaks** to the helium bath appears in the table below: the biggest single source of heat inleak is the current leads, while the horizontal service funnel brings an additional penalty of about 3.5 W.

BREAKDOWN OF ESTIMATED CRYOSTAT HEAT INLEAKS (W)		
Radiation from heat screen	0.3	calculated
Warm bore superinsulation	1.9	calculated
Conducting along supports	1.3	calculated
Service funnel with current leads		
- at zero current:	8.0 ± 0.5	measured on model
- at 2000 A:	10.5 ± 0.5	measured on model
Total: - at zero current:	11.5 ± 0.5	
- at 2000 A:	14.0 ± 0.5	

TESTS AND PERFORMANCE

After assembly and pressure tests, the cryostats had their insulation spaces evacuated and leak tested. All cryostats exhibit an overall internal leak-rate below 10^{-10} mbar l s^{-1} with liquid helium, and can be operated without external pumping, maintaining an insulation vacuum better than 10^{-6} mbar throughout pressure cycles induced by magnet quenches.

Heat inleaks to liquid helium have been evaluated by measuring the boil-off rate of the cryomagnets at different liquid levels, with and without liquid transfer, and at zero and endurance (1900 A) currents. Comparative results are presented in Fig. 4, showing reproducibility and agreement with estimated values. The efficiency of the vapour-cooled screen is illustrated in Fig. 5. It must be noted that the thermal time constant of the insulation system of the cryostat is about 20 hours, so that meaningful cryogenic performance measurements can only be performed after several days of operation.

Pressure release behaviour at quench was fully satisfactory. The quench relief device, a full-lift spring-loaded safety valve, set at 3 bar nominal, limited the pressure rise in the cryostat to 3.5 bar.

CONCLUSION

The eight cryomagnets have operated satisfactorily during reception tests. They are now being integrated into the LEP machine support structures prior to being installed in late 1988.

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The cryomagnets were constructed by Alsthom, Belfort (France) as main contractor. The cryostat vessels were subcontracted to Labeille, Pont-de-Claix (France), while Date, La Motte d'Aveillans (France) supplied the heat screens.

REFERENCES

1 LEP Design Report, vol. II, 'The LEP Main Ring', CERN-LEP/84-01, (1983).

2 Taylor, T.M. 'Technological aspects of the LEP low-beta insertions', IEEE Trans. Nucl. Sci., vol. NS-32, No. 5, (1985), pp. 3704-3706.

3 Lebrun, Ph., et al., 'Design, test and performance of the prototype superconducting quadrupole for the LEP low-beta insertions', Proc. MT-10, Boston (1987).

4 Blessing, H., et al., 'Modular thermostatic vapour-cooled current leads for cryogenic service', Adv. Cryo. Eng., vol. 29 (1984), pp. 199-206.

5 Mylar, Kapton and Teflon are registered trade marks of Du Pont de Nemours.

6 Burgess, W., and Lebrun, Ph., 'Compared performance of Kapton- and Mylar-based superinsulation', Proc. ICEC 10, Butterworth (1984), pp. 664-667.

7 ECCOFLOAT EF-38 by Emerson & Cuming, Westerlo (Belgium).

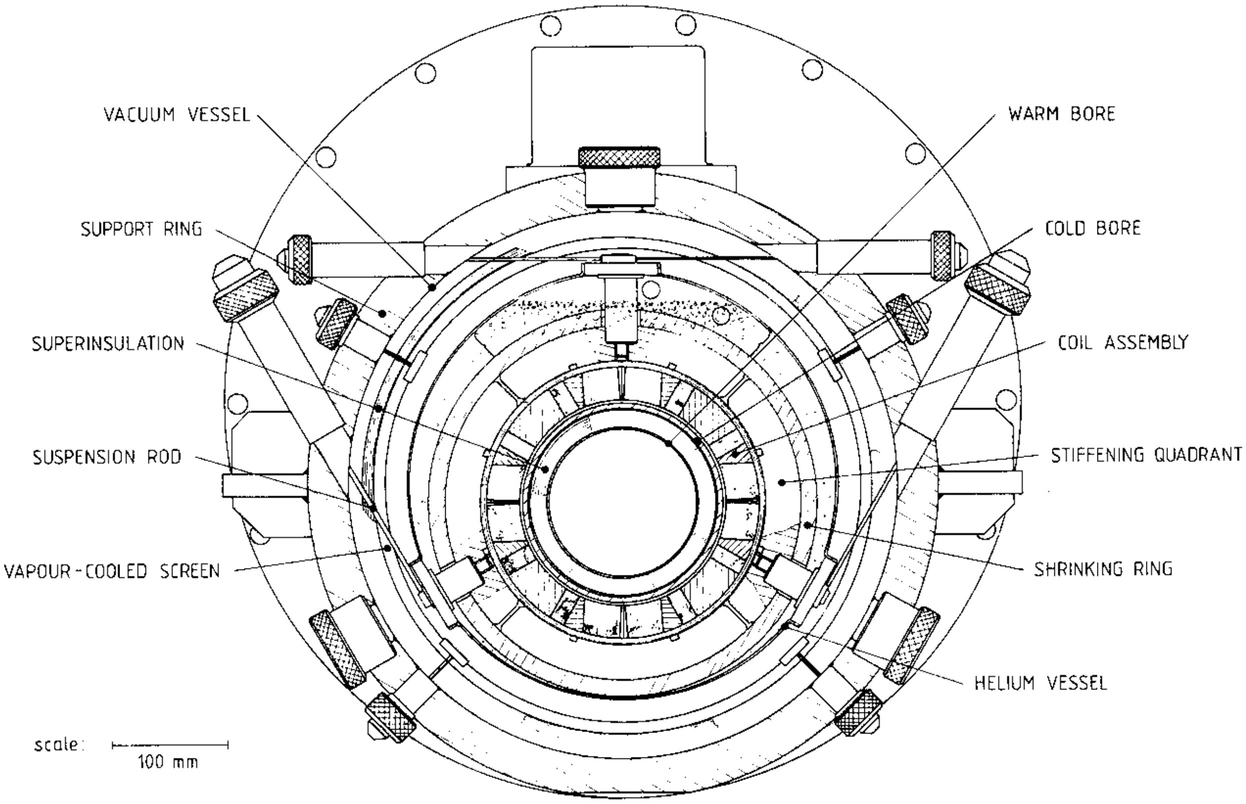

Fig. 1 Transverse cross-section of cryomagnet

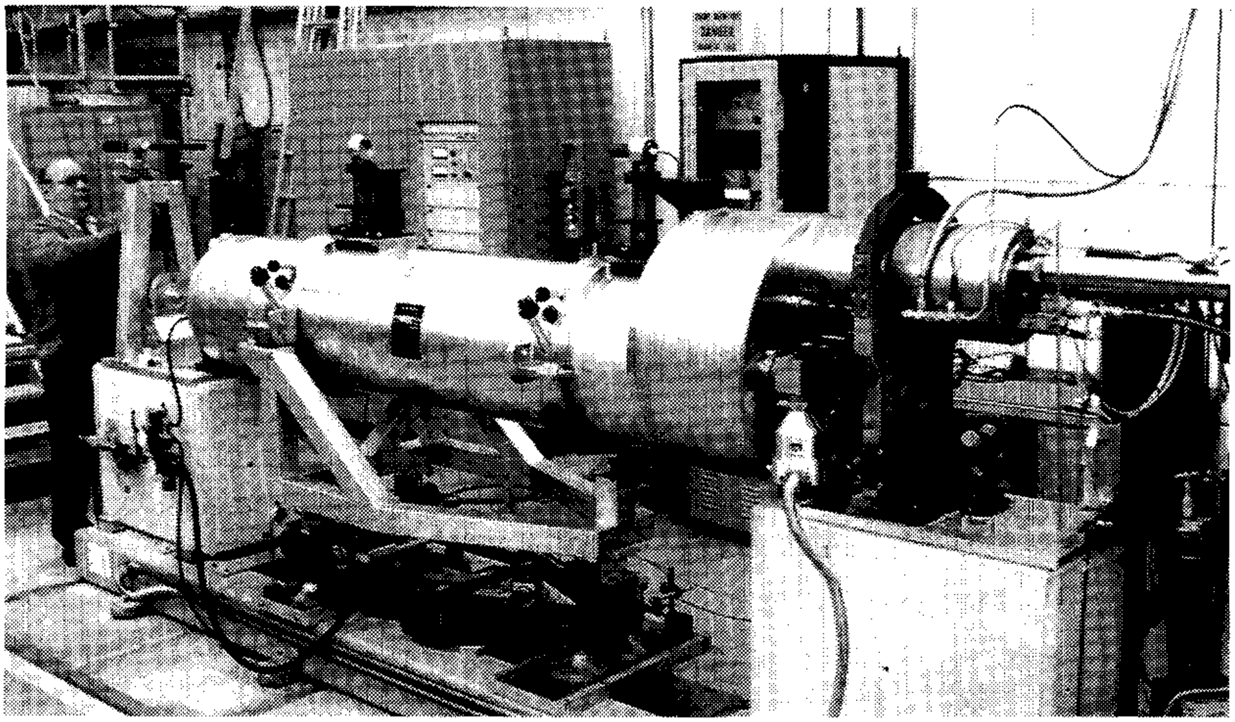

Fig. 2: Completed cryomagnet under test

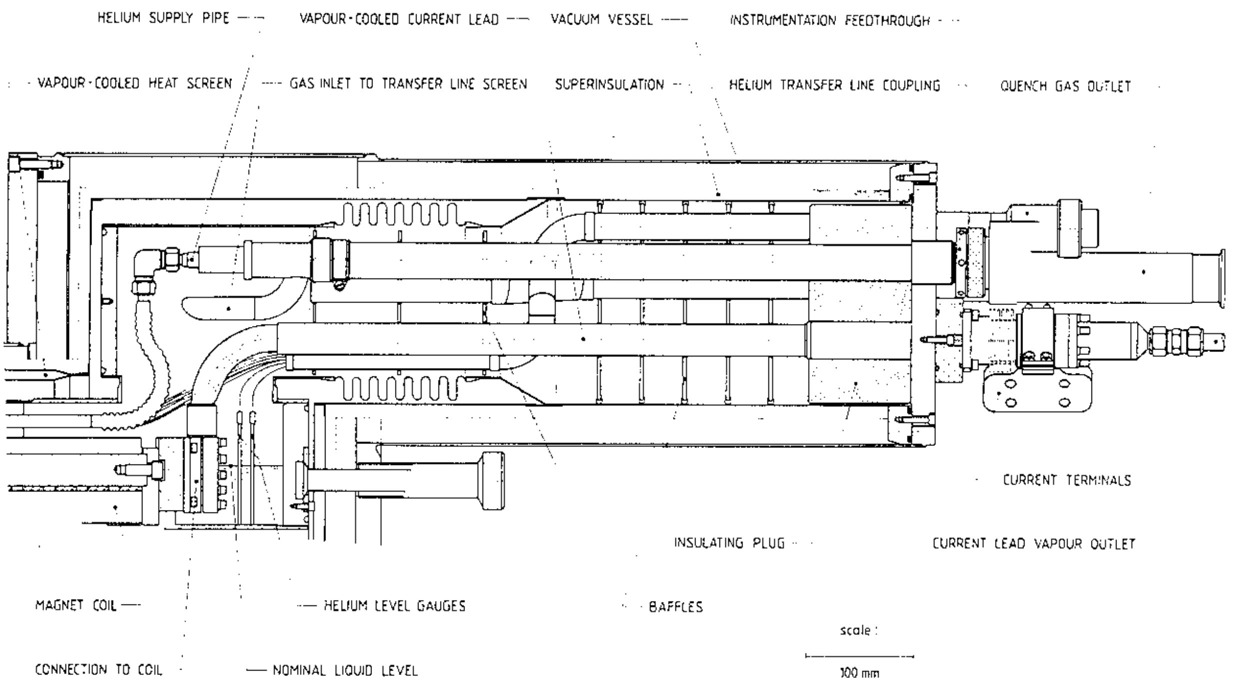

Fig. 3: Longitudinal cross-section of cryostat service funnel

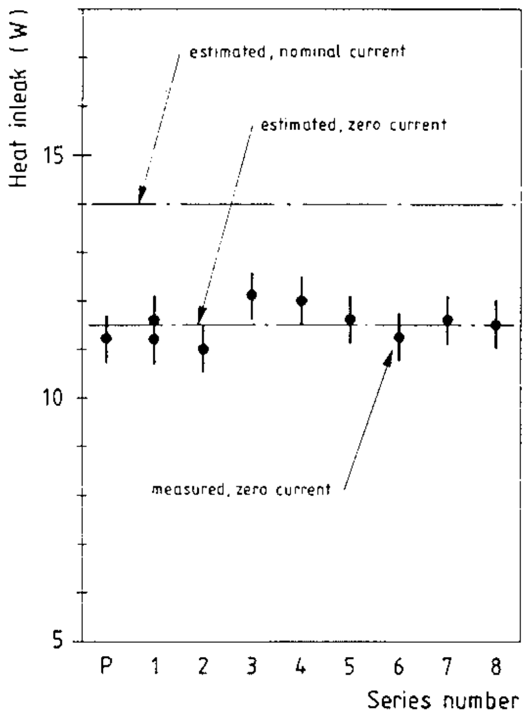

Fig. 4: Measured heat inleaks of series cryostats

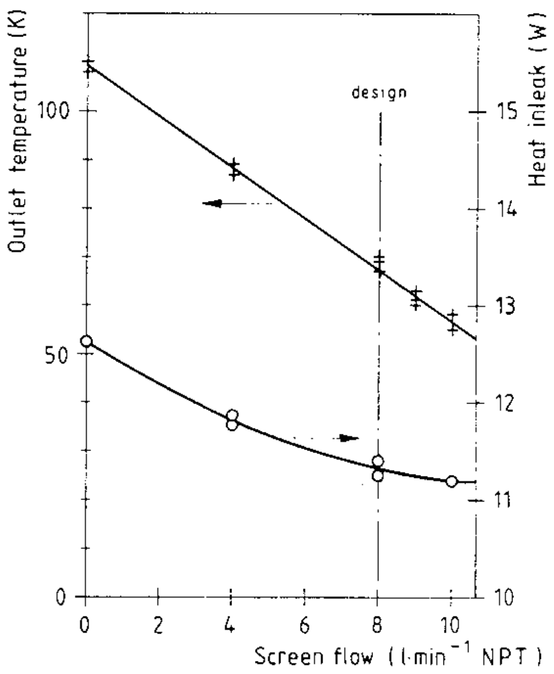

Fig. 5: Performance of cryostat heat screen