SUPERKEKB POSITRON SOURCE TARGET PROTECTION SCHEME*

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Abstract

The SuperKEKB requires an intense beam with a large number of positrons, which is generated by a high energy electron beam strike on a solid tungsten target. The pulsed electron beam distributed the energy non-uniformly over the target. In that case, a mechanical stress appears due to the large thermal gradient during each pulse, which could potentially destroy the target. Based on the analysis of the SLAC damaged target, peak energy deposition density (PEDD) should not exceed 35 J/g to ensure a long term of safe operation. One way of reducing PEDD is increasing the beam spot size. Hence we proposed a target protection scheme, in which a beam spoiler is placed upstream of a generation target. The aim is to maintain the generation targets PEDD below 35 J/g even with a very small size primary electron beam. In this paper, we will introduce graphite, aluminum and copper as the protection target material candidates. And also present the PEDD and positron yield evaluation as a function of various parameters such as protection target thickness and drift space.

INTRODUCTION

The SuperKEKB primary electron is 3.5 GeV with intensity of 20 nC/pulse, and the frequency repetition rate is 50 Hz. The electron beam will strike on a tungsten target after passing through the pulsed steering coil and quadruple. The generated positrons are focused by the optical matching device before injecting into a 2 m long large aperture s-band accelerating structure for acceleration. The principle layout is shown in Fig.1. In order to achieve requested luminosity at the interaction point (IP), a high intensity positron beam is necessary. In this scheme, the thermal gradient difference due to the pulsed irradiation may lead to the target destruction. Such kind of target damage has been experienced at SLAC [1]. After a series of experiments, the peak energy deposition density (PEDD) has been described as the parameter to evaluate the safety margin and to determine the incident beam size to avoid the target damage. The threshold value of the PEDD is about 35J/g. The primary electron beam spot size is one of the key parameters that determine the PEDD. For SuperKEKB, at upstream of the positron target, there are pulsed steering coil and quadruple. That does bring the possibility of misfocused primary electron beam strikes on the target with an extremely small spot size which could destroy the target.

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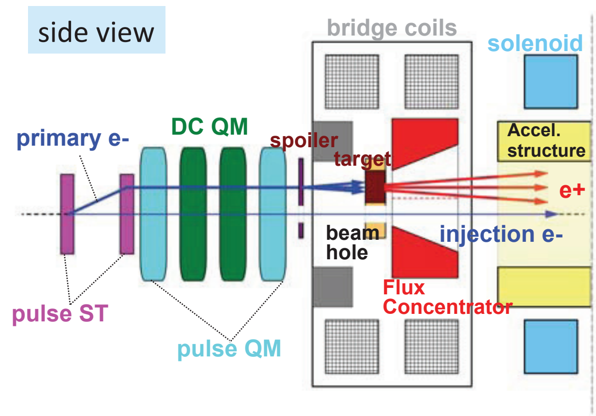

Figure 1: Schematic view of the SuperKEKB positron source configuration.

Hence in this paper we would like to introduce a spoiler as a protection system, whose function is to enlarge the spot size to make sure the PEDD on the target is well below the destruction limitation value of 35 J/g.

SPOT SIZE, PEDD AND POSITRON YIELD

The basic design of the SuperKEKB positron target is a 14 mm long cylinder made of tungsten with 2 mm radius, which is surrounded by copper conductor including cooling system. The rate of PEDD in tungsten target according to a Monte Carlo calculation is shown in Fig.2 in the same frame with the theoretical calculation and simulation results of the positron yield.

In Fig.2, black line is the PEDD value as a function of incident primary electron spot size on target, and the horizontal red dash line represent the destruction limitation value of 35 J/g. The blue stars show tracking simulation results of positron yield until Damping Ring. There are three examples has been shown which are pinpoint electron beam, spot size 0.5 mm and 0.7 mm. The blue dash line is obtained by applying theoretical cut to the positrons generated from target then normalized to fit the tracking simulation results (blue stars).

From the Fig.2 we could see that when the spot size is reduced from 1 mm to 0.2 mm, the PEDD increase exponentially. Comparing the PEDD of the 0.5 mm and 0.7 mm spot size cases, for 0.5 mm beam spot the PEDD is about 25 J/g which is below the threshold of 35 J/g. However, the safety margin is rather thin. In this case, a little bit

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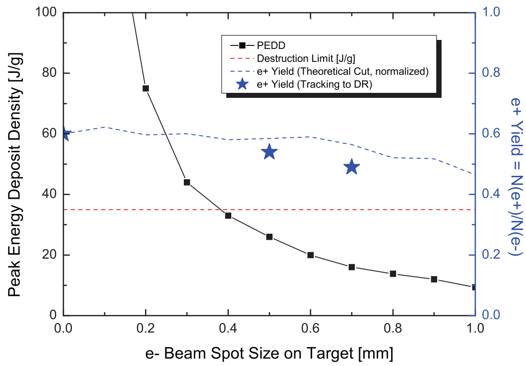

Figure 2: PEDD (black line) and positron yield (blue color) as a function of electron beam spot size on the target.

mis-focus from upstream pulsed quadruple could lead to a smaller spot size then seriously damage the target. Hence, enlarge the electron spot size is necessary, and half of the threshold value or lower would be a reasonable choice. When we increase the beam size, we need to bear in mind that the positron yield will be reduced as the blue stars and line shows. Hence, a spot size of 0.7 mm is a better option. With this parameter the PEDD is about 15 J/g. This value is less than half of the limitation. As a tradeoff, the positron yield would suffer a degradation about 10%.

PROTECTION SPOILER

In order to make sure the primary electron beam strike on the positron target with a spot size larger than 0.7 mm, a protection spoiler needs to be placed between the focus magnet and target. We have investigated three kinds of materials including Copper, Aluminum and Graphite as listed in table 1. Each of them has the unique physical properties that could lead to some advantages to be used as a spoiler. For example, the copper is a well-known conductor that could deal with heat much easier. The aluminum is a popular choice for beam size enlargement. And graphite is light material with much longer radiation length, which could avoid too thin target when drift space is long.

In the previous section we have discussed the relationship between spot size on target and PEDD. A spot size of 0.7 mm is preferred. To achieve that, we have evaluated the required spoiler thickness as a function of drift space from spoiler to target for different materials as shown in Fig.3. In the plot, it also shows the positron yield corresponding to the thickness and material. These three kinds of materials show an identical contribution to the positron yield and required similar thickness in unit of radiation length. When the drift distance reduces, which means the spoiler get closer to the generation target, a thicker spoiler is needed to enlarge the scattering angle. In this process, the positron yield could also be affected that reduce from 1.2 positrons/electron to 0.7 positrons/electron.

Table 1: Material Candidates for the Positron Source Spoiler

	Copper	Aluminum	Graphite
Atomic No.	29	13	6
Density ($g \cdot cm^3$)	8.96	2.7	2.09
Melting Point(K)	1358	933	3500
Thermal Cond. ($W \cdot m^{-1} \cdot K^{-2}$)	44.7	11.3	32.2
Radiation length (mm)	14.4	89	188

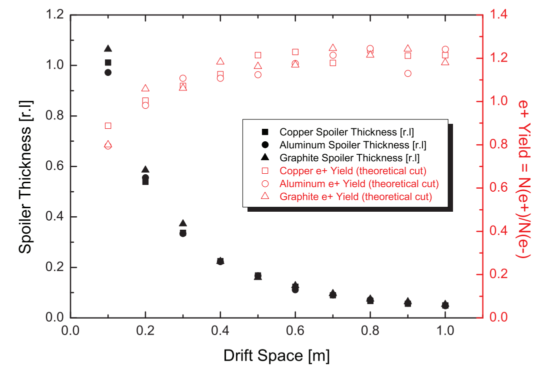

Figure 3: Spoiler thickness (black color) and positron yield (red color) as a function of drift space between spoiler and target. The electron spot size on target is 0.7 mm. Three kinds of material are Copper (square), Aluminum (circle) and Graphite (triangle).

Due to the restriction of the beam line layout, there are few places where the spoiler could be installed. Based on the proposed structure, the spoiler could be installed either at positions of 0.7 m or 3 m upstream of the generation target. The required spoiler thickness for 0.7 m and 3 m schemes is about 0.09 and 0.006 radiation length respectively. In order to place the spoiler near the pulsed quadruple to avoid the small beam size, we prefer to place the spoiler to the position of 3 m. In this case, if we use copper for spoiler, the spoiler thickness is about 0.08 mm, which is too thin to handle. Whereas the graphite could have sufficient thickness, but its hardness is a concern. Studies of choosing a suitable graphite alloy is undergoing. Therefore, aluminum maybe a better choice because of a good balance between strength and radiation length. PEDD is the other consideration when we make a choice of 3 m scheme. At the position of 0.7 m, the electron beam spot size can be in the region of few tens micron, so that the PEDD on spoiler is too high to handle. Whereas at the position of 3 m, because it is close to the quadruple, the electron beam could have a large spot size of few hundreds micron. The detailed investigations will be discussed in the later section.

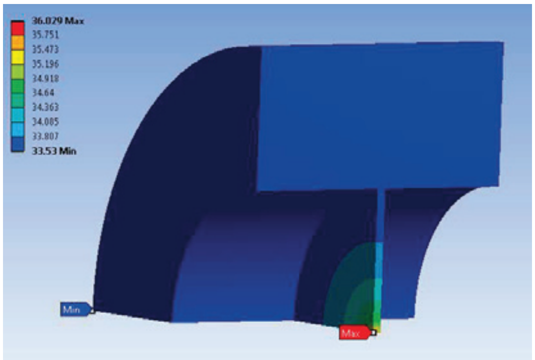

Figure 4: ANSYS thermal calculation of temperature increase after applying air cooling on the outer surface of the chamber.

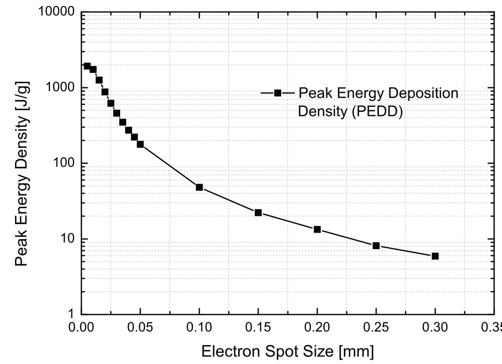

Figure 5: PEDD as a function of electron beam spot size on the spoiler when it is placed at 3 m upstream of the target.

THERMAL CONDITION

Assuming a 0.5 mm thick aluminum spoiler locating 3 m upstream of target is irradiated by a 20 nC 3.5 GeV primary electron beam. The thermal condition is a concern, which ought to be looked after by designing a sufficient cooling plan. Our ANSYS analysis indicates that with the simplest case, an aluminum disk with radiative cooling could reach a peak temperature of more than 300 degree. That's below the aluminum melting point. However, it will still be considered as a threat to the supporting structure and operational environment. Therefore, we apply air flow on the chamber's outer surface as showing in Fig.4. In this simulation, the spoiler thickness is 0.5 mm and radius is 10 mm. The spoiler is connected to the chamber which is 10 mm thick made of aluminum. We assume a forced air convection with a film coefficient of 50 $W/m^2{\cdot}K$ has been applied to the outer surface. The result shows the peak temperature is well controlled below 50 degree. In fact, due to the relatively thin spoiler, the energy deposition is fairly small, so that thermal condition is rather trivial.

SPOILER CHALLENGE

As we have mentioned in the previous section, the generation target needs to maintain a PEDD below 35 J/g to avoid destruction. And the PEDD increases hugely with a small beam size. The purpose of the spoiler is to enlarge the beam spot size to protect the generation target, so an extremely small beam size could hit the spoiler in some cases. For example, if there is a 0.005 mm spot size electron strike on the spoiler made of 0.5 mm Aluminum, the PEDD value is about 1900 J/g, which is far more than the safe threshold. Even when we assume a spot size of 0.05 mm. The PEDD is still as high as 177 J/g. The scan of PEDD as a function of incident beam size has been shown in Fig.5. As the figure show, a spot size increase from 0.005 mm to 0.05 mm could reduce the PEDD but not enough. Therefore, the 3 m scheme is preferred, because the location is fairly close to pulsed quadruple, from where the beam spot size could be as large as few hundreds microns because the distance to quadruple is much shorter than the focus length. Then we look at the Fig.5 again in the range from 0.1 mm to 0.3 mm. Now the PEDD is reduced from 48 J/g to 6 J/g. To sum it up, we propose to place the spoiler 3 m upstream of target to make it close to the quadruple maintaining a large spot size at least 0.15 mm, which will have a PEDD value of 22 J/g. That's help us overcome the challenge of spoiler survive under intensive primary electron beam.

CONCLUSIONS

In this paper we have proposed a spoiler protection system for SuperKEKB positron target. The principle of this scheme is to place a spoiler at upstream of the target. The spoiler will be used to scatter the electron beam to avoid extremely small beam spot. And the motivation of the scheme is that the peak energy deposition density could be well controlled under the limitation so that the target destruction will not happen to SuperKEKB positron target. After investigating a few kinds of material, all the materials shows an identical behavior for the scattering effect. Aluminum is a preferred choice due to his good balance of strength and radiation length. And our thermal analysis shows that an air cooling outside chamber surface would be enough to maintain the temperature under 50 degree. Regarding the location, 3 m upstream of target is chosen, since we need a spot size larger than 0.15 mm. The location close to the pulsed quadruple could help us achieve that. The spoiler scheme should be able to protect target from damage and maintain a long term stable operation.

REFERENCES

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