BUNCHING FOR SHORTER DAMPING RINGS FOR THE ILC *

David Neuffer, #
Fermilab, Batavia, IL 60510, U.S.A.

Abstract

A variant rearrangement of the bunch trains for the ILC that enables much shorter damping rings is presented. In a particular example the ~2820 bunches are regrouped into ~550 subtrains of five adjacent bunches. These subtrains are extracted from the damping rings at ~1.8μs intervals, obtaining the 1ms macrobunch length of the baseline TESLA collider scenario. If the baseline damping rf frequency is 325 MHz and the kicker rise and fall times are ~20 ns, a ring circumference of ~5.8km is required. Variations of the scheme could easily reduce the circumference to ~4km, and faster kickers could reduce it even further.

INTRODUCTION

In the baseline TESLA design, streams of ~2820 electron and positron bunches are collided, with the bunches evenly spaced over a 1ms spill time (300000m). [1] This constraint results in a key difficulty in the TESLA design: the unwieldy length of the damping rings (~17km each). The damping ring length greatly increases cost, and gives the beams undesirably large space charge effects. The circumference was set by requiring that the ring store 2820 bunches and that the bunches be separated by the rise and fall times of the injection/extraction kickers, which are set at ~20ns. Schemes that reduce the required circumference of the rings by reducing the kicker rise and/or fall times are being developed.[2, 3] In the present note we consider enabling the extraction of a small number of bunches in each kicker pulse, separated by the damping rf wavelength, and keeping the 20ns rise/fall time.

To simplify the discussion we require that the damping ring rf frequency be a subharmonic of the main Linac rf frequency, which is 1300 MHz with TESLA cavities. In the present case, this means 1300, 650, 433, or 325 MHz rf. With this constraint every rf bucket in the damping ring is properly timed to provide an accelerated bunch in the linac, and the maximum possible flexibility in bunch scenarios is maintained. (The 2001 TESLA design had 500 MHz rf, and the buckets match the linac cycle only in one of 5 rf cycles; The 1997 design had 433 MHz, which is an integer 3 subharmonic.)

With 325 MHz rf, 2820 bunches requires a circumference of at least 2600m; 650MHz requires 1300m (with no extra gaps for injection/extraction etc.). A 20ns bunch to bunch spacing implies a minimum circumference of 16.9km, if we require a minimal 20ns extraction kick spacing between each bunch. This sets the scale of the damping ring circumferences. We propose to reduce the ring circumference by grouping the bunches into subtrains separated by extraction gaps.

EXAMPLES

To generate some numerical examples, we choose a 325 MHz damping ring rf system, set the number of bunches per subtrain to 5 (n_b = 5). We set the extraction kicker rise and fall times to 20ns (6m), which corresponds to ~6.5 wavelengths. We set a n_s = 7 wavelength spacing between bunch trains, making the gap + bunch subtrain length equal to $(n_b + n_s - 1)\,\lambda_{rf}$ = 11 wavelengths or 10.154 m. (An extraction pulse and bunch subtrain is shown in fig. 1.) To obtain 2820 total bunches we need 564 such units or ~5.73km ring circumference. This is ~1/3 of the Tesla damping ring.

To determine a damping ring circumference with evenly spaced extractions, we can set up a bunch configuration such that the extraction kickers fire at constant intervals during the 1ms spill, with the interval matched to an appropriate integer multiple of the 10.154m bunch + gap subtrain unit length. A simple division of 300000 by 564 obtains 532m, closest to n_{ext} = 52 subtrains. If the spacing between kicks is 52 subtrains and the circumference of the ring is (52×N ±1) subtrains long, where N is any integer, then ring will empty with evenly spaced kicks. We choose N to be the closest to 52×N=564 or N =11, and choose the + 1 convention for the odd bunch, obtaining a final circumference of (52×11 + 1)×10.154 = 5818m. After this numerical exercise we end up with a total of 2865 bunch slots, slightly more than the TESLA reference value of 2820. (Note that, if the circumference is not precisely fitted to the desired number of bunches, the kicks could be slightly unevenly spaced. The resulting, slightly uneven, beam loading/unloading scenarios are probably not very difficult.)

We can shift the numerology by choosing a 650MHz rf system (λ = 0.4615m), and choose n_b = 6 bunches per train. The reference time of 20 ns is equal to n_g = 13 wavelengths and our $(n_b + n_s - 1)\lambda_{rf}$ subtrain length becomes 18 wavelengths or 8.307m. With 470 such units we would need a circumference of 3904m, almost 2 km less than the 325MHz, 5-bunch example.

The numerology for the bunch trains is slightly better matched than the previous case. We require a total of ~2820/6=470 bunchtrains, and ~300000/470 ≅ 638m bunch extraction spacing, if we maintain the ~1ms spill. 638m corresponds to ~76.8 complete subtrains and we can choose N=6. We obtain almost exactly the 2820 bunches with n_{ext} = 78, obtaining a circumference of (6×78 + 1)× 8.307 = 3896m. (This numerical exercise gives us a slightly smaller total number of bunches (2814).) The circumference is almost 2 km less than the 325MHz, 5-bunch example.

*Work supported by the US Department of energy under contract No. DE-AC072-76CH0300.
#neuffer@fnal.gov

The numbers in the examples cited above depend on the values of the number of bunches per subtrain, the rf wavelength, the extraction gap length, spill length, and all of these numbers can change when the ope rational choices are changed, but the overall scenario can still be reconstructed and readapted with the parameter variations. Note that the parameters of the ring should be chosen to maintain maximum flexibility in redefining the bunch spacing and arrangements, allowing for improvements in kicker performance, and maintaining the possibility of increasing luminosity by filling more buckets. Requiring the damping ring rf frequency to be an exact linac subharmonic maintains that type of flexibility.

These first examples used 5 or 6 bunches per subtrain; similar scenarios with 2, 3, 4, 5, 6, … bunches could be developed, with similar properties. Within a scenario, the number of bunches per subtrain could be varied operationally to increase luminosity or reduce beamstrahlung, provided the extraction kick is accommodated. (One bunch per subtrain recovers the TDR scenario.) More than ~8 could possibly become too unwieldy.

In Table 1 we display results from several examples, in which we have applied the constraints described in the above scenarios: a total number of bunches approximately equal to 2820, a total spill time of ~1ms, and evenly timed extraction kicks that advance by one subtrain on each revolution, and space for 20ns extraction kicks before and after the bunch subtrains. The parameters that are varied are the number of bunches per subtrain (~4—6) and the rf frequency (325, 433, 650 MHz). As shown in Table 1, the damping ring circumference is reduced to 4—6 km. (The ±1 subtrain rule is not essential; the extraction spacing and the ring circumference need only be relatively prime.) Figure 2 shows a simplified example with only 24 bunches, to illustrate the general principle with simplified numerology.

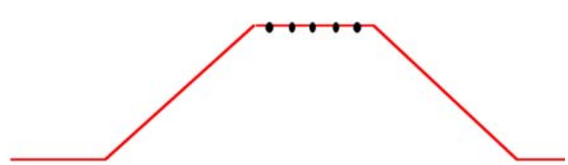

Figure 1: Schematic view of an extraction pulse with an extended flattop suitable for extracting 5 evenly spaced bunches. Rise and fall times are roughly equal and the flattop is a bit more than half the rise time.

Table 1: Damping Ring parameters – Sample cases

Rf frequency	f_{rf}	325	433	650	650 MHz
Bunches per subtrain	n_s	5	5	4	6
Gap length (>)	n_g	7	9	13	13
Subtrain length	L_{st}	10.15	9.0	7.384	8.307m
Extract spacing	n_{ext}	52	56	58	78
Ext. periods/ring	N	11	10	12	6
Total bunches	n_{total}	2865	2808	2788	2814
Circumference	C	**5818**	**5049**	**5147**	**3879 m**

POTENTIAL DIFFICULTIES

The bunch reconfiguration does change some of the Linear Collider operating conditions. The bunch trains will deplete the rf cavities a bit unevenly, with a bit more field at the head than the tail, and some correction may be needed. The correction required should be small; much smaller than that used in NLC scenarios. To estimate the potential effect, we note that each ILC bunch has 2×10^{10} electrons (or positrons), and acceleration through a ~1m long TESLA 9-cell cavity requires ~0.096J. The total energy stored in the TESLA cavity is given by:

$$U = \frac{V_t^{\,2}}{R/Q\,\omega_0}$$

The factor R/Q is ~1000Ω for the TESLA 1300 MHz cavities, and V_t is ~30MV. The resulting value of U is ~110J. Thus the bunch only removes $\sim10^{-3}$ of the cavity energy, which implies a gradient drop of $\sim0.5\times10^{-3}$ if uncompensated, increasing to $\sim2\times10^{-3}$ with 4 leading bunches. This could lead to a corresponding energy variation in the final beam. While compensation will not be absolutely necessary, it would be desirable, and an optimal scheme is left as an exercise to the reader.

Some care must be taken to insure that the different bunches do not overlap in the collision area (crossing at small angle or …). Note that the NLC design had bunches spaced at 714MHz (1.4 ns), more closely than even the 650MHz spacing.

The kicker pulse needs a rise time of 20ns, a flat top sufficient to deflect all of the subtrain bunches (~12.5ns for 325 MHz, ~6.5 ns for 650MHz with a 5-bunch flattop), and a 20ns fall time, as schematically shown in fig. 1. This should not be too difficult. The scenario is readily readjusted if the kicker rise and fall times are different from 20ns.

We have not designed the injector into the damping ring, except that it must provide bunches matched to the desired pattern. Note that the TDR positron source, in which each positron bunch is obtained from the corresponding electron bunch in the previous pulse, could match properly into these scenarios. If the positron source is separately generated, a predamper/buncher for the positrons may be desirable. The predamper could be used to group the positrons into the bunch pattern desired for the damping ring and resultant collider.

COMMENT ON RF FREQUENCY

In constructing the scenarios we have used rf that is an integer subharmonic of the Linac. Then any rf bucket in the damping ring can feed the center of a Linac Collider bucket. This enables considerable flexibility in parameter changes. The extraction gap can be increased or decreased as needed and the number of bunches per subtrain can also be changed.

This flexibility would be desirable in any scenario, including the 17km TDR. The bunch spacing can be increased/decreased to accommodate different rise/fall times., and the number of colliding bunches could be increased to reduce space charge or increase luminosity. For example, in the TESLA damping ring scenario, the luminosity could be doubled simply by filling two adjacent bunches, after obtaining a slightly faster kicker.

SUMMARY

A shorter ILC damping ring that maintains the same total number of beam bunches in collision as the TESLA Design Report, with the same extraction kicker rise and fall times, can be obtained by rearranging the bunches into small trains. Some potential schemes are presented and others may be developed by simple variations.

To maintain maximum flexibility, the damping ring rf frequency should be an exact rf subharmonic of the Linac rf frequency, in all damping ring scenarios.

REFERENCES

[1] *TESLA Technical Design Report,* DESY 2001-011, http://tesla.desy.de/new_pages/TDR_CD/start.html (March, 2001).

[2] L. Emery, et al. "Studies Pertaining to a Small Damping Ring for the ILC".FERMILAB-TM-2272-AD-TD, September 28, 2004.

[3] S. Kuroda and J. Urakawa, KEK, unpublished (2005).

[4] R. Brinkmann et al., "Conceptual Design of a 500 GeV e^+e^- Collider with Integrated X-Ray Laser Facility", DESY 1997-048 (1997).

[5] The NLC Design Group, "Zeroth Order Design Report", SLAC 474 (1996).

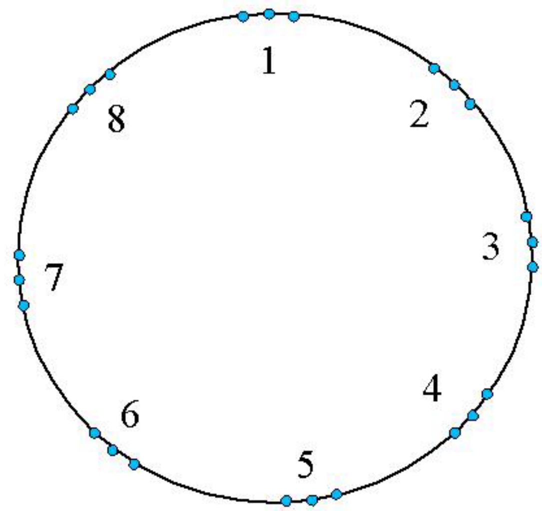

Figure 2: Simplified example of a subtrain-loaded storage ring, with with n_b = 3 bunches per subtrain separated by gaps of n_g = 5 λ. With an extraction spacing of n_{ext} = 3 subtrains, and N=3, we have a total number of bunches (3×3-1)n_b or 24 bunches (choosing the –1 rather than +1 convention for odd slots). Starting with bunch 1, the subtrains would be extracted in the following order: 1, 4, 7, 2, 5, 8, 3, 6. (This example has 24 bunches; ILC requires ~2800.)