Target hardness examination for ILC positron production target at KEKB

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Abstract

ILC (International Linear Collider) is a linear collider project make electron and positron collision in 1 TeV center of mass energy. One train contains up to 2800 of 3nC bunches with 327 ns bunch spacing resulting 0.9ms train length. Because of this extremely large amount of beam in a train, a serious damage on the positron production target driven by 6 GeV incident electron, concerns. As ILC positron source, several different methods are proposed and the target hardness is a key on the selection. In this article, we propose a test experiment to examine the target hardness by using the stored beam in KEKB HER(High Energy Ring). The project name is IPPAK(ILC Positron Project At KEKB) which sounds like "ippaku" (one night stay in Japanese). By manipulating the abort kicker, a condition similar to that of ILC positron production target, can be reproduced. The experiment will be carried out in the end of June 2005. Possible results and impacts to the ILC positron production scheme, are also discussed.

INTRODUCTION

ILC(International Linear Collider)[1] is a linear collider project promoted by ICFA(International Committee for Future Accelerators)[2]. In Summer of 2004, ICFA decided to promote ILC project based on the super conducting technology according to the report of ITRP(International Technology Recommendation Panel)[3].

In the super conducting accelerator, the pulse length will be much longer than that of the normal conducting accelerator for efficient acceleration. In ILC case, one RF pulse length will be 0.9 ms. The system will be operated in 5 Hz. To achieve the luminosity in a range of $2.0 \times 10^{38}\mathrm{m}^{-2}\mathrm{s}^{-1}$, 2800 of 3nC bunches are filled in a train resulting 327ns bunch spacing. The positron beam is usually produced by pair-creation process in a heavy material driven by high energy electron beam. In the target, electro-magnetic shower grows up generating mixed flux of electron, positron, and gamma. From the flux, positron beam is selected.

If we produce this bunch train with this conventional method, the target will be broken immediately because more than 9kW of the beam energy will be concentrated in a small spot (typically several mm^2). According to an experiment carried out at SLAC[4], damage threshold for single bunch was $320\mathrm{J/mm}^2$ for W(75)Re(25) alloy. If we assume $1\mathrm{mm}^2$ spot size and 6GeV drive beam giving positron yield per incident electron to be 1.0, the energy deposit will be $2800 \times 6 \times 3 = 50400\mathrm{J/mm}^2$ which is clearly more than the threshold.

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A totally new method to generate the positron beam was proposed by originally TESLA collaboration[6]. In this method, high energy gamma ray (up to 26 MeV) generated by 70m planar undulator with 250 GeV electron beam, is injected into the production target, but the radiation length is much smaller than the conventional case, $0.4\mathrm{X}_0$ resulting less damage. This method is however a totally new method which is never built. It is impossible to examine the feasibility prior to the real ILC machine. One might concern about the total availability of ILC because this method makes a dependence between the electron and positron systems.

Another more conventional way to avoid the target break is rotating the target to spread widely the energy deposition. Technically, 3600 RPM with 1m radius giving 360 m/s moving speed is possible[5]. This rotation speed is decided to prevent a fatigue effect on the target material (W-Re allow). Even with this high speed rotation, the power density is close to the threshold.

By the way, the threshold for the target break observed in SLAC, was obtained with the single bunch injection. In ILC, the bunch is coming with a relatively large bunch spacing, 327ns. The energy flux defined as the power per time, is much different for ILC and SLAC cases. It is possible that the threshold depend on the duration of the incident beam and the target break threshold is larger for ILC case.

In IPPAK, stored beam of KEKB HER[7] is injected into a test material placed inside of the beam dump. By manipulating the beam fill pattern and abort kicker, beam condition similar to the ILC positron production drive beam, can be reproduced. IPPAK can demonstrate the possible damage on the ILC positron production target and examine a feasibility of the conventional positron production for ILC.

SET UP

The experiment is carried out at KEKB HER(High Energy Ring)[7]. A beam abort system is implemented to reserve radiation safety and protect sensitive components in BELLE detector. In the abortion, the circulating beam is deflected by the kicker system and guided to the dump line[8]. At the end of the dump line, a beam dump is placed to dispose the electron beam and seal the radiation.

The system has two kicker magnets for horizontal and vertical deflection respectively. The kicker magnets are conventional window-frame type magnets with ferrite core driven by a single power supply. Horizontal kick is enhanced by a Lambertson Septum magnet. [8]

As results of the vertical and horizontal sweeps, the aborted beam follows a semi-sinusoidal shape as shown in Figure 1. This pattern is observed as illumination from an

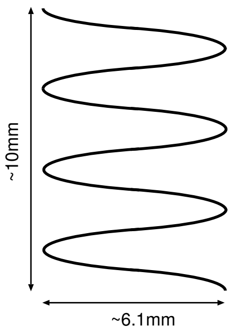

Figure 1: Trace drawn by the aborted bunches on the beam dump. This pattern is made from vertical and horizontal kicks. This pattern is observed with an alumina plate set in the dump line.

alumina plate placed in the dump line[9].

Figure 2 shows the experimental layout of IPPAK. The test target is deeply inserted into the cave drilled on the dump wall with 600 mm depth. The beam dump is composed from iron, lead, and concrete. Because the beam dump is used since KEKB operation has been started, the material of the dump is activated radiologically. To prevent radiation pollution by scratching the inner wall when the test target is mounted and dismounted, the inner surface of the cave is covered by a guide pipe.

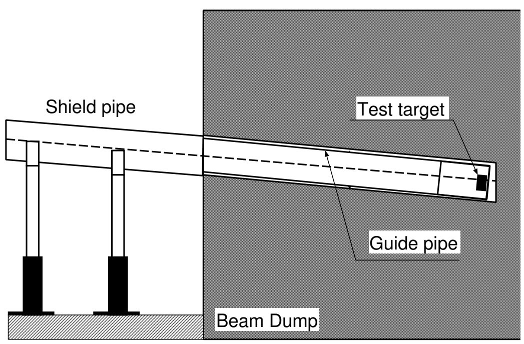

Figure 2: Schematic view of the basic experimental setup. Test target is inserted into the end of the dump cave. To prevent any radiation pollution during the experiment (loading and unloading the target), a guide pipe is inserted to cover the radiated dump wall.

Test material is mounted in a cassette which has 74mm diameter and 200 mm tall. There are two purposes of the cassette. One is to mount and unmount the test material quickly to/from the cave. It is very important to shorten the access time for the efficient operation and especially for the radiation safety policy. The second purpose of the cassette is to keep the distance from the dosed material when we handle it. As mentioned later, the radioactivity of the dosed target, can not be ignorable. That is why it is important to keep the distance from the material to reduce the exposure.

EXPERIMENTAL MODES

If the trace shown in Figure 1 is approximated to be a sinusoidal function(3.1mm amplitude and 2850ns revolution), a detail beam profile on the beam dump can be analyzed. The bunch spacing is 6 or 8ns, but let me assume here 7ns. The step size for each bunch, i.e. the distance between the injection points of the neighbors bunches, depends on the position of the pattern. The step size is maximized at the zero-cross of the sinusoidal curve, to be 53 μm. The minimum is 7 μm at the extremum. If the energy deposited in the target distributed in a circle of 0.64mm radius making $1\mathrm{mm}^2$ area constantly[1], the expected energy density accounting the bunch overlap can be calculated.

Table 1: Summary of the beam parameters and expected energy deposited in ILC drive beam and KEKB stored beam. For ILC, 50 m/s target rotation is assumed.

Item	ILC	KEKB
Bunch charge (nC)	3	10
Beam energy (GeV)	6	8
Bunch power (J)	18	80
Step size (μm)	17	7-53
Bunch overlap	71	23-172
Power density (J/mm^2)	1270	1810-13700
Duration (μs)	24	0.16 - 1.2

Table 1 summarize the estimated power density on the target. For the comparison, ILC drive beam parameters are also listed. For ILC, a target rotation with a speed of 50 m/s giving 17μm displacement during 327 ns is assumed. Since the lowest energy density of KEKB is 1810 J/mm^2, ILC drive beam can be reproduced by reducing the KEKB HER beam intensity with a factor of 2/3 or more. Let us call this experimental mode as KEKB mode.

Although the power density is reproduced in KEKB mode, the duration is much different. To reproduce the both power density and flux which is defined as the ratio of power and duration, another experimental mode, ILC mode, is considered. By turning off the vertical kicker, the trace of the beams becomes an oscillation instead of the sinusoidal wave, with 2850 ns revolution period. If only appropriate bunches around the zero cross, are filled, several bunches on a same spot with 1425 ns spacing can be made.

If only one bunch is filled at each zero cross position, totally 7 bunches are coming each 1425ns. Since the power of one bunch is $8\mathrm{GeV} \times 10\mathrm{nC} = 80\mathrm{J}$, the total power density and flux are $80 \times 7 = 560\mathrm{J}/\mathrm{mm}^2$ and $560/(1.425 \times 6) = 65.5\mathrm{J}/\mu\mathrm{s}$. If we put two bunches for each zero cross position, the total power density and flux are $2 \times 80 \times 7 = 1120\mathrm{J}/\mathrm{mm}^2$ and $1120/(1.425 \times 6) = 131\mathrm{J}/\mu\mathrm{s}$. The displacement of the neighbor bunches is only 7 μm that is negligible compare to the spot size of $1\mathrm{mm}^2$. In ILC drive beam, the power density and flux are estimated to be $18 \times 70.6 = 1270\mathrm{J}/\mathrm{mm}^2$ and $18/0.327 = 55.0\mathrm{J}/\mu\mathrm{s}$. Therefore, ILC mode 1 and 2 reproduce the power flux and the power density of ILC drive beam respectively. ILC mode parameters are summarized in Table 2.

[1] The beam size at the entrance of the dump line is 0.6mm horizontal and 0.3mm vertical. This size is slightly increased by passing air 4m long.

Table 2: Summary of the beam parameters and expected power density and flux in ILC drive beam (ILC) and KEKB with ILC mode(ILC m1 and m2).

Item	ILC	ILC m1	m2
Bunch charge (nC)	3	10	10
Beam energy (GeV)	6	8	8
Bunch power (J)	18	80	80
Bunch overlap	71	7	14
Energy density ($\mathrm{J/mm^2}$)	1270	560	1120
Duration (μs)	24	8.55	8.55
Flux ($\mathrm{J}/\mu\mathrm{s}$)	55.0	65.5	131

Table 3: Summary of the experimental menu.

	Density ($\mathrm{J/mm^2}$)	Flux ($\mathrm{J}/\mu\mathrm{s}$)	Shots
KEKB	600-4600	3780	1
ILC 0.5	280	32.8	2
ILC 1	560	65.5	2
ILC 2	1120	131	2

POSSIBLE RESULTS AND CONSIDERATIONS

By considering IPPAK experimental menu, the boundary conditions are 1) IPPAK can take two shifts as the dedicated beam time, and 2) It is ambiguous whether bypassing the vertical kicker is possible or not. These conditions lead that both modes (KEKB mode and ILC mode) can not be made because the kicker work spend almost 1 shift and the target in KEKB mode, have to be cooled down at least 24 hours. We have to make a selection depending on the kicker work.

In KEKB mode with 33% of the full intensity, the power density will be from 600 to 4570 $\mathrm{J/mm^2}$ which cover that of ILC. In ILC-mode, addition to mode 1 and 2, reduced mode 1 is meaningful if the damage was observed in mode 1 and 2. Table 3 summarizes the experimental menu. KEKB mode will be made only with W-Re target, but in ILC-modes, W and W-Re are used for each configuration. This experimental menu fits to 16 hours including the kicker work and 5 hours for target cooling down.

If any damage was not observed in the KEKB mode, it was confirmed that any sudden (short time) effect on the ILC e+ production target is not an issue. This statement is also true for ILC modes. If some damage was observed, the threshold can be extracted from its position because the power density depends on it. In ILC-modes, we can mention only a range of the threshold.

RADIATION SAFETY

The radiation safety is a big issue in two contexts: radiation safety regulation and damage to KEKB system. Because the test material is placed inside of the beam dump, the radiation flux to surroundings is same as that in the usual dump. In this context, IPPAK does not break the radiation safety regulation and does not damage any device in KEKB. On the other hand, the target is replaced after the experiment and some radiation exposure is expected. We have to consider the exposure.

According to an estimation by K. Saito of KEK radiation science center, the absorbed dose right after the experiment with the full intensity of KEKB stored beam is 3.81×10^2 Sv/h at 1cm away from the target. In the estimation, 1.5cm W target where 20% of the beam energy deposited in, is assumed. It goes down to 2.92×10^{-1} Sv/h 1 hour later and 9.32×10^{-4} Sv/h 24 hours later. According to these numbers, the radiation exposure was estimated during the experiment with assumptions of: 10cm distance from the target, 2 minutes for the cassette handling, the cassette unloading 1 hour after for ILC mode, 24 hours after KEKB mode. The estimated total exposure was $9.9 \times 10^{-2}\mu$Sv for KEKB mode and $3.85 \times 10^{-1}\mu$Sv for ILC mode. These numbers are even lower comparing to KEK radiation safety policy, e.g. less than 0.5 mSv/day[10].

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