CONCEPTUAL DESIGN OF AN ELECTROMAGNETIC DRIVEN UNDULATOR BASED POSITRON TARGET SYSTEM FOR ILC*

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Abstract

There have been intense activities on development of the fast spinning Ti wheel positron target for ILC in the last few years. As in many high power target design, it requires solutions for many technical challenges, such as vacuum, thermal stress and radiation damage control, just to name a few. Due to the unique beam timing structure, in this paper, we present a target system based on an electromagnetic mechanical system that drives a bullet type Ti slug (~ 1.4x1.4x10 cm, weigh ~ 50 g) as the target system. The mechanism is similar to a reloadable EM rail gun driven projectiles. The system can be compact, vacuum isolated, and ease of cooling. Conceptual design layout and parameter estimations are presented.

INTRODUCTION

The ILC baseline positron source[1] is a helical undulator based positron source which produces 2×10^{10} positrons per bunch at the IP with the nominal ILC bunch structure and pulse repetition rate. It is designed with a 50% overhead and can deliver up to 3×10^{10} at injection into the 0.075 mrad transverse dynamic aperture of the damping ring. The main electron linac beam has an energy that varies between 100 and 250 GeV and passes through ~150m of helical undulator, with a 1.15 cm period and a K value of 0.92. At 150 GeV, the first harmonic cut-off of the photon drive beam is 10.1 MeV and the beam power is ~63 kW. Approximately 4.4 kW of this power is deposited in the target in ~1mm rms spot. A windowless moving target is required to handle the high beam power and heat deposition.

The ILC baseline positron production target[1] is a rotating titanium alloy wheel. The target wheels sit in a vacuum enclosure at 10^{-8} Torr (needed for NC RF operation), which requires vacuum seals for access to the vacuum chamber. The rotating shaft penetrates the enclosure using one vacuum passthrough. The R&D of target remains on-going. Even though the vacuum specification of the rotating vacuum seal, has been demonstrated, its lifetime and reliability still requires further R&D. Also thermal stress and radiation damage control of the rotating target system has not yet demonstrated and thus whether the target will meet the 2 year operational life time requirement or not is still unknown.

Thinking out of the box, since ILC is to be working at 5Hz with a pulse length of about 1ms, the target doesn't have to be one continuous object. It can be a system with a lots of short slugs passing through the photon beam at

the right time and at a fast enough speed. A conceptual design of such system is discussed in detail in this paper.

CONCEPTUAL DESIGN

The new target system is a closed loop of vacuum pipes. Inside this closed loop, there are a lots of short Ti slugs which will be the positron conversion target when they passing through the photon beam generated by the helical undulator upstream of the system. As illustrated in Fig. 1, the system consists of 3 major parts, the EM rail gun to launch the target slug, the electromagnetic braking and catching system to slow down and catch the target
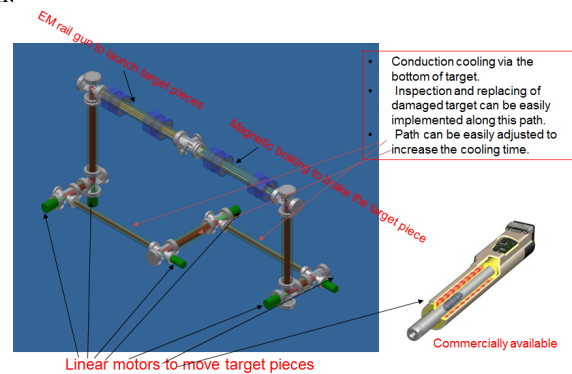

Figure 1: Conceptual illustration.

slug after it has pass through the photon beam, the cooling and circulating system to cool the target slug and transport them back to the EM rail gun.

EM Rail Gun

An EM rail gun[2] is adopted to launch the Ti target slugs. The use of EM rail gun concept eliminated the mechanical motion coupler of any kind between inside and outside of vacuum and thus eliminated the potential life time and reliability problem of the current ILC target system. As illustrated in Fig. 2, EM rail gun is consist of two electrical conducting rail. The projectile is a metal object inserting between the two rails. The EM force
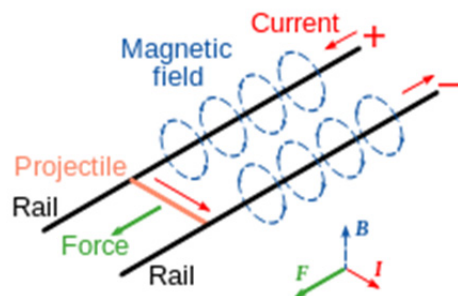

Figure 2: EM rail gun illustration.

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between magnetic field produced by the currents running in the rail and the currents passing the projectile is used to power the device.

In our conceptual design, permanent rare earth magnets are also used to improve the performance. The target slug has been chosen to have a cross section of 1.4cm by 1.4cm so that it can be used as positron conversion target no matter which side the photon beam comes in and will thus improve the life time and reliability of the target system. The length of the slug is determined by the 1ms pulse length of ILC bunch train and the speed at which the conversion target transvers the photon beam. The current ILC rotating target has a tangential speed of 100m/s and its highest peak deposited energy density is 475J/cm^3 ECM upgrade. Since our new target scheme can have more effective ways for cooling and also each damaged slug can be easily replaced, we lowered the speed down to 50m/s so that it consumes less power. With speed of 50m/s, the length of the slug is thus chosen to be 6cm with 50 micro seconds timing jitter tolerance.

We further assume that the length of conducting rail to be 1m long. The length of rail should not be too long or too short. A rail too short will require too much power and thus raises the cost of engineering and operation. A rail too long will make the accelerating time so long that it won't be compatible with ILC timing structure. To accelerate the Ti slug target from stationary to 50m/s, the work needs to be done is about 71J and the force required is thus 71N for the assumed 1m long rail. Since the Lorenz force on a current from magnetic field is,

$$\vec{F} = I\widehat{dl} \times \vec{B},$$

and the perpendicular B field between the two rails is given as

$$B_y = \frac{\mu I}{\pi|x - 0.014|}$$

Together with 1T external B field, the total Lorenz force applied to the projectile is then derived as,

$$F = 0.014I + \frac{\mu I^2}{\pi}1.0986$$
$$= 0.014I + 4.3944I^2 10^{-7}$$

The current required is then calculated as about 4450A and the power required is then estimated at about 3.4kW. The energy required for each shot is about 140J and average power consumed is then 700W.

Electromagnetic Braking and Catching System

The movement of the Ti slug through the magnetic field creates eddy currents in the slug. The Lorenz force between the magnetic field and eddy currents will provide the braking force to slow down the slug. The net result is to convert the motion of the target slug into additional heat deposition which will be removed later together with

the energy deposition received from photon beam while making positrons. A solenoid will be at the end of brake to provide some tuning capability, as shown in Fig.3.
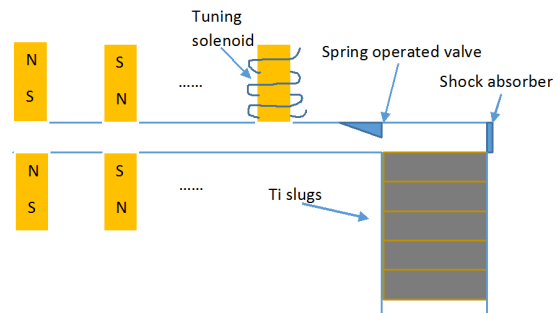

Figure 3: Braking and catching system.

Eddy current braking has been used in railroad train and many other areas. There shouldn't be any technical challenge for implementing it into our system. The eddy current calculation is somehow not so trivial and the designing of such brake for our system requires more detailed numerical simulation.

The catching is needed to catch the slug after it passed through the electromagnetic braking section and sent it down to circulating and cooling subsystem. The current plan for the catching is a simple spring operated wedge. We will design the eddy current brake in a way that the slug will still be carrying some kinetic energy after braking so that it can push the wedge up and stop on top of the Ti slug stack as illustrated in Fig. 3. When the slug at the bottom of stack got removed, all slugs in the catching well will be lowered by gravity and the braking and catching system is ready for the next shot.

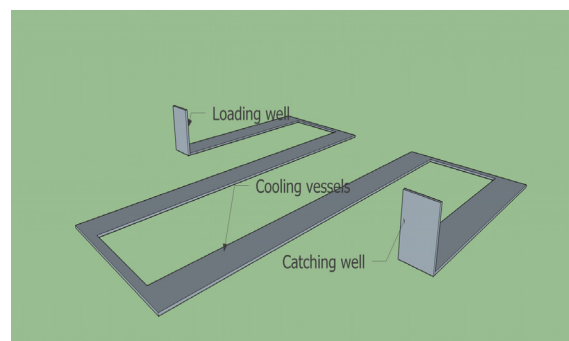## Circulating and Cooling System

Figure 4: Sketch of circulating and cooling system.

The circulating and cooling system performs two functions, to transport the slugs back into EM gun and cool the slugs back down to ambient temperature. As illustrated in Fig. 4, the circulating and cooling consists of catching well, cooling vessel and loading well. The Ti slugs are moved around by pushing from vacuum compatible linear motors. The total path length of this section is flexible and the slugs are moving in small steps.

The total time for a slug to get back into EM rail gun from the top of catching well can be easily designed to be about a minute.

As illustrated in Fig. 4, the catching well is filled with Ti slugs. The Ti slug just caught is sitting on top of the stack. A linear motor at the bottom of the well will push the bottom one out at the designed time and the other slugs in the well will then move down by the height of 1 slug, 1.4cm, and make room for the next used slug.
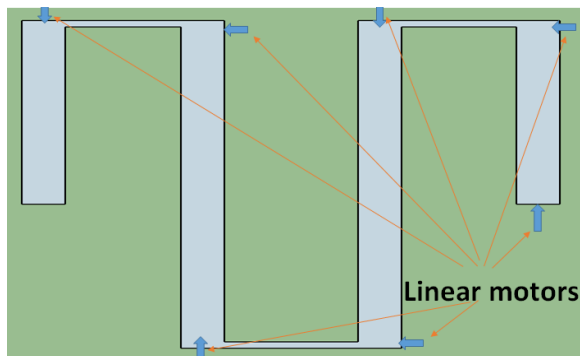

Figure 5: Sketch illustrating the movements of slugs in the cooling system.

The slugs in the horizontal cooling vessels will be moving in straight sections actuated by linear motors. Each section is completely filled with Ti slugs and behaves like a first in first out buffer. Cooling is done via conduction cooling on the bottom of the vessel where slugs are in good contact with due to gravity. The total cooling time can be increased by making the path length longer via extending the length of each turn around. Accurate calculation of required cooling time requires detailed numerical simulation due to the non-uniform heat deposition from the photon beam. But an over estimation with exaggerated parameter where the slug got heated up to 200°c above room temperature shows that the cooling time required to cool it back down to 25°C using 10°C cooling agent outside on bottom of the vessel can be estimated as about 46 seconds. We have plenty of time to cool the slug down before we reload it back into the gun.

The loading well is filled with completely cooled Ti slugs. For a well deep enough for 50+1 slugs, the vertically mounted linear motor on bottom of the loading well will push the stack of 50 Ti slugs up by 1.4cm each time so that the top piece will be pushed into the chamber and ready to be launched. After the vertical actuator retracted, the bottom of the loading well is empty and ready for the next one to move in. The work need to be done for the loading actuator is estimated at about 0.39J per motion.
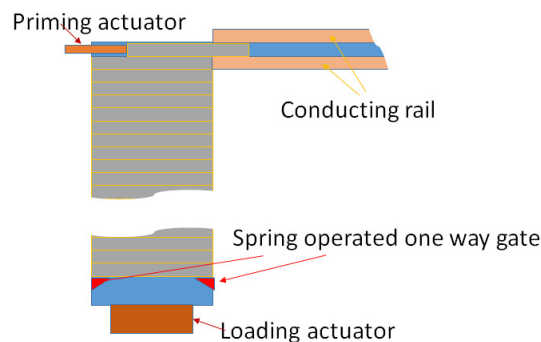

Figure 6: Sketch illustrating the loading and launching of slug.

A priming actuator is used to push the slug in between the two conducting rail of EM gun and thus launch the Ti slug.

SUMMARY

The conceptual design of a new positron conversion target system for ILC undulator based positron source is presented in this paper. Estimation of the some key parameters has been provided and looks very promising. Detailed numerical simulations are needed to complete the engineering design.

ACKNOWLEDGMENT

REFERENCES

[1] ILC Technical Design Report, Vol 3, Part II; http://www.linearcollider.org/ILC/Publications/Technical-Design-Report

[2] http://en.wikipedia.org/wiki/Railgun