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# LEP INJECTION

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## Summary and Introduction

Studies have commenced of an injector for LEP[1], the CERN 100 GeV $e^+$-$e^-$ storage ring design. The minimum energy for injection is 20 GeV, and a synchrotron injector is chosen in preference to a linac for cost reasons and to obtain faster ring filling. Factors involved in the design of the injector synchrotron are discussed and 2 alternative schemes are outlined for the filling of the 32 $e^+$ and 32 $e^-$ LEP bunches.

## Synchrotron Design

The lowest operating energy for LEP is 20 GeV. This energy is provisionally chosen as the injection energy after considerations of cost and complexities in the injection process. The complexities result from the long betatron damping time in LEP at 20 GeV and also from the large length of RF structure (2800 m) which gives pronounced beam loading effects.

During injection into LEP, particles have large betatron amplitudes and it is important to limit the input momentum spread, $\Delta p/p$. For an injector synchrotron of 20 GeV the bending radius must be $\approx$ 160 m to give an output $(\Delta p/p)$ of about 0.25% ($2\sigma$). Even if there is initial matching of the longitudinal motion between the injector and LEP, there will be some mismatch towards the end of the injection process as the stored beam begins to load heavily the accelerating cavities. The growth in $(\Delta p/p)$ of the injected beam must be limited to < ± 0.75% as it is difficult to provide stable betatron motion in LEP over a momentum range larger than this value. Bunch widening effects at injection into LEP may set limits for the luminosity and it is best to operate with the minimum length of RF structure until the highest LEP energies are required ('missing RF structure' operation).

Two lattice designs have been evaluated for the injector synchrotron, each with 4 superperiods. The first has hybrid unit cells containing both combined function and zero gradient magnets as illustrated in Figure 1. The second consists of pure separated function cells. In both lattices, long straight sections are provided by omitting dipoles from 4 consecutive cells per superperiod to obtain $2\pi$ insertions (since the betatron phase shift per cell is designed to be $\pi/2$).

Parameters for the hybrid lattice are given in Table 1. Each superperiod has 9 normal cells and a 4 cell insertion. To overcome the natural radial betatron antidamping, there are different equilibrium fields in the 3 types of magnets (BD/B = 1.3 and BF/B = 0.7), to give a $J_x$ value of 0.9. Figure 2 shows the variation of radial emittance versus time as a function of $J_x$ for 50 Hz, biased-sinusoid operation of the synchrotron, with an injection energy of 380 MeV and an injected emittance of 10 mm mrad. The alternative separated function lattice has 19 normal cells and a 4 cell insertion in each superperiod; the bending radius is unchanged but the mean radius is increased from 221 m to 273 m and the $\gamma_t$ value from 11.88 to 19.63. Table 2 gives some details.

The first lattice gave a cheaper machine and was initially favoured. However, recent estimates of beam loading at injection in LEP show that a higher $\gamma_t$, as provided by the second lattice, is important. The second lattice also has a smaller output emittance.

## LEP Filling Schemes/Times

The maximum LEP intensity is for 50 GeV operation with 3.3 $10^{13}$ particles required per beam and with 32 bunches per beam. The initial stage of the injection scheme is a 380 MeV $e^-$ linac which is followed by a positron convertor and a 380 MeV $e^+$ linac. Two alternative filling schemes are discussed separately.

The betatron damping time in LEP at 20 GeV is $\approx$ 3 s (no wiggler magnets[2]), $\approx$ 0.95 s (with luminosity wigglers) and $\approx$ 0.68 s (with luminosity and low dispersion point wigglers). Assuming: the value of 0.68 s for the damping time, an electron linac providing 1 A peak current, an $e^+/e^-$ conversion factor 8 $10^{-3}$, the acceleration of 32 equally spaced $e^+$ bunches in the injector synchrotron, a ratio of ring circumference between the injector and LEP of 1/n (n integral = 37), repeated filling of 32 x n bunches in LEP, 50 Hz operation of the injector synchrotron, a modified Tigner scheme[3] for compressing the 32 x n $e^+$ LEP bunches to 32 with appropriate bunch slippage, single filling of $e^-$ bunches once per damping time and 50% overall injection efficiency; there results a 12 min filling time to reach the maximum LEP intensity. The lengths of the transfer lines between the injector and LEP must be such as to allow bunch slippages of ± 1.

In the second filling scheme, the $e^+$ and $e^-$ linac energies are increased to 650 MeV and a 650 MeV $e^+$ storage ring is introduced between the $e^+$ linac and the injector synchrotron. A similar scheme has already been considered for use with PETRA[4]. The storage ring must have a damping time of $\approx$ 40 ms. A possible set of parameters for the storage ring are bending radius 1.6 m, mean radius 13 m, and number of bunches 9. The linacs pulse at 25 Hz, with a peak $e^-$ current of 4 A. This gives the same filling time as in the first scheme. It is possible to have a reduced cycling rate of the injector synchrotron (10 Hz) and a longer damping time in LEP.

## Comparison with a 20 GeV Linac

The cost of a 20 GeV, 50 Hz linac injector is approximately double that of the proposed synchrotron system. In the filling process it would be necessary to use single S-band linac bunches at a peak current level $\approx$ 100 times that envisaged for the filling of PEP by the SLAC linac (but at low average current).

## References

1. R Billinge et al 'Design Concept for a 100 GeV $e^+$-$e^-$ Storage Ring.' Proceedings of 1977 Particle Accelerator Conference, Chicago.
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3. M Tigner 'Improved Method for Filling an Electron Storage Ring from a Synchrotron.' Particle Accelerators Vol 6 No. 4 (1975).
4. G Hemmie, A Febel and G Strange. Discussions at ECAS $e^+$-$e^-$ Study, DESY Feb. 1977.

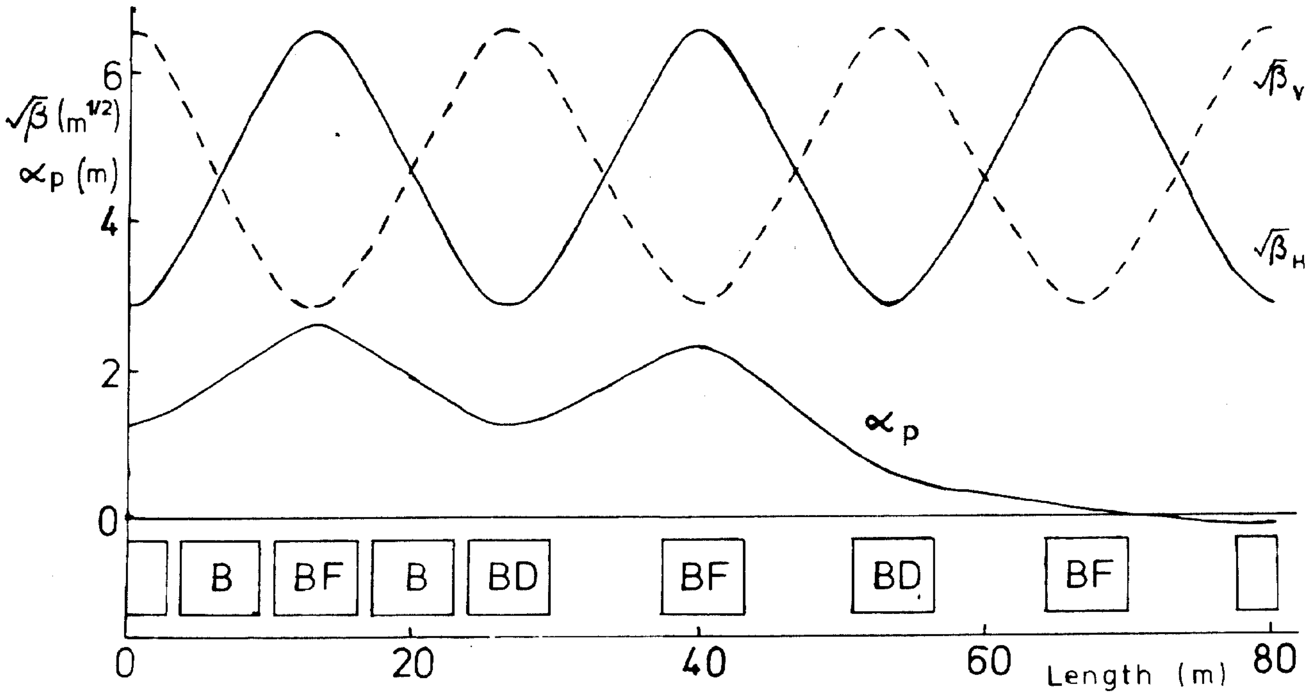


Figure 1 Dynamic Functions for the unit cell and half insertion of Lattice 1.

Table 1 Parameters for Lattice 1

| | | |
|---|---|---|
| Peak energy | (GeV) | 20 |
| Mean radius | (m) | 221.35 |
| Dipole bending radius | (m) | 159.3 |
| No of superperiods | | 4 |
| Horizontal, vertical betatron Q value | | 12.85 |
| Value of gamma at transition, $\gamma_t$ | | 11.88 |
| Peak energy loss per turn | (MeV) | 88.9 |
| R.F harmonic number | | 1664 |
| R.F frequency | (MHz) | 358.68 |
| R.F phase angle at 20 GeV | (deg) | 50 |
| Peak R.F Voltage at 20 GeV | (MV) | 116 |
| Total R.F structure length | (m) | 152 |
| Transit-time corrected shunt impedance | (MΩ/m) | 19 |
| Peak R.F structure power | (MW) | 4.66 |
| Modified radial damping partition no, $J_x$ | | 0.9 |
| Revolution time | (μs) | 4.64 |
| Emittance at peak energy (2σ) | (mm mrad) | 2.3 |

Table 2 Modifications for Lattice 2

| | | |
|---|---|---|
| Mean radius | (m) | 273.0 |
| Dipole bending radius | (m) | 160.0 |
| Horizontal, vertical betatron Q value | | 23.25 |
| Value of gamma at transition, $\gamma_t$ | | 19.63 |
| R.F harmonic number | | 2048 |
| Radial damping partition number, $J_x$ | | 1.0 |
| Revolution time | (μs) | 5.72 |
| Emittance at peak energy (2σ) | (mm mrad) | 0.6 |

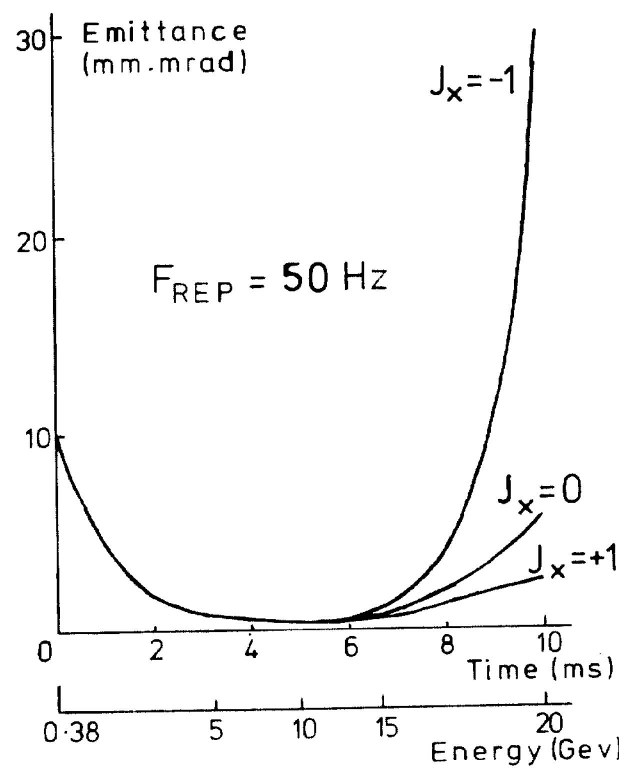


Figure 2 Emittance vs time in Lattice 1.