Alternative TESLA Damping Ring Injection/Extraction Scheme

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Motivation

•The long TESLA train (to take advantage of the superconducting linac) and a minimum injection/extraction kicker rise+fall time lead to a large circumference for the TESLA damping rings.

•The large circumference leads to a space charge coupling bump, and makes it desirable to share the tunnel with the linac, with its noisy electromagnetic environment.

•A smaller circumference may result in lower costs, may make it practical to use separate tunnels for the damping ring and linac, and remove the need for the coupling bump.

•*Note*: carefully designed stripline kickers ring at the level of –25 to –30 dB relative to the main pulse. It is very difficult to achieve a fast kicker fall time with acceptable ringing.

Possible solution

•Always inject and eject at the tail of a bunch train. The kicker need not have a very fast fall time, as a gap will follow the train.

•Problems with this approach:

- •Beam loading varies, causing oscillations of the damped bunches (a solution will be offered);
- •Injection rate ≠ ejection rate, so positron production by the electron beam is no longer possible (this may be a virtue in disguise!).

Compensation of beam loading using a second, small ring

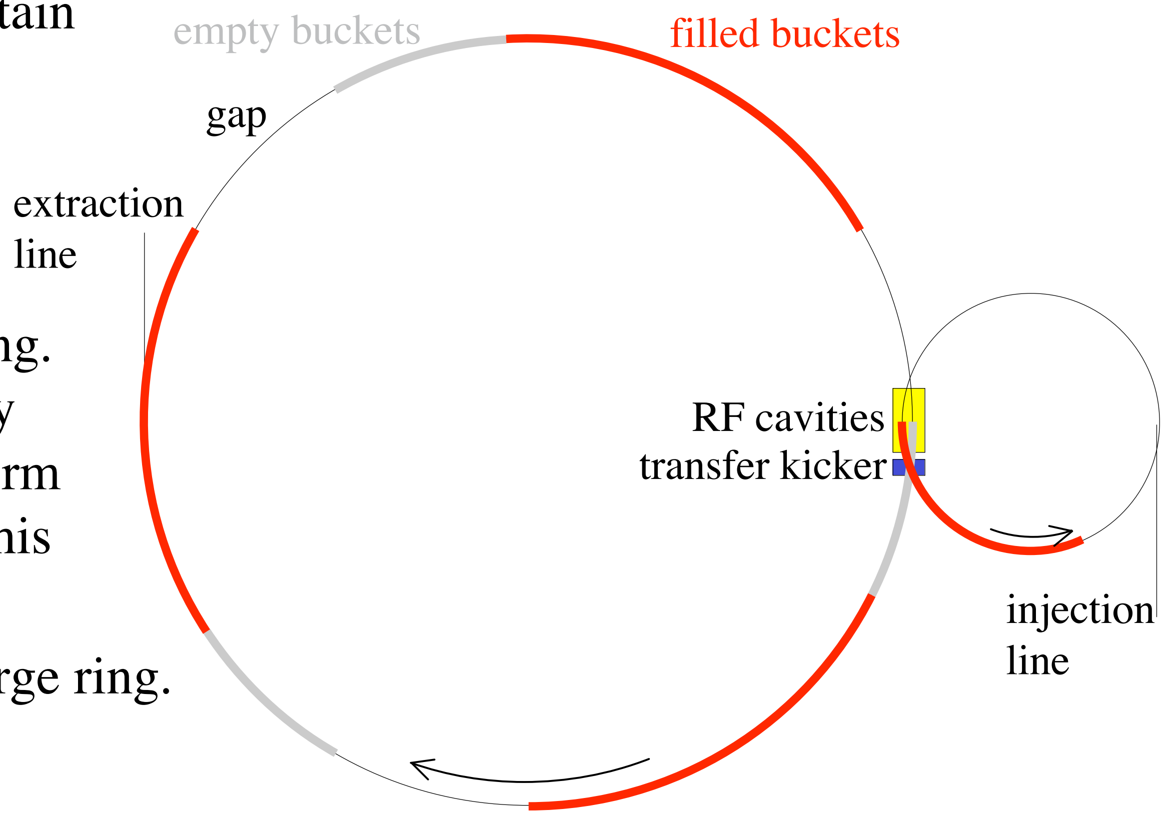
•Both rings share an RF section.

•As bunches are ejected from tail of the trains in the large (damping) ring to the bunch compressor and main linac, bunches are injected at the tail of a train in the small ring to maintain uniform beam loading.

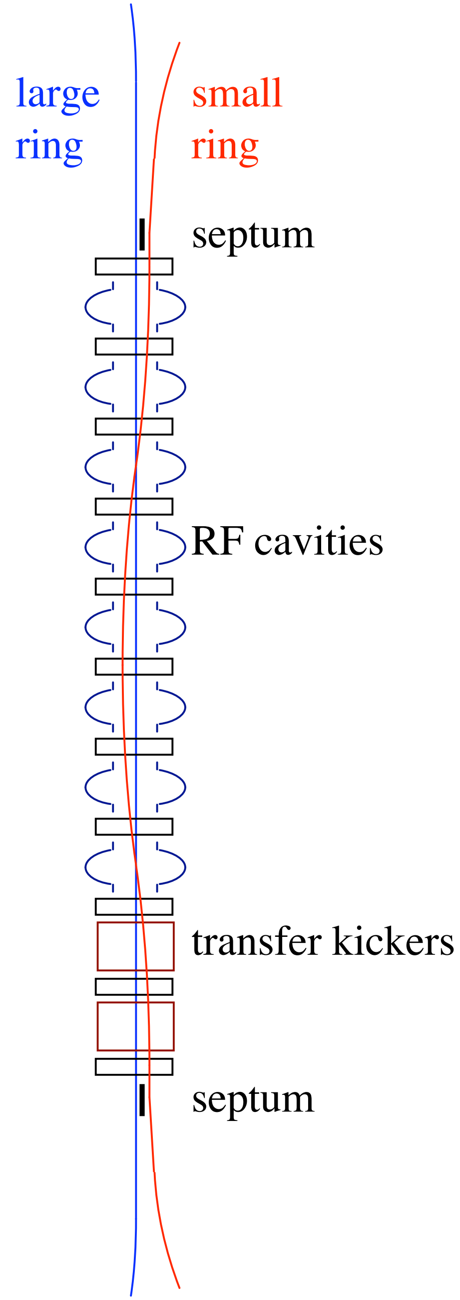
•When the large ring is empty, a train is transferred from the small ring to the large ring. The large ring is filled by repeated transfers. Uniform Beam loading is lost at this time.

•Bunches damp in the large ring.

•The cycle starts again.



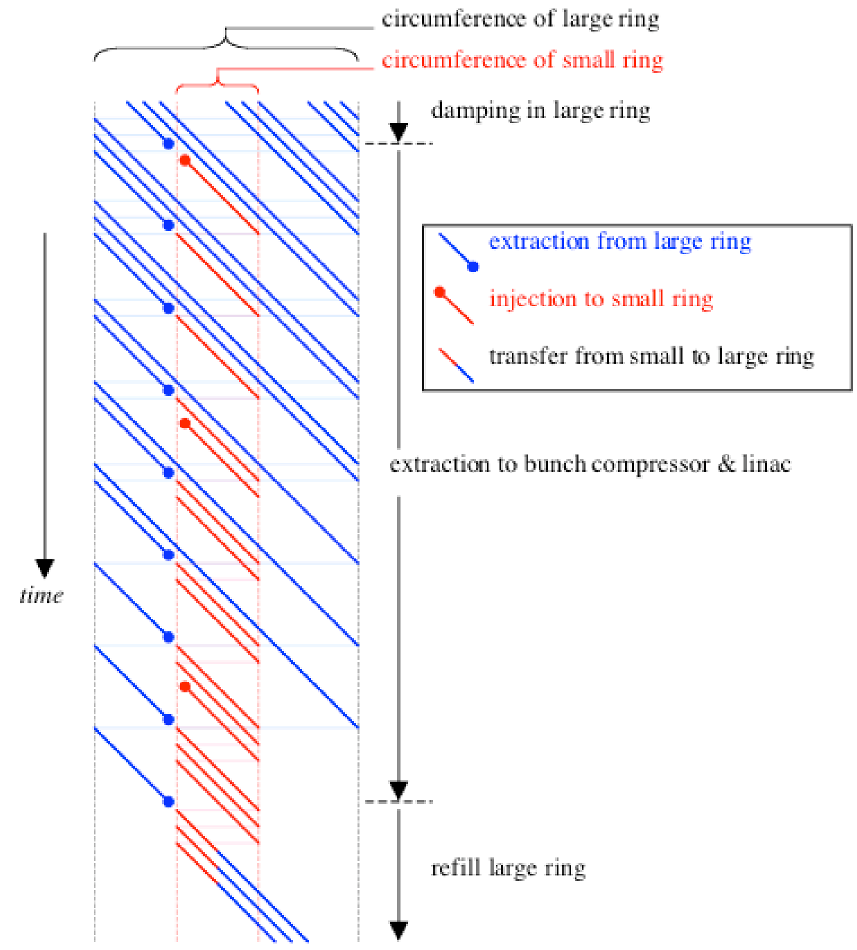
Schematic layout of RF straight



Simplified timing example

Simplified example for 3 trains of 3 bunches.

Note: injection rate into the small ring is reduced by ≈ the ratio of trains in the small ring to trains in the large ring. Relaxes requirements on the positron source (which can be conventional).



General timing constraints

Bunch spacing in RF bucket units (either ring)	k
Number of trains (large ring)	N
Number of trains (small ring)	1
Maximum number of filled buckets in a train (either ring)	b
Maximum number of bunches (large ring)	Nb
Number of short gaps (large ring)	$N-1$
Number of long gaps (large ring)	1
Short gap length (number of missing bunches) (large ring)	g
Long gap length (number of missing bunches) (large ring)	$g+1$
Harmonic number (large ring)	$H = k\,[N\,(b+g)+1]$
Harmonic number (small ring)	$h = k\,(b+g)$

Bunches are ejected from the large ring to the main linac at bucket passages

$$k(b+g)i, \quad i = 0,1,2,\ldots Nb-1$$

Bunches are injected into the small ring at bucket passages

$$k\left[N(b+g)+1\right]i, \quad i = 0,1,2,\ldots Nb-1$$

Trains are transferred from the small to large ring starting at bucket passages

$$k\left[(Nb-1)(b+g)+\left[(Nb-1)(b+g)+b\right]i\right], \quad i = 0,1,2,\ldots N-1$$

Design example— timing

RF frequency		500 MHz
Bunch spacing in RF bucket units (either ring)	k	2
Number of trains (large ring)	N	40
Number of trains (small ring)		1
Maximum number of filled buckets in a train (either ring)	b	70
Maximum number of bunches (large ring)	Nb	2800
Number of short gaps (large ring)	$N-1$	39
Number of long gaps (large ring)		1
Short gap length (number of missing bunches) (large ring)	g	15
Short gap length (last bunch of train to first bunch of next train)		64 ns
Long gap length (number of missing bunches) (large ring)	$g+1$	16
Harmonic number (large ring)	H	6802
Harmonic number (small ring)	h	170
Linac repetition time		200 ms
Interval between start of extraction from and last transfer to large ring		38.08 ms
Time available for damping in large ring		161.9 ms
Interval between extractions from large ring		340 ns
Interval between injections to small ring		13.6 μs
Interval between transfers from small to large ring		0.952 ms

Design example— large ring lattice parameters

parameter	value
Circumference	4078 m
Energy	3 GeV
Total length of arcs	3778 m
Total length of straights	300 m
Number of arc TME cells	80
Phase advance per TME half-cell μ_x, μ_y	108°, 36°
TME dipole magnet field	0.15 T
Maximum wiggler field	2 T
Wiggler period	0.71 m
Average beta in wigglers $< \beta_{x,y} >$	5 m
Total length of wigglers	158 m
Ratio of wiggler to arc damping $I_{2,wiggler}/I_{2,arc}$	33.6
Approximate tunes ν_x, ν_y	56, 24
Damping times τ_x, τ_y, τ_z	22.0, 22.0, 11.0 ms
Equilibrium horizontal emittance $\gamma\epsilon_x$	8.0×10^{-6} m rad

Design example — small ring lattice parameters

parameter	value
Circumference	101.9 m
Energy	3 GeV
Total length of arcs	61.9 m
Total length of straights	40 m
Number of arc FODO cells	12
Phase advance per arc half-cell μ_x, μ_y	$108°$, $108°$
Approximate tunes ν_x, ν_y	6, 6
Dipole magnet field	1.7 T
Dipole magnetic length	1.54 m
Quadrupole gradient	1.43 T/m
Quadrupole magnetic length	0.434 m

Kicker considerations

The deflection of an ultrarelativistic beam by a stripline kicker is

$$\Delta p_{\perp}(t) = \int_{-\infty}^{\infty} V(t')S(t-t')dt'$$

where

$$S(t) = \begin{cases} eg_{\perp}/b \text{ if } 0 < t < 2l/c \\ 0 \text{ otherwise} \end{cases}$$

b is the half-gap, and $g_{\perp}$ is a geometrical factor of order unity.

A rough optimization between small deflection rise time and large maximum deflection occurs when $2l/c \approx$ pulser rise time.

Design example — kicker parameters

parameter	value
Gap between stripline plates $2b$	100 mm
Stripline plate width g	130 mm
Geometric factor $g_\perp$	0.77
Stripline length	0.300 m
Stripline "time constant" $2l/c$	2 ns
Pulser risetime	2 ns
Pulser flat-top	$\geq$ 2 ns
Pulser voltage (into 50 Ω)	3 kV
Beam energy E	3 GeV
Deflection produced by a single stripline kicker	9.2 μrad
Number of stripline kickers	65
Total deflection	0.6 mrad

Pulser parameters correspond to commercial MOSFET devices, *e.g*. Behlke Electronic GmbH.

Stripline similar to Grishanov, *et al*. prototype but with different parameters.

A variant— a single ring with active beam loading compensation

- Eject from tail of each train until ring is empty.
- Beam loading transients are handled with active beam loading compensation.
- Inject to the tail of each train until ring is full (with gaps) and damp.
- The cycle repeats.

Note: limitation is klystron bandwidth, which may be good enough.

Bunches are ejected from the ring to the main linac at bucket passages

$$k(b+g)i, \quad i = 0,1,2,\ldots Nb-1$$

Bunches are injected into the ring at bucket passages

$$k\left[N(b+g)+2\right]i, \quad i = 0,1,2,\ldots Nb-1$$

Items requiring investigation

- Better estimate or measurement of pulser risetime and repetition rate.
- Evaluation of different types of kicker/driver technology.
- Effect of multibunch instabilities (*e.g*. electron cloud) with increased average current.
- Detailed lattice.
- Longitudinal matching.
- Feasibility of beam loading compensation with a gap of ≈ 60 ns or less.

Advantages and disadvantages

Advantages of the alternative injection/extraction scheme:

- Fast kicker more feasible.
- Reduced circumference (and cost).
    - Coupling bump not required.
    - Conventional positron source possible.

Disadvantages:

- More complex damping system.
- Higher average currents may lead to worse multibunch instabilities.
- Incompatible with polarized positron production.