PRESSURE ACOUSTIC WAVES IN POSITRONS PRODUCTION TARGETS FOR FUTURE LEPTON COLLIDERS*

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Abstract

Future high energy lepton colliders demand high luminosities to achieve the physics goals. For the electron-positron linear collider, the generation of an intense positron beam is a non-trivial problem: the positron production target has to a withstand a huge amount of energy deposited by the intense beams of electrons or photons used to generate positrons. The rapid increase of the temperature in the target within a very short time period results in thermal and mechanical stress which could exceed the limits for the target material. In this work, we study linear effects of induced stress through pressure acoustic waves using a hydrodynamic model. The survivability issue of the target is discussed.

INTRODUCTION

One of the major criteria for any future high energy linear collider is the high luminosity. In case of the International Linear Collider (ILC), a luminosity of 10^{34} cm^{-2}s^{-2} is required. The intense photon beam will be produced by passing electron beam through helical undulator. The circulary polarized photon beam will hit a conversion target and generate electron-positron pairs. The positrons are collected and accelerated. Since the photon beam spot size on the target is small, a high energy deposition density is possible which could damage the target material and reduce the target lifetime.

The experience with the positron target used at the Stanford Linear Collider (SLC) can now be used to design the target for the ILC. Comparing the positron source of SLC and ILC there is still wide margin between them [1], for instance, the amount of positrons produced per second at SLC positron source is approximately 80 times less than the required amount at ILC positron source. Also the energy deposited per second on the SLC conversion target was estimated to be 5 kJ and the target was decommissioned after 5 years of operation due to major cracks at the exit-end of the target [2]. We can sense the feeling and the severity of the heat load problem on the conversion target for ILC from the fact that the amount of energy that will be deposited on target per second is approximately 2 times greater than for the SLC conversion target, this is without taking into account the differences in beam structure, target thickness and material [2, 3] between the two accelerator.

In this study we investigated the real time evolution of induced pressure by using the hydrodynamic model to describe the dynamic behavior and evolution of pressure on the target; and the energy deposition on the target was described analytically using a Gaussian distribution.

MODEL DESCRIPTION

The model used for this investigation comprises of:

1. the continuity equation;
2. the momentum equation; and
3. the Grüneisen equation of state.

These three equations were linearized and used to derive a linear acoustic pressure wave in the target material (for full description of the model see [4]):

$$\partial_{tt} P - \nabla \cdot (c_s^2 \nabla P) = \Gamma \partial_{tt} Q_v \tag{1}$$

Eq. 2 describes the rate of energy deposited per time and volume on the target using a Gaussian distribution [5] below for a single bunch of the photon beam:

$$\partial_t Q_v = \frac{2cQ_{bunch}}{\sqrt{\pi}\sigma_z V} \cdot \frac{z}{l_T} \exp\left(-\frac{(z-ct)^2}{{\sigma_z}^2}\right) \exp\left(-\frac{r^2}{{\sigma_\perp}^2}\right) \tag{2}$$

where P, c_s, Γ, V, $\sigma_\perp$, σ_z, l_T, Q_{bunch}, and c denote pressure, speed of sound, Grüneisen coefficient, the spot volume at which the energy is deposited($V = \pi\sigma_\perp^2 l_T$), bunch transverse size, bunch length size, target thickness, energy deposited per bunch and speed of light respectively.

METHODOLOGY AND PARAMETERS

In order to investigate the acoustic pressure wave evolution in the target, the wave propagation is described by Eq. 1 which is inhomogeneous partial differential equation was solved in conjuction with Eq. 2 by using **FlexPDE**. FlexPDE is a finite element model builder and numerical solver for partial differential equations [6]. To describe our problem we use the 2-dimensional coordinates (z,r).

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Intial Conditions:

The initial pressure at time (t = 0) is equal to zero, because the target is in vacuum, that is:

$$P(r,z,t)\mid_{t=0}=0$$

Taking the time derivative of Grüneisen EOS, we have:

$$\partial_t P(r,z,t)\mid_{t=0}=\Gamma\partial_t Q\mid_{t=0}$$

Boundary Conditions:

The model contains dynamic boundaries, which are time dependent. Using Grüneisen equation of state, the boundary condition are:

$$\left.\begin{array}{rll} \nabla_n P(r,z,t)\mid_{r=0}=0; & 0\le z\le l_T, \\ P(r,z,t)\mid_{z=l_T}=\Gamma Q_v; & 0\le r\le R, \\ P(r,z,t)\mid_{r=R}=\Gamma Q_v; & 0\le z\le l_T, \\ P(r,z,t)\mid_{z=0}=\Gamma Q_v; & 0\le r\le R, \end{array}\right\}\forall \text{ values of } t\ge 0$$

Here Q_V stands for the energy deposited per volume, which can be defined as below;

$$Q_v := \int_0^t \partial_t Q dt = \frac{zQ_{bunch}}{l_T^2\pi\sigma_\perp^2}\exp\left(-\frac{r^2}{{\sigma_\perp}^2}\right) Erf\left(\frac{ct}{\sigma_z}\right)$$

We investigated for Ti-Alloy (Ti-6Al-4V) which is the ILC baseline for conversion target material in the positron production [3]. The parameters for Ti-Alloy (Ti-6Al-4V) and the photon beam used for simulation can be find in Table (1):

Table 1: Target Material and Photon Beam Parameters

Parameters	Symbol	Units	Ti-Alloy
Target thickness	l_T	mm	14.88
Radius	R	mm	5
Grüneisen constant	Γ	-	1.262
Sound speed	c_s	ms^{-1}	5072.83
Density	ρ	Kgm^{-3}	4430
Photon Beam Parameters			
Parameters	**Symbol**	**Units**	**Value**
Beam length	σ_z	mm	0.3
Beam spot size	$\sigma_\perp$	mm	2
Energy deposition per bunch	Q_{bunch}	J	0.4

PRESENTATION AND DISCUSSION OF RESULT

The presented result and discussion will be divided in two steps: During the "photonic time scale" which is the time photons bunch crosses the target and the second step covers the time after the bunch left the target.

Target Reaction At Photonic Time

Here we looked into the instantaneous response of the target during the photonic time scale. The induced peak pressure during the time of flight of the photon beam in the target are shown in Fig. (1) and Fig. (2). One significant observation within this photonic time scale (that is, from 0 to 4.96×10^{-11} sec) was that positive peak pressure induced within the volume was linearly growing in time, which implies that the target experience linearly growing compression during the time photon beam crosses the target.

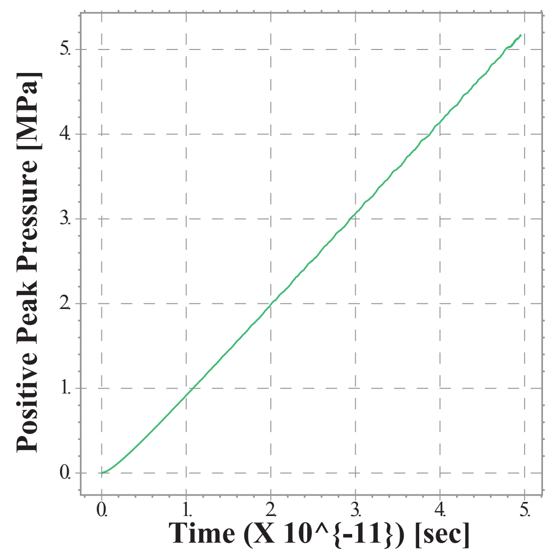

Figure 1: Positive Peak Pressure evolution in time over the whole volume, up to photonic time scale.

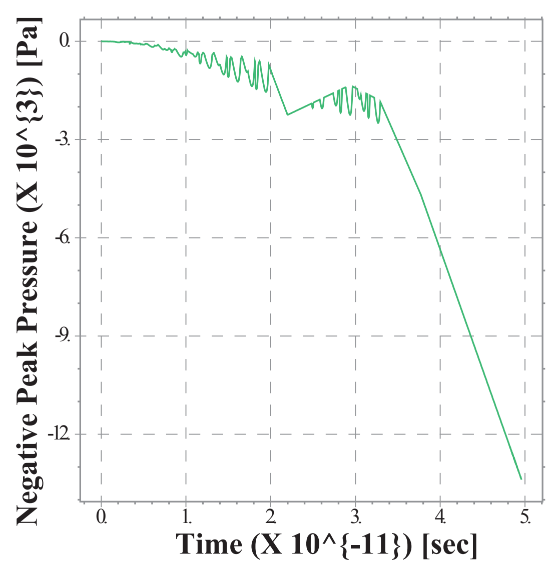

Figure 2: Negative Peak Pressure evolution in time over the whole volume, up to photonic time scale.

At 4.96×10^{-11} sec (see Fig. (1)), the peak positive pressure induced just immediately when the photon beam exit the target is $\sim 5.1\ MPa$ which is far less that Ti-Alloy (Ti-6Al-4V) material compression yield strength (1.07 GPa) [7]. The tensile ultimate strength of Ti-alloy is 1.17 GPa [7] and the peak negative pressure induced at 4.96×10^{-11} sec is $\sim 0.013\ MPa$ (see Fig. (2)).

Target Reaction After Photonic Time

The time evolution of peak positive and negative pressures in the target after the photon beam had already left are shown in Figures (3) and (4) up to the time of 10 $nano - secons$. The pressure has a tendency to saturate at the level of 33 MPa for the positive (which is, approximately 3% of Ti-Alloy compressive yield strength) and 60 MPa (in magnitude) for the negative pressures (which is, approximately 5% of Ti-Alloy tensile ultimate strength).

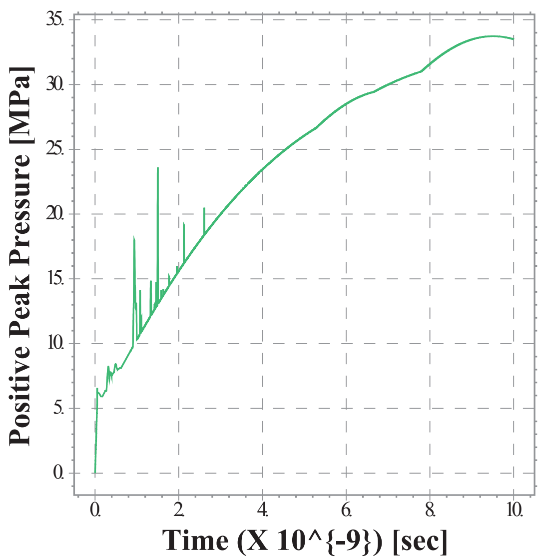

Figure 3: Positive Peak Pressure evolution in time over the whole volume, up to 10 ns.

SUMMARY

In this ongoing study, we analyzed the pressure generated by the energy deposition in conversion target for future linear collider. This simulation result indicates that Ti-Alloy material for conversion target of positron will not be damaged within time simulated, since both induced positive and negative peak pressure is far below the compressive and tensile yield stength.

So far, a Gaussian distribution was assumed for the energy deposition on the target, only one bunch and only linear waves effect have been investigated; a more detailed analysis is in progress. The multi-bunch effects, target rotation and possible non-linear wave effects have to be studied in the future.

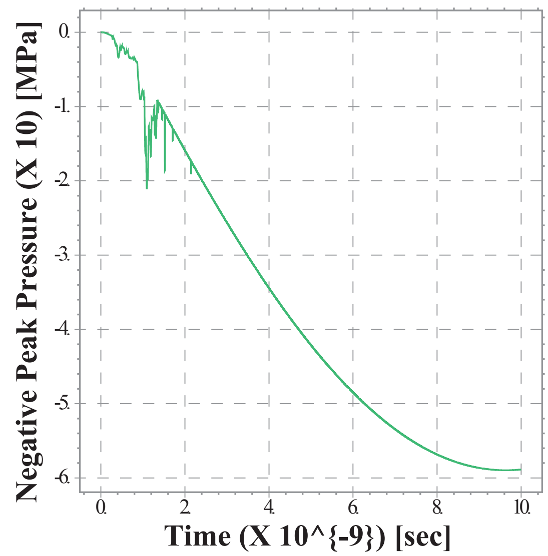

Figure 4: Negative Peak Pressure evolution in time over the whole volume, up.to 10 ns.

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