Commissioning of the SPS as LEP Injector

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Introduction

The original design report [1] on the Large Electron-Positron storage ring (LEP) proposed a LEP injector based on a new 22 GeV synchrotron. Subsequently, in order to reduce the cost of the project it was proposed [2] to use the existing Super Proton Synchrotron (SPS) together with its injector, the CERN Proton Synchrotron (CPS) in order to accelerate electrons and positrons up to 20 GeV/c for injection into LEP. It was further proposed to accelerate leptons in the dead time between proton cycles imposed by the average power consumption in the SPS magnets. This implied major changes to the SPS software and hardware, in particular to the master timing generator and to the function generators, in order to operate in a "multicycling" mode with at least one hadron and four lepton cycles per supercycle. Commissioning of the injector chain started in 1987 and continued into the first half of 1988.

Beam Conditions

The CPS accelerates leptons from their accumulation energy of 600 MeV in the EPA (electron-positron accumulator) to 3.5 GeV before extraction towards the SPS. Details of the performance of the CPS complex can be found elsewhere [3]. In the nominal scenario [4], 8 bunches of electrons or positrons each with up to 1×10^{10} particles per bunch are extracted from the CPS every 1.2 seconds and accelerated to 20 GeV in the SPS. The nominal parameters of the injected beam are σ_L = 16 cms, $\sigma_{E/E}=10^{-3}$. The bunches are captured at 200 MHz (h=4620) with a nominal capture voltage of 500 kV and a synchrotron tune Qs = 1.4×10^{-3}.

The radial synchrotron radiation damping time is at the injection energy of the order of 7 seconds so no useful damping at low energy is obtained. Therefore the injection must be very carefully adjusted in order to avoid undue emittance blowup.

The SPS Supercycle

The standard SPS cycles for proton acceleration is of 14.4 seconds duration with a 1.2 second injection platform at 14 GeV/c and a flat top at 450 GeV/c of 2.82 seconds. In order that the maximum allowable mean power consumption is not exceeded, a dead time of 4.44 seconds is required. In this dead time, 3 lepton acceleration cycles can be accommodated (fig. 1). This is adequate for commissioning of the machine with leptons although finally, for LEP filling, the supercycle length will need to be increased in order to accommodate a fourth lepton cycle. The first two cycles can be used for positron injection and acceleration, whereas the third cycle can only be used for electrons since the magnetic elements in the injection beamline common to both protons and positrons cannot ramp quickly enough to allow positron injection at 3.5 GeV followed by proton injection at 14 GeV.

The magnetic cycle for lepton acceleration is shown in more detail in fig. 2. The injection field for 3.5 GeV/c particles is only 157 Gauss, whereas the high-energy flat top preceding the lepton cycles is above 2 Tesla. Therefore the injection conditions are extremely sensitive to remanent field and eddy current

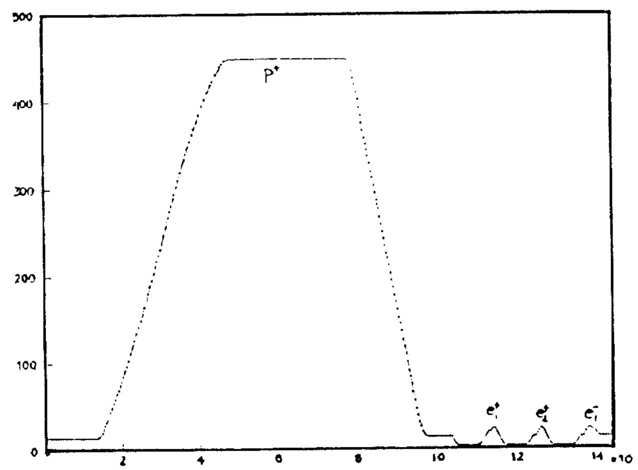

Fig. 1 The SPS supercycles with one proton and three lepton cycles

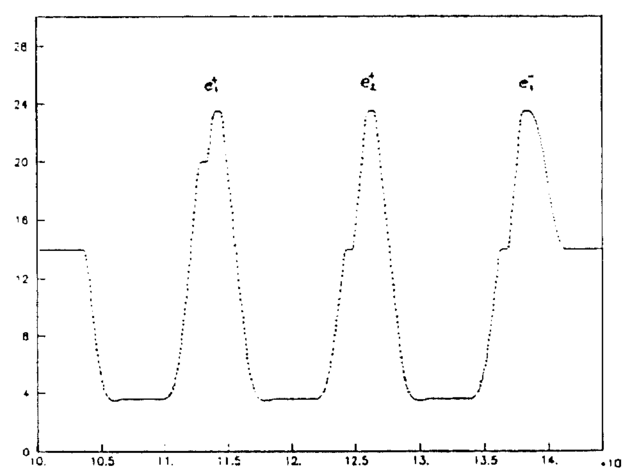

Fig. 2 The three lepton cycles

effects. It is vital that all lepton cycles can be independently trimmed (B-field, tune, chromaticity, closed orbit etc.) It is also important that the individual cycles are as much as possible magnetically decoupled from one another so that trimming of one of the cycles does not affect the others. This is achieved by making a small "undershoot" of 0.1 GeV at the beginning of the cycle and an "overshoot" to 23.5 GeV at the high-energy end. When trims are made, care is taken so that both of those levels remain unchanged. In the supercycle shown in Figs. 1 and 2, the first lepton cycle has a short flat top at 20 GeV, whereas the two following cycles have flat tops at 14 GeV. The reasons for this are explained below. The acceleration time from 3.5 GeV to 20 GeV is of the order of 250 msec with an overall lepton cycle duration of 1.2 seconds.

Power Supplies

The same power supplies are used for the lepton cycles as for the proton cycle. This poses particular problems for the main dipole and quadrupole supplies as well as for a number of power supplies in parts of the transfer lines common to both 3.5 GeV/c leptons and 450 GeV/c protons. In order to achieve the required precision of $\Delta I/I < 10^{-3}$ for the dipoles and 10^{-4} for the quadrupoles at the injection level, the low-level current control loops are switched between proton and lepton cycles.

Chromaticity Correction

Three main effects contribute to the chromaticity. They are a) remanent sextupole field in the dipoles and in the correction sextupoles themselves, b) sextupole fields generated by eddy currents and c) the natural chromaticity of the machine itself. The time-variation of the chromaticity is parametrised by three coefficients a, b, c such that

$$\xi = a + b/p + cp/p$$

where $\xi = (\delta Q/Q)/(\delta p/p)$

Measurement of the chromaticity at 3 different points in the cycle allow the three constants to be computed. For the lepton cycles used above, they are:

$a = -0.7$, $b = -6.5$, $c = 0.30$ for the horizonal plane.
$a = -1.42$, $b = +12.6$, $c = -0.28$ for the vertical plane.

Using these coefficients the chromaticity correction can then be computed for the whole cycle. Figure 3 shows the computed curve together with the measured values of the corrections required to produce zero chromaticity throughout the cycle. The agreement with the model is clearly very good.

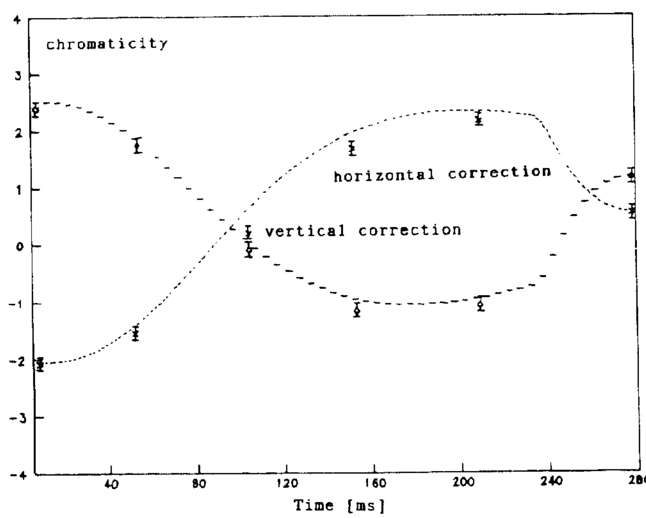

Fig. 3 Applied chromaticity correction along the ramp for a lepton cycle.

Closed Orbit

Due to the very low injection field, establishing a circulating beam is considerably more difficult than for the proton beam. Initial steering is made with the beam position monitors in "first-turn" mode using a modified version of the MIKADO program [5] initially developed for the ISR. Once a circulating beam is established the orbit is corrected. All dipole power supplies are driven by function generators so dynamic orbit correction can be made throughout the cycle. Once the orbit has been corrected for one of the lepton cycles the corrections can be copied into the other cycles.

Radiofrequency

The standard SPS radiofrequency system for proton acceleration consists of 4 travelling-wave cavities giving a total of about 7MV per turn. This system cannot be used for lepton acceleration for LEP injection because a) the voltage is only sufficient to reach around 14 GeV and b) the travelling-wave cavities are "directional" so they can only accelerate protons and positrons in the same supercycle. The required 30 MV to reach 20 GeV/c will be provided by a set of 32 standing-wave cavities operating at 200 MHz. At the present time 24 of these cavities have been installed and 16 of these have been conditioned to full voltage. The first of the three lepton cycles was used to commission the standing wave cavities and their associated beam control electronics with positrons. Using these cavities a positron beam has been accelerated up to 18 GeV/c parasitically parallel to fixed-target proton operation.

On the second lepton cycle the normal travelling-wave system was used to accelerate positrons to 14 GeV/c in order that fine tuning and extraction tests could proceed independently of the work being done on the first cycle.

A third radiofrequency system was used in 1987 to accelerate positrons to above 14 GeV/c. This consists of a prototype 5-cell superconducting cavity operating at 352 MHz. [6]. It was developed for the LEP phase II project (increasing the LEP energy to 100 GeV per beam) and gives about 8 MV per turn. One particular problem with this cavity is that its impedance must be reduced by a large factor during the time that the intense proton beam is in the machine. This cannot be done with movable damping loops as for the standing wave cavities. Instead, an active feedback system [7] has been developed using the power amplifier itself to oppose the beam - induced voltage.

Injection and Extraction

The layout of the transfer lines from PS to SPS and from SPS to LEP is shown schematically in fig. 4. Four separate systems are needed for lepton

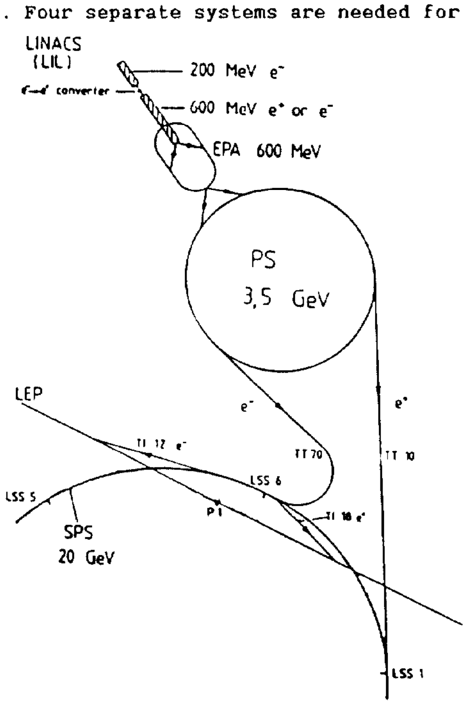

Fig. 4 Schematic layout of the transfer lines between PS, SPS and LEP

injection and extraction. The most straightforward of these is the e^+ injection system. Positrons are transferred to the SPS along the existing transfer line TT10 and are injected using existing kickers for proton injection with some modifications to their pulse forming networks in order to allow injection of 8 bunches.

Positron extraction is made through the LSS6 extraction channel which also carries the 450 GeV/c proton beam. Using this system, positrons have been extracted at 14 GeV on the second lepton cycle and transported to a temporary beam dump at the beginning of the injection beamlime (TI 18) to LEP.

Electrons are transferred to the SPS at 3.5 GeV through the beamline TT70 originally built for antiproton transfer and are injected through the same magnetic channel as for positron extraction. The beamline and inflector have been successfully commissioned with beam.

The final system, still to be commissioned is the e^- extraction system.

Synchrotron Radiation

Synchrotron radiation poses no great problems to the SPS machine itself except at 20 GeV where the radiation starts to penetrate the vacuum chamber and irradiate the coils of the main dipole magnets, which are in the median plane. In order to minimise the radiation damage an extensive program of installing masks both inside and outside the vacuum chamber has been implemented.

In order to provide a slow spill of protons for the fixed-target program, electrostatic septa are used to shave off the large amplitude particles. Synchrotron radiation from the positron beam illuminates the cathodes of these septa producing a high photo-electric current and sparking. This sparking becomes intolerable when the beam is accelerated above about 5 GeV. In order to protect the septa from the synchrotron radiation it has been necessary to install movable shutters which shadow the cathodes from the synchrotron radiation whilst leaving adequate space for the circulating beam. These shutters have proved to be highly effective, at least up to the highest energy (18 GeV) obtained to date.

Beam Stability

In the transverse plane the classical "head-tail" instability is easily suppressed by imposing a small positive chromaticity throughout the acceleration cycle. However, a fast transverse instability has been observed above a threshold of about 1.3×10^{10} particles/bunch immediately after injection. It manifests itself by an abrupt beam loss (fig. 5) after relatively few turns accompanied by a growing signal in the microwave region on a transverse difference pickup. The phenomenon has been analysed in terms of the theory of "transverse turbulence". A detailed account of the experimental observations and comparison with the theory is given elsewhere in these proceedings [8].

Conclusions

Commissioning of the SPS as LEP injector is well under way. The SPS now operates in a multicycling mode in which lepton cycles can run parasitically during the fixed-target physics operation. With three lepton cycles in a supercycle, beam has been injected on all three cycles, with positron acceleration on the first two and electron injection on the third.

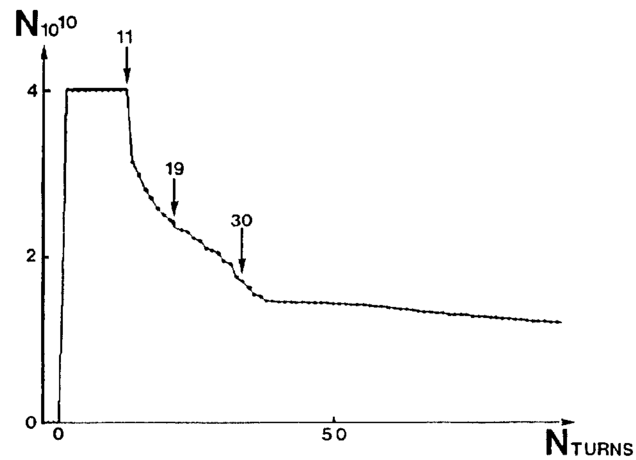

Fig. 5 Positron bunch intensity as a function of the turn number

Positron bunches above the nominal intensity of 8×10^9 e^+/ bunch required for LEP injection have been accelerated to 18 GeV/c using part of the standing-wave cavity system. The maximum bunch intensity is limited in the SPS to around 1.3×10^{10} particles/bunch by a fast instability on the injection platform. The threshold for this instability is close to that predicted for transverse turbulence.

The positron extraction system has been commissioned in preparation for the injection of beam into the first octant of LEP scheduled for the summer of 1988.

References

[1] The LEP Study Group CERN/ISR/79-33 (1979).

[2] Y. Baconnier, O. Gröbner, K. Hübner, The SPS as LEP Injector, LEP Note 212 (1980).

[3] Y. Baconnier et al, the CERN PS as e^+/e^- Accelerator in the LEP Injector Chain: First Results, Proc. 1987 PAC, Washington, (1987).

[4] LEP Design Report, Vol. 1, The LEP Injector Chain, CERN-LEP/TH/83-29.

[5] B. Autin, Y. Marti, Closed orbit correction of AG machines using a small number of magnets CERN ISR-MA/73-17, (1973).

[6] D. Boussard et al, Test of a 352 MHz Superconducting cavity in the SPS, these Proceedings.

[7] D. Boussard, H.P. Kindermann, V. Rossi, RF Feedback applied to a multicell superconducting cavity, these Proceed- ings.

[8] D. Brandt, J. Gareyte, Fast instability of positron bunches in the CERN SPS, these Proceedings.