PROGRESS REPORT

Investigation and Prototyping of Fast Kicker Options for the TESLA Damping Ring

Personnel and Institution(s) requesting funding

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Project Overview

The large number of bunches (2820) and the relatively large inter-bunch spacing (337 ns) in the TESLA linear collider design give a bunch train which is more than 200 km long. A damping ring of this size would be very costly, and so the bunch train is damped in a compressed form, with a bunch spacing of 20 ns, leading to a damping ring circumference of 17 km.

In the TESLA baseline, the rise and fall time of the damping ring injection and extraction kickers determine the circumference of the ring. There is considerable leverage in developing faster kickers, as this translates directly into a smaller circumference ring. The baseline system for 500 GeV (cm) parameters has a 20 ns specification for the kicker pulse width; this becomes about 12 ns for the 800 GeV (cm) parameters. Designs and prototype results exist [1] for conventional kickers with widths of 7 ns, and designs have been developed for more novel ultrafast schemes [2] using electron beams.

As of the time of this progress report, a baseline configuration for the international linear collider has been selected [3]. This baseline configuration employs essentially the same bunch structure in the main linac as that specified for TESLA. However, the baseline recommendation for the damping rings is a single 6 km ring for electrons and a pair of 6 km rings for positrons. Smaller circumferences were found to be unacceptable due to the risks involved. In particular the greatest risks associated with a shorter ring were deemed to be electron cloud effects in the positron ring, ion effects in the electron ring, and kicker issues in each.

For a 6 km ring, the injection and extraction scheme must accommodate bunch spacings of approximately 6 ns in the baseline design. This means that the overall time-dependent kick seen by the beam must have a duration of less than 12 ns. Presentations at the November 2005 meeting of the ILC Working Group 3B [1] showed that conventional stripline kicker and pulser technology is close to demonstrating the necessary performance specifications for the baseline design [4, 5]. Thus the baseline recommendation specifies conventional stripline kickers but identifies the three critical areas needing final validation:

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[1] The purpose of this meeting was to generate the baseline damping ring recommendation which was subsequently accepted by the Global Design Effort team into the baseline configuration.

- the pulse rise and fall times which determine the minimum bunch spacing that can be used;
- the pulse repetition rate which must be compatible with the machines train structure;
- the kick amplitude stability which is required in order to avoid beam jitter at the collision point.

Another feature of the baseline configuration document is that investigations will go forward with respect to the possibility of operating the main linac with roughly double the number of bunches (5640). The implications for the damping rings are that R&D must continue on extraction schemes capable of handling bunches which are spaced by only a few ns.

We propose to continue our exploration into the operation of very fast stripline kickers as described in the references above [1, 5]. Given that these kickers appear technically feasible, we propose to build a device based on one of the existing designs and test it using a high energy electron beam. We will also continue to work closely with our collaborators from the University of Illinois and Fermilab in exploring their novel fast kicker concept.

Progress Report

As noted above, the original proposal suggested that we would explore the physics issues associated with the use of damping rings of a much smaller circumference than the baseline TESLA TDR design, in order to determine the smallest feasible circumference for the damping ring. This circumference determines the required rise and fall time for the kickers, which is a key element of the specification. In our previous progress report we adopted the strategy of choosing a circumference which was the smallest that could be realistically considered and used that to determine the rise and fall time requirements of the kickers. This approach effectively decoupled the physics studies of the ring, which were being actively explored by many researchers, from the kicker development, thus allowing both to proceed in parallel.

We chose a ring circumference of 3 km (similar to the PEP-II ring) as the smallest feasible circumference, and focused on the development of a kicker, with its associated pulser, appropriate for that ring. In a 3 km ring, 2820 equally spaced bunches have a 3.5 ns spacing. To inject and extract individual bunches means that the overall time-dependent kick seen by the beam must have a duration of less than 7 ns. Even though a 3 km ring is no longer under active consideration for the ILC, the necessity of investigating a 5640 bunch option for the 6 km ring means that the 7 ns specification previously obtained is still the correct one.

Specifications Summary for Kicker and Pulser

In our previous progress report we described the work that had been done to arrive at pulser and kicker specifications for bunches with a 3.5 ns spacing. As noted above, these specifications remain the relevant specifications for further kicker and pulser R&D in the era of the ILC Baseline Configuration Document. We provide a brief overview of those parameters here and note what adjustments are needed when considering the possibility of increasing the number of bunches in a train and reducing their spacing by a factor of 2.

The overall requirement for a system of fast kickers is that they must deliver a kick of 0.6 mrad to a 5 GeV electron beam. The length l of a single kicker module is constrained due to the requirement for a rapid rise time. Consequently, a number N_k of kickers will be required in series. Table 1 gives two possible sets of pulser voltage, current, and power parameters, one corresponding to 3 kV pulses, and one to 10 kV pulses. In the former case, 50 kickers (100 pulsers) are required. In the latter case, 15 kickers (30 pulsers) are needed. The 10 kV pulser dissipates about 100 W in the terminating load. If higher voltages than 10 kV are available, such a pulser, which requires even fewer kickers than 15, would be preferable.

Table 1: Possible fast kicker parameters. The total kick angle required is taken to be 0.6 mrad. The kicker is assumed to have a 50 Ω impedance. The voltage V_0 refers to the peak amplitude of the voltage pulse from the pulser.

V_0 [kV]	l [mm]	θ[mrad]	N_k	I [A]	P_{peak} [kW]	E_{pulse} [mJ]	f_{avg} [kHz]	P_{avg} [W]
3.0	360	0.012	50	60	90	0.648	14.1	9.2
10.0	360	0.040	15	200	2000	7.2	14.1	102

In a given pulse train, the relative pulse-to-pulse repeatability requirement on the total kick angle given to a beam bunch is 7×10^{-4}. If N_k kickers are used, and the pulsers driving each kicker have random voltage fluctuations about an average over the train, with an rms value of σ_V, then we require

$$\sigma_V \leqslant \sqrt{N_k} \times 7 \times 10^{-4}.$$

For example, for the case of $N_k = 15$, we need $\sigma_V \leqslant 0.27\%$.

Pulse rate requirements are determined by the bunch structure in the main linac. In the baseline ILC design, the 2820 bunches are spaced by 308 ns and trains have a 5 Hz repetition rate. This means that the pulser must have a burst pulse rate of 3.25 MHz. The average pulse rate is $2820 \times 5 = 14,100$ Hz. In the event that 5640 bunches with a 154 ns spacing are employed, the burst pulse rate and average pulse rate both double.

Implementation of the Fast Pulser

To implement the fast pulser, we need a very fast rise and fall time device, capable of delivering voltage pulses in the kilovolt range, with an burst pulse repetition frequency of 3 MHz, capable of 1 ms bursts at 5 Hz, and extremely high pulse-to-pulse reproducibility. Meeting these demanding requirements is very challenging. Compared to gas-filled amplifiers, solid-state devices can potentially have very good reliability and reproducibility, but have difficulty meeting the high-power-pulse rise and fall time requirements.

We are presently working with a relatively new high-power ultra-fast-switch technology, based on a 4-element npnp structure called a fast ionization dynistor [7, 8, 9, 10, 11, 12, 13, 14, 15]. Ultra-fast high voltage pulse generators based on this technology are now commercially available [16, 17]. We have contacted a commercial firm, FID Technology, Ltd., which makes these pulse generators, and made them aware of the pulser requirements discussed above. They have responded with several sets of possible pulser specifications that they feel they can meet. These are presented in Table 2. These specifications are very close to what is needed for the ILC baseline design. One possibility for the increased pulse rates required in the case of 5640 bunches would be to allow for alternating pairs of units to be fired.

Work In Progress

Since the time of our last progress report, we have acquired an FPG2-3000-MC2 pulser The pulser has been extensively bench-tested into 50Ω loads and has been found to match the performance specifications found in Table 2. We have, however, encountered a single unexplained loss of output from the unit. The recovery was spontaneous and has not recurred.

Unfortunately, there is no suitable stripline kicker in the CESR accelerator complex with which we can conduct further tests locally. Thus our next step is to test the unit with the

Table 2: FID Technology Pulser Specifications[18]

Pulser	FPG2-3000-MC2	FPG1-3000	FPG3-3000	FPG10-3000
Output impedance[Ω]	50	100	100	100
Maximum output per channel [kV]	±1	1	3	10
Number of channels	2	1	1	1
Rise time 10-90% of amplitude [ns]	0.6-0.7	0.6-0.7	0.6-0.7	0.6-0.7
Pulse duration at 90% of maximum [ns]	2-2.5	2.5-3	2.5-3	2.5-3
Fall time 90-10% of amplitude [ns]	1-1.5	1-1.5	1-1.5	1.2-1.7
Maximum PRF in burst mode [MHz]	3	3	3	3
Maximum PRF in continuous mode [kHz]	15	15	15	15
Triggering - internal, external 5-10 v [ns]	20	20	100	100
Amplitude stability in burst mode [%]	0.3-0.5			
Pre- and after-pulses [%]	0.3-0.5			
Timing jitter, relative to trigger [ps]	20			

stripline kicker available at the Fermilab A0 photoinjector. Our collaborators at Illinois have already implemented a data acquisition and analysis system for the A0 beamline as part of their kicker work. We are presently scheduled to conduct tests during the first week of February 2006. If tests at A0 are successful, our intention is to immediately purchase and test a pulser with ± 3 kV output.

Next year Project Activities and Deliverables

Pending the successful completion of our present round of beam tests at the Fermilab A0 photoinjector using our current pulser and the subsequent purchase of a higher voltage unit, we intend to proceed directly to constructing a stripline kicker based on one of the existing designs [1, 5]. We will also begin preparations to install the kicker at the end of the linac which is the first stage the CESR injector. This linac can provide electron beams with energies between 100 and 300 MeV. We will then fully characterize the performance of the kicker and higher voltage pulser and evaluate their suitability for use in an ILC damping ring application.

Budget justification:

In order to build and install a kicker at the end of the Cornell linac, we will require funds for the fabrication of the stripline components. This will include vacuum chamber components, feedthroughs, stripline parts, and miscellaneous items such as cabling. Note that we intend to work from an existing design. We estimate that these components will cost $15,000.

In order to test the kicker, we will require additional 2 additional BPMs to be installed after the kicker. We will also need to build additional readout electronics (of an existing design) for those units. Including miscellaneous items such as cabling, the estimated cost for these components is $10,000.

0.325 FTE of technician time will be required for design, fabrication, testing and work.

We have also budgeted $4,000 in travel funds to meet with our collaborators.

Two-year budget, in then-year K$

Item	Next year	Subsequent year	Total
Other Professionals	27.1	0	27.1
Graduate Students	0	0	0
Undergraduate Students	0	0	0
Total Salaries and Wages	27.1	0	27.1
Fringe Benefits	8.943	0	8.943
Total Salaries, Wages and Fringe Benefits	36.043	0	36.043
Equipment	25.0	0	25.0
Travel	4	0	4
Materials and Supplies	0	0	0
Other direct costs	0	0	0
Total direct costs	65.043	0	65.043
Indirect costs(1)	23.292	0	23.292
Total direct and indirect costs	88.335	0	88.335

Indirect costs are calculated using Cornell's 58% rate on modified total direct costs.

References

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