

THE PERFORMANCE OF THE SPS AS LEP INJECTOR

K.Cornelis, R.Schmidt

European Organization for Nuclear Research (CERN) 1211 Geneva 23, Switzerland

Abstract

The injection of positrons into the first octant of LEP during the LEP injection tests in 1988 required the SPS being operational as an injector for LEP. Positrons were accelerated in the SPS from an energy of 3.5 GeV to about 18 GeV and extracted into LEP during the test which lasted one week. This test as well as the further commissioning of the SPS with leptons could be made without any perturbation to the physics program. The leptons were accelerated in three cycles, interleaved in between the proton cycles and 4 bunches of positrons or electrons were accelerated on each of them. Bunches with intensities exceeding the design value of  $0.8 \times 10^{10}$  were accelerated. Following preliminary studies countermeasures against various collective effects allowed the acceleration of up to  $2.6 \times 10^{10}$  particles per bunch. The required momentum for LEP injection of 20 GeV for next year could also be achieved.

1. Introduction

After the commissioning of the SPS as LEP injector started in 1987 [1], three main directions of the studies to be performed in 1988 were distinguished. The first objective was to set up the accelerator to inject positron bunches into the first octant of LEP during at least one week in July 1988 in an operational way. The second purpose was to understand the beam dynamics of leptons in the SPS and its limitations in order to subsequently optimize the beams for an efficient filling of LEP. Finally, and since the SPS schedule would not allow any further tests with leptons until the start-up of LEP in 1989, it was necessary to commission all systems needed to accelerate beams of positrons and electrons up to 20 GeV, provided the necessary hardware was available. The three aims were satisfactorily achieved. In table 1 the parameters achieved in 1988 are compared with the design values (see [2] and [3]).

2. Multicycling

During the entire fixed target period the SPS was operated with a magnetic supercycle of 14.4 s comprising two cycles for positron acceleration and one cycle for electron acceleration which followed the 450 GeV proton cycle. Parallel to the physics run with protons the lepton cycles were used for different studies.

In the second positron cycle the particles were accelerated up to 18 GeV for injection into LEP, the other cycles had a maximum energy of 20 GeV (see Fig.1). The LEP injection tests were performed at 18 GeV instead of 20 GeV as foreseen for the final LEP operation, because there was not enough RF voltage available to assure a continuous operation at 20 GeV. Only 24 of the 32 standing wave cavities which will eventually be available during LEP operation had been installed in 1988.

In order to avoid any influence of one of the lepton cycles on subsequent cycles (and in particular on the proton cycle), the magnets were ramped to a field corresponding to 23.5 GeV after a 30 ms long extraction plateau for all lepton cycles. This allowed small changes of quadrupole and bending currents in the lepton cycles without an adverse effect on the protons.

Table 1: Performance of the SPS as LEP injector		
	Design	Achieved
Nominal energy [GeV]	20	20
Injection energy [GeV]	3.5	3.5
Number of bunches per cycle	8	4
Number of cycles in Supercycle	-	3
<u>Parameters during the LEP injection test :</u>		
Energy [GeV]	20	18
Intensity/bunch [ $\times 10^{10}$ ]	0.8	1.2
Hor.emittance $\sigma^2/\beta$ [mm.mrad]	0.09	0.05
Ver.emittance $\sigma^2/\beta$ [mm.mrad]	0.02	0.04
<u>Parameters achieved during machine studies :</u>		
Maximum Intensity/bunch [ $\times 10^{10}$ ]		2.6
Intensity in 4 bunches [ $\times 10^{10}$ ]		8.6
bunches injected with $\sigma_E/E = 0.001, \sigma_s = 4$ ns		

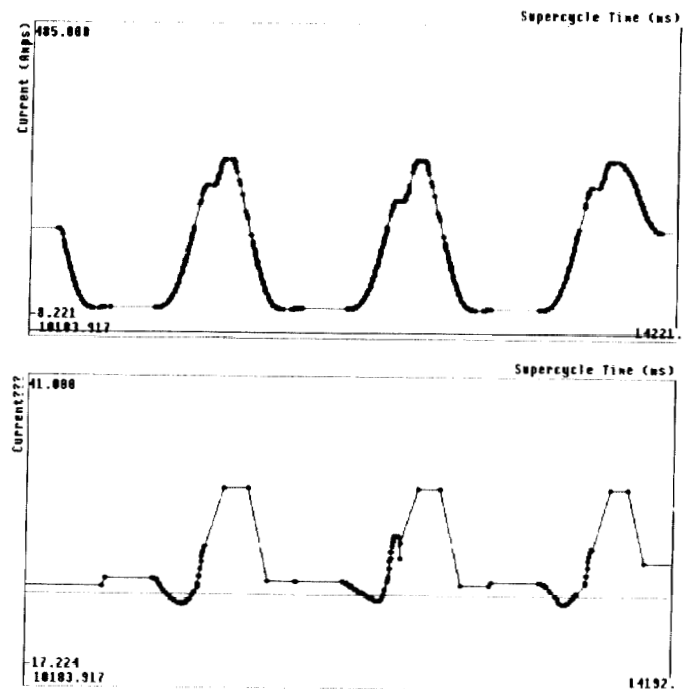


Fig.1a) The Lepton cycles in the SPS-Supercycle  
b) Chromaticity correcting Sextupole current during the Lepton cycles

### 3. Injection

Positrons and electrons are transferred from the CPS to the SPS along the same transfer lines used for the transfer of protons and antiprotons. A complication arises from the fact that part of the injection channel for the electrons is used for proton extraction to one of the experimental areas. Since the voltage of the electrostatic septum cannot be pulsed within the super-cycle the trajectories of protons and electrons have to be different. For that reason the closed orbit of the electrons at the injection point is modified. The injection has to be done precisely onto the closed orbit to avoid emittance dilution and losses since at 3.5 GeV the effect of synchrotron radiation is negligible and leptons behave like protons.

The alignment of the quadrupoles in the SPS is precise enough to establish the first turn for proton injection at 14 GeV without the need for corrections. This is not the case for the injection of leptons at 3.5 GeV. Remanent field errors of dipole magnets are so important that their correction is compulsory to establish one turn. This was achieved with a newly developed closed orbit correction procedure, which includes an automatic steering of a beamline [4]. Another option of this procedure was used for the closed orbit correction: the mean radial position of the beam is determined by the RF frequency. This frequency is determined by the synchronization of the RF systems between the different accelerators. In general, the beam is not centred on the nominal trajectory and the mean radial position has a nonzero value. Dipole fields cannot correct for this, any attempt to correct this error with dipoles leads to wrong results. The new correction procedure calculates the energy error and modifies the measured beam positions by the appropriate amount.

### 4. RF systems

For first acceleration tests the travelling wave 200 MHz RF system for protons was used which allowed an acceleration to 14 GeV. During this time the new 200 MHz standing wave RF system could be commissioned, 24 cavities provided a total voltage of about 20 MV [5]. With this voltage the bunches could be accelerated to 18 GeV. To accelerate leptons to 20 GeV at least 25 MV are needed in order to compensate for the losses due to synchrotron radiation (20 MV per turn) as well as parasitic mode losses and to guarantee a sufficiently large bucket area. Fortunately, the superconducting 350 MHz cavity which had been installed in the SPS for test purposes could be used when it was necessary to reach the maximum energy [6]. Finally a 100 MHz cavity system was tried out to capture bunches with a length of 6 ns, i.e. double of the bunch length for normal operation. The voltage of the 100 MHz system was sufficient to accelerate the bunches to about 6 GeV. At this energy the bunch length decreased to a value which allowed the capture and further acceleration to 18 GeV with the 200 MHz standing wave cavity system.

### 5. Extraction

For both electrons and positrons the extraction kickers were commissioned at an energy of 20 GeV. For positrons the same channel is used as for the extraction of protons and the injection of electrons. As already mentioned, the voltage of the electrostatic septum is set for the extraction of 450 GeV protons. In order to extract the positrons at 20 GeV a closed orbit bump was required. The electrostatic septa were protected against synchrotron radiation by movable screens to avoid sparking due to ionisation. These screens were moved out automatically during proton extraction. For the beam profile monitors in the extraction channel special care

had to be taken to discriminate the signal due to the synchrotron radiation coming from the circulating beam.

For positrons the transfer channel to LEP was commissioned during the LEP injection tests and its performance was as expected [7].

### 6. Beam Monitoring

The transverse dimensions of the lepton bunches were measured with wire scanners especially equipped in order to measure lepton beam profiles [8]. To measure the horizontal beam size two wire scanners were used, one in-

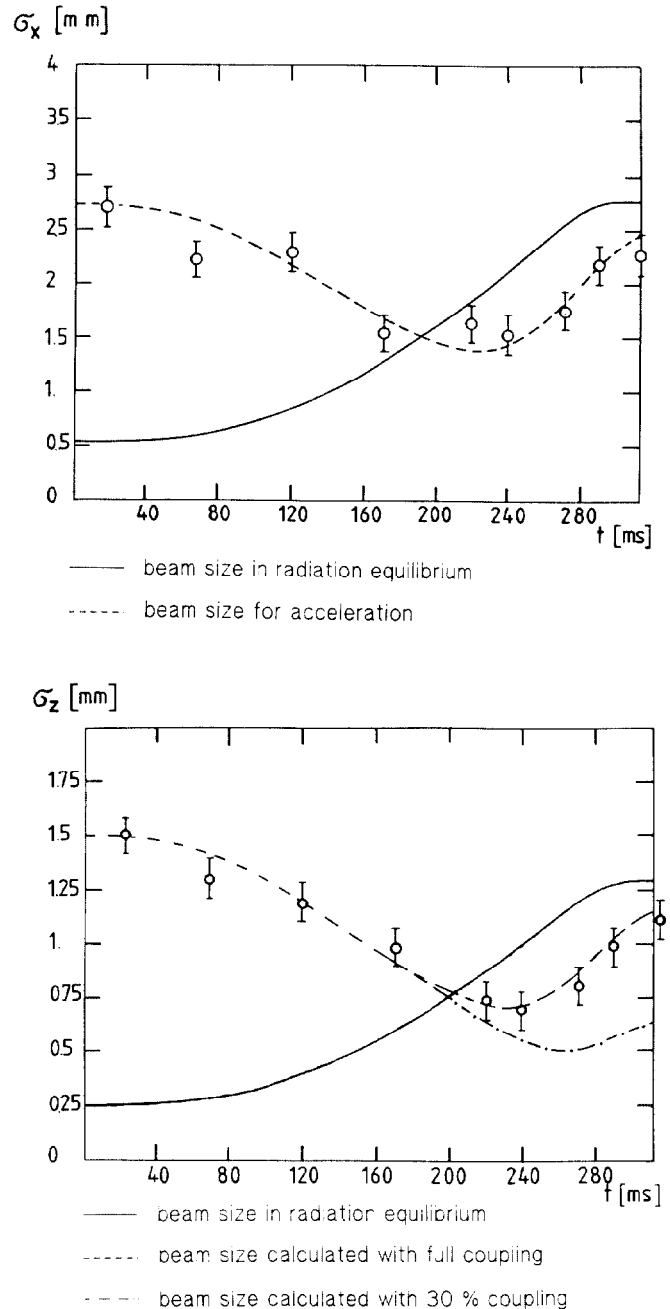


Fig.2) Beam sizes during acceleration.

stalled in a dispersion free region, the other at a position with high dispersion. This allowed the measurement of the momentum spread of the particles in the bunch : the beam size at a position with dispersion is given by:

$$\sigma = \sqrt{\sigma_x^2 + \sigma_{\delta p/p}^2}$$

with  $\sigma_x = \sqrt{\beta_x \epsilon_x}$ ,  $\beta$ ...Beta,  $\epsilon$ ...emittance

and  $\sigma_{\delta p/p} = \sqrt{D^2 \delta p/p}$ ,  $D$ ...Dispersion,  $\delta p/p$  momentum spread

The emittance  $\epsilon_x$  is known from the beam size measured at zero dispersion. Another measurement yields the beam size at the position with non zero dispersion and the momentum spread can be calculated. The dynamic behaviour of the bunches could also be observed by using the synchrotron light detector which is installed for nondestructive measurements of proton or antiproton emittances during collider operation.

## 7. Cycle optimization

A substantial part of the lepton studies was dedicated to the adjustment of the basic machine parameters, like closed orbit, betatron tunes and chromaticity. These adjustments were very critical, mainly because the injection energy of 3.5 GeV is very low compared to the maximum energy of the SPS. For instance, the current in the bending magnets, which reaches 6000 A at the maximum energy, is only 37 A at 3.5 GeV and must be controlled to a precision of about 10 mA. The natural chromaticity is modified by two effects : the remanent sextupole fields in the dipoles and the sextupole fields generated by eddy currents. Its compensation cannot be done simply by ramping the sextupole current with the beam energy. The current has to follow a complicated path (see Fig.1b). After the optimization a transmission of more than 90 % was achieved for positron bunches of nominal intensity, namely  $0.8 \times 10^{10}$  per bunch.

## 8. Beam dynamics

Bunches with nominal intensity can be comfortably accelerated without approaching the limit for instabilities. The calculated change of the bunch size agrees well with the data obtained from beam measurements (Fig.2). The decrease of the bunch size is caused by the acceleration process. At higher energies the time for damping by synchrotron radiation is reduced (e.g. for 3.5 GeV the damping time is about 8 s, at 15 GeV about 100 ms) and the bunch size approaches the size given by the equilibrium between synchrotron radiation damping and excitation.

At the moment of extraction the emittances for the horizontal and vertical plane are similar (see table 1). This indicates the existence of a large coupling between both planes. This coupling is probably due to an insufficient control of the tunes at the end of the energy ramp, where the working point may cross the coupling resonances. The magnet currents are ramped with a speed corresponding to 90 GeV/s. At the end of the ramp the currents stop ramping within 30 ms, during which they cannot be controlled accurately.

The studies performed to understand the possible limitations of the bunch current are published in [9]. The ultimate limit of the bunch intensities is the transverse beam-break-up instability at injection energy. Table 2 gives an overview of the measured thresholds for different bunch lengths. For LEP injection it was decided to work with a bunch length of 3 ns ( $4 \sigma$ ) giving a threshold of about  $2 \times 10^{10}$  particles per bunch. These measurements were compared with computer simulations giving a refined estimate of the high frequency coupling impedance of the SPS [10].

Table 2 : Stability limit as a function of bunch length

bunch length	$\frac{\sigma_E}{E}$	$I_{lim.}$
2.1 ns	$.7 \times 10^{-3}$	$1.3 \times 10^{10}$
2.9 ns	$1.0 \times 10^{-3}$	$2.5 \times 10^{10}$
4.2 ns	$.7 \times 10^{-3}$	$3.0 \times 10^{10}$

If the time for acceleration is big compared to the damping time, the instability threshold increases with increasing energy. This is not the case in the SPS, after the start of acceleration the bunches still may become unstable because their length and their energy spread decrease with increasing energy. If the threshold for the microwave instability is reached first, bunch length and energy spread increase without particle losses pushing the threshold for transverse instability to higher values. If the threshold for transverse instability is reached first, part of the bunch is lost. Both cases were observed in the SPS. By keeping the bunches artificially long through RF shaking the stability could be increased.

## 9. Summary and Outlook

The SPS is well prepared for the start of the LEP injection in July 1989. The design parameters were achieved, in particular the intensity of the bunches which can be accelerated is well above the design goal. A high luminosity version of LEP currently under study [11] requires the beam intensity to increase by about one order of magnitude. To keep the filling time within acceptable limits, the acceleration of bunches with an intensity above, say,  $3 \times 10^{10}$  will be desired. This requires the injection of bunches of at least 6 ns length. It has to be further investigated if such bunches can be accelerated in the SPS and captured with the LEP RF system.

## 10. Acknowledgement

The whole project of the commissioning of the SPS with leptons was a major effort to which all groups in the SPS contributed. It is impossible to give all the names, but we like to thank all colleagues involved in this project, not only for their contributions, but also for the positive spirit in which the presented results were achieved.

## 11. References

- [1] The SPS Lepton commissioning team, Commissioning of the SPS as LEP Injector, European.Par.Acc.Conf, Rome 7-11 June, 1988
- [2] E.Brouzet, SPS Lepton Performance in 1988 and expectations for 1989, contrib. to LEP injection tests report.
- [3] The LEP injector study group, The LEP injector chain, CERN-SPS/83-26
- [4] W.Herr, T.Limberg, J.Miles, R.Schmidt, A new closed orbit correction procedure for the CERN-SPS, these proceedings.
- [5] P.Faugeras et al., Installation and Operation of the new RF system for Lepton acceleration in the CERN-SPS, these proceedings.
- [6] D.Boussard, Long term test of a LEP prototype superconducting cavity in the CERN-SPS, these proceedings
- [7] N.Siegel, CERN-SPS/ABT-xx to be published
- [8] A.Burns et al., Wire scanner news in the CERN-SPS, these proceedings
- [9] D.Brandt et al., Beam dynamics effects in the CERN SPS used as a Lepton accelerator, these proceedings
- [10] D.Brandt, SPS/AMS-Note 88-15
- [11] J.Jowett, More bunches in LEP, these proceedings.