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A NOVEL INJECTION/EXTRACTION SCHEME FOR SHORT BUNCH SEPARATION IN ACCELERATOR RINGS,

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Abstract

A new scheme is proposed which allows a dense filling of accelerator ring and with separation between following bunches shorter than the rise and fall time of the injection or extraction kickers. It there fore permits a significant reduction of the minimum cir cumference of facilities such as accumulators or damping rings where each bunch has to be injected or ex tracted individually. It is based on a local orbit deformation close to the septum which is modulated from bunch to bunch with RF transverse deflectors working at a sub-har monic of the bunch repetition frequency. After analysis of its implications and limitations, the principle of this very general scheme,is applied as an example to the damping rings of the CLIC and TESLA linear collider proposals.

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A Novel Injection and Extraction Scheme for Short Bunch Separation in Accelerator Rings

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Abstract

A simple scheme is proposed which allows a dense filling of individual bunches in rings with separation between following bunches shorter than the rise and fall time of the injection or extraction kickers which is the usual limitation. It therefore permits a significant reduction of the minimum circumference of facilities such as accumulators or damping rings where each bunch has to be injected or extracted individually or conversely to accomodate more bunches in the same circumference.

It is based on a local orbit deformation close to the septum which is modulated from bunch to bunch with RF transverse deflectors working at a sub-harmonic of the bunch repetition frequency.

The principle of this very general scheme, after analysis of its implications and limitations, is applied as an example to the damping rings of the CLIC and TESLA Linear Collider studies.

1. DESCRIPTION OF THE SCHEME

1.1. RF local bump using sub-harmonic deflectors

In order to illustrate the principle of the scheme, let us assume bunches to be extracted at a regular time interval equal to half of the rise or fall time τ of the fast kicker. A set of 2 RF transverse deflectors powered at a period equal to τ is placed in the accelerator ring at π betatron phase advance with identical deflections such that their kicks cancel each other outside this area. They produce a local bump whose amplitude is modulated from bunch to bunch. Figure 1-a shows the deflection seen by the different bunches and fig. 1-d the corresponding trajectories in real space..

1.2 Fast extraction using a combination of an RF transverse deflectors and a fast kicker

Taking advantage of the modulation of the oscillation amplitude from bunch to bunch, one particular bunch can be extracted by a combination of RF transverse deflectors and fast kickers with a rise and fall time double of the bunch interval.

Phasing the maximum deflection of the fast kicker on bunch 4 as shown on fig. 1-b strongly amplifies its overall amplitude of oscillation with respect to that of the others (fig. 1-c).

Introducing a septum magnet at the location of maximum amplitude allows the extraction of this particular bunch falling in the field area of the septum without affecting all the other bunches circulating in the inner side of the septum without any field (fig. 1-d).

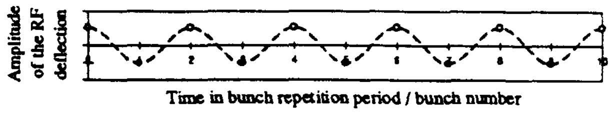

Figure 1-a RF dipole deflection on the different bunches

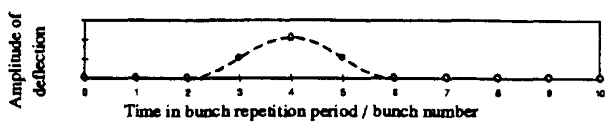

Figure 1-b Fast kicker deflection on the different bunches

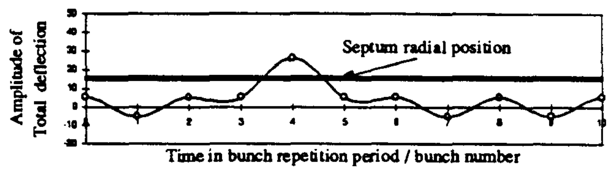

Figure 1-c Total deflection on the different bunches

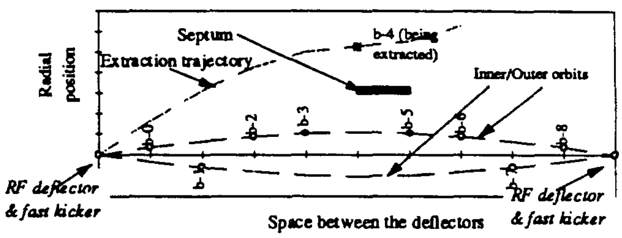

Figure 1-d Bunches trajectories in real space with RF dipoles and fast kickers

The residual oscillation of the circulating bunches is cancelled by an identical ensemble of RF transverse deflectors and kicker magnet at π betatron phase advance.

1.3 Reduction of the bunches distance

The distance between bunches can be further reduced using the same RF dipole frequency and the same fast kicker rise time but at the expense of a larger RF transverse deflector amplitude as shown on fig. 2-a to 2-c.

Another way to reduce the bunch distance without increasing the RF transverse deflector strength too much is to add a second pair of RF transverse deflectors working at a harmonic of the previous one. As an example, on fig. 3-a and 3-b, a system consisting of 2 pairs of RF transverse deflectors powered at subharmonic 2 and 4 of the bunch repetition frequency allows one to reduce the bunch distance by a factor 4 as compared to the usual fast kicker system.

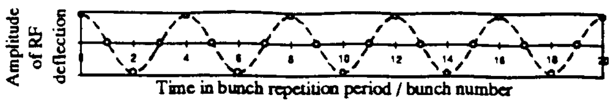

Figure 2-a RF dipole deflection on the different bunches for 4 bunches in the rise time of the fast kicker

Figure 2-b Fast kicker deflection on the different bunches for 4 bunches in the rise time of the fast kicker

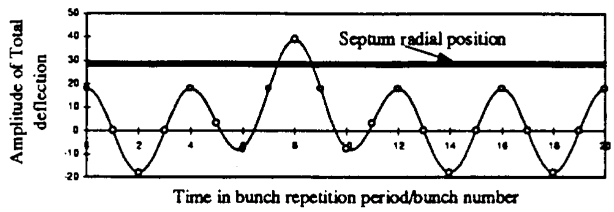

Figure2-c Total deflection on the different bunches for 4 bunches in the rise time of the fast kicker

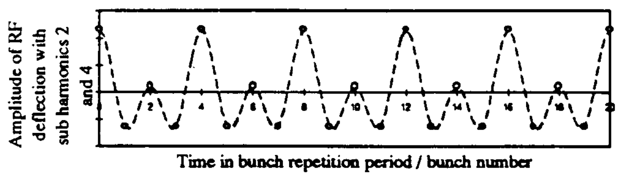

Figure 3-a RF dipole deflection on the different bunches for subharmonic 2 and 4 with 4 bunches in the rise time of the fast kicker

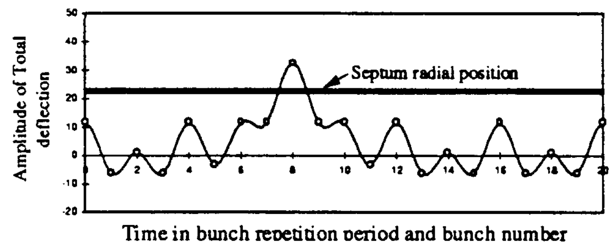

Figure 3-b Total deflection on the different bunches for sub harmonic 2 and 4 with 4 bunches in the rise time of the fast kicker

2 KICKS AND RADIAL APERTURES AT SEPTUM

With q bunches circulating in the rise or fall time of the fast kicker of common duration τ and of amplitude K_f, K_{RF} being the RF transverse deflector amplitude and τ its period equal to the rise or fall time of the fast kicker, d being the radial position of the septum of thickness e and r the beam radius at the septum, the conditions to be satisfied are

$K_f(0) \geq e + 2 \cdot r$ for the extracted bunch 0

$K_f(i) + K_{RF}(i)_i \leq d - r$ for bunches $i = 1 \ldots q$

The minimum fast kicker amplitude is obtained by using the equal sign in the above inequalities; by using trigonometric approximations, the RF transverse deflectors and the radial position of the septum can be calculated for various bunch intervals: τ/q.

Application to some particular cases

Table 1 below shows examples of the dependence of K_f, K_{RF} and d versus e and r for 2 and 4 bunches in the fast kicker rise time τ and table 2 the dependence of the same parameters versus e and d for a multi-subharmonic scheme with two RF transverse deflectors pairs and 4 bunches in the rise / fall time of the fast kicker. Numerical approximations for the strength of the elements versus e and r have been used to ease comparisons. These three cases are illustrated in fig 1, 2 for the single RF deflectors scheme and in fig 3 for the double RF deflectors scheme.

Table 1.

Number of bunches in the interval τ	2	4
K_f	1.00 e +2.00 r	1.00 e +2.00 r
K_{RF}	0.25 e + 0.50 r	0.85 e +1.70 r
d	0.25 e +1.50 r	0.85 e +2.70r

Table 2.

K_{ff}	1.00 e + 2.00 r
$K_{RF\,2}$	0.25 e + 0.50 r
$K_{RF\,4}$	0.30 e + 0.60 r
d	0.55 e + 2.10 r

3 LIMITATIONS OF THE SCHEME

Apart from the collective effects resulting from the increased total current and close bunch distance, the main limitation of the scheme comes from the exact cancellation of the deflections affecting the non-extracted bunches. The requirements on identity of amplitude, shapes and phasing of the RF transverse deflectors and fast kickers can be pretty tight in particular cases like damping rings with small emittances. One possible solution consists in powering the pairs of kickers in series.

4 APPLICATION TO THE EXTRACTION OF THE TESLA DAMPING RING

In the TESLA damping ring a train of 800 bunches has to be extracted bunch by bunch at intervals of 1 µs [1]. Using a classical extraction technique with a rise and fall time of the fast kicker of 25 ns, leads to a ring circumference of about 6 km. Using an extraction with 2 pairs of RF deflectors at sub-harmonics 8 and 4 of the bunch repetition frequency reduces the ring circumference by a factor 8 down to 750 m. This corresponds to some 320 circulating bunches with a time delay of 3ns.

4.1 Extraction scheme

In order to keep the necessary kick strengths as low as possible a double septum system, constituted of a thin electrostatic septum followed by a thick magnetic one is introduced (fig. 4).

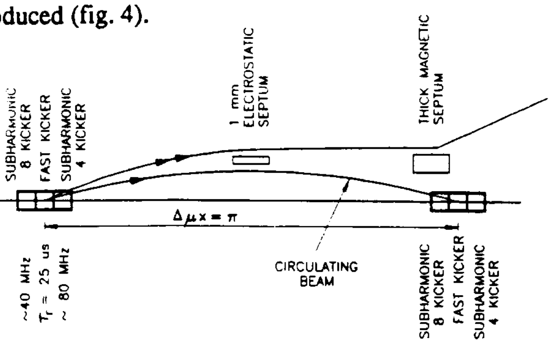

Fig.4 TESLA DAMPING RING EXTRACTION SCHEME

The fast kicker, with τ = 25 ns, is pulsed every 1 µs. The maximum deflection of the RF deflectors is moved from the last extracted bunch to the next one 1 µs later by using frequencies slightly different from the exact sub-harmonics of the bunch repetition frequency. The RF transverse deflectors are powered during the 800 µs of the extraction process with frequencies close to 40 MHz for the 8 th sub-harmonic and 80 MHz for the 4 th sub-harmonic.

4.2 Possible deflections requested

The requested deflections to be produced by the fast and RF transverse kickers at subharmonic 8 and 4 for an acceptance of the extraction channel of 3 10^{-8} π rad.m and an electrostatic septum thickness of 1 mm can be calculated using as an example a β_x value of 10 m at the kicker and at the septum location. These values, as summarised in table 3 below, seem feasible but detailed calculations should be done once the optics of the extraction area is defined.

Table 3.

Fast kicker deflection	0.21 mrad
RF transverse deflection at suharmonic 8	0.05 mrad
RF transverse deflection at suharmonic 4	0.20 mrad
d minimum aperture at septum	2.9 mm

5 Injections and Extractions for the CLIC Damping Rings

In the CLIC pre-damping and final-damping rings [2], single bunches of leptons are injected and extracted at a repetition frequency of 1.7 kHz. The time spent in the ring by a bunch for damping is directly proportional to the number of bunches circulating simultaneously. Shortening the bunch distance from 25 ns to 12.5 ns allows the reduction of the operating momentum of the ring and consequently its normalised equilibrium emittance by a factor 2.

5.1 Injection and extraction scheme

The rise or fall time of a fast kicker being 25 ns, a pair of RF kickers working at subharmonic 2 of the bunch repetition frequency is 40 MHz. The same ensemble of thin electrostatic septum and thick magnetic septum as in the Tesla case will be used, both for injection and extraction. In order to limit the transient beam loading on the RF cavities during the injection and ejection processes as well as the amount of hardware to install, the extraction and the injection will be done at the same time in the same RF bucket. A possible extraction scheme is shown on fig.5.

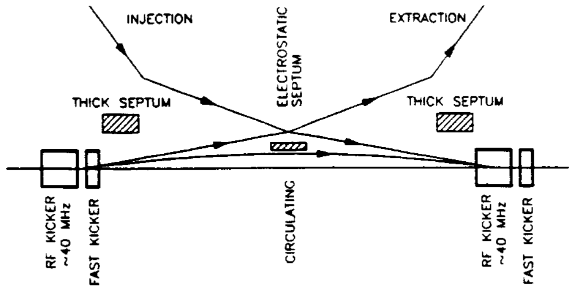

Fig.5 CLIC DAMPING RING INJECTION AND EXTRACTION SCHEME

In the same way as for Tesla, the requested kicker strengths have been evaluated. In table 4 below, the deflections to be produced by the kickers and the septum radial distance of the CLIC pre-damping for an acceptance of 1 10^{-5} radm are shown.

Table 4

Fast kicker deflection	2.1 mrad
RF transverse deflection at subharmonic 2	0.53 mrad
minimum aperture d at septum in mm	15.0 mm

6. Conclusion

A general injection and extraction scheme is proposed. It is based on RF transverse deflectors, allowing a reduction of the bunch distance in facilities such as accumulators or damping rings where each bunch has to be injected or extracted individually. Applied, as examples, to the damping ring of the CLIC linear collider, it could increase the number of bunches in the ring by a factor 2, or in the TESLA linear collider damping ring reduce its circumference by a factor 8.

8. References

[1] A Proposal to Construct and Test Prototype Superconducting RF Structures for Linear Colliders, TESLA report 93-01.

[2] J.P.Delahaye and J.P.Potier, Reverse Bending Magnets in a Combined-Function Lattice for the CLIC Damping Ring, Particle Accelerator Conference, Nice 1989.