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FAST BUNCH TO BUNCH INTENSITY REGULATION IN THE ILC CONVERSION SCHEME WITH INDEPENDENT ELECTRON/POSITRON SECTIONS[1]

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Abstract

In this publication, the undulator based positron source scheme for linear collider is explained in more detail. The variant of the scheme considered allows independent operation of electron or positron parts of the linac. So every bunch in a train regenerates itself by the conversion system. Population of each bunch in a sequence kept steady at desirable level with the help of fast feedback system. If the regeneration coefficient goes higher for some reason, delivering more and more particles to IP, the feedback reduces number of positrons captured in a damping ring and vice versa. This particular feedback system realization is considered here for the first time.

INTRODUCTION

The Future Linear Collider ILC, if build, will be equipped with undulator conversion system. This system allows polarized electron/positron collisions and makes problems for target less critical [1], [2].

In principle, undulator scheme allows polarized electrons generation in the same way. One just needs to select energetic electrons instead of positrons after the target. The level of positron/electron polarization can reach 85% with a 200-m long undulator [1]. We mentioned many times, that utilization of solenoidal field in collection optics allows ~equal number of electrons and positrons (with ~15% domination of Compton electrons). So the first sections of accelerating structure are loaded by these extra electrons only.

Independence of electron and positron wings of linear collider is very suitable property of LC. First, there is no necessity for transport channel traversing IP. Second, as the collider will be filled by structures from one side until it is completed, the possibility to make a choice which one it is –electron or positron –is much appreciated.

Similar to asymmetric B-factory, no doubt, Linear Collider (LC) will be used with the beams having *different* energy. This allows intermediate particle to move some distance out from the point of creation. This might be especially important is search of Higgs and short-lived resonances.

Bunches in LC are following with 300 ns spacing one after another, what corresponds to ~90 m spatial separation. Meanwhile in a damping ring (DR) the bunches separated down to 20 ns (6m) in some variants. In any case bunches in DR circulating under strong feedback supervision.

[1] Work supported by NSF. Electronic version is available at http://www.lns.cornell.edu/public/CBN/2005/CBN05-18/CBN05-18.pdf

In this publication we will consider some details of the scheme with independent electron/positron operation. Namely we will investigate here fast feedback system which allows bunch to bunch population control. Technical details of Starter electron source, which serves for initial accumulation of particles (se lower), when they are lost, will be described in other place.

LINEAR COLLIDER

Scheme which allows independent operation of positrons and electrons in ILC is represented in Fig.1 [1].

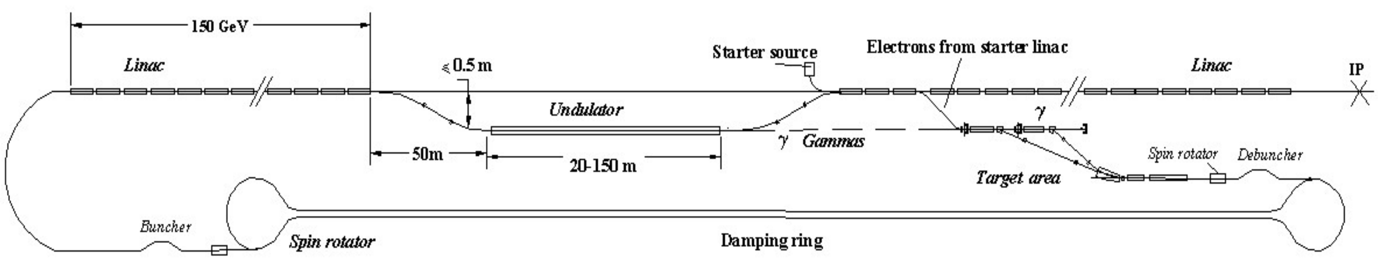

FIGURE 1: Base scheme for positron production which allows independent operation electron and positron sections of the linac. Electron wing also has undulator if polarized electrons created by this way. If polarized electrons are generated from solid-state photocathode, then undulator in electron part is omitted.

Here basically ~150 GeV positrons deflected from the accelerator line into undulator, generate there gammas, which are directed to the conversion target. Meanwhile these primary positrons are returned to the acceleration line and are going further to IP. So the new positrons just generated from radiation emitted by these primary ones. Generally speaking the positrons generated from electricity. In Fig.1 the scheme shown with two targets for gamma-beam installed in series.

Collection from each target is going independently and combining damping ring is going in longitudinal phase space [2], [3].

A debuncher is required if the lengthening of the bunch after conversion is not enough, so injected bunch can develop instability if it's length much shorter, than equilibrium. Remember that the bunch is short in linac; normally there is few stage buncher after the ring.

To restore the positron population after occasional lost, the electrons are used here. Electron Starter source, Fig. 1, is a ~ 1 MeV accelerator delivering electrons with the pattern of normal bunch sequence. These electrons are then accelerated in the main structure up to ~0.2 GeV. This starter source is a kind of quasi-DC pulsed generator with High Voltage ceramic vacuumed tube immersed into pressurized SF_6. So *the electrons* after acceleration in a part of main linac (to 0.2 GeV as mentioned above) directed onto the same positron target, which serves for polarized positron production[2]. Here *electrons* are generating positrons, which are collected by the same

[2] For better accumulation thin positron target (~$0.5X_0$) used for positron generation from gammas, can be replaced quickly to a more thick one suitable to 0.2 *GeV* electrons, what is ~$2X_0$.

optics used in undulator production. After the necessary amount of positrons is accumulated (stacked) in the damping ring, the beam from the damping ring goes into main linac in a usual way. After few cycles, the polarized positron beam becomes restored.

The point of concern here is in stability of the scheme. If positron bunch, for some reason, fluctuated in intensity, then next round it will generate more/less positrons in a bunch, next round even more and so on. The bunch can acquire this variation in intensity in a damping ring as well, due to imperfection in injection, for example. So this will randomize the bunch population and might bring the losses as a sequence. At first look there is no way to make this scheme stable. That is why, the similar scheme, proposed in times of VLEPP [3], remains undeveloped until today.

We have mentioned, however, that with appropriately designed feedback system, this scheme can be brought into stability. Let us consider some possible scenario for such a feedback system.

First, the positron conversion scheme for polarized positron production deals with selection only ~half of the positrons created in a target. So there is a mechanism of some kind of energy collimation (selection), leaving the only energetic ones.

Even without polarization the secondary beam is going through some electro-optical elements naturally having controllable dispersion, see Fig. 1 at target area. Namely here it was suggested to make scrapping the particles with low energy, see [4] and references there. The additional controllable selection of particles can be done with *fast kicker* by perturbation of dispersion at some point with low envelop function and scrapping particles at this point in accordance with the bunch population. Scrapping is made by adjustable collimator.

Let us consider one of such schemes.

SCHEME FOR PARTICLES SELECTION

Namely, let us scale the view of target area in Fig.1 [4].

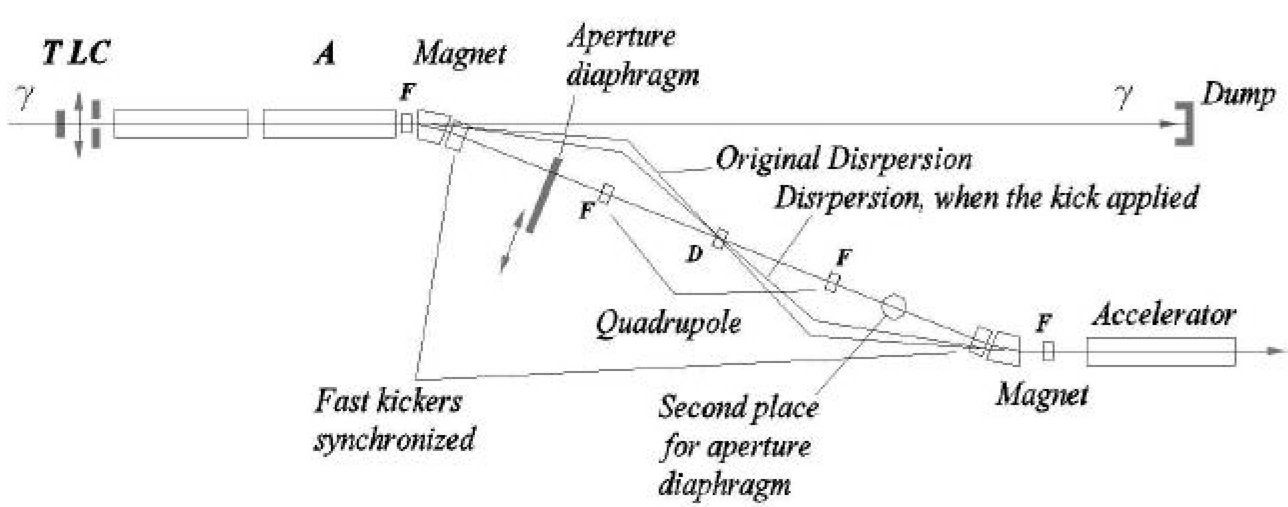

FIGURE 2: Achromatic bend with aperture diaphragm. *T*–is a target, *L*–is a short focusing lens, *C*–stands for collimator. *F* and *D* stand for focusing and defocusing lenses respectively. *A* stands for RF accelerator structure.

Achromatic bend arranged with the help of two bending magnets and two radially focusing quadrupoles located in between and marked F in Fig 2. This scheme was proposed in [5]. The same achromatic bends used in main beam transport to the undulator axis, as is seen in Fig.1.

Let us make some analytical estimation first. At the end of the magnet M the dispersion goes to be proportional to the bending radius and is rather simple function of angle

$$D \cong r \cdot (1 - Cos j), \quad D'(s) = Sin j, \quad j = s / r, \tag{1}$$

where $r = (HR)/H_m$ stands for the bending radius, $(HR) = pc[eV]/300\,[G{\cdot}cm]$ is a magnetic rigidity, H_m magnetic field in a bending magnet, s is a path length along equilibrium trajectory. At the location of lens F, in the middle of it, the dispersion goes to be

$$D\big|_l \cong r \cdot (1 - Cos j) + L \cdot Sin j, \tag{2}$$

where L is a distance between the magnet and lens. Let $j = p/12$ (15^o), L=300cm, $r = 100cm$, then $Sin(p/12) \cong 0.26$, $Cos(p/12) \cong 0.96$ and

$$D\big|_l = 100 \cdot (1 - 0.96) + 300 \cdot 0.26 \cong 4 + 78 = 82\ cm. \tag{3}$$

If the energy delivered by accelerator structure E_{10}= 200MeV, $E_{g\,\max} \cong 20MeV$ and we collect half of this interval, i.e. $15 \pm 5MeV$, then the energy at the out of accelerating structure goes to be E_1=215$\pm$5 MeV and full radial displacement at the lens location will be

$$\Delta r \cong D\big|_l \cdot \frac{\Delta E}{E} = 82 \cdot \frac{10}{215} \cong 3.8\text{cm} \sim (\pm 2cm) \tag{4}$$

For reduction of systematic energy spread introduced by RF roll-off, one can consider acceleration of positron bunch in first section A at one side of RF, and the last half of section at another side. Anyway as the cut in intensity done by scraper any way, linearity is not important, generally (see lower).

Focal distance of the lens is $L = (HR)/(Gl)$, and l stands for the length of the lens. Supposing that the length of the lens is l=10 cm, then gradient must be

$$G = \frac{(HR)}{L \cdot l} = \frac{600kG \cdot cm}{200cm \cdot 10cm} = 0.3kGs/cm. \tag{5}$$

Here the magnetic rigidity (HR)= 600 $kG\cdot cm$ was substituted for ~200 MeV beam. So the lens is rather weak.

Result of calculation of channel just described with computer program is represented in Fig. 3. One can see that this is absolutely symmetric channel with respect to the central lens.

Let the scraper to be located ~at the middle between lens and the magnet, the radial displacement will be here as big as $\Delta r \cong \pm$ 1cm. Within this aperture spread all particles will be located. Here, between two radially focusing lenses, the minimum of envelope function can be arranged. Typical value of envelop function in minimum comes to be ~4 cm or even less. With emittance of the beam $\sim ge_{x,y} \cong 2cm \cdot rad$, the transverse betatron size is going to be

$$x_b \cong y_b \cong \sqrt{ge \cdot b / g} \cong \sqrt{2 \cdot 4/400} \cong 0.14\ cm, \tag{6}$$

while the beam size arising due to the energy spread according to (4) is $x_D \cong y_D \cong \pm 2cm$, so the energy resolution is high enough.

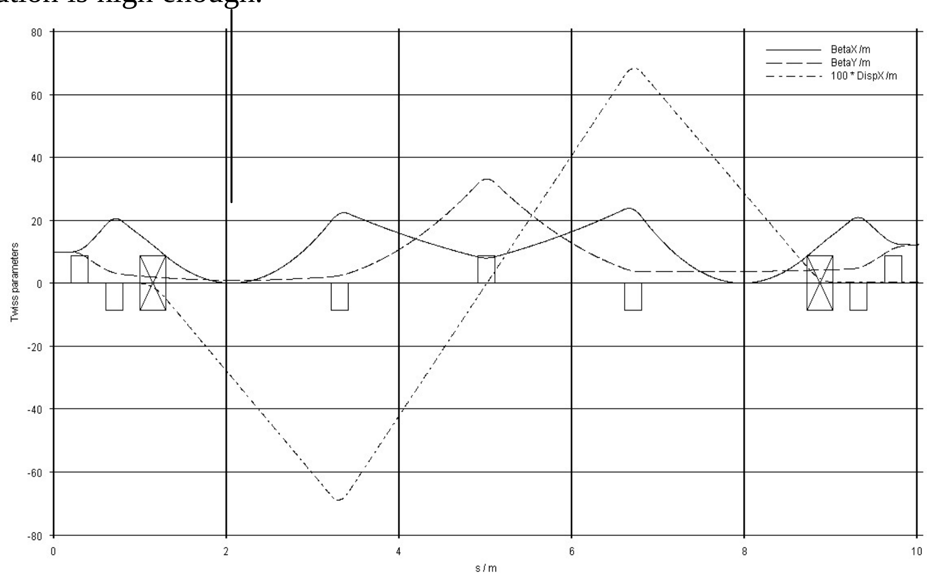

FIGURE 3: Example of more detailed design of channel. Envelope functions and dispersion are given in meters. Scraper location indicated by arrow. Radial beta-function in minimum is ~4 cm.

So the aperture scraper in first place will cut all positrons with low energy. It also allows controllable change of energy pass interval by installation of two fast kickers, located at the edge of each of bending magnets, see Fig. 2.

KICKER AND AMPLIFIER

These fast kickers feed from a powerful amplifier. We would like to stress one more time, that this is namely powerful *amplifier*, not pulser. In its turn it gets the signal from pickup, located in the dumping ring. Signal from this pickup processed, so the zero level can be controlled in a way desired. Spacing between bunches ~20 ns allows easy resolution the individual bunch population. That might be a signal from feedback system installed in the ring or additional pickup. Anyway 20 ns bunch spacing is well below the possibilities of present day electronics. As we mentioned, the bunches after target are following with 300 ns spacing one after another, giving a lot of time for rise and down. The spacing in 300 nsec between bunches corresponds to the frequency ~3.3 MHz only, then the requirements for the technical realization of amplifier is rather relaxed.

Let us estimate the power required, however. If we suggest 1% of variation of dispersion at the scraper location and, hence, 10% of $\Delta r \cong \pm$ 1cm, then fast kicker must deliver ~10% of D'. This angle is $D' \times 0.1 = Sin(p\ /12) \times 0.1 \cong 0.026$, so the kicker field integral must be as big as

$$\int Hds\Big|_{kicker} \cong (HR) \cdot D' \times 0.1 \cong 600 \times 0.26 \times 0.1 = 15.6\ kG{\cdot}cm. \quad (7)$$

If we suggest, that the effective length of this kicker is $l_k \cong 10\ cm$, then the field in it goes to be H=1.56 kG. If we suggest that aperture of this fast kicker is as big as a=4 cm, then the feeding current for this kicker will be

$$I \cong \frac{Ha}{0.4p} \cong \frac{1.56 \cdot 4}{1.2} \cong 5.20 \; kA{\cdot}turns. \tag{8}$$

If we suggest that the number of turns in coil n=10, the current from power source is ten times less, i.e. ~520A. If the impedance of the cable feeding kicker is Z~25O, then the pulsed power running through it becomes as big as

$$P_{peack} = I^2 Z \cong 6.8 \; MW, \tag{9}$$

with the voltage $V = I \times Z \cong 520 \times 25 \cong 13 \; kV$.

Although the pass time is $t \cong s_l / c \cong 30 \; ps$ for the bunch with the length ~1 *cm*, the pulse duty will be longer. One physical limitation is the pass time of electric current through the coil wiring. For ten turns having ~30 *cm* each, the total length of conductor goes to be l~3m. So the pass-time corresponding to this length does to be $t \cong l/c \cong$ 10 nsec. Thus, the pulse duration is 17 ns, brining the maximal average power

$$P \cong 6.3 \cdot 10^6 \times 2820 \times 5 \times 17 \cdot 10^{-9} \cong 880 \; W. \tag{10}$$

These numbers can be easily scaled to the energy other, than 200 MeV. Inductance L of the kicker's coil can be found from the following equation (in MKSA units)

$$LI^2 \cong m_0 H^2 l_k ab\,, \tag{11}$$

where b stands for the width of aperture, $m_0 = 4p\,10^{-7} H/m$ is magnetic permeability of vacuum. Here all dimensions taken in meters. We suggested also, that all energy concentrated in vacuum gap. As magnetic field in these units is

$$H \cong \frac{nI}{a}\,. \tag{12}$$

Substitute this equation in (11), one can obtain estimation

$$L \cong m_0 n^2 l_k \frac{b}{a}\,. \tag{13}$$

For parameters under discussion, n=10, a=0.04m, b=0.1m, l_k =0.1m one can obtain from (13)

$$L \cong 4p\,10^{-7} 100 \times 0.1 \frac{0.1}{0.04} \cong p \cdot 10^{-5} H \cong 30 \mu H.$$

Of course in reality the power will be lower as there is no visible reason to pulse this system each time at full scale when the bunch passes, mostly of time it will be idle. This power at idle mode depends on what level of zero kick will be taken for steady value. For minimization of RF pulsed kicker power one can suggest, that during steady operation DC current in amplified signal goes to zero, but current in bending magnet is adjusted to compensate this change. So in this scenario pulsed kicker is working together with dc bending magnet. Field variation in bending magnet could be made fast enough for these purposes.

The cables even with lower impedance can be used here. This impedance defined by the kicker design.

Fast kickers having rise time ~2 ns described in [6], [7]. One of these has ferrite core, but another has laminated iron core. Here in [8] it was shown, that magnetic field in c-shape magnets comes to equilibrium extremely fast, practically with *nsec* level. That was explained by specific mechanism of magnetic field establishment-first the field propagates between the laminations, generating over-equilibrium value, and, then diffuses into laminations from both sides. As this initial value of the field between lamination is much bigger, than equilibrium, the process is going faster. This allows fabrication of kickers with nsec rise time with laminated iron core [6].

Mostly adequate solution for the controllable power supply is in usage of vacuum tubes (tetrods) designed for SW transmitters. Tetrode(s) enveloped into appropriate holders. These tubes and amplifiers are available on the market. So basically we are talking about the last (end) cascade of RF transmitter. One possible scheme for such amplifier is represented in Fig. 4.

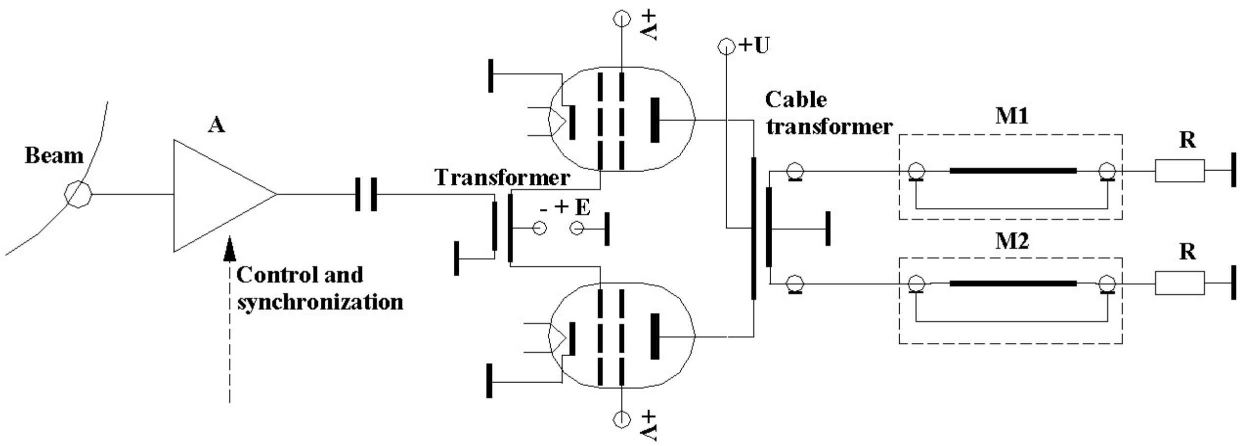

FIGURE 4: Tetrode amplifier. *M1* and *M2* stands for the kickers. *A* –controlled pre-amplifier. Voltages *E*, *V*, *U* applied for proper operation of tubes. *M1*, *M2* stand for the kicker magnets, *R* stand for the loads.

Solid state pre-amplifiers for these vacuum tubes are available on the market and are in use for fast feedback in damping/storage rings. Even for these solid-state pre-amplifiers typical average power is 2 kW. Thus, the scheme can be realized without doubts.

We considered the simplest scheme of this kind. More complicated schemes can be made so that RF buckets having carrier frequency ~3 *MHz* applied to the kickers during the bunch train duration, but with amplitude modulation in accordance with bunch population. The best point of application of such amplitude modulation is modulation of displacement grid voltage E in Fig.4. So in this case we are talking basically about amplitude modulation of carrier signal with 3.3 *MHz* and having duration about 1*msec* and repetition rate 5 *Hz*. So this regime is pretty easy for amplifier. Phase modulations (numerous types) can be used here as well too.

DISCUSSION

Independent operation of positron/electron wings of linear collider has undoubted advantage and could be realized with relatively simple feedback. Stability diagram for this feedback loop looks pretty guaranteed.

We considered the scheme in bending channel. This principle can be realized with fast kickers installed in other parts of transport channel as well. For example, it could be the place in bending loop in front of main linac. Namely here is the best place for fast feedback for correction of beam displacement and angle before injection into linac. Angle and position mismatch is read at the entrance of the loop and applied directly at the entrance of linac. This idea came from the times of the very first descriptions of linear collider schemes in many Labs.

Dynamic range of feedback system must be higher, that the possible source of particles losses variation from bunch to bunch. We suggest 10% of dispersion change. In linear approximation this gives ~10% modulation of intensity as the positron creation differential cross-section is pretty flat with energy. Remember, ~50% of lower energy positrons are not in use here.

Principle of operation of such a feedback system can be tested at CESR. In this case the amplifier can feed the fast quadrupole and change the betatron frequencies of each individual bunch in a train, as these were fond to be different for each bunch at present. Fast quadrupole can be designed to have about the same electric loading parameters as the fast kicker.

CONCLUSION

So coming to a conclusion, the scheme in Fig.1 can be technically realized and delivers flexibility, economy and ability to work for electron and positron part of collider *independently*. The scheme allows equalizing the bunch population also.

A detailed design of fast kicker will be done in separate publication. There is no apparent limitation in construction of such fast kicker however.

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