Status of the LEP Energy Upgrade

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Abstract

Beams approaching 90 GeV are planned for LEP by the year 1994. To this end, it is foreseen to install in LEP a total of at least 192 superconducting cavities. The LEP energy upgrade also requires a new low-emittance optics, layout modifications, new collider components, 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. Project execution has started in December 1989 and by now good results have been achieved with the new optics and components are being delivered. The progress of the various activities is presented, with the aim of providing a view of the project goals and present status.

1. INTRODUCTION

The LEP collider has been designed [1] so as to allow its upgrade from an initial energy of about 50 GeV per beam (Phase 1) to an optimum energy near to 90 GeV, the ultimate limit being set at 125 GeV by the magnet system. To run LEP at high energy in an economical way, SC cavities (SCC's) have been developed [2] since the beginning of the LEP design. Various schemes [3] for the energy upgrading by adding SCC's were worked out; the one retained consists in 32 SCC's added to each of the LEP Pts 2 and 6, where the copper cavities are presently installed, and of the installation of 64 SCC's at each of the Pts 4 and 8, where new RF accelerating stations will be created. A pilot project for the installation of a first set of 32 SCC's at the LEP Point 2 was launched in 1988. In December 1989 a programme [4] termed LEP 200 was started, aiming at upgrading the beam energy above the W pair production threshold by 1994.

2. OPTICS AND LATTICE MODIFICATIONS

A low-emittance optics, achieved by increasing the phase advance in the arcs from 60° to 90°, is necessary for high energy operation, so as to maximize luminosity by keeping the colliding beams near to the beam-beam limit. In this way a luminosity of about 1.5 10^{31} cms^{-2} could be reached around 87 to 90 GeV. Such an optics has been successfully commissioned up to 46.5 GeV during machine development studies in the course of 1991 [5]. With respect to the 60° optics used up to now for operation at 45 GeV, this new optics promises advantages in specific luminosity, available beam aperture and background and will therefore be tentatively used for physics during 1992. Furthermore the 90° optics is also well suited for the 8-bunch scheme ("pretzel" scheme) being commissioned [6], designed to increase luminosity by a factor two, which is extremely useful at high energy.

A number of geometry modifications of the original LEP lattice are necessary at the even and odd points of LEP, because of quadrupole magnets running out of focusing strength above 65 GeV and also because of an increase in length of the SC RF cells , due to the longer length of the SCC's assemblies. All the relevant studies [7] have been completed during 1991 and at present layout drawings are being made in view of installation in the next long winter shut-downs.

3. THE SC ACCELERATING SYSTEM

3.1 SC cavities

The SCC's are installed in LEP as 4-units modules, 11.285 m long. The first set of 32 SCC's, at Pt2, consists of eight prototype Nb sputtered cavities (two modules) made at CERN and 24 Nb sheet cavities (six modules), out of which four are prototypes made in 1989, and 20 are series units, delivered by industry during 1991. For these cavities, a nominal gradient of 5 MV/m with a quality factor (Q) of 3 10^9 was specified.

This performance has been achieved in general and exceeded by the Nb sputtered prototype units and by the 17 series Nb sheet SCC's accepted so far (7 MV/m have consistently been attained with Q values between 2 and 3 10^9). The three SCC prototype modules operated in LEP during 1991 could not be fully tested to nominal performance prior to their installation because of the lack of cryogenic power. In LEP they were run with beams [8] up to an average of 3.7 MV/m, delivering a total voltage of up to 76 MV. The Nb sheet SCC module is limited by uneven excitation of its four cavities (one unit has a 20 % larger power input and reaches its limit of 5.3 MV/m before the other ones), because of geometry tolerances of the power coupler/cavity assembly. This difficulty has been overcome by the design of an adjustable power coupler (allowing an individual setting of the coupling for each cavity), presently in the pre-series manufacturing stage. The Nb sputtered SCC modules turned out to be limited at about 4 MV/m because of the insufficient cooling of a new type of high order mode (HOM) coupler, which prevented a further RF processing of the modules beyond that value.The tests carried out in October 1991 on the first module assembled with the series Nb sheet SCC's showed similar difficulties. The cooling of these couplers has therefore been improved; the revised LHe distribution scheme is presently under test. In view of introducing the necessary modifications, the assembly at CERN of the series Nb sheet SCC modules has been stopped for a few months; their installation will occur during the 92-93 shutdown at the latest.

LEP Pts 6, 8 and 4 will be equipped with Nb sputtered [9] SCC modules, to be delivered fully assembled by industry. A nominal gradient of 6 MV/m with a quality factor of 4 10^9 has been specified for this type of SCC's. Prototype units have been delivered since July 1991 by the the three firms to which manufacture was entrusted in September 1990. The know-how [10] transfer by CERN to industry is by now practically completed, a first prototype has already reached, in December 91, a performance of 5 MV/m with a Q of 3 10^9; prototypes fulfilling the 6 MV/m, Q = 4 10^9 specification, are expected in the near future.

3.2 RF power and control

Twelve new RF units are required for the 192 SCC's. Each unit consists of a 1.3 MW klystron and circulator, the waveguide distribution system and 22 racks of electronics for the controls, low and high power. (The present copper system consists of eight RF units). The contracts for klystrons, circulators and waveguides have been adjudicated in September 1991 with the first deliveries expected by June 1992. Control electronics, RF amplifiers, power meters, temperature stabilized fibre optics for RF reference distribution and associated transmitting equipement have also been ordered in 1991; the corresponding deliveries are progressing to schedule.

A central control of the total 20 RF units, which will be available in 1994, will be ensured by a global RF control system, designed to adjust synchrotron tune and to keep an optimum RF balance. A software version of this system has already proven very useful with the present copper RF system; a hardwired version will become operational this summer.

3.3 Cryogenics

At each of the even LEP Points there will be a cryoplant [11] with an initial cooling power of 12 kW at 4.5 K and an ultimate one of 18 kW. These cryoplants will consist of a surface upper cold box for the 300 K to 20 K temperature range, connected by vertical transfer lines in the machine shafts to an underground lower cold box for the 20 K to 4.5 K range. The corresponding contracts were adjudicated in December 1990; their execution is progressing according to the contractual planning (e.g. the heat exchangers for the cold boxes have already been delivered, the manufacture of the cold box vacuum vessels is in progress, the installation of the vertical transfer lines at Point 6 will start by April 92).The commissioning of the cryoplants at Points 6 and 8 is foreseen by end 1992. Those at Points 4 and 2 will be commissioned by mid-1993.

Two 6 kW cryoplants have been delivered and are at present being commissioned. One has been installed underground for cooling the SCC's at Pt2 during 1992 and 1993, and the other one equips the SM18 cryogenic test facility, where the acceptance tests of the SC cavities and LHC magnet development work will take place.

The installation of the He transfer lines for supplying the SCC's at Pt 2 has been completed in February 92, according to schedule; those for Pt 6 have been installed in the LEP tunnel in March 92, before the tunnel closure. The delivery of all other components for the cryogenic system (e.g. high and low pressure storage vessels, piping for He gas) is progressing according to schedule.

4. COLLIDER COMPONENTS AND INFRASTRUCTURE

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

The present SC quadrupoles at the even IP's will be replaced during the 1993-1994 shut-down by new ones [12], having the same outer overall dimensions, but with a magnetic field gradient increased from 36 to 55 T/m. Their manufacture is in progress, a prototype magnet is due by May 92 and the series production is expected to start in September 92.

The steel-concrete cores of the present injection dipoles saturate as from 70 GeV and will be replaced by classical steel laminated cores; all the twenty-four units have already been delivered, their installation will occur in the 92-93 shut-down.

To keep sufficient beam separation [13] during acceleration up to 100 GeV, two additional electrostatic separators, identical to those already in operation, will be added at each of the even IP's.The vacuum tanks and the electrodes for these eight new separators have been ordered; their installation is foreseen for the 93-94 shutdown.

The performance of the vacuum system in presence of the high energy synchrotron radiation impinging on the vacuum chamber walls has been extrapolated from various measurements [14], and a beam-gas lifetime of about 20 hours is expected. The modifications of the odd and even IP's, and that of the RF straight sections, require that about 120 vacuum chambers for drift spaces and quadrupole magnets be manufactured or modified. The aluminium vacuum chambers will be modified at the CERN workshops, whereas the stainless steel chambers have been ordered to industry. The planning presently foresees that the odd IP and some of the RF straights be modified during the 92-93 shut-down, the remaining RF cells and the even IP's during the 93-94 shut-down. The cooling of the vacuum chambers will be upgraded during the 93-94 shut-down so as to cope with up to 32 MW of synchrotron power, i.e. 1.6 kW/m (electron and positron beams of 6 mA each at 95 GeV will radiate about 28 MW of synchrotron power). This cooling upgrade will be achieved by changing from series to parallel the water flow in the cooling channels of the vacuum chambers of the LEP lattice cells. The lead shielding along the beam path will be completed at about 2700 locations also during the 93-94 shut-down.

The major modifications to the beam instrumentation equipment concern the addition or the replacement of collimators, so as to cope with the higher energy deposition by synchroton radiation. Sixteen collimators in the arcs, shielding the even IP's from off-momentum particles will be replaced (the absorbing material will change from aluminium to tungsten) and installed at positions compatible with the 90° optics. The contract for the manufacture of these collimators was awarded in February 92 and their installation is presently planned for the 92-93 shut-down. To shield the SC cavities from synchrotron radiation, sixteen new collimators will be installed at the outer ends of the RF straight sections; the corresponding call for tender will be issued in April 1992 and their installation is presently foreseen for the 92-93 and 93-94 shut-downs. The even IP's will also receive additional collimators.

The present magnet power converters (PC's) are designed for operation up to 65 GeV; those for LEP 200 are foreseen for a maximum beam energy of 100 GeV. For the LEP bending magnets, the new PC's have been delivered in October 1991. Their installation had been planned during the 91-92 shut-down, but because of difficulties with the thyristor units, their installation has been postponed to 92-93 shut-down. Four additional PC's for the arc quadrupole magnets will be delivered by September 92. Nearly all the existing medium (50-100 kW) power converters for the other magnet circuits will be reused in different configurations for high energy operation; in addition, about 40 new PC's are necessary. The corresponding deliveries have begun and will be completed by September 1992.

Ten new klystron power converters (40 A, 100 kV), identical to those already in use for the present RF system, are necessary. The corresponding contracts were placed in March 1991; deliveries are progressing as scheduled, the last batch is planned for March 1993.

4.2 Power distribution, cooling, civil engineering

The power distribution system requires major extensions at Pt 2, where the main dipole PC's (2 x 8.1 MW) are located, and at Pts 4 and 8, where the new RF units are situated (4 x 4 MW at each point). The cryoplants need about 3 MW from the grid at each of the even points, where the power converters (4 x 1.1 MW) for the arc quadrupoles are also situated. Additional power will also be necessary for all the other magnet power converters, for the new RF units at Pts 2 and 6, for cooling and ventilation and other services. To cope with these requirements, 50 MVA power links (10 km of trenches) from the Prévessin 400 kV/66 kV station to Pts 4 and 8 have been realized in 1991. Extensions of the 66 kV substations at Pts 2, 4 and 8 with new 38 MVA transformers will be completed in the first half of 1992. All contracts for power distribution equipment, harmonic filters, reactive power compensation, HV and LV switchgear have been placed and deliveries are according to schedule.

To cope with the increase in power dissipation, the number of cooling towers will be increased from four to six at Pts 2 and 6, and from one to five at Pts 4 and 8 (Pts 2 and 6 need additional cooling capacity because of the presence of the copper RF system and resistive experimental magnets). Major extensions of the air and water cooling facilities are needed at Points 4 and 8, because of the new RF units. Nearly all main contracts for these activities have been placed; their execution will take place from June 92 to May 93.

New klystron galleries (2 x 230 m) are necessary at Pts 4 and 8 for housing the RF units. At Point 8, the UA83 and UA87 galleries have been completely excavated, their junction with the LEP tunnel and all waveguide holes have been made, the concrete casting is finished to 70 %. The installation of infrastructure in these galleries will start as from mid-April 92. The excavation of the galleries at Pt 4 will start by early April 92, for delivery by April 93.

Two out the five new sound-proofed compressor buildings (600 m2) are equipped and in service. At Pts 4 and 8 extensions are needed for the rectifier halls (2 x 300 m2) and the water pump stations (2 x 170 m2). The new cooling towers described above will also be made out of concrete, as are the original ones. The building construction is in full swing; all these activities are progressing according to schedule and will be completed by Spring 1993.

5. SUMMARY

The commissioning of a high energy optics for LEP is well in hand. The operation of three prototype SCC modules in LEP during 1991 has allowed to gain precious experience, necessary for improving some hardware and operational procedures. The delivery of SCC's by industry is expected to be within performance specifications and an acceptable schedule, compatible with the Project aims. All activities for machine components and infrastructure are in regular progress.

6. ACKNOWLEDGMENTS

In such a short article it is unfortunately not possible to describe or even mention all the Project activities. The ingenuity, determination and untiring efforts of all those contributing to the success of the LEP Energy Upgrade Programme are gratefully acknowledged.

7. REFERENCES

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