HEAT LOAD STUDIES IN TARGET AND COLLIMATOR MATERIALS FOR THE ILC POSITRON SOURCE*

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Abstract

An intense polarized positron beam for future linear colliders can be produced using a high power beam of circularly polarized photons which penetrates a thin titanium-alloy target. The degree of polarization can be increased by cutting the outer part of the photon beam generated in a helical undulator using a collimator in front of the target. However, the photon beam induces substantial heat load and stress inside the target and collimator materials. In order to avoid failure of these components the stress evolution has been simulated. The results as well as the corresponding material arrangements for the photon collimator design are presented.

ILC POSITRON PROCUCTION

The ILC will provide e^+e^- collisions in the energy range from 200 to 500GeV, upgradable to 1TeV [1]. The e^- beam will be polarized, $P \geq 80\%$.

The positron beam will be produced using the electron 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]. The positrons are captured using a flux concentrator, accelerated to 5GeV and injected into the damping ring. Depending on the undulator parameters, a polarization of about 30% can be achieved for the positron beam which can be enhanced up to 60% using a photon collimator. The corresponding intensity reduction of the positron beam has to be compensated by a longer undulator.

Collimator Aperture and Positron Polarization

In the ILC baseline design the undulator is located at the end of the main linac; so the properties of the photon beam are directly coupled to the drive beam energies. This concerns the photon cut-off energy as well as the opening angle of the photon beam and finally also the positron polarization. The opening angle of the polarized photon beam produced in the helical undulator is determined by the energy of the electron beam; it is proportional to $1/\gamma$. The opening angle of the higher harmonics cone is K/γ. Since the outer part of the photon beam is dominated by photons with lower average polarization, the degree of positron polarization can be increased by cutting this part using a collimator [4]. However, the collimator has to withstand a huge heat load. A multi stage collimator system is proposed to achieve a high degree of positron polarization for all ILC beam energies [5]. This system is flexible and avoids critical heat loads in the collimator materials. The table presents for a three stage system the degree of polarization for different drive beam energies and undulator K-values [6]. The positron yield is Y=1.5e+/e- for the aperture of the last collimator stage. The parameters for 1TeV are still under discussion.

Table 1: Degree of Polarization $\mathbf{P_{e+}}$ for Different Drive Beam Energies $\mathbf{E_{e-}}$, **K**-Values and Collimator Apertures **r**

collimator aperture r	$\mathbf{P_{e+}}$ **150GeV K=0.92**	$\mathbf{P_{e+}}$ **250GeV K=0.92**	$\mathbf{P_{e+}}$ **500GeV K=2.0**	$\mathbf{P_{e+}}$ **500GeV K=3.0**
∞	30.2 %	22.2 %	10.6%	11.2%
2.2 mm				19.3%
2.0 mm	55.3 %	29.5 %		
1.8 mm			15.0%	
1.6 mm				38.7%
1.4 mm		42.0 %		
1.2 mm			33.0%	52.2%
1.0 mm		50.3 %		
0.8 mm			51.3%	

Collimator Stages on Material Layers with Continuously Decreasing Radiation Lengths

In order to achieve 60% positron polarization, up to 50% of the photon beam have to be absorbed in the collimator [7, 8]. To keep the collimator length z_{colli} as short as possible, layers of materials with decreasing X_0 are implemented as shown in Fig. 1. About 80% of the absorbed power is deposited in the first and longest collimator part made of pyrolytic Carbon [9]. The following layers of Titanium, Iron and Tungsten stop the shower and reduce the intensity of the absorbed photon beam part to less than 0.1%. A critical region is the transition to the next material with higher Z (lower X_0) due to the strong immediate power deposition and heat load concentration at the begin of the material. A sufficient length of each material part must reduce the power to an uncritical value for the transition to the next part. In addition, in the Carbon and Titanium parts, a

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conical bore ensures a more homogenous heat load distribution over a large region.

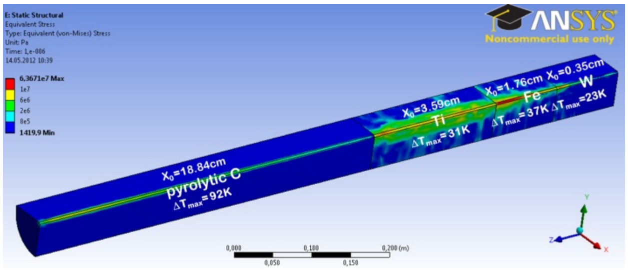


Figure 1: Stress in the first collimator for E_{e-}= 250GeV, K=0.92 and r=2.0mm achieve a positron polarization degree of about 29.5%. The ANSYS Multiphysics FEM software performed the static stress evolutions (P_{max}=64MPa) induced by beam heat loads calculated with FLUKA [10, 11].

Multistage Collimator Concept to Prevent Overload Induced by Electron Beam Jitter

Any electron beam jitter propagates to a jitter of the photon beam and can result in a misaligned photon beam which can overload the collimator with small aperture located 400m away from the undulator. Therefore, a multistage collimator system with up to three collimator stages and decreasing aperture is recommended [12]. Dependent on the beam conditions the collimator stages starting with the largest aperture are inserted on axis into the photon beam path. The resulting positron polarization can be obtained from table 1. Each collimator is designed with safety-factors and can resist a specific overload. However, for a safe long-term collimator operation diagnostic elements are required, and due to the activation of the collimator components a remote handling system is needed.

DESIGN SPECIFICATION AND HEAT LOAD OF THE COLLIMATOR

Fig. 2 shows a summary table of collimator options depending on the ILC machine parameters [13, 14]. For the low energy option ($E_{cm} \leq$ 150GeV) a 10Hz-scheme of alternating physics and positron production electron beam is suggested. An additional electron drive beam of 150GeV produces polarized photons for the positron production. A short collimator ($z_{colli}\approx$100cm) with an aperture of r=2.0mm is sufficient to achieve more than 50% positron polarization. However, without a bypass also the electron beam for physics passes the undulator and creates photons that increase the heat load on the target and also in the collimator.

For a beam energy of 175GeV ($E_{cm} \geq$ 350GeV) two collimator stages with a final aperture of r=1.4mm are required to achieve a polarization degree ≥50%. At a beam energy of 250GeV the collimator aperture must be r=1.0mm to get P=50%, so a third stage is necessary. The suggested design is also feasible for the luminosity upgrade with the doubled number of bunches per train.

Concerning a high positron polarization, the upgrade to 1TeV using the undulator-based source is a challenge. Also with modified undulator parameters a high e+ polarization can only be achieved for very small collimator apertures. Higher K-values up to K=3.0 could be a solution. But further studies have to be performed to evaluate the drive beam energy losses and loads in the superconducting undulator as well as the overall source performance to optimize the parameters for the 1TeV option.

Energy Deposition in Collimator and Temperature Distribution in the Target for 250GeV and 500GeV e^- Drive Beam

The energy loss is calculated with FLUKA for the considered parameter. The PEDD for these parameter sets and three collimator stages are shown in table 2-4.

Table 2: Max. Energy Loads for Three Collimator Stages

E_e =250GeV, K=0.92		**pyr. C**	**Ti**	**Fe**	**W**
1.collimator r=2.0mm	E_{max} [J/g]	77	19	16	3
2.collimator r=1.4mm	E_{max} [J/g]	109	19	15	2
3.collimator r=1.0mm	E_{max} [J/g]	121	20	17	3

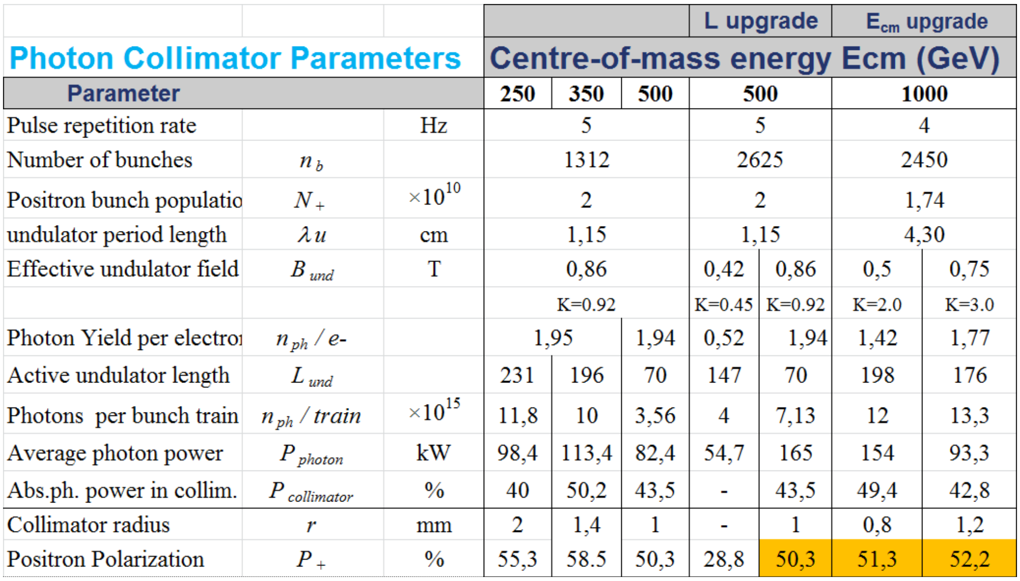
Table 3: Max. Energy Loads for Three Collimator Stages

E_e =500GeV, K=2.0		**pyr. C**	**Ti**	**Fe**	**W**
1.collimator r=1.8mm	E_{max} [J/g]	114	22	18	3
2.collimator r=1.2mm	E_{max} [J/g]	194	33	26	4
3.collimator r=0.8mm	E_{max} [J/g]	297	38	32	4

Table 4: Max. Energy Loads for Three Collimator Stages

E_e =500GeV, K=3.0		**pyr. C**	**Ti**	**Fe**	**W**
1.collimator r=2.2mm	E_{max} [J/g]	101	14	12	2
2.collimator r=1.6mm	E_{max} [J/g]	97	10	8	1
3.collimator r=1.2mm	E_{max} [J/g]	104	9	9	1

Three collimator stages degrade the photon beam radius down to 1.0 mm to achieve 50% positron polarization at E_{cm}=250GeV. The photon beam power is concentrated on the axis, the beam opening angle is ~1/γ. To keep the peak energy deposition density (PEDD) in acceptable limits, the part consisting of pyrolytic carbon must be long for smaller apertures. All PEDD values are below the fatigue stress limits (including safety-factors) for each material component [15, 16].



						L upgrade		E_{cm} upgrade	
Photon Collimator Parameters			**Centre-of-mass energy Ecm (GeV)**						
Parameter			**250**	**350**	**500**	**500**		**1000**	
Pulse repetition rate		Hz	5			5		4	
Number of bunches	n_b		1312			2625		2450	
Positron bunch populatio	N_+	$\times 10^{10}$	2			2		1,74	
undulator period length	λu	cm	1,15			1,15		4,30	
Effective undulator field	B_{und}	T	0,86			0,42	0,86	0,5	0,75
			K=0.92			K=0.45	K=0.92	K=2.0	K=3.0
Photon Yield per electron	$n_{ph} / e\text{-}$		1,95		1,94	0,52	1,94	1,42	1,77
Active undulator length	L_{und}		231	196	70	147	70	198	176
Photons per bunch train	$n_{ph} / train$	$\times 10^{15}$	11,8	10	3,56	4	7,13	12	13,3
Average photon power	P_{photon}	kW	98,4	113,4	82,4	54,7	165	154	93,3
Abs.ph. power in collim.	$P_{collimator}$	%	40	50,2	43,5	-	43,5	49,4	42,8
Collimator radius	r	mm	2	1,4	1	-	1	0,8	1,2
Positron Polarization	P_+	%	55,3	58.5	50,3	28,8	50,3	51,3	52,2

Figure 2: Photon collimator parameter table

A collimated photon beam (r=1.0mm) on a rotating target wheel (see [3]) yields the temperature distribution shown in Fig. 3.

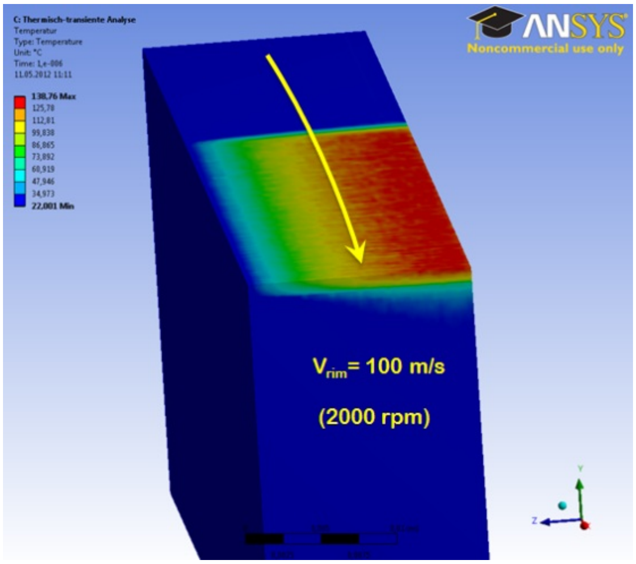


Figure 3: Temperature distribution in the rotating ILC Ti-alloy target wheel (T_{max}=138.8°C). The temperature input file for the ANSYS software is calculated by FLUKA.

FATIGUE STRESS LIMITS

In order to avoid failure of target and collimator components, the temperature and stress distributions have to be below ultimate limits. To afford a long-term operation, the acceptable peak stress values as well as the fatigue limits of the materials may not be exceeded. Table 5 shows the fatigue stress limits for materials used in the collimator and positron production target design.

Table 5: Fatigue Stress Limits for the Used Materials

material	**fatigue yield strength,40% R_{max} [Ma]**	**fatigue energy [J/g] ($\Delta T * c_v$)**	**fatigue temperature ΔT [K]**
pyrolytic C	36	753	900
Ti6Al4V	356	314	600
Fe (St70)	280	58	130
W, annealed	440	24	185
W26Re	600	64	500

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