Injection and Transport of Beams of Positrons into and through an Octant of LEP

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Abstract In July 1988 the first successful injection and transport of a beam of positrons at ~ 18 GeV through the first completed octant of LEP was achieved on the 'first shot'. Subsequently, many beam tests were performed on various LEP hardware and measurements made on the optics parameters. Detailed analyses are given on the betatron phase advance per cell for several optics configurations, the transverse beam acceptance, the betatron parameters (amplitude function, coupling, transfer matrices etc.), and the magnetic reproducibility. The injection errors, and the momentum deviation were measured by fitting a betatron trajectory through the position monitor readings. Following correction of these errors the measured residual deviations were used to estimate alignment errors. These turned out to be significantly smaller than expected. The betatron phase advances in the arc were determined from a difference measurement of trajectories obtained with two opposite settings of single corrector magnets. This showed a slight (but easily correctable) phase difference between the horizontal and vertical planes. These injection tests have proved extremely useful for the preparation of the ultimate commissioning of LEP, foreseen for July 1989.

1 Introduction

One of the principal objectives of the program was to make a full installation of $\frac{1}{8}$ of LEP and to check out all systems in an operational environment. During the period leading up to the test with beam, individual systems were commissioned and tested as soon as the equipment was installed and available. The culmination of the Injection Test Program was the injection and transport of positron beams through the octant. We will describe below the results of this work which was performed by many people spread across several divisions of CERN.

2 Status of the Octant for the Test

To deliver positrons to LEP for the test, the whole of the injector chain was exercised, [1]. A single extracted pulse (containing from 1 to 4 bunches) was available from the SPS. The transfer line for positrons was tested earlier in the year but installation in the LEP tunnel prohibited the transport of particles along its entire length.

The LEP magnets and vacuum chamber [2] were all installed but the sextupoles were not powered. The vacuum system had been baked-out and commissioned as it was installed. Some changes in the connections of magnets to the power converters was required: the F and D quadrupoles were connected in series, only $\frac{1}{2}$ of each insertion quadrupole chain was installed, and only 1 of the 2 converters for the main dipoles was used. In addition to the unusual loads for the power converters, they were working below their nominal lower limit which corresponds to 20 GeV.

The Beam Instrumentation available comprised 2 Split-Foil Monitors (in the injection region), 3 luminescent screens (2 close to injection, 1 at the end of the octant), 1 beam stopper and 14 beam position monitors (through the first half of the octant).

Control was through Apollo and PC_AT consoles connected via Token Rings and bridges to Process Control Assemblies (PCA) located at points 1 and 2 of LEP. The PCA's (PC_AT's) were connected by mil-1553 links to the micro-processor equipment controllers (power converters, vacuum, beam instrumentation etc.). Synchronisation for the beam instrumentation was achieved through a special hardwired system. The injection elements were controlled from the SPS control system.

The software was as close as possible to the final product, but in general lacked the man-machine-interface. The data (optical configurations, calibrations, network addresses) were extracted in the normal way from remote Oracle databases and loaded into the data structures in the control system.

3 Sequence of Events during the Test

Following a cold check-out of LEP on 11th July, preparations for injection were started on the 12th. The following are the significant entries from the log for the 12th.

13h00 Tunnel Search Started
16h00 LEP ready for Beam
23h15 Beam Centred in Injection Channel
23h40 LEP magnets re-cycled to 17.71 GeV
23h55 Beam traverses complete octant

The whole Injection Test lasted for ~ 100 hours and following the initial success, a detailed program of studies was carried out and this is reported below.

4 Beam optics measurements

The beam went through the transfer line (TI-18), which contains horizontal and vertical bends, without loss or instability and arrived at the LEP injection point. Detailed measurements showed that all of the hardware and software of TI-18 behaved well and that the optical behaviour, including the emittance exchange scheme, was as expected.

Using the beam position monitors in the first half of the octant and the fluoresent screen at the end of the octant with the horizontal and vertical corrector magnets, some beam optics measurements were carried out.

After the beam was injected and approximately centred on the last two injection screens with the septum and the third kicker magnet, the residual distortion of the trajectory was measured in a few position monitors. Using an application program the energy off-set and the amplitude and phase of the beginning betatron oscillation were determined. First, the energy setting of LEP was adjusted to that of the SPS. Then the betatron oscillation was corrected using a pair of corrector magnets in each plane.

The beam optics was checked mainly with so-called trajectory difference measurements. One corrector magnet was used to make first a positive and then a negative deflecting angle. For both conditions the beam trajectory downstream of the correc-

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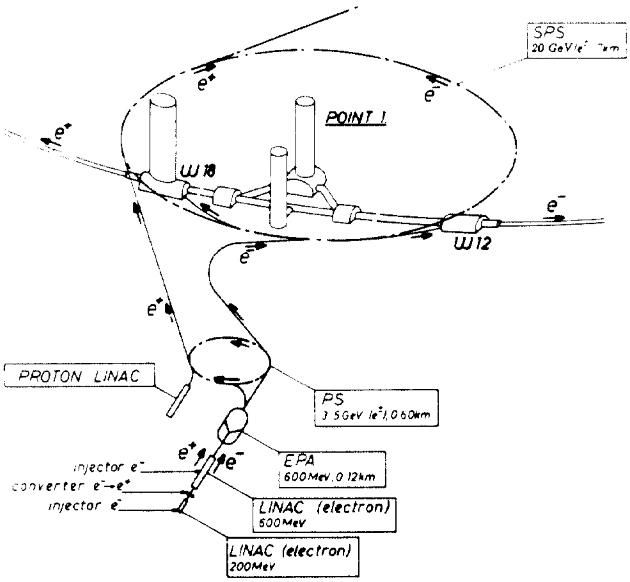

Figure 1: Layout of the injector chain and the LEP octant

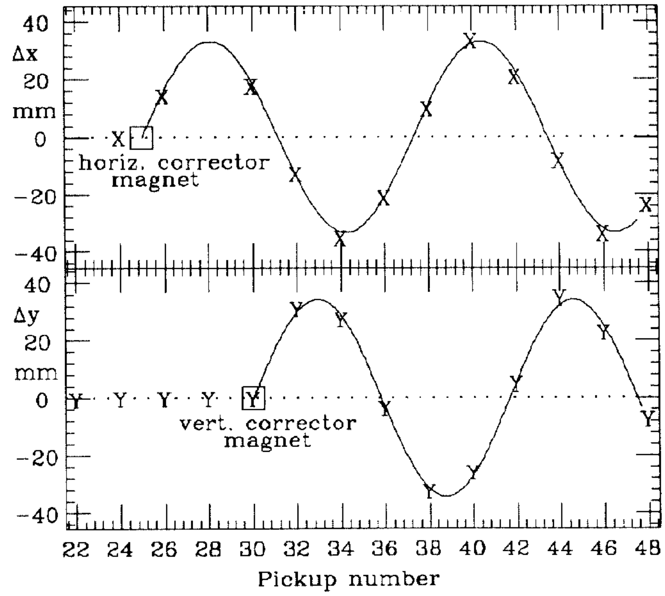

Figure 2: Trajectory difference measurements

tor was measured and the difference calculated. Since all the position monitors are located at the same value of the beta function, a sine function with origin at the corrector can be fitted through the measured position differences. The result of such measurements in the two planes is shown in Fig. 2. This method proved to be very accurate because the monitors worked well and the beam injected from the SPS had very small variations in angle and energy. The measured points were analysed using a least square fit and with a cross correlation. The results obtained from many injections were very reproducible and practically the same for the two fitting methods. The phase advances per cell for the two planes were

$$\mu_x = 58.5^0 \pm 0.1^0 \ , \ \mu_y = 61.8^0 \pm 0.2^0.$$

The slight difference from the nominal phase advance of 60^0 in both planes will be discussed later. The amplitude of the fitted curve was used later to check the calibration of the corrector magnets and the monitor readings.

A pair of horizontal and vertical correctors, separated by 60^0 phase advance, were then used to probe the aperture available to the beam. The screen at the end of the octant was used to determine the deflection necessary to scrape about half of the beam. The obtained apertures at the maximum beta values were

$$\Delta x \sim \pm 58mm \ , \ \Delta y \sim \pm 33mm$$

which is in very good agreement with the half diameters of the elliptical vacuum chamber of 65 mm and 35 mm. This result indicates that there are no large trajectory distortions in the second half of the octant where no beam position measurements are available.

To check the optics in this second half of the octant, trajectory difference measurements were carried out using the screen at the end to measure the beam position change x_1, for a given angle change x'_0 at the corrector. The experiment measures the element R_{12} of the transfer matrix between corrector and screen

$$\begin{pmatrix} x_1 \\ x'_1 \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \cdot \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix} .$$

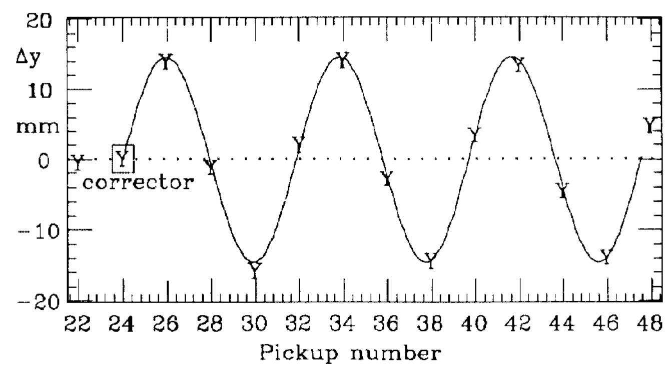

Figure 3: Trajectory difference for the 90^0 lattice

This matrix element was measured for most of the correctors and compared with the calculated values. For both planes the rms. discrepancies were smaller than 10% of the maximum value of this matrix element, which is satisfactory considering the limited accuracy with which the beam position could be measured from the television monitor showing the screen.

The off-axis injection, which will be used later for accumulation, was tried out successfully by choosing the proper injection angle. For future operation of LEP at higher energies an optics with 90^0 phase advance is planned. This was tried out during the test and gave the expected parameters.

5 Equipment Tests with the Beam

After correction of the injected trajectory with a pair of corrector magnets at the beginning of the octant, the residual deviations observed in the position monitors located further downstream were used to estimate the combined error of quadrupole alignment and position monitor reading. It was observed that all the monitors had the same systematic off-set of 2 mm in the vertical reading which is so far not completely explained. After subtracting this common off-set the rms. values for the alignment and reading errors were about 0.25 mm in the horizontal and 0.12 mm in the vertical plane. Both are smaller than the specified value of 0.3 mm.

The amplitudes obtained by fitting a sine function through trajectory difference measurements gave a combined calibration of position monitors and corrector magnets. Assuming the expected sensitivity of the monitor one finds a calibration for the standard horizontal corrector of 0.21 mrad/A which is in very good agreement with the expected value of 0.214 mrad/A. In the vertical plane the measurements were slightly less accurate. For large amplitude trajectories, small non-linearities could be observed in some monitors.

The split foil monitors and the current transformer were also tested with the beam to check the timing and the intensity dependence.

Some time was spent measuring the magnetic properties of the dipole magnets by cycling them on different hysteresis loops. The dipole and quadrupole fields were monitored by observing the energy deviation of the beam and the phase advances per cell. The observed behavior corresponded closely to the expectations [3] as far as relative measurements are concerned. However, there was always a constant slight error in the betatron phase advance as mentioned before. This was later explained by the presence of a minute amount of ferromagnetic material in the bond between the lead and the aluminum of the vacuum chamber. Its effect is being corrected with small shims at the end of the dipole magnets.

In the injection test the beam went through some RF-cavities before reaching the screen at the beam stopper. The single traversal of the bunches excited some parasitic modes in the cavities and these were observed with a spectrum analyser. To see the transverse modes the beam had to be displaced from the axis of the cavities with a corrector magnet. Strengths and frequencies of the parasitic modes agreed roughly with measurements made in the laboratory.

The pressure of the vacuum system was in the 10^{-11} Torr range or better for most of the octant. As expected for the low average intensity, no outgassing caused by the beam could be observed.

Radiation detectors were installed in several strategic locations in the octant. The measured doses were in agreement with expectations [4].

6 Conclusion

The injection test was successful. The fact that the beam went through the whole octant on the first attempt without correction indicated that the magnets, power supply and the alignment were correct. Later detailed measurements showed that practically all components operated to specification or better. The only error found was the slight deviation in the phase advance due to the presence of a minute amount of ferromagnetic material. Thanks to the measurements done during the test, this could be corrected before the final commissioning of LEP. The optics of the machine behaved very well and many measurements could be carried out. In addition, the off-axis injection and the 90^0 lattice were successfully tried out.

References

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[3] J. Billan et al., contribution O8 to this conference.

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