IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

TECHNOLOGICAL ASPECTS OF THE LEP LOW-BETA INSERTIONS

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Abstract

In order to obtain the highest luminosity at LEP, it is necessary to use superconducting quadrupoles for the final vertical focusing of the beams. The low-beta structure is such that these quadrupoles must be virtually integrated into the experiments, imposing severe constraints on their design. In particular, at LEP these magnets must be iron-free, occupy minimum space in the transverse direction, and be supported together with other beam- and experiment-related equipment on mobile cantilever girders. The constraints are analyzed, and the proposed system is described.

Introduction

Colliding beam machines create a special challenge for those responsible for the interface between machine and experiments. Difficulties accumulate with increasing energy, because the need for high luminosity increases, requiring high-performance low-beta insertions and inevitably pushing the final focus quadrupoles deeper into the experimental apparatus. The latter also tends to become bigger itself, in order to achieve the necessary mass resolution. Moreover, the complexity of the central detectors is such that it must be possible to make frequent access.

As seen by the users, a low-beta insertion should be designed to provide the experiment with the following:

i) maximum luminosity,

ii) minimum background,

iii) maximum free space,

iv) minimum coupling between fields of detector magnet and quadrupoles,

v) ready access to central detectors,

vi) the possiblity to disengage beam line from experiment for major interventions.

In the case of LEP, the initial design studies [1] provided a free space of ± 5 m between the end faces of the nearest (very large, conventional technology) quadrupoles, within which it was expected to accommodate the experiments, the minimum value of the vertical betatron function at the interaction point, β_V^*, being set at 0.1 m. More sophisticated low-beta insertions were promised for later phases of the machine. The success of the low-beta insertions at the ISR and PETRA, however, encouraged the LEP experimental teams to insist on higher performance insertions from the outset. It should also be said that besides the higher luminosity, the reduced mass and transverse dimensions of a superconducting quadrupole - necessary to achieve the required gradients even for the first phase of LEP if we were to reduce β_V^* significantly - also appealed strongly to those who could already see that the large normal quadrupoles at ± 5 m would be a significant obstacle to providing the necessary access to the central detector.

This report describes the compromise solution to satisfying the above criteria in the case of LEP, employing machine components in the close vicinity of the experiment, which, despite the space restrictions, should be reliable, stably-supported and adequately instrumented.

The LEP Low-Beta Insertions

A detailed parameter study [2] of the scaling of low-beta insertions for LEP assuming acquired technology for the winding of the superconducting quadrupole, revealed that for LEP Phase 1 ($\leq$ 65 GeV) β_V^* could be reduced to a minimum of 0.06 m for the same degree of chromaticity as considered in the original design study [1], but that this would require reducing the free space between the inner faces of the final quadrupoles to ± 2.5 m, and accepting very large apertures in the succeeding quadrupoles. However, β_V^* = 0.07 m could be achieved with a free space of ± 3.5 m and relatively modest apertures. As the real free space available for the detector is reduced by at least another 500 mm in order to accommodate a vacuum pump and valve which are necessary because the thin-walled vacuum chamber traversing the experiment is captive and cannot be baked out, it was therefore agreed that ± 3.5 m between the superconducting magnet (cryostat) ends was indeed the minimum which could be reasonably accepted [3].

With regard to background, the same parameter study incorporated apertures chosen to satisfy both beam-stay-clear and background criteria. In addition to collimators 100 m upstream, which intercept the remains of synchrotron radiation from the arcs, adjustable collimators will be located between the first and second quadrupoles. Protection is also afforded by initially fixing the aperture through the experiments at 160 mm diameter (compared with 120 mm through the first quadrupole). Catastrophic beam loss in the region of the insertion will be prevented by adjusting collimators in the arcs to ensure that, for any choice of low-beta tuning, the projected aperture around the machine is always limited in the arcs [4].

The approved LEP experiments all use solenoids for momentum analysis. In three of the experiments, the final quadrupole projects into the pole of the solenoid and in the fourth it is wholly within the field. The quadrupole must thus be iron-free, both to avoid non-linear coupling and large longitudinal forces, and the coil suitably derated to take into account the effect of the external field. The hole in the pole must also be sufficiently large to reduce to an acceptable level the effects of unwanted multipoles and lateral forces due to the inevitable eccentricity (some millimeters) of the poles with respect to the quadrupoles. The largest hole which is compatible with obtaining sufficiently uniform fields for the TPC detectors, is of 900 mm diameter; as the field outside the quadrupole falls as the inverse cube of the radius, this is sufficient to satisfy the above constraints.

In order to provide a relatively easy access to the central detectors, i.e. one which does not require opening the vacuum of the machine, it is necessary to pull back the pole, forward detectors and end muon chambers, over the superconducting quadrupole and following beam components. The expected frequency of this "First Level Access", is about once per month. Since there are important reasons why the pole and forward detectors must surround the beam pipe (e.g. the incorporation of circular correction coils on the pole face), this implies that the support must be cantilevered from a distance of 7.9 m from the interaction point. A 900 mm diameter tunnel is thus available to accommodate the superconducting quadrupole, other beam

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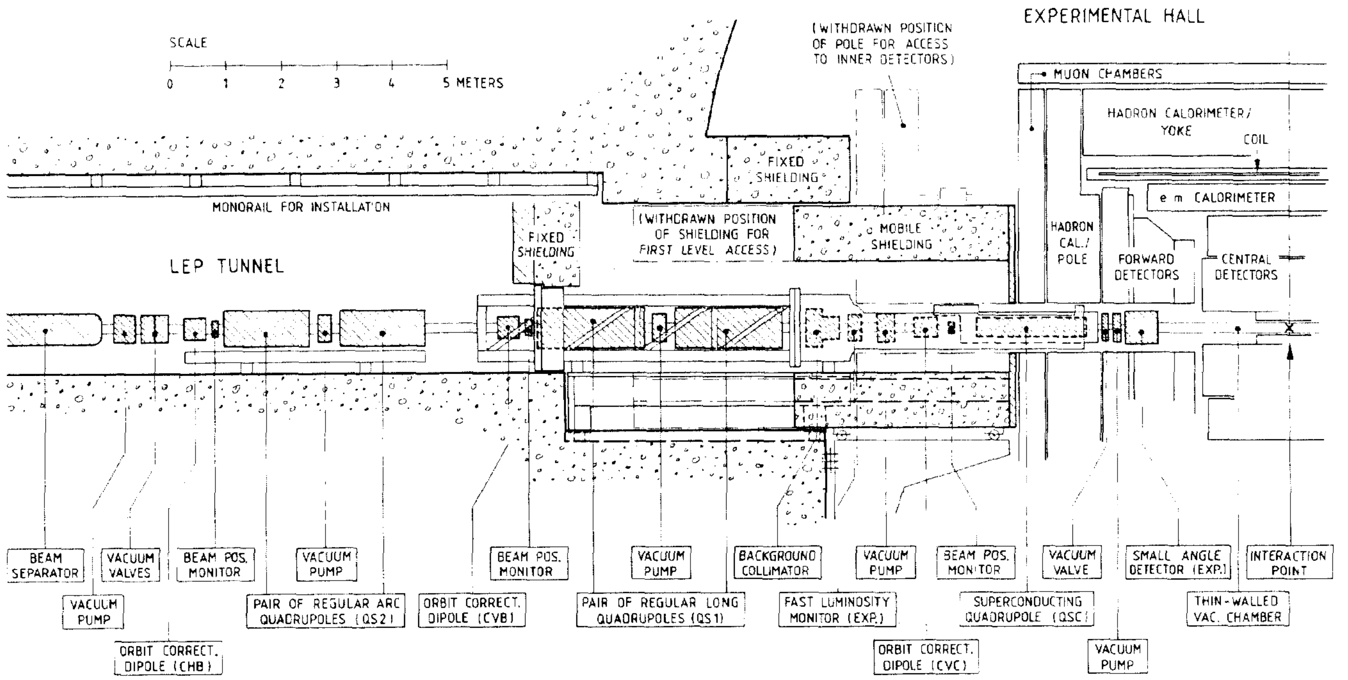

Fig. 1 Schematic view of one side of a LEP machine/experiment interface

line components and their support structure. Another implication is that the warm-cold transition in the superconducting quadrupole must be made horizontally.

The three smaller experiments will be preassembed in a garage position off the beam line. Their mobility permits withdrawal from LEP for major interventions. It is not anticipated that this so-called "Second Level Access" will be requested more than once per year. Nevertheless, this facility requires that the cantilever girder which provides support for the beam elements should also be retractable in the direction of the beam line (after breaking the vacuum). The arrangement also allows for a certain decoupling between the finishing of the assembly of the experiments and the initial commissioning of LEP, and can be exploited for the relative beam-line installation.

The final practical layout is shown schematically in Fig. 1. The second (horizontally-focusing) quadrupole QS1 consists of two of the longer standard LEP quadrupoles which are used in the straight sections, and the back-up quadrupole QS2 consists of two standard arc quadrupoles. It is recalled that the four low-beta insertions are optically independent, and should a superconducting system not be available (e.g. if one of the experiments which uses an SC solenoid, sharing its refrigerator with the local SC quadrupoles, is not installed on the beam), LEP will still be able to operate using a back-up low-beta insertion formed by reversing the polarity of QS1 and exciting QS2. This arrangement provides a β_v^* which is a factor of 2.8 greater than that provided by the standard insertion, for the same chromaticity [3, 5].

The self-shielding nature of the three smaller LEP experiments requires that the gap bridging the experiment to the LEP tunnel must be provided with adequate radiation shielding. This evidently has to retract when the pole is displaced, meaning that the shielding should be mobile (and adding somewhat to the complication of the support for the beam line).

The Superconducting Quadrupole

This is a warm-bore, bath-cooled magnet providing a maximum gradient of 36 T m^{-1} over a useful aperture of 100 mm diameter and having an effective length of 2 m. It has been designed to take full advantage of the experience gained from the successful development, manufacture and operation of the quadrupoles provided for the ISR superconducting low-beta insertions [6, 7, 8]. Monolithic conductor of cross-section 1.8 mm x 3.6 mm, composed of 1500 NbTi 45 μm fialments in a copper matrix, is wound in four 184-turn, 2-block quadrants to form an approximation to a cos 2 θ geometry. The coil is fully epoxy-impregnated, and azimuthal prestress is provided by aluminium shrinking rings.

There are two important differences between the ISR-type magnet and that required for LEP, namely its iron-free nature and the horizontal service funnel. Tests have been performed to verify that these differences can be accommodated, and the results of the tests provided useful input for the design. This is shown in Figs. 2 and 3. Blocks must be placed to within a precision of better than 0.2 mm to ensure the required accuracy of 2.5 10^{-3} on the gradient at the limit of the useful aperture. The ability to achieve this precision in industrial conditions has been proved with the ISR quadrupoles. Moreover, the measured block positions in the quadrants will be used to indicate the azimuthal combination which minimizes the least desirable multipoles (octupole and dodecapole). A further reduction

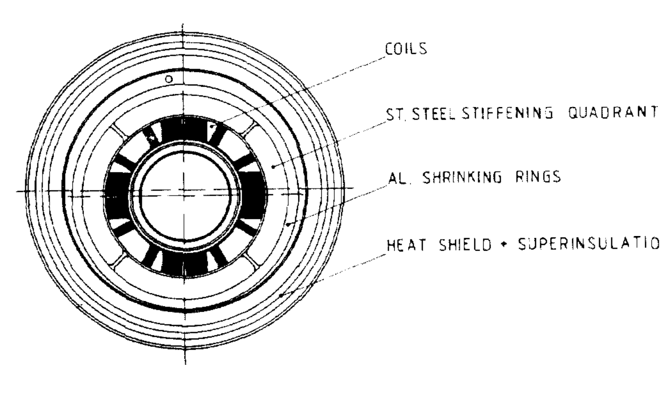

Fig. 2 Cross-section of the SC quadrupole

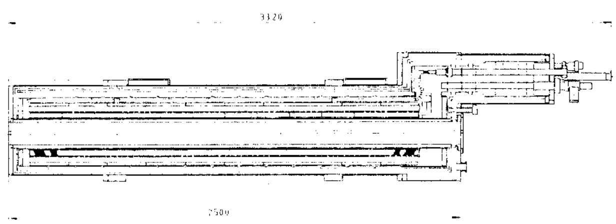

Fig. 3 Longitudinal section of the SC quadrupole

in the contribution of these magnets to resonance excitation can also be achieved by using the results of their magnetic measurements to give a preferred combination of locations for the different units.

One prototype and eight series magnets have been ordered from industry to a detailed CERN specification.

Cryogenics

The magnets will be supplied with liquid helium from a single refrigerator installed at each interaction point, via an intermediate dewar. Helium level in the cryostat will be controlled by valves at the dewar end of semi-flexible transfer lines, the screens of which are cooled using the cold gas return. Besides their high performance and convenience of installation [9], the flexible nature of these lines provides the possibility of leaving in place the delicate coupling between line and cryostat when the magnet is retracted on its girder for Second Level Access to the experiment.

Similar lines were also used successfully for the ISR installation, but with a significantly smaller difference in height between dewar and cryostats. Recent tests have demonstrated that adequately controlled flow can be achieved from a dewar placed up to 25 m above the level of the cryostat.

The Support System

Beam line equipment closer to the interaction point than 7.9 m will be supported by a cantilever girder in the form of an open stainless steel tube held via an intermediate box structure to a rigid lattice beam (Fig. 4). A large bolted flange joint will be provided for installation of the preassembled halves in manageable lengths (< 6 m). The cross-sections are chosen such that the ensemble forms a rigid elastic structure when supported on jacks under the embedded section and under the rear part of the lattice beam section, the two units forming QS1 providing an adequate counterweight. The magnets and other machine elements will be aligned mutually on the girder, which will be subsequently aligned as a whole with respect to the adjacent elements of the LEP machine. The girder will also be equipped with wheels and motor drive to allow retraction on rails over a distance of about 5 m for Second Level Access, for which manoeuvre the back-up quadrupoles (QS2) will be removed to provide the necessary space. The initial installation of this complex girder will also be performed in the retracted position.

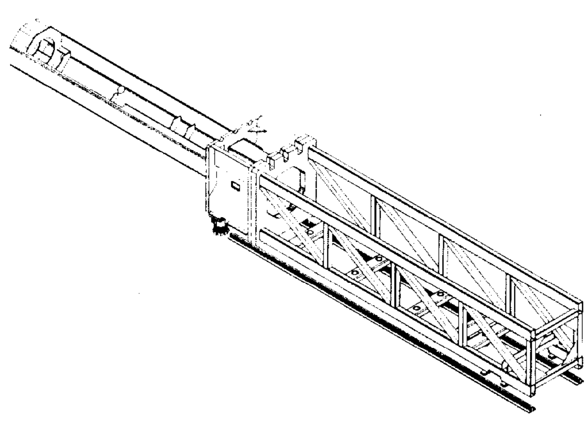

Fig. 4 The cantilever support structure

In order to accommodate the mobile shielding, when the girder is in its operational position it rests on the rampart via an inverted U-beam. This is threaded by a shielding beam, supported by cross-members in the shielding chassis, in such a way as to provide a chicane for radiation directed downwards into the experimental hall. In the case of the large stationary experiment (L3), which is not self-shielding, this intermediate beam is replaced by a 13 m long girder constructed from steel I-beams, projecting into the 32 m long tube which traverses the experiment and supports the ensemble of the detector apparatus independently of the fixed solenoid.

Acknowledgements

The solution of the many problems posed by the various elements of this complex system would not have been possible without the substantial contribution of a number of competent specialists. Thanks are due in particular to T. Tortschanoff (magnetic calculations), Ph. Lebrun and H. Blessing (cryogenics), C. Hauviller, T. Renaglia, G. Trinquart and L. Williams (mechanical engineering and detailed design) and S. Pichler (SC quadrupole manufacture). It is also a pleasure to acknowledge the continued support and encouragement of L. Resegotti, who is globally responsible for the LEP magnet system.

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