

SIMULATION OF STRESS IN POSITRON TARGETS FOR FUTURE LINEAR COLLIDERS *

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Abstract

Future linear collider projects require intense positron sources with yields of about 10^{14} positrons per second. The positron source for the ILC is based on a helical undulator passed by the accelerated electron beam to create an intense circularly polarized photon beam. The positron beam produced by these photons is longitudinally polarized. The intense photon beam causes rapid temperature increase in the target material resulting in periodic stress. The average and peak thermal and mechanical loads are simulated. Implications due to long-term target irradiation are considered.

UNDULATOR BASED ILC SOURCE FOR POLARIZED POSITRON PRODUCTION

The ILC will provide e^+e^- collisions in the energy range from 220 to 500GeV, upgradable to 1TeV [1]. The positron beam will be produced using the e^- beam which passes a superconducting helical undulator to generate circularly polarized photons [2]. The polarized photons hit a Titanium-alloy target located 400m downstream the undulator to produce polarized positrons [3]. Depending on the undulator parameters, a polarization of about 30% can be achieved for the positron beam which can be enhanced up to 50% using a photon collimator [4]. The corresponding intensity reduction of the positron beam has to be compensated by a longer undulator section.

In order to distribute the heat load of the photon beam a rotating Ti-alloy wheel with a radius of $r=0.5m$ is proposed. The rim velocity is $v=100m/s$. The thickness of the rim is $0.4X_0=1.48cm$ for Ti [1].

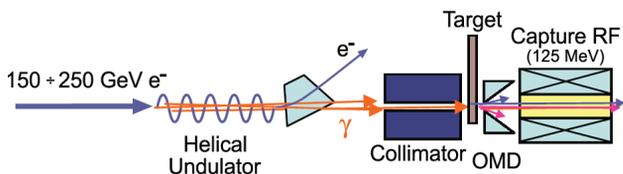


Figure 1: Scheme of the undulator based ILC positron source.

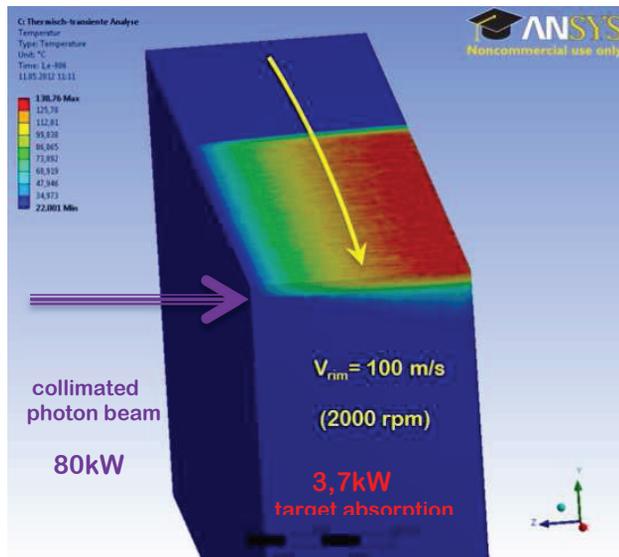


Figure 2: Temperature distribution in the rotating ILC Ti-alloy target wheel ($T_{max}=138.8^{\circ}C$). The temperature input file for the ANSYS [6] software is calculated by FLUKA [7].

ILC positron source parameters

In Table.1 the ILC positron source parameters for different centre-of-mass energies are shown. The degree of polarization can be increased by a photon collimator; the corresponding positron yield reduction is compensated by a longer undulator. The power absorption in undulator, collimator and target depends on the electron beam energy. Since the photon beam power is concentrated on the axis and the beam opening angle is $\sim 1/\gamma$, the maximum energy deposition increases with the electron energy. Further, for $E_{cm}=250GeV$ a 10Hz scheme is considered alternating between 150GeV drive electron beam for positron creation and the electron beam for physics.

HEAT LOAD IN THE TARGET WHEEL

In Fig.2 the energy loss calculated with FLUKA [6] for the parameter set 500GeV (high lumi) and 50.3% positron polarization is shown.

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Table 1: Positron Source Parameter Table ($Y=1.5^{e^+}/e^-$)

parameter	[unit]	cms energy of the e^- drive beam [GeV]						
		250	350	500	500 (high lumi)			
Pulse repetition rate	Hz	5.0			5.0			
Number of bunches	n_b	1312			2625			
Positron bunch population	N_+	$\times 10^{10}$			2.0			
undulator period length	lu	cm			1.15			
Effective undulator field	B_{und}	T			0.86	0.42	0.86	
					K=0.92	K=0.45	K=0.92	
Photon Yield per electron	n_{ph}/e^-				1,95	0.52	1.95	
Active undulator length	L_{und}	m	231.0	196.0	70.0	147.0	70.0	143.5
Photons per bunch train	$n_{ph}/train$	$\times 10^{15}$	11.8	10.0	3.6	4.0	7.2	14.6
Average photon power	P_{photon}	kW	98.5	113.8	83.1	95.1	166.2	340.5
Ph. power after collimation	$P_{collimation}$	kW	50.4	45.1	39.4	95.1	78.9	84.5
PEDD Ti target	E_{max}	J/g	61	61	32	51	63	82
Abs. ph. power in Ti target	P_{target}	kW	4.3	3.2	1.9	4.6	3.7	4.2
Collimator radius	r	mm	2.0	1.4	1.0	non	1.0	0.7
Positron Polarization	P_+	%	55.3	58.5	50.3	28.8	50.3	58.7

The photon beam hits the target rim in bunch trains of 961ms duration with 5Hz repetition. After collimation the photon beam have a power of about 79kW. The instantaneous difference temperature is roughly 120K per one bunch train. Due to the rotation the heat load will be distributed on the wheel rim. Only after 7.4s the beam hits the same place again.

Deformation and stress evolution in the target

The ANSYS Multiphysics FEM software [6] can perform static and dynamical stress evolutions induced by time dependent heat loads. The temperature input file is calculated by FLUKA [7]. Fig.3 shows the parameter set for a 250GeV electron beam. The collimated photon beam ($r=1.0\text{mm}$) leads to the shown maximum temperature distribution on the rotating target wheel. The static deformation and stress is shown after 3.2s and 7.2s. The maximum deformation is 60mm and the corresponding maximum stress amounts to 160MPa assuming a radial rim thickness of 3cm.

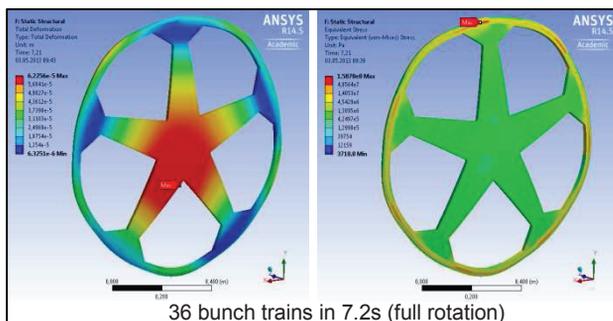


Figure 3: Deformation and stress evolution after 36 bunch trains.

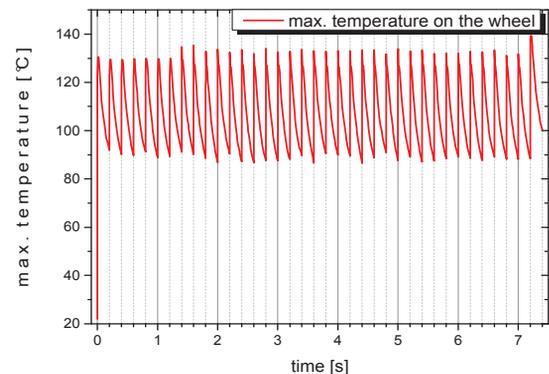


Figure 4: Maximum temperature at the target wheel calculated by ANSYS and FLUKA software.

Fig. 4 shows the maximum temperature at the target wheel for a 250GeV electron beam with cooling. The instantaneous temperature rise per bunch train is about 120K; the temperature at these spots decreases by about 30K until the next bunch train hits the target rim. The average temperature at the wheel rim is defined by the cooling power.

Wheel design for high stiffness and cooling

The cooling of the rotating target is a complex issue and is not considered in detail here. However, the radial dimension of the rim must have sufficient thickness to

house the cooling channels and to stabilize deformations due to the impinging photon beam. Enlarging the radial thickness of the rim from 3cm as foreseen in a first design up to 10cm improves the stiffness of the wheel during photon beam treatment and offers more space for a larger cooling channel cross section. However, the weight of the rim material is increased by 30%. The transient stress in the rim is shown together with sketched cooling channels (light blue). The stress maxima are limited to the area where the photon beam hits the target.

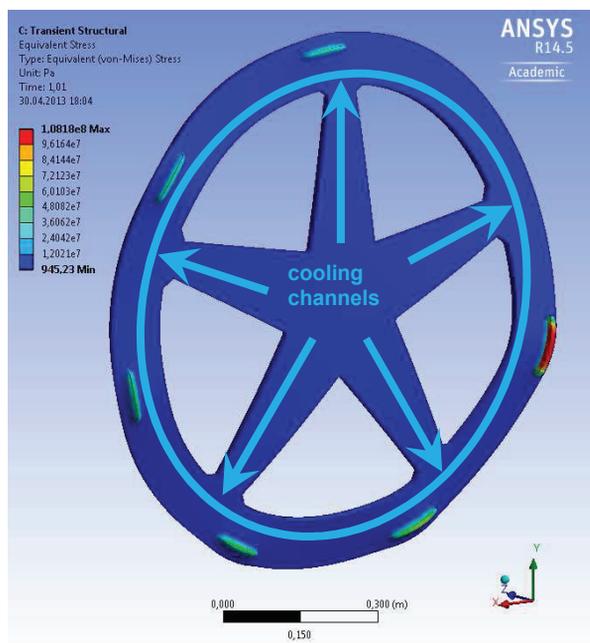


Figure 5: Maximum temperature at the target wheel calculated by ANSYS and FLUKA software.

The final dimension for the water channel and rim thickness must take into account not only the cooling and weight of the rim material but also dynamic deformation. These dimensions have still to be optimized.

FATIGUE STRESS LIMITS

In order to avoid material failure of the production target, the temperature and stress distributions have to be below ultimate limits [8]. To afford a long-term operation, the acceptable peak stress values as well as the fatigue limits of the material may not be exceeded. R_{max} is the yield strength for plastic deformation. For metals the fatigue strength is roughly 40% of R_{max} . The peak energy density deposition (PEDD) in the target wheel is for each parameter set below the fatigue stress limit.

Table 2: Fatigue Stress Limits for the Used Ti-alloy

	fatigue yield strength,40% R_{max} [Mpa]	fatigue energy [J/g] $(\Delta T * c_v)$	fatigue temperature ΔT [K]
Ti6Al4V	356	314	600

OUTLOOK

The target wheel design is a challenge. This concerning in particular the vacuum seals and the high rotation speed (see [9]). However, also the asymmetric stress along the rim has to be considered in order to avoid deformation causing rotational imbalances.

Based on the simulations of the static and dynamic stress a thicker rim is recommended. The optimum thickness has to be designed taking into account also the cooling along the rim.

The simulation of long-term behavior of the wheel including cooling is planned for future work. In addition, also the dynamic response of the wheel on the beam impact and its influence on the forces on the target wheel will be studied.

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