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INJECTION AND ACCELERATION WITH PHYSICS OPTICS IN LEP

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Abstract

Up to now injection into LEP has been done using a dedicated injection optics, with a vertical β^*_v = 21 cm. After accelerating to higher energies a progressive optics change is made with beam to the 'physics' optics, where β^*_v = 5 cm. The use of synchrotron injection as the normal means of accumulation in LEP has opened up the possibility of injecting directly into the 'physics' optics. This has many advantages ranging from an easier operation, including a faster turnaround from injection to physics conditions, to allowing more flexibility in the optics design and matching. Results from machine development sessions are presented showing that there is no fundamental reason for not implementing this scheme. Potential drawbacks and limitations, especially for the maximum accumulated beam current are, however, discussed.

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INJECTION AND ACCELERATION WITH PHYSICS OPTICS IN LEP

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ABSTRACT

Up to now injection into LEP has been done using a dedicated injection optics, with a vertical β^*_v = 21 cm. After accelerating to higher energies a progressive optics change is made with beam to the 'physics' optics, where β^*_v = 5 cm. The use of synchrotron injection as the normal means of accumulation in LEP has opened up the possibility of injecting directly into the 'physics' optics. This has many advantages ranging from an easier operation, including a faster turnaround from injection to physics conditions, to allowing more flexibility in the optics design and matching. Results from machine development sessions are presented showing that there is no fundamental reason for not implementing this scheme. Potential drawbacks and limitations, especially for the maximum accumulated beam current are, however, discussed.

1. INTRODUCTION

The main reason for the use of a dedicated injection optics in LEP is the difficulty in injecting and accumulating beams with the normal 'physics' optics. In the injection optics the vertical β^*_v is detuned to 21 cm and the maximum β_v in the straight section is around 170 m. For the physics optics the β^*_v is reduced to the nominal value of 5 cm. Here the maximum β_v occurs in the low-beta quadrupoles immediately next to the experiment and is almost 400 m. The horizontal optics is virtually unchanged between the two cases. The vertical beta functions at one side of a LEP experiment are shown in figure 1 for each case.

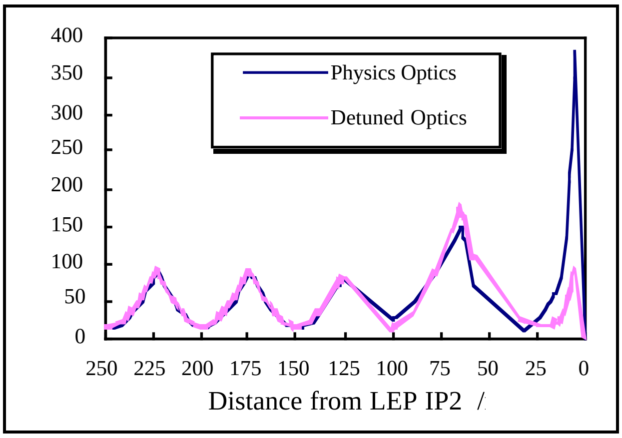

Figure 1 : Vertical Beta Functions for the Physics and Detuned Optics around one low-beta IP in LEP

In LEP, the beam is injected horizontally into the machine. Any residual vertical injection oscillations can therefore be corrected out. In the horizontal plane, however, there will always be some injection oscillations, due to the finite thickness of the injection septum. These can either be in the form of betatron oscillations, or energy oscillations if synchrotron injection is used. Tests, made several years ago, had shown that accumulation into a physics optics was not possible with betatron injection. At the time it was assumed that the large betatron oscillations in the low-beta straight sections caused the injected beam to be lost.

2. WHY BOTHER?

There are several reasons why the use of the same optics for injection and for physics is considered to be desirable. Firstly for ease of operation. For a fixed optics propagation of orbit corrections to high energy has been found to either be as a constant strength kick (for correcting quadrupole mis-alignments), or as a constant field (to correct for the LEP experimental solenoids). However when the optics are changed the propagation of such corrections becomes much more complex. For quadrupole mis-alignments the strength of the corrector should follow the strength of the quadrupole, if the correction is local. If the correction is non-local, or solenoid corrections are involved, then the changing optics means that different correctors might be required, or at least that the strength might change considerably. For this reason the passage through the optics squeeze has always been delicate in LEP.

Additional advantages come from matching considerations. The necessity to detune a given physics optics places constraints on the optics itself. This comes mainly from the requirement that a smooth path exist for all intermediate optics between the two extremes. Finding this path is not always obvious and often results in non-monotonous variations in quadrupole excitation functions. For the normal conducting quadrupoles, hysteresis effects complicate the beam behaviour during the optics change. Figure 2 shows optics change portion of a typical quadrupole strength function used for operation in 1995. The normalised strength of the quadrupole is kept constant during the energy ramp (vector 0 to 205).

When designing a new optics for LEP, many constraints have to be taken into account. These include constraints from the bunch-train bumps [1], coupling and experimental background conditions which are all concentrated in the low-beta insertions. It is proving increasingly difficult to satisfy all the known constraints and still be able to detune the optics to inject at a β^*_v of 21 cm. Removing the need for this de-tuning helps ease the matching process.

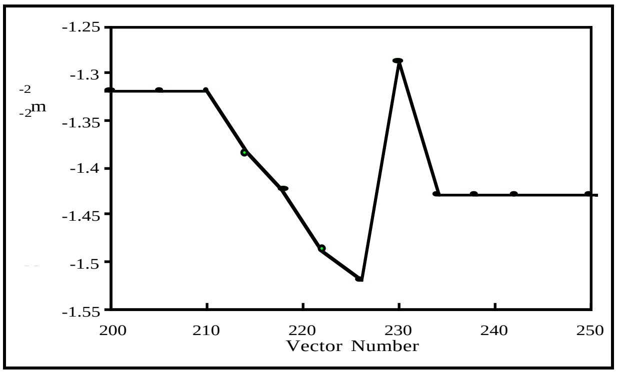

Figure 2 : Typical LEP Insertion Quadrupole Function. Vector Zero Corresponds to Injection. The Squeeze Takes Place (at 45 GeV) Between Vectors 210 and 232.

3. SYNCHROTRON INJECTION

During the last year, LEP has been operated with injection in synchrotron phase space [2] . This mode of operation is characterised by very high injection and accumulation efficiencies and easy operational maintenance. One of the main features of synchrotron injection is the absence of injection oscillations in the straight sections of the machine. The beam is injected with an energy offset ($\Delta P/P$) and adjusted such that it follows the natural closed orbit of a particle having that energy. The injected beam then performs energy oscillations at the synchrotron tune (Q_s), which translate into transverse motion of the beam only in regions where the (horizontal) dispersion is non zero. Typical examples of first turn trajectories for betatron and synchrotron injection are shown in figures 3 and 4 respectively.

In addition to the flat trajectories in the insertions, synchrotron injection offers faster damping and a larger dynamic acceptance than betatron injection. Also, with reduced betatron injection oscillations, a transverse feedback system can work more effectively.

With the reduced oscillations in the straight sections it was decided to try again to inject into the physics optics.

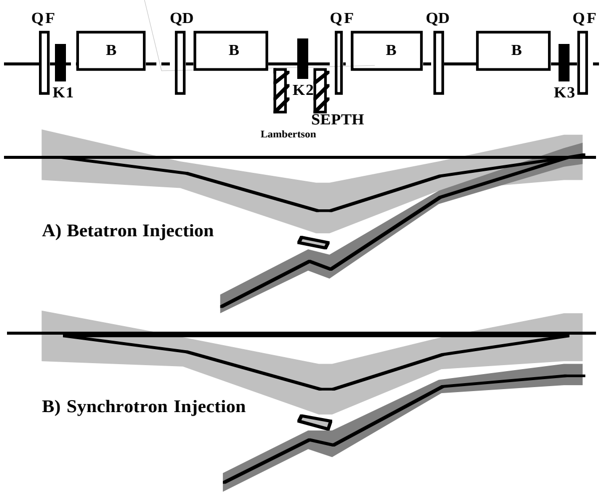

Figure 3 : Comparison Between Injection Point Steering for A) Betatron and B) Synchrotron Injection.

4. RESULTS

Using synchrotron injection beam was successfully injected and accumulated with the squeezed optics. Figure 5 shows the quality of the injection, characterised by the injection efficiency into an empty machine as a function of the energy offset of the injected beam.

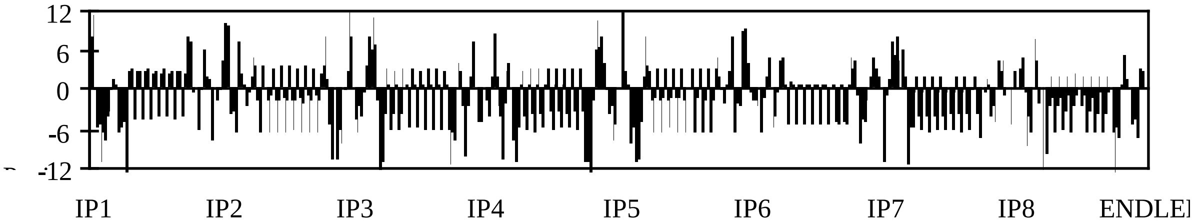

Figure 3: Horizontal First Turn Trajectory for Betatron Injection into LEP.

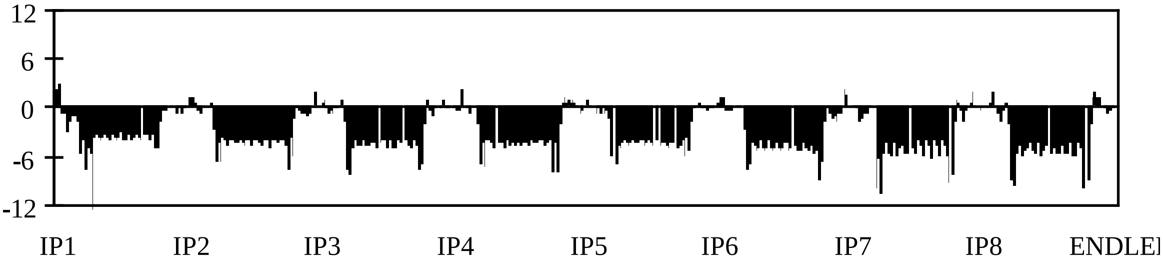

Figure 3 : Horizontal First Turn Trajectory for Synchrotron Injection with $\Delta P/P$ at -0.6%

Curves for the detuned optics, as well as the physics optics are shown. $\Delta P/P = 0$ corresponds to pure betatron injection, below 0.6% a mixture of synchrotron and betatron injection has to be used, due to the finite thickness of the septum. Above 0.6% the betatron oscillations at injection can be completely suppressed and we have pure synchrotron injection.

Both curves show a similar behaviour. At small values of $\Delta P/P$ betatron injection oscillations cannot be completely suppressed and the injection efficiency decreases as the oscillation amplitude increases (lower $\Delta P/P$). In the case of the physics optics this results in the efficiency dropping quickly towards zero at the smallest energy offsets. In figure 5, for the physics optics, the point at a very small $\Delta P/P$ was not obtained as part of the same experiment [3].

The reduction of the injection efficiency at higher values of energy offset comes from the detuning of the optics with momentum, principally driven by the chromatic correction of the machine. The sextupole correction in the physics optics is much stronger and hence the range is much more restricted. The curves of figure 5 have been found to match closely the momentum detuning functions given by MAD [4].

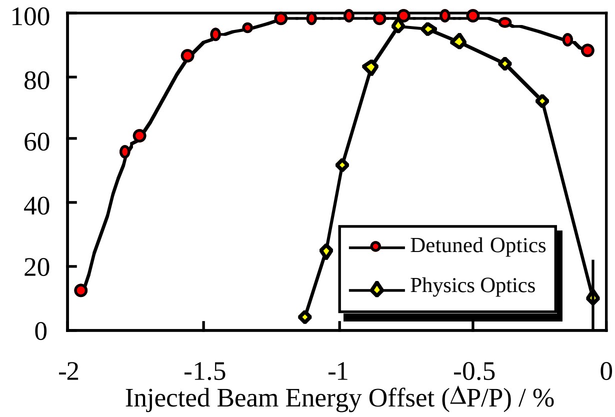

Figure 5: Injection Efficiency (into an Empty Machine) vs. Injected Beam Energy Offset for the physics and Detuned optics.

A peak efficiency in the range 0.6 to 0.8% was found for the physics optics. Using an energy offset in this range tests of accumulation were made with a single beam of positrons. Under similar operational conditions the same bunch current could be accumulated in both the physics and the detuned optics. In both cases the bunch current limitation came from the transverse mode coupling instability (TMCI) and was therefore not connected with the injection process. After switching on the vertical bunch-train separators, both electrons and positrons could be accumulated simultaneously to a moderate intensity of 2 mA total beam current, limited by the time available to complete the machine development session.

Normally the optics change in LEP takes place at 45GeV, after which a second energy ramp takes the beams to the desired physics energy. For injection into physics optics to be acceptable as a potential mode of operation it was necessary to prove that an energy ramp could still be made without significant beam loss. After some optimisation of the orbit correction during the energy ramp the complete 2 mA beam was successfully accelerated to 50 GeV without loss.

5. TRACKING STUDIES

Tracking is routinely used to study the dynamic aperture of LEP. The results from these simulations match the measurements of dynamic aperture for the circulating beam at injection on the detuned optics. Simulations for the squeezed optics show a dynamic aperture which should allow betatron injection to accumulate beams. For both the physics and the detuned optics, the reduction in efficiency at low values of $\Delta P/P$ cannot be explained by the dynamic aperture of the machine. Investigations on this subject are presently in progress.

6. CONCLUSIONS

Injection into the physics optics of LEP has been successfully achieved using synchrotron injection. The reason why it works for synchrotron injection and not for betatron injection is not yet fully understood. More studies will be undertaken during the coming LEP operational period.

The efficiency of injection into the physics optics has been found to be good and no significant difference in the maximum accumulated beam currents have been found. Further studies for the two beam case are needed.

One potential problem for the physics optics is that the range of $\Delta P/P$ for good injection is much more restricted than for the detuned optics case (figure 5). The limit is caused by $\Delta P/P$ detuning. Optimisation of the Q vs. $\Delta P/P$ curve is now a standard part of the matching process.

As a consequence of the present study the optics at injection will be changed for the next LEP run. Instead of injecting into a detuned optics having a $\beta^*_v = 21$ cm, an intermediate optics with $\beta^*_v = 10$ cm will be used. With further studies on injection into squeezed optics it is hoped that we can make injection into the full physics optics operational in the near future.

7. REFERENCES

[1] Wyss C. ed., LEP Design Report, Vol. III : LEP 2, CERN AC 96-01(LEP2).

[2] Collier P., *'Synchrotron Phase Space Injection into LEP.'*, Proceedings, PAC-95 Conference, Dallas.

[3] Koutchouk J.P., private communication.

[4] MAD - Methodical Accelerator Design Program, CERN SL/90-13(AP), Rev. 4, 1995.