DESIGN OF THE PHOTON COLLIMATORS FOR THE ILC POSITRON HELICAL UNDULATOR*

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Abstract

A number of photon collimators are placed inside the helical undulator to protect the cold surfaces of the vacuum vessel from being hit by the photons and thus achieving the baseline pressure requirement. Computer simulations were run in order to determine the energy deposition and instantaneous temperature rise in these collimators and various material candidates were studied. This paper presents the status of the simulation.

INTRODUCTION

The baseline positron source for the International Linear Collider (ILC) is a helical undulator design which produces polarised positrons with an intensity greater than the most intense sources currently available [1]. A 150 GeV electron beam is sent through the helical undulator [2] to generate circularly polarised photons and the multi-MeV photons produced in the helical undulator then strike on a thin Ti-alloy target and produce longitudinally polarised positrons which are then collected and accelerated through the beamline.

The helical undulator vacuum chamber will be bombarded by photons generated in the undulator and achieving the vacuum specifications of $\sim$100 nTorr is a highly demanding task [3]. A calculation of the peak SR power per meter has been done previously and it showed the need to place photon collimators along the undulator line to absorb this power and to keep the vacuum pressure at an acceptable level [4]. It was stated that these collimators should have axially symmetric apertures with a diameter smaller than the beam pipe thereby screening the elements situated downstream of the collimators. However, a complete design of the photon collimators hasn't been done so far, therefore a collimator model is proposed in this paper so that the photon absorption, secondary particles production, vacuum pressure and energy deposition are effectively controlled within the acceptable level.

PHOTON COLLIMATOR DESIGN

An investigation into possible collimator designs has been carried out with the primary scope to stop a large number of photons incident on the collimator. Two materials were chosen: titanium alloy and copper. Titanium alloy has a lower electrical conductivity than copper and a radiation length of 3.56 cm (for copper it is 1.44 cm) but a higher melting point (1941 K as opposed to 1358 K for copper).

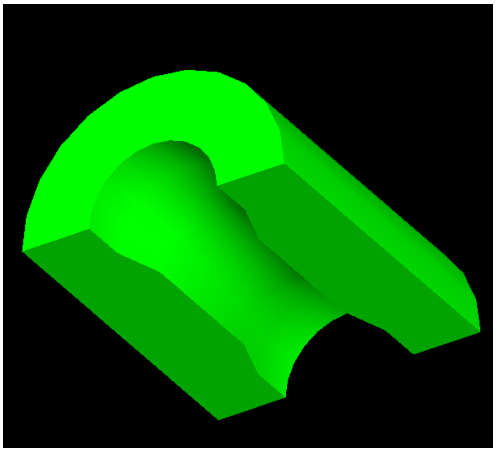

Figure 1: A longitudinal section through the beam pipe showing a typical photon collimator modelled with GEANT4.

A typical photon collimator having an upper flat section of 14 cm (this region is where the beam pipe radius is 2.2 mm as opposed to 2.85 mm in rest of the undulator) and a lower flat section of 20 cm (this starts where the beampipe

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* Work supported by the Commission of the European Communities under the 6^{th} Framework Programme "Structuring the European Research Area", contract number RIDS-011899.

radius is reduced up to 2.2 mm and ends where it is increased back to 2.85 mm) was modelled using GEANT4.

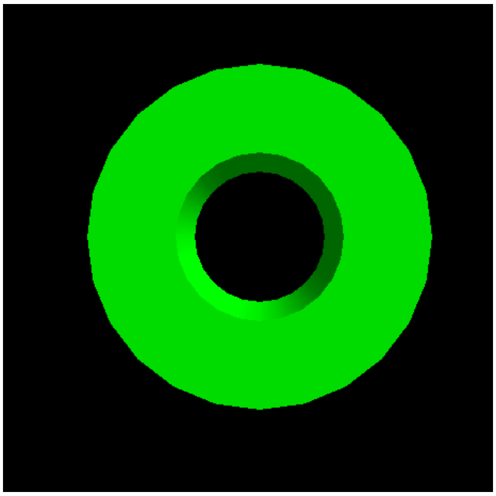

Figure 2: A transverse section of the beam pipe showing the photon collimator in the beam view.

The beam pipe radius in the helical undulator is 2.9 mm. At the collimators, the radius is 2.2 mm and the transition from the beam pipe radius to the collimator half gap is smooth to reduce the transverse wakefields. A longitudinal section through the beam pipe showing a typical photon collimator is shown in Fig. 1 while Fig. 2 shows the photon collimator in the beam view.

PHOTON ABSORPTION

The synchrotron radiation spectrum from a helical undulator was calculated using the numerical code SPECTRA. For low energy photons ($<$100 keV) corresponding to large angles or distances less than $\sim$30 m from the undulator module, the SPECTRA code is too time consuming for a standard computer for accurate calculation of the spectrum and for this reason a new code is being specifically developed to deal with these unusual cases [5]. Therefore, in this initial study the photon collimator was placed at 30 m away from the undulator module and six such combinations of undulator-collimator were modelled in GEANT4. The photon spectrum produced in the undulator is in the range 1 MeV to 100 MeV and between the angles of 67.9 and 97.35 μrad and hits the downstream collimator. The helical undulator and the electron beam parameters assumed are given in the Table 1.

Simulations were performed using the collimator geometry described previously and photon beams produced by each undulator module placed upstream of the collimator and having 100000 photons. Computer simulations showed that 96% of the photons are stopped when the material used is Ti alloy while for copper the photon absorption is even better due to the shorter radiation length: 99% of the photons are stopped.

Table 1: Undulator and electron beam parameters used to calculate the photon spectrum incident on the collimator.

Parameter	**Unit**	**Value**
Energy	GeV	150
Current	μA	45
Undulator Period	mm	11.5
Undulator K Parameter		0.92, 0.92
Undulator Aperture	mm	5.85
Undulator Length	m	150
Electron Beam Size	μm	66.75, 4.45
Electron Beam Divergence	μrad	0.3, 4.45

SECONDARY PARTICLES

The photons passing through the collimator generate secondary particles (electrons, positrons, photons). A major advantage of GEANT4 is its capability to model electromagnetic showers in different materials and the output includes not only the number of the secondaries produced but also their energy spectra. The energy distributions for electrons, positrons and photons are shown in Fig. 3, Fig. 4 and Fig. 5. The difference in the energy spectra for the two collimator designs are due to the fact that the photons deposit more energy inside the copper collimator as the collimator length of 20 cm is equivalent to $\sim$14 radiation length in this case. These secondaries have a low energy spectrum in the range of 0-30 MeV. It can be noticed that Ti has a higher transmission than Cu for this design.

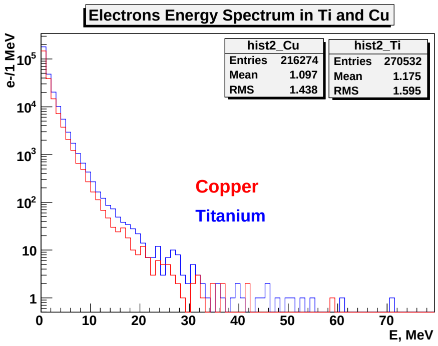

Figure 3: Electron energy spectrum.

ENERGY DEPOSITION

The energy deposition in the collimator is due to the electromagnetic shower as the photons pass through it. The energy peak is at the collimator location while in the beam pipe immediately after the collimator less energy is deposited (100 MeV/20cm in Titanium and about 10 MeV/20cm in Cu). The energy deposition profile in a collimator slice of 2 cm width with a transverse bin size of 0.5 mm×0.5 mm is shown in Fig. 6. The maximum energy deposition is in the collimator on a radius of 2.9 mm while

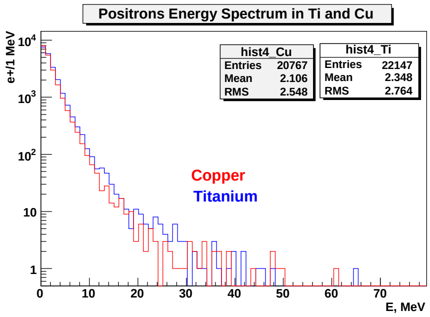

Figure 4: Positron energy spectrum.

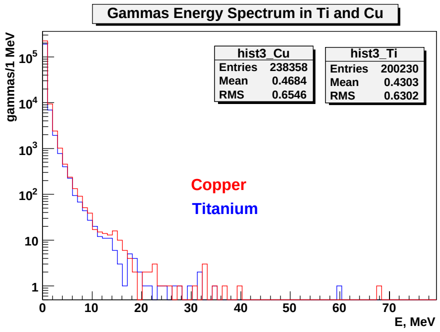

Figure 5: Photon energy spectrum.

the energy deposition in the beam pipe is lower and is due to showering. The energy deposition is useful when determining the increase in the temperature. The temperature is calculated using the material properties (density, specific heat) and the volume of the bin size. The temperature rise in Ti is $6{\cdot}10^{-9}$K and in Cu is $2{\cdot}10^{-8}$K. The instantaneous temperature rise in copper is shown in Fig. 7. In both cases, the temperature increase is small such that the fracture temperature is not exceeded and the collimator temperature is still lower than the plastic deformation temperature. Therefore the collimators will not be damaged.

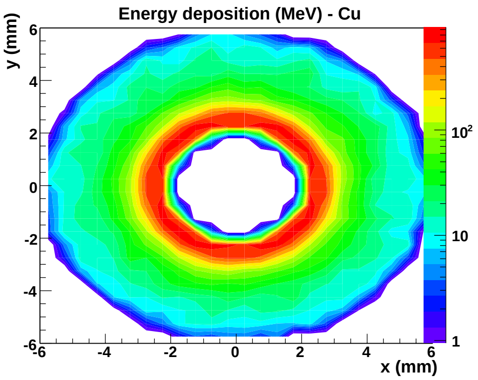

Figure 6: Energy deposition profile for a copper collimator.

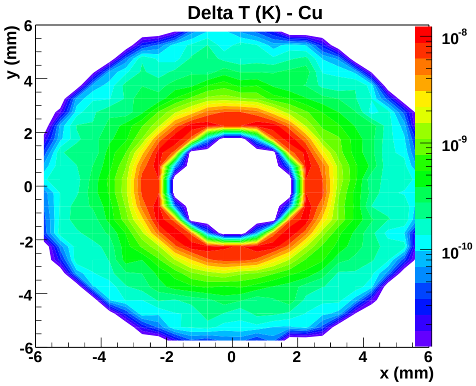

Figure 7: The instantaneous temperature rise in a copper collimator for 100000 photons.

CONCLUSION

A possible collimator geometry with a high photon absorption efficiency has been modelled for two different materials. Copper is a better candidate for the collimator bulk as it stops 99% of the incident photons. The secondaries have a low energy spectrum which is an important factor in determining the change in the vacuum pressure. Energy deposition and temperature increase studies proved that for these particular beam parameters, the collimators are safe. A favourable solution might be to have a photon collimator made of bulk copper since this would have the additional advantage of high conductivity and so minimise any harmful wakefield effect. Another option could be to make the Cu collimator shorter in case that there will be less room when all individual cryomodules will be put together in a consistent engineering design. The next step will be to develop a system engineering design for the whole undulator which includes all the necessary diagnostics, quadrupoles, corrector magnets, vacuum pumps and photon collimators. Further studies that are required include vacuum calculations to select the corect pump sizes, geometric and resistive wakefield calculations for the collimator sections and activation estimates for the collimator.

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