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Power Incident on the ILC Helical Undulator Wall

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An undulator-based positron source is proposed for the future International Linear Collider (ILC): the high-intense electron beam passes through a helical undulator to produce a multi-MeV circularly polarized photon beam before it is directed to the interaction point (IP). The photon beam strikes a thin target to produce electron-positron pairs. A maximum active undulator length of 231 m is expected to be appropriate for the ILC center-of-mass energy range $E_{\mathrm{cm}} \geq 250$ GeV. Since the photon produced by the undulator is created with an opening angle, some of these photons will hit the superconducting undulator wall. Therefore, photon masks must be installed along the undulator line to keep the power deposited into the undulator walls due to the synchrotron radiation (primary photons) at an acceptable level (1 W/m). This paper will discuss the power deposited into the undulator walls due to the primary photons and secondary particles. Masks inserted in the undulator line are discussed, assuming ideal and realistic undulator fields. In terms of materials, copper or tungsten are considered in detail.

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1. Introduction

The positron source for the International Linear Collider (ILC) [1] is based on a helical undulator. The high-energy electron beam passes through a helical undulator in order to produce a multi-MeV circularly polarized photon beam. The photon beam is directed to hit a thin rotating titanium alloy target to produce electron-positron pairs. After the target photon and electron beams are dumped, the positron beam is captured and sent to the damping ring. Since the photon beam is polarized, the positron beam is longitudinally polarized. The nominal ILC parameters are 2×10^{10} electron/bunch, 1312 bunches/pulse, and 5 Hz pulse repetition rate. A positron yield of 1.5 e^+/e^- is desired. Prototype studies [2] showed that superconducting undulators with period $\lambda = 11.5$ mm and K factors up to 0.92 are possible.

The center-of-mass energy (E_{cm}) at the first stage of the ILC is 250 GeV. In order to produce the required intensity of photons, the entire active undulator length of 231 m and a K factor of at least K= 0.85 ($B_{\text{axis}} = 0.789$ T) must be used. The complete undulator will be built from 66 cryomodules; each is 4.1 m long and consists of two helical undulator modules with a length of 1.75 m for each. To steer and focus the electron beam, quadrupoles are placed after three cryomodules. The total length of the undulator is 320 m. Since the photons produced by a helical undulator have an opening angle determined by the energy of the electron beam (which is proportional to $1/\gamma$) and travel through a very long undulator with a 5.85 mm undulator aperture, some of these photons will bump the undulator walls. However, the maximum power deposited from synchrotron radiation in the walls of the superconducting helical undulator is 1 W/m [3]. In this paper, the power deposited into the undulator walls is studied for both ideal and non-ideal (realistic) undulators using the actual parameters for ILC250. Copper and tungsten are the considered materials for masks. The uncertainty of the undulator B-field used in the realistic case for the studies here is based on the size of the B-field errors measured from helical undulator prototypes [2].

2. Mask System for Machine Protection

The TDR [1] does not include a design for photon masks to protect the undulator vacuum. A possible photon mask design with a high photon absorption efficiency is shown in [4] and is used here. The mask design is a cylindrical geometry, 30 cm in length with 15 cm outer diameter. To reduce the wake-fields, the inner radius of the mask is tapered in the first and last 5 cm of the mask length. The first 5 cm of the inner radius is tapered from 2.925 mm to 2.2 mm, and the inner radius in the last 5 cm of the mask length is tapered from 2.2 mm to 2.925 mm to correspond to the undulator aperture. The inner radius of the photon mask between the two tapered sections is 2.2 mm. Figure 1, left plot, shows a longitudinal section of the photon mask.

To keep the power deposited into the undulator vacuum below the limit, 22 masks must be installed along the undulator line. Each mask is placed after a quadruple. Due to the opening angle of the photon beam, mask number 22 (Mask-22), which is located at the undulator exit, receives the highest amount of deposited power. Therefore, this mask is essential to determine the maximum energy deposition and instantaneous temperature rise in masks. In addition, mask number 21 (Mask-21), the last mask located inside the undulator line, is vital to studying the highest power that leaves the mask and is deposited on the walls. Therefore, these are the only masks studied here.

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This study proposes two different materials for masks, namely copper (Cu) and tungsten (W). These materials have been selected based on their properties. Tungsten has a shorter radiation length of 0.35 cm compared with 1.44 cm for copper, but a higher melting point of 3695 K as opposed to 1358 K for copper.

Figure 1, right plot, shows the maximum deposited energy at Cu and W masks for both ideal and realistic undulators. Figure 2 shows the number of secondary particles along Cu and W masks for realistic undulators. Results of these studies showed that both W and Cu masks are safe against failure. For example, the Peak Energy Density Deposition (PEDD) and the instantaneous temperature rise (ΔT_{max}) on the Mask-22 are 8.7 J/g/Pulse (12.6 J/g/Pulse) and 22.5 K/Pulse (94 K/Pulse) for Cu (W) mask, respectively, in case of realistic undulators.

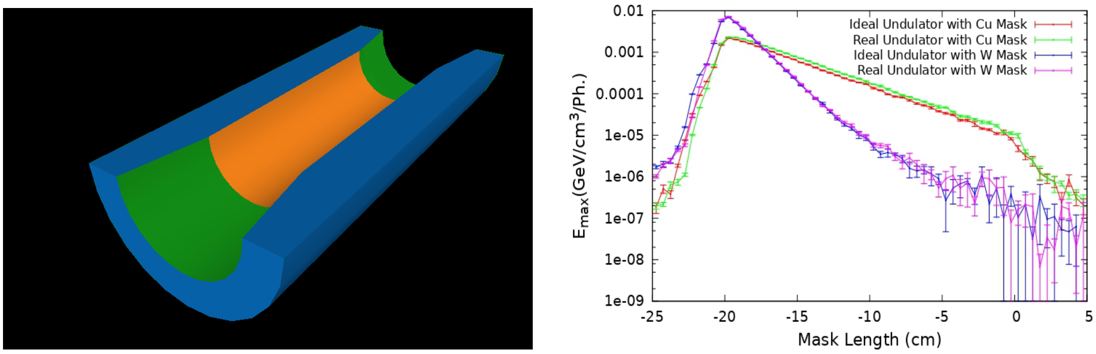

Figure 1: Left: A longitudinal section of the photon mask. Right: The maximum energy deposited (E_{max}) along mask number 22 with Cu and W materials for both ideal realistic undulators.

3. Incident Synchrotron Radiation Power into Undulator Walls

The power deposition into the undulator walls is simulated by the Helical Undulator Synchrotron Radiation (HUSR) code [5]. HUSR can simulate not only the ideal photon spectrum, but also the realistic photon spectrum and photon polarization (P_γ). The power deposited along the undulator walls is simulated by increasing the distance between observation points along the undulator line and the exit of an undulator module. Since it is too time-consuming for HUSR to calculate an accurate photon spectrum when the distance between observation points and the undulator exit is below 25 m, HUSR results at a distance above 25 m from the exit of the module have been considered.

Before installing masks, the maximum power deposited by primary photons is 21 W/m, which is a too high heat load for the undulator walls. By installing 22 masks along the undulator line, the maximum power deposited by primary photons can be reduced from 21 to 0.021 W/m. Here it is assumed that the photon masks are ideal and will perfectly absorb all primary photons. Since it is impossible to have ideal masks, the power deposited into walls by back-scattered photons and secondary particles which leave Cu and W masks need to be considered. Therefore, the photon distribution from ideal and realistic undulators simulated by HUSR is used as input to FLUKA. FLUKA is a Monte Carlo code for particle tracking and the interaction of particles with matter [6].

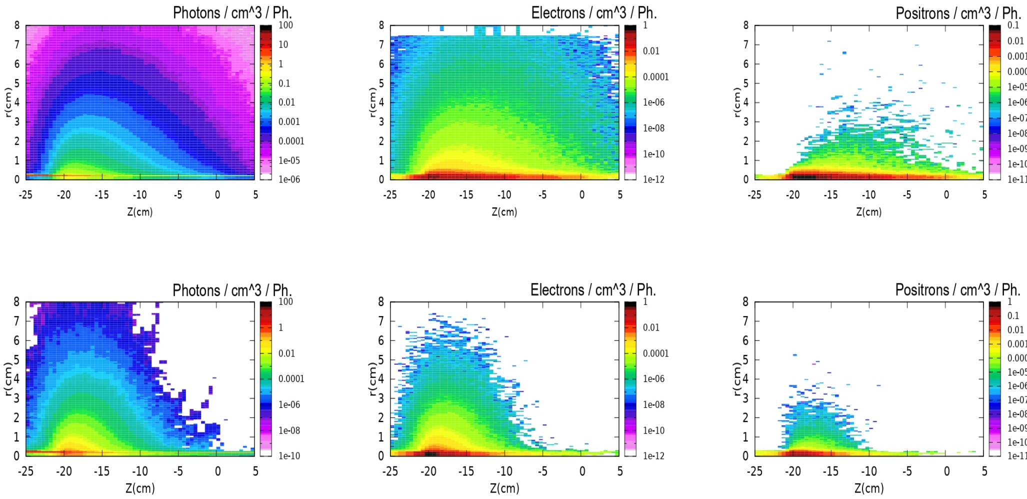

Figure 2: The number of photons, electrons and positrons per cm^3 per primary photon (from left to right plots) , respectively, along a Cu (top plots) or W (bottom plots) Mask-22 assuming realistic undulators.

Figure 3 shows the power deposited along the realistic undulator walls using two different materials for masks. As expected, tungsten masks stop more power than copper does. The maximum power deposited, which is at the first meter of the undulator after Mask-21, is 0.034 and 0.22 W/m for W and Cu masks, respectively, in the case of ideal undulators. In contrast, they are 0.035 and 0.26 W/m for W and Cu masks, respectively, in the case of realistic undulators. Roughly 90% of the power deposited due to secondary particles is photons, while the positrons form less than 2% of the secondaries deposited into the walls. Table 1 summarizes the study results.

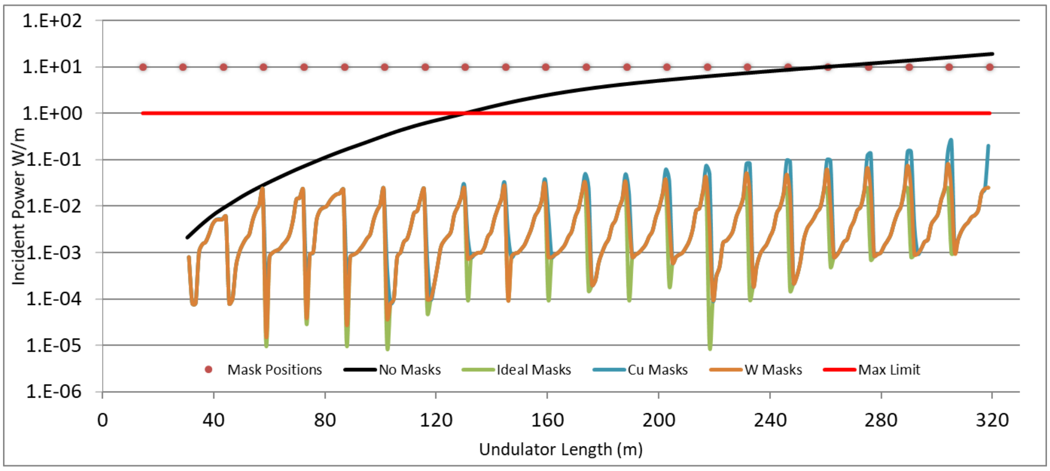

Figure 3: Total power deposited by primary photons and secondary particles in the walls of a realistic undulator. Green, blue and orange lines represent the total power deposited in undulator walls in the case of ideal, Cu and W masks, respectively. Red points represent the position of the photon masks. The red line shows the acceptable limit of the deposited power on the walls. For comparison, the black line gives the power deposited in the walls of an ideal undulator without masks.

Case	E^{γ}_{ave} (MeV)	P_{mask} (W)	$Mask$ $Material$	$PEDD$ $(J/g/Pulse)$	ΔT_{max} (K)	$P_{max}(W/m)$ $at\ wall$	P_{stop} (%)
Ideal	1.8	270	Cu	7.0	18.0	0.22	98.3
			W	9.8	73.0	0.03	99.6
Realistic	2.00	311	Cu	7.6	20.0	0.26	97.2
			W	11.0	82.0	0.04	98.4

Table 1: The average incident photon energy (E^{γ}_{ave}) and the incident photon power (P_{mask}), PEDD and the instantaneous temperature rise (ΔT_{max}) on Mask-21 also shows the power stopped by Mask-21 (P_{stop}) and the maximum power deposited on the walls (P_{max}) for both ideal and realistic undulators.

4. Summary

The power deposited into the undulator walls due to primary photons, back-scattered photons and secondary particles for ideal and realistic undulators with E_{cm}= 250 GeV has been studied. Two possible masks have been modeled from materials with a high photon absorption efficiency. Study results of energy deposition and temperature increase along both Cu and W masks proved that photon masks are safe against damage for these particular beam parameters. More importantly, both mask materials can keep the power deposited into walls below the acceptable limit. An appropriate solution might be to use a W mask since its length can be shorter, which could help implement the masks into the undulator line. The next step will be to study the polarization of the photon beam generated by a realistic undulator at the target. This will be conducted for the center-of-mass energies 250, 350 and 500 GeV.

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