THE BEAM CUTTING EJECTION FROM THE CERN ELECTRON-POSITRON ACCUMULATOR

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Abstract

Beam cutting ejection permits filling of the LEP by several batch transfers of 8 positron bunches. The charge per transferred bunch is thereby kept low, thus reducing the possibility of instabilities in the injector chain. Suitable arrangement of transfer cycles could then boost the future LEP filling rate.

The beam cutting ejection has been successfully tested in EPA. The concept and experimental results are reported.

Introduction

The LEP injector chain [1] is composed of a 600 MeV Linear accelerator, a 600 MeV Electron Positron Accumulator (EPA), the 28 GeV Proton Synchrotron (CPS) used up to 3.5 GeV/c, and the 400 GeV proton synchrotron (SPS) providing final acceleration to 20 GeV, and transfer to the LEP. Bunch cutting is one of the possible ejection modes from EPA to the PS.

One of the most important limiting factors in the LEP accumulation rate are the SPS instability thresholds of longitudinal and transverse turbulence. As these thresholds cannot be calculated accurately, possible variant injector schemes have had to be planned. The EPA extraction scheme is designed for transferring the positrons in either 2 x 4 bunches or 2 x 8 bunches to the CPS per SPS supercycle. In the first case, the 8 bunches accumulated in EPA are ejected in 2 batches each consisting of 4 bunches. In the second case, the bunches are cut in half by an electrostatic septum producing 2 batches of 8 bunches.The bunch current can thus be modulated by a factor of 2 while still transferring the whole beam accumulated in EPA during every injector chain supercycle.

For simplicity of operation, the start-up of LEP was planned with 4 bunch transfers, implying that bunch cutting was not initially required. During the running-in, higher threshold of instabilities than expected have been found allowing retention of this 4 bunch scheme for physics runs. However, it was seen that the LEP filling rate could be increased over its nominal value considerably, by use of an 8 bunch scheme with bunch cutting [3]. The results of the preliminary tests performed in Autumn 1988 were briefly reported in [2]. Experiments are described in full detail in [4].

Beam cutting ejection principle

The beam cutting ejection of EPA is an extension of the normal e^+, e^- 8 bunch ejection facility (Fig. 1). It shares the fast kickers, KFE49 and KFE51, the ejection septum magnet SMH00 and its slow closed orbit bump. The beam cutting device SEH21, an electrostatic septum dipole, is placed in the EPA injection region and can use the injection slow bump BSW32 and BSW12 in reverse polarity. An additional pair of pulsed quadrupoles QCB31 and QCB11, encloses the cutting septum.

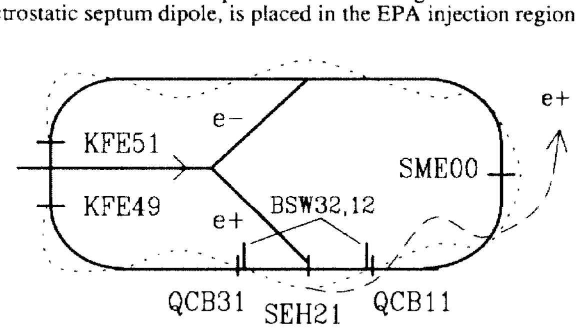

Fig. 1. Schematic cutting ejection layout in EPA.

In a first approximation the lattice functions of EPA can be considered as regular, providing equal Twiss parameters at all equipment locations. Fig. 2 shows horizontal phase relations and phase space trajectories (without slow orbit bumps). The quadrupoles QCB31 and QCB11 have equal strength and, due to the phase advance of π, form a local β bump. The overall machine tune is (ideally) not perturbed when these quadrupoles are pulsed, but the enclosed Twiss parameters are modified such that the beam envelope widens at the electrostatic septum. With the cutting septum at $\pi/2$ distance from the quadrupoles one can derive the modified β-function as $\bar{\beta}_{SEH} = \beta_o[1 + (K\beta_o)^2]$, where $\beta_o \approx 14$ m is the non perturbed β-function and $K[m^{-1}]$ the normalised integrated quadrupole strength.

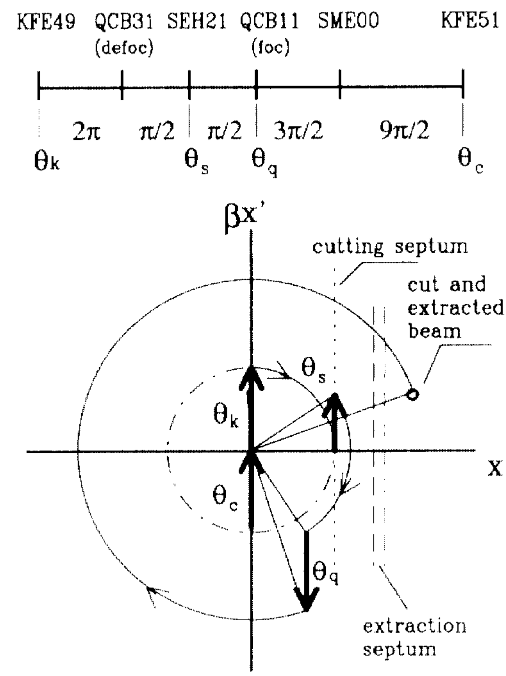

Fig. 2. Horizontal phase plane trajectories of cutting ejection.

The fast kicker KFE49 directs individual bunches onto the electrostatic septum dipole SEH21 where the bunch is cut into halves. The part which experiences the electric field passes off-axis through the downstream quadrupole QCB11, where it receives an additional kick $\theta_q = K\theta_s\beta_o$, ($\theta_s$ = deflection strength of cutting septum), such that after further 3 $\pi/2$ of phase advance it can get into the ejection septum magnet to be extracted from EPA (Fig. 2).

With 2π phase advance between the fast kicker and the quadrupole insertion one finds that the normal betatron trajectory is ideally not perturbed, neither inside nor outside the insertion.

The rest of the bunch, not seeing the cutter field, passes through the quadrupoles on-axis and follows its normal fast ejection trajectory. The closed orbit position at the ejection magnet SME00 is now chosen such that the oscillation amplitude is insufficient even to touch the septum. The beam stays in the machine and after completing one turn, the coherent oscillation is cancelled by the second kicker KFE51.

The separation between direct and cut beam is easily calculated for the assumed ideal conditions and becomes

$$\begin{pmatrix}\Delta x\\ \Delta x'\end{pmatrix}=\begin{pmatrix}-\theta_s\cdot K\beta_o^2\\ \theta_s\end{pmatrix}$$

The cutting septum deflection strength follows then as

$$\theta_s=\frac{n\cdot\sqrt{\varepsilon_H\beta_o}+d}{K\beta_o^2}$$

where $\varepsilon_H(\pm 1\sigma)$ = horizontal equilibrium emittance

d = magnetic ejection septum width.

n is the full beam width in units of σ. The fast kicker strength becomes

$$\theta_K=\frac{n}{2\beta_o}\left(\overline{\beta}\varepsilon_H\right)^{1/2}\text{ for 50\% beam cutting.}$$

Basing calculations on a beam width of 10 σ (n = 10) is sufficient to avoid particle losses when placing the beam at the septum. However, imperfect kick cancellation of the remaining beam will increase its apparent size and has to be taken into account (recommended margin : add 50% of calculated strength). It is worthwhile to note that the cutting septum as well as the other ejection equipment sits in a place with zero dispersion which makes the process insensitive against small momentum changes of the machine.

The fraction p of the beam lost on the cutting septum is proportional to its effective width s and inversely proportional to the beam width, blown-up by the modified β–function $\overline{\beta}$ at this location. For a Gaussian distribution and 50% cutting ratio one gets approximately

$$p=s\cdot(2\pi\varepsilon_H\overline{\beta})^{-1/2}$$

With s ≈ 0.06 mm and β ≈ 40 m losses are of the order of 1.2%.

Experimental results

Machine and equipment parameters

EPA:

Betatron tunes	$Q_H = 4.58$; $Q_v = 4.36$
Energy	E = 500 MeV
Hor. equil. emittance	ε_H (± 1 σ) = 0.10 π.mm.mrad.
Particles/bunch	$2.5\cdot 10^{10} e^+$
Damping constants	τ_x= 60 ms; τ_E = 120 ms;

Fast kickers [5] :

Deflection strength	θ_K = 1.5 mrad
Pulse shape	see Fig. 3

Electrostatic septum deflector :

Deflection angle	θ_s = 0.85 mrad (30 kV)
Nominal strength	60 kV over 2 cm gap; septum length 0.25 m

β-bump quadrupoles :

Strength $$|K|=\frac{1}{B\rho}\frac{\partial B}{\partial x}\ell_Q=0.1m^{-1}$$

Half sine current pulse with 5 ms base width.

Cancellation of fast kick

Fig. 3 shows a typical kick cancellation of the circulating beam together with the kicker pulse shape. The slow orbit bump at the cutting septum was not pulsed here.

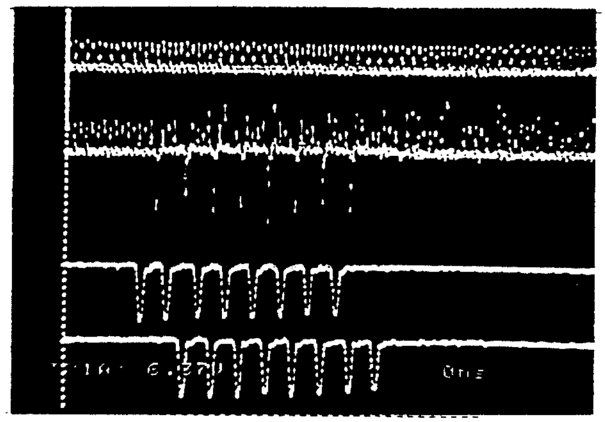

Fig. 3. Cancellation of full beam oscillations.

From top to bottom:
- Sum pick-up in ring
- Horizontal position
- Pulse shape of exciting kicker KFE49 .
- Pulse shape.of cancelling kicker KFE51

(Kicker pulse spacing : 262 ns)

Achieved cutting ejection

Fig. 4 shows the achieved cutting ejection, adjusted for a cutting ratio of ~50%.

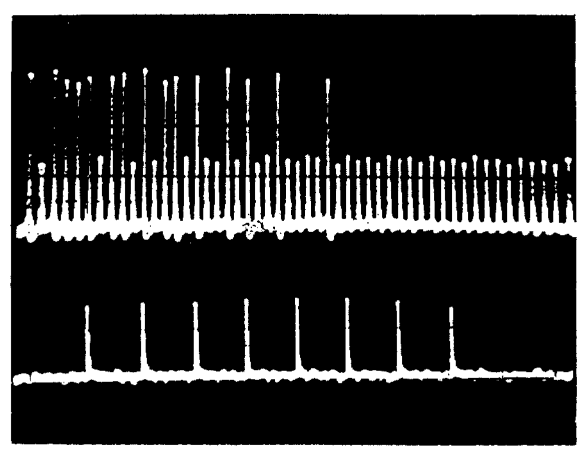

Fig. 4. Ejected beam, bunch cutting ratio of 50%.

Upper trace : Sum pick-up in ring shows halving of bunches.

Lower trace: Intensity of extracted bunch halves measured in beam transfer line (spacing 262 ns).

Fig. 5a shows an EPA cycle with e^+ accumulation and beam storage followed by a cutting ejection of ~50%, beam storage, and dumping of the remaining positrons. An operational scheme would replace this beam dumping by a normal 8 bunch fast extraction to the PS ring. Fig. 5b demonstrates beam cutting in several cycles, always halving the remaining beam intensity.

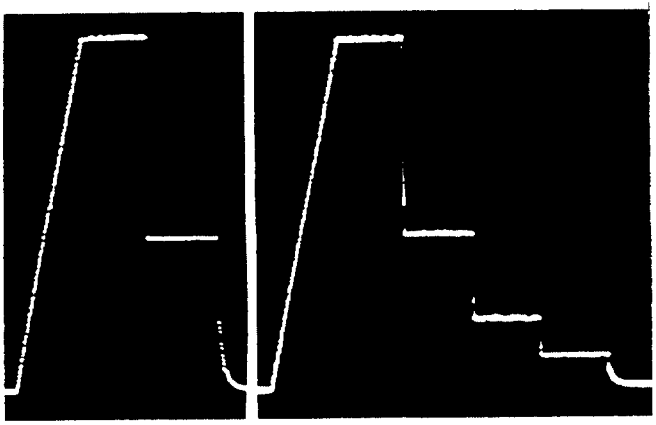

Fig. 5a) Fig. 5b)

Beam current signal in EPA.

5a) Cutting of 50% of the positron beam, storage of 1.2 s and dumping of the remaining beam.

5b) Successive beam cutting of the same beam, always halving the remaining beam intensity.

Operational aspects

Timing

Up to eight bunches circulate in EPA with a bunch spacing of 52.4 ns. The ejection sequence of 8 bunches is 1, 6, 3, 8, 5, 2, 7 with 262 ns spacing (5 RF periods) in order to fill the following PS with equidistant bunches within one turn of the PS. The cancelling kicker is delayed by 8 RF periods (1 turn).

Adjustment problems

Setting up of an 8 bunch fast extraction with 52 ns bunch spacing in EPA and 262 ns between ejected bunches is already a demanding task. In addition, the bunch cutting scheme is based on the cancellation of the remaining beam oscillation, bunch by bunch. Imperfect cancellation increases the apparent size of the remaining beam with the risk to lose beam at the septum passages. However, higher kick strength can cope with this situation easily, such that one can accept as much as, say, 30% of rest oscillation.

Non ideal kicker pulses unavoidably disturb neighbouring bunches before they get cut and ejected. The cancelling kicker helps to reduce this effect only in principle. The bunch position at the cutting septum now varies from bunch to bunch and individually adjustable kickstrength for all 8 bunches is needed to obtain equal cutting ratio, a facility not yet implemented in an operational way.

Once cutting uniformity is achieved, the ratio can be easily controlled with only one parameter, namely the slow bump amplitude at the cutting septum. A feedback system could be imagined in the case that slow drift were to become a problem.

Sensitivity of cutting

The cutting ratio should be a linear function of either the fast kicker strength or the slow bump amplitude, which was verified to be true within the measurement tolerances. In fact, the cutting process was used to test the predictions of the EPA modelling and gave good agreement within ~5% of the theoretical equilibrium beam width.

Stability problems of the slow bump or kicker amplitude can naturally affect the cutting ratio. It was verified that the predicted stability requirement of ~1% is sufficient; the time jitter of kicker pulses should stay below ~2 ns. The stability over a few hours was good.

Conclusions

Tests of the 8 bunch beam cutting facility in EPA have shown the feasibility of this scheme. In spite of an unavoidable complication of the ejection procedure we are confident that future transfer schemes to LEP can be based on this process.

Acknowledgements

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References

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