RESONANT KICKER SYSTEM FOR HEAD-ON-COLLISION OPTION OF LINEAR COLLIDER*

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Abstract

The separation of incoming and outgoing (electron and positron) beams at the interaction point of a linear collider is investigated using a resonant kicker system. It should enable head-on-collisions at the interaction point with the use of staggered passing times for each bunch at certain locations. Magnetic core materials for such a resonant kicker with a frequency of 6MHz are under investigation. Such a kicker system should minimize the perturbation of the incoming bunch with a finite bunch length, while it kicks the outgoing bunch by more than 1 millirad. Various arrangements of such kickers along the beam lines are discussed.

INTRODUCTION

At the interaction point (IP) of the International Linear Collider (ILC), two beams are colliding with each other to reveal new interaction processes. Almost all of them will go on their way after the IP and thus two beams going in opposite directions have to be handled in the final focus system. Because the two opposing beams have different polarities (electrons and positrons), a magnetic field device cannot separate them. The TESLA proposal [1] used electrostatic separators with compensating magnetic field for incoming beam and septum magnets. In order to avoid difficulties coming from such a high voltage system, especially discharge problems, current ILC designs use finite crossing angles at the IP, where the choice of crossing angle is still under discussion. Although the baseline design chooses a finite crossing angle, the natural way seems to be a head-on-collision and thus such a possibility has been studied.

BASIC RF KICKER CONCEPT

Although a static magnetic field device cannot separate the beams as stated before, we can use the time structure of the beams to separate them (see Fig. 1). The bunches are separated by about 300ns (~100m) and the positron bunch locates at the center of electron bunches after 75ns from the collision. When we apply a magnetic field at this timing, we can separate the outgoing beam from the incoming beam, while the incoming beam is kept un-kicked. Possible waveforms for such a requirement are shown in Fig. 2. The top option has only one frequency and the second one has two frequencies for flat bottom but needs DC bias, which demands high amplitude precision for these components. Although the third one does not have DC bias, it still uses cancellation of two amplitudes at the incoming beam timing. If we allow two separate beam lines for the outgoing beam, which need two beam damps or a funneling mechanism, option d) may be possible, where the base frequency is half and the slope of the waveform is flattened by adding another component. The fifth one has only one kick direction but the kicker location should be closer than former one. The bottom one has the doubled frequency of the fourth one; only one the kick direction for 3MHz bunch spacing and two kick directions for 6MHz bunch spacing that is supposed be adopted for future energy up grade.

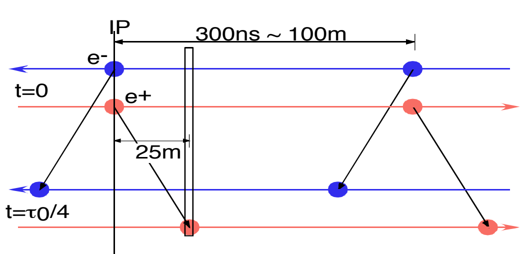

Fig. 1 RF kicker timing scheme.

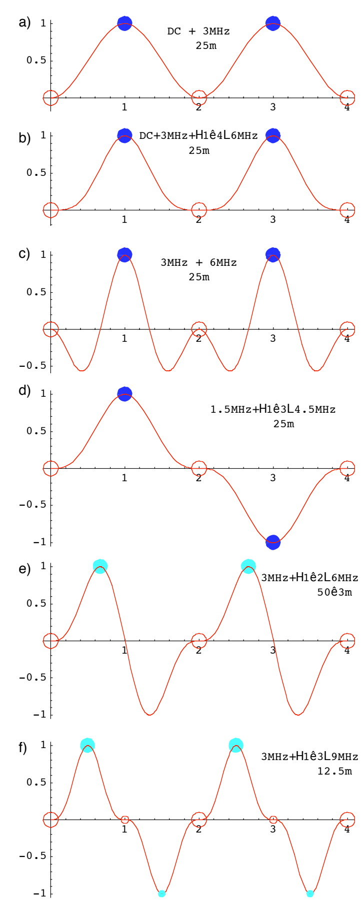

Fig. 2 Waveform options.

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RF CORES

The required BL integral is assumed to be about 1 Tm, while the total kick angle is 1 m rad. The total core length and magnetic field amplitude at these assumptions can be 4m and 0.25 T, respectively. A possible kicker configuration is shown in Fig. 3. Each core has a resonant circuit and is excited by an RF power source. The large number of power sources (more than 100) may give a redundancy to the kicker system for better reliability, reducing failure time. This multiple power source configuration also enables a phasing operation of the system for an incoming bunch not to feel any magnetic field during its passage in the kicker system. Some of the core parameters are listed in Table 1. These numbers may have to be modified per requirements based on background issues. The core can be arranged as shown in Fig. 4 for higher packing factor, keeping spaces for current loops on all cores. It also exhibits a better symmetry and a magnetic field shielding.

Table 1: Assumed Specifications

Gap height	2 cm
Gap width	4 cm
Core Length	2~3 cm
Total Length	~ 4 m
Magnetic Field	1/4 T
Frequency	6 and 12 MHz
Stored Energy in a Gap	10^2 J
Coil Current @1/4T	4 kA
Inductance	100nH
Coil Voltage	7 kV

Although the first choice of such an RF core material may be ferrite, it can generate less magnetic field amplitude because of its ferrimagnetics. Magnetic alloy (MA) materials such as FINEMET became famous for inductive loads in accelerating cavities for these days, which was initiated from studies of untuned cavities and promoted by related projects [2,3,4]. The very high permittivity of this material makes the shunt impedance of an accelerating cavity fairly high while it has rather low Q (<1). It also has good temperature stability and high magnetic flux density, because of its high Currie temperature and ferromagnetics. Since it is supplied as very thin tape (~18μm), it should be wound to form a core. Fig. 5 shows a sample core with resonant circuit. This kind of material configuration, unfortunately, makes this material difficult to use when the core has very large gap and a lot of stray magnetic flux penetrates the thin tape layers around the edge of the gap, even if the anisotropy is considered (see Fig. 6). The eddy current losses caused from this effect raise the core loss and degrade the Q value of the resonant circuit too low. Thus, this material may not be adequate for this purpose.

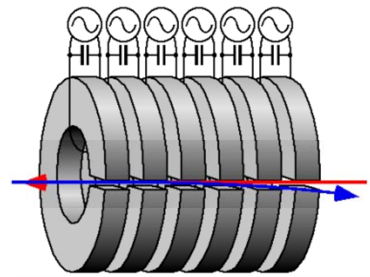

Fig. 3 A possible RF kicker.

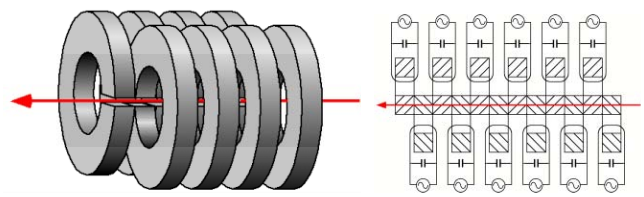

Fig. 4 Symmetric core configuration with less dead space.

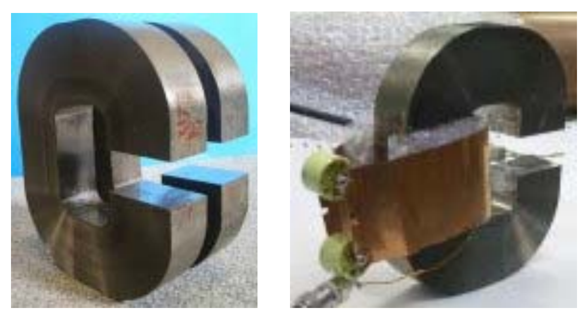

Fig. 5 Large gapped FINEMET core with coupling loop and capacitors for a rough measurement.

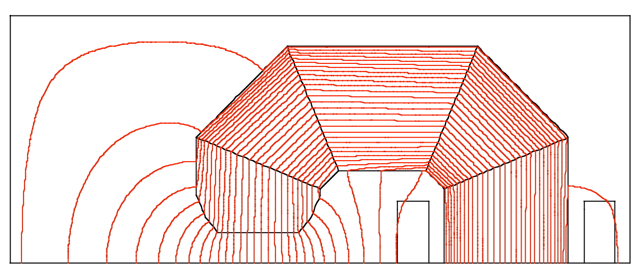

Fig. 6 Magnetic flux distribution in a core. The core material is simulated as anisotropic. Flux concentration at the inner corner and the eddy current loss at the edges of gap may cause problems.

Other materials such as ferrite cores and dust cores have to be revisited for this purpose. Samples of these core materials are under collection and test results will be presented in the near future. Ferrite cores, which are usually used for these applications, should be OK if the magnetic flux density can be reduced to half with a longer total length.

MORE TIMING CONSIDERATIONS

When we use the kicker system of the finite length, we need to consider the phase advance during the bunch travel in the kicker. As stated before, the kicker consists of more than 100 core sections with separate amplifiers for each, which allows phasing operation to synchronize the RF timing for each core to the incoming bunch velocity. This operation, however, causes phase slips for the outgoing bunch, which reduces the effective kick angle. Since the total length of four meters is shorter than the quarter wave length, even at 12MHz (~6m), it may be better to distribute the kickers along the beam line. Fig. 7 shows a possible configuration of the kickers, where k1, k2 and k3 are the kickers with 1m, 2m, 1m lengths, respectively. When the distances between the kickers hold to the following relations, the net kick angle for incoming bunches is always zero; even for electrons in the wrong buckets such as those caused by dark currents from the linac cavity wall, while the outgoing bunches get net kicks.

$$\begin{cases} \omega\tau_k = \pi/4 + n\pi/2 & \left(\lambda/8 + n\lambda/4\right), \\ \omega\tau_c = \pi/2 + m\pi & \left(\lambda/4 + m\lambda/2\right) \end{cases} \quad (n,m = 0,1,...)$$

The timing chart and the detailed locations are shown in Fig. 8. Each kicker is phased for incoming bunch not

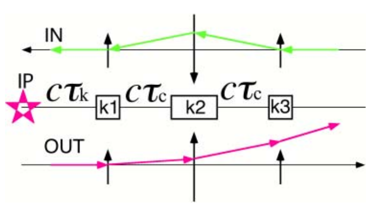

Fig. 7 Three kicker configuration. Bending angles for the incoming bunch (top figure) is exaggerated for clarity.

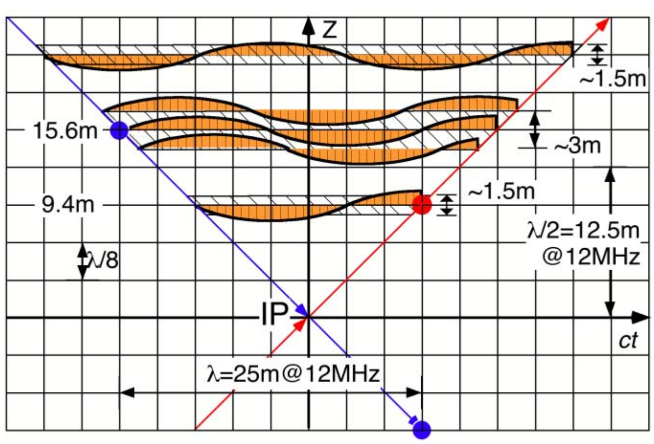

Fig. 8 RF kicker timing chart. The horizontal axis and the vertical axis show time and longitudinal coordinates, respectively. Blue dot shows the bunches going into interaction point (IP), while red one shows leaving bunch. Because both bunches meet at IP, it seems that a bunch coming from the top left corner is reflected at the IP and goes up to the right, which may ease the understanding of this chart.

to give a net kick angle. The outgoing bunches are kicked, although a slight phase slip exists. The total kicker system in the figure has length of 6m, whose BL integral can be 1.2Tm at 0.2T field level in a gap. This corresponds to 1.4 mrad kick angle for 250GeV/c bunch. Because the maximum kick angle in a shorter section is 0.36 mrad, the maximum displacement of a bunch is 2.25mm at the center section. The gap width for the outmost section may have to be larger .

DISCUSSIONS

In the macroscopic view, the total system forms a traveling wave going outwards, while each section has incoming wave. In summary, the configuration has following three points: 1) an outgoing bunch gets net kick 2) any incoming bunch does not get net kick and 3) incoming bunch with right timing does not feel any kicks.

For a single RF frequency operation, the tolerance of phase jitter seems very tight to keep the upper limit of beam deflection angle. It may be relaxed by harmonic operation and/or increase of the number of sections to decrease the sensitivity of a section.

Since the output energy of the damping ring is 5GeV, the dark current emitted in the main linac is always 2% less than 250GeV main bunch, if the kicker works fine. Such low energy electrons should be cut by appropriate collimators in the final focus system. Although optics studies for the zero-crossing angle option have been made in addition to the kicker study[5], more study is needed if this option is to be considered.

This device may also be used as a sweeping system for the dark current emitted from cavity walls and eventually accelerated in the cavity, which may cause unnecessary background and radiation along the accelerator and beam delivery system. By distributing sweeping kickers at an appropriate period, such dark current can be eliminated.

In order to reduce the heat dissipation in the core and the total RF power requirement, low loss core material is important. Various Ferrite and magnetic alloy materials are under investigation.

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