

The LEP Energy Upgrade Project

Carlo Wyss
CERN Laboratory
1211 Geneva 23
Switzerland

Abstract

Beams approaching 90 GeV are planned for LEP by the year 1994. To this end, a total of at least 192 superconducting (SC) cavities will be installed in LEP until 1994, partly near the present copper RF accelerating cavities and partly at two new locations.

The LEP energy upgrade requires also modifications of the collider layout, a complete reinstallation of the magnet power converters, powerful cryogenic plants, and a general upgrade of the LEP infrastructure, which will have to distribute and cool away about twice the present energy requirements.

The various activities and their planned milestones are presented, with the aim of providing a general view of the project goals and of the present status.

I. INTRODUCTION

The LEP collider has been designed [1] so as to allow its progressive upgrade from an initial operating energy of about 50 GeV per beam (Phase 1) to higher energies, the ultimate limit being set at 125 GeV by the magnet system.

Following the conclusions of meetings [2] between the experimental and machine physicists, the LEP Main Ring has been optimized for a beam energy of about 90 GeV, so as to allow the study of the W bosons.

To run the collider at the above optimum energy in an economical way, the development of SC cavities (SCC's) has been vigorously pursued during the LEP construction and has led to the successful installation of prototype units in the SPS [3] and LEP [4].

A pilot project for the installation of a first set of 32 SCC's at the LEP Point 2 was launched in 1988; after the running-in of the collider in August 1989, a programme termed LEP 200 has started at CERN, aiming at upgrading the beam energy above the W pair production threshold by 1994.

Various schemes [5] for the LEP energy upgrade by adding SCC's have been worked out; the one retained consists in the addition of 32 SCC's at each of the LEP Pts 2 and 6, where the copper cavities are presently installed, and of 64 SCC's at each of the Pts 4 and 8, where new RF accelerating stations will be created. Fig. 1 shows the expected beam energy range versus cavities installation schedule and performance.

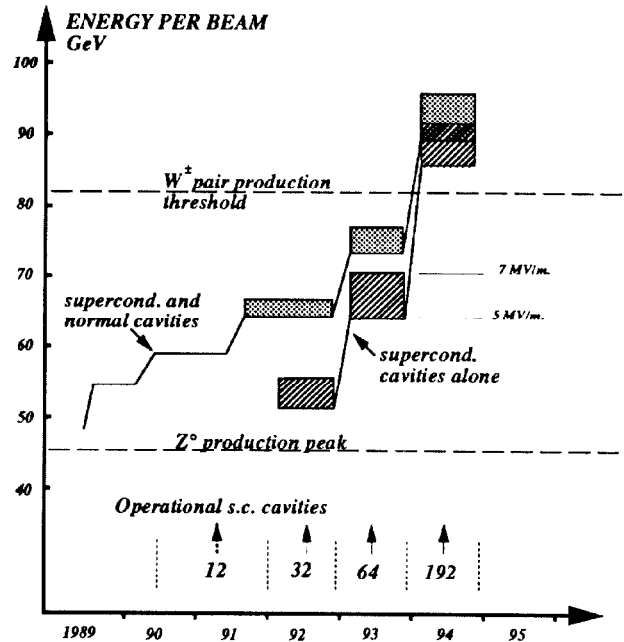


Figure 1 LEP Energy Upgrade Schedule

II. OPTICS AND LATTICE MODIFICATIONS

2.1 New optics, expected luminosities

To maximize luminosity at high energy by reaching the beam-beam limit, the phase advance in the regular arc cells will be increased from 60° to 90°. A chromaticity correction with four sextupole families for this new optics, showing a better performance than that being used for the low-energy 60° optics, has been computed.

These new optics will be studied during machine development time in the course of 1991, so as to understand and remove intensity limitations at injection energy encountered in early tests in 1990.

Assuming a nominal current intensity of 3 mA per beam and four bunches, a luminosity of about 2 to 3 10³¹ cms⁻², according to the success which it will be possible to achieve in controlling the beam size, is expected at high energy.

2.2 RF cells

The SCC's, installed in the RF cells as two 4-units modules, each 11.453 m long, require 28 m long cells, longer by about 4 m than those for the copper cavities, because of the cold/warm transitions and the vacuum valves at the modules ends.

On both sides of Pts 4 and 8 six new RF cells have been designed, so as to house a maximum of 48 SCC's, between 80 m and 232 m from the interaction point (IP). The increase of the beta functions due to the increased cell length is less than 10%.

On both sides of Pts 2 and 6, in addition to the four RF cells for the copper cavities, situated between 148 m and 244 m from the IP, two cells situated between 62 m and 125 m from the IP will house 16 SCC's.

2.3 Insertions at the even and odd IP's

For the low-beta insertions at the even IP's, the layout of the SC quadrupoles and of the classical quadrupole doublets (QS1) behind them will be maintained, but the so-called back-up scheme, which made use of a second classical quadrupole doublet (QS2) designed to allow LEP exploitation up to 65 GeV without the SC quadrupoles, will be abandoned. At the place of QS2 one classical quadrupole only, is presently foreseen, which will allow back-up operation at injection energy only, or reinforce the QS1 doublet beyond 90 GeV. The insertion will be able to provide a minimum vertical beta value of 5 cm at the IP, up to 100 GeV.

The present high-beta insertions at the odd IP's, which are the detuned equivalent of the even IP's, are limited at 65 GeV because of the strength of the classical quadrupoles. To remove this limitation, two solutions have been studied. The first one maintains the optical characteristics of the original insertion, but requires additional quadrupole magnets and enlarged vacuum chambers. The second one uses most of the present hardware at the price of a large increase of the vertical beta at the IP; with extra costs, an insertion for colliding beams with a useful luminosity at one odd IP could still be implemented.

III. THE SC ACCELERATING SYSTEM

3.1 The SC cavities

The first set of 32 SCC's which will be installed at Pt2 will consist of 24 Nb sheet cavities, mainly made by industry, and eight Nb sputtered cavities made at CERN. For these cavities, a nominal gradient of 5 MV/m with a quality factor of $3 \cdot 10^9$ was specified. The development at CERN of both cavity types has shown that in comparison with Nb sheet cavities, Nb sputtered cavities present a better stability with respect to thermal quenches, allowing to reliably reach higher gradients, and are insensitive to the inhomogeneous parasitic magnetic fields present in the LEP tunnel.

It was therefore decided to order the Nb sputtered type from industry for the 160 SCC's necessary for equipping Pts 4, 6 and 8. Three contracts have been placed in October 1990 with three different firms, who are to deliver the series prototypes by June 1991; series manufacture is foreseen to start in October 1991 and be completed by October 1993. The manufacturers will deliver to CERN first "bare" cavities to be tested in a vertical cryostat, and then fully assembled modules consisting of four cavities inside a common cryostats, ready for installation after reception tests. A nominal gradient of 6 MV/m with a quality factor of $4 \cdot 10^9$ has been specified for these 4-cavity modules.

Two 4-cavity modules, fed by a same klystron, are presently installed in LEP at Pt 2; the first one has already been used in August 1990 during physics runs for about 180 hours, at an average gradient of 3.8 MV/m. The nominal performance of 5 MV/m could not be reached because of limits encountered on the RF power coupler of one cavity; adjustable power couplers have been designed and tested up to 100 kW in the meantime to overcome the above difficulty. These new couplers will be used operationally in LEP as from March 1992.

The second module is being run in; the installation of a third one is foreseen by the end of June 1991. The experience gained with these three first SCC's modules will allow to make the necessary improvements to the series components.

3.2 RF power and global control

The SCC's will be fed in groups of 16 by a common klystron; following successful tests on the present LEP klystrons, the ratings of the new klystrons and circulators, to be delivered as from October 1992, have been increased from 1 MW to 1.3 MW, so as to make full use of the full 100 kV, 40 A ratings of the klystron power converters.

The design of the RF units follows closely that of LEP phase I [6], with additional control electronics for the cavities magneto-strictive tuning devices and cryogenics.

In total, twelve new RF stations, initially equipped with one klystron each, will be added to the present eight RF stations feeding the copper cavities. If the eight bunch scheme very recently proposed for LEP [7] is successful, the option of adding twelve additional klystrons will be considered, so as to be able to operate LEP with beam intensities of 6 mA/bunch at high energy.

A global RF control system, monitoring and adjusting the 20 RF units feeding the 192 SCC's and the copper cavities will be implemented, so as to ensure the control of the synchrotron tune and the best balance of accelerating voltage in real time.

3.3 Cryogenics

Each of the four even LEP points will be equipped with a cryoplant having an initial cooling power of 12 kW at 4.5 K, and an ultimate one of 18 kW [8]. The initial capability will

allow to operate at least 64 SCC's at a gradient of up to 7 MV/m; the reserve capability might be used to operate cavities at higher gradients and lower quality factor and also for a possible future LHC collider [9]. To avoid the excavation of underground halls for housing the cryoplants, an upper cold box, situated at the top of the machine pit, will contain the heat exchangers and turbines for the 300 K to 20 K range, whilst a lower cold box, situated in an existing underground service area, will contain the items for the 20 K to 4.5 K range and the connections for the transfer lines to and from the SCC's. The commissioning of the cryoplants at Pts 6 and 8 is foreseen by the end of 1992 and of those at Pts 4 and 2 by mid-1993. At Pt 2, a 6 kW cryoplant, installed underground, will cool the SCC's as from early 1992, until its replacement end 1993. Another 6 kW cryoplant will also equip as from end 1991 a cryogenic test facility, to be used for the SCC's series manufacture acceptance tests and also for LHC magnet development work.

IV. COLLIDER COMPONENTS AND INFRASTRUCTURE

4.1 Magnets, separators, vacuum system, instrumentation, power converters

The present eight SC low-beta quadrupoles (max. gradient 36 T/m), limited at 75 GeV, will be replaced by 55 T/m ones, but within the same overall dimensions thanks mainly to the general progress achieved in SC wires. The steel-concrete cores of the injection dipoles, which have twice the field of the arc dipoles, will be replaced with steel laminated cores.

To achieve sufficient beam separation for high energy operation, two additional electrostatic separators, similar to those already in operation, will be installed near to the existing ones, at each of the four even IP's.

The redesign of the lattice cells in the RF straight sections and around the even and odd IP's will require about 120 new vacuum chambers for drift spaces and quadrupole magnets, to be made out of aluminium or stainless steel.

In spite of the stronger synchrotron-radiation-induced outgassing, a beam-gas lifetime of about 20 hours is expected at high energy and nominal beam current (3 mA). The higher thermal load due to synchrotron radiation (up to 1.5 kW/m for 32 MW total RF beam power) requires that the cooling channels of the vacuum chambers, presently series connected, be parallel connected in each of the lattice cells.

The lead shielding along the beam path will have to be completed at about 2700 locations, where gaps have been left in the present shielding, e.g. at bellows.

New collimators are necessary at the end of the even arcs to shield the SCC's from synchrotron radiation; those in the arcs must be modified to cope with the increase in synchrotron radiation power, those protecting the experiments at the even IP's need to be moved to positions consistent with the new optics, the necessity of new ones is being assessed.

A number of beam position monitors will also be added or replaced.

It is presently planned to complete all major modifications to the collider proper by 1993, so as to devote 1994 mainly to the installation of the large number of SCC's at Pts 4 and 8.

The present LEP magnet power converters (PC's) are limited at 65 GeV; the new PC's are designed for 100 GeV operation. The new main dipole PC will be installed already at the end of 1991, whilst a general upgrade of all other magnet PC's is foreseen by 1993. The upgrade will consist in a redistribution of the present PC's, and the purchase of more than 40 new ones.

4.2 Power distribution, cooling, civil engineering

The high energy operation of LEP requires an increase in installed power from 70 to 160 MW and a corresponding increase in power distribution and cooling capability, to be available by early 1993; the major extensions (50 MVA power links and substations, cooling towers for 40 MW) will occur at Pts 4 and 8, where the new RF stations will be situated.

At each of these points new auxiliary galleries (2 x 230 m) will be excavated on both sides of the IP, for housing klystrons and RF controls; the galleries at Pt 8 will be equipped in 1992 and those at Pt 4 in 1993.

Sound-proof compressor halls (5 x 600m²), the extension of rectifier halls (2 x 300 m²) and other buildings, and eight new cooling towers are the major items of the surface civil engineering work required for the LEP energy upgrade. All civil engineering work will be completed by early 1993.

V. ACKNOWLEDGMENTS

This short article can only partially describe or even mention the large number of activities contributing to the realization of the LEP Energy Upgrade; as project leader, the author gratefully acknowledges the professional competence and the untiring efforts of all the teams working for the success of the Project.

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