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THE BEAM TEST FOR THE TI EXTRACTION WINDOW DAMAGE

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Abstract

Ti extraction window will be used at the SuperKEKB beam abort system [1]. The damage of the window caused by the beam was estimated with KEKB electron beam. Thin Ti and Ti alloy plates were tested as candidates of extraction window material. The damages were observed as a function of beam current density. From the result of this experiment, the horizontal spot size on the extraction window was determined for SuperKEKB abort system.

INTRODUCTION

The SuperKEKB is an asymmetric electron-positron collider. The accelerator consists of a 4 GeV positron ring (LER) and a 7GeV electron ring (HER). Table 1 shows the machine parameters of the SuperKEKB.

Table 1: SuperKEKB Machine Parameters

	LER	HER
Beam Energy	4 GeV	7 GeV
Beam Current	3.6 A	2.6 A
# of Bunches	2500	2500
Emittance (εx/εy)	3.2nm/8.6pm	4.6nm/12.9pm
Bunch Current	1.44 mA	1.04 mA

Motivation

For the design of SuperKEKB beam abort system, it is important to know the breakdown limit of extraction window, which is the key of the system. Since the beam emittance will be much smaller than KEKB and beam current will be increased, the requirements for the extraction window are very severe. To protect the window material from the damage, the beam abort system enlarge the beam size at the extraction window using pulsed quadrupole magnets in LER and a sextupole magnet in HER. In order to estimate the necessary beam spot size at the window, the window material breakdown limit had been investigated with KEKB HER beam.

EXPERIMENT

KEKB Beam Abort System

The KEKB abort system [2] is composed of horizontal kicker magnets, a vertical kicker magnet and a Lambertoson Septum magnet. Kicker magnets kick out the beam outside of vacuum chamber through Ti window. The Lambertoson magnet guides the beam to the dump, which is made of iron, lead and concrete. In order to enlarge the beam cross section at the extraction window effectively, the sinusoidal oscillation has been introduced in the horizontal direction and swept in the vertical direction. Figure 1 shows the pulse waveform and the trajectory of the beam at the beam dump.

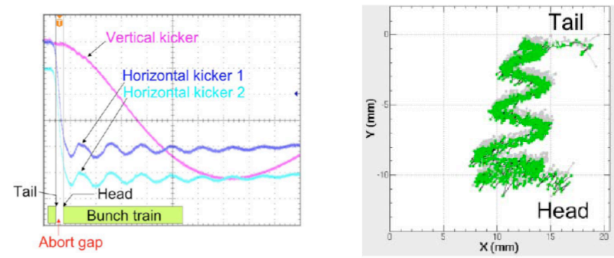

Figure 1: Abort kicker magnet current (Left) and beam trajectory at the extraction window (Right).

Experiment Setup

Figure 2 shows the setup of the beam irradiation experiment. Test sample was inserted into the bottom of the beam dump in 600 mm depth to prevent the radiation pollution.

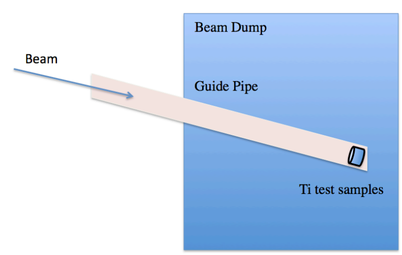

Figure 2: Schematic view of the electron beam irradiation experiment.

The sample is shown in Figure 3. The sandwich of Ti and iron plates was used. The extracted electron beam was amplified by the shower occurred in the iron plates. Ti plates are inserted among the iron radiator and damages were observed as a function of current density. The irradiation experiment had been done for the two kinds of samples. One is Ti plate and another is Ti alloy plate. The used Ti alloy is the Timetal 110* (Ti-6Al-2.8Sn-4Zr-0.4Mo-0.45Si), which has an excellent heat resistance. Pure Ti plates† (JIS H 4600 IP270C) are annealed before the experiment. The thicknesses of the sample plate are 1mm, 0.5mm, 0.1mm, and 0.2mm. Thermal paper was attached in each Ti plate to see the position that the beam strikes. The thickness of the iron plate is chosen as 0.25 radiation length. Iron plates of 2.5 radiation length in total are used as radiators. They amplify the electric charge 50 times larger by shower development.

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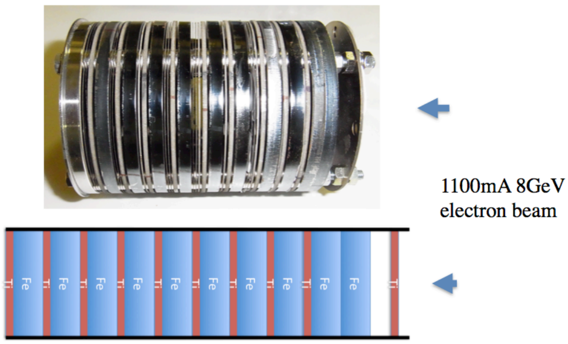

Figure 3: The test sample: sandwich of Ti and iron plates. Ti plates and iron plates are not in contact with each other.

Experiment

Table 2: Beam Condition of the Experiment

Total Beam current	1150mA
# of Bunches	1584 bunches
Bunch charge	7.2 nC
Bunch spacing	6 or 8 nsec
Beam Energy	8 GeV
Horizontal Beam size @window	$\sigma x = 0.7$mm
Vertical Sweep	10mm

Table 2 shows HER beam condition at the experiment. In the Figure 1, around the crest of sinusoidal beam trajectory, the beam stay constant in the horizontal direction and it determines the breakdown limit. So we simplified the beam trajectory like Figure 4. On the extraction window, vertical spot size of bunched beam is 20μm.T sweep speed is 6μm per bunch, i.e. the adjacent bunch is overlapped on the window. In order to enlarge the effective spot size, the important parameter is horizontal spot size and vertical sweep length. Horizontal spot size is σx=0.7mm and vertical sweep H=10mm.

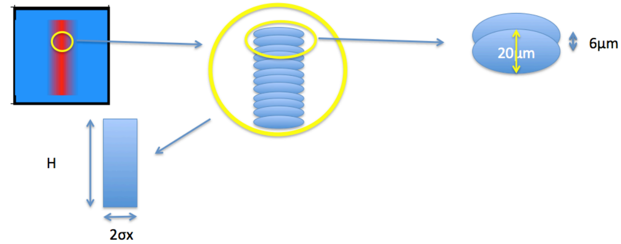

Figure 4: Schematic view of bunched beam on the extraction window.

Experiment Result

Table 3 summarizes the experimental results. The beam irradiation experiment was done twice. One is for Ti sample and another is for Ti alloy sample. Figure 5 shows damaged Ti and Ti alloy plate. In Table 3, charge density is normalized to the charge density at the extraction window. In order to estimate the beam spot size in each Ti plate, the shower development was simulated with EGS code.

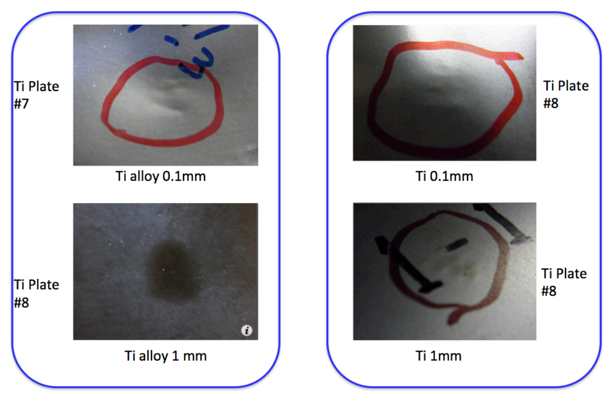

Figure 5: Damaged Ti/Ti alloy plates.

Because thickness of Ti plate is much thinner than radiation length, energy deposition in the Ti plate is considered to be the minimum ionizing power deposition. Table 4 summarizes property of Ti plate.

Table 3: Damage of Ti and Ti Alloy Plates. Current density is normalized by the current density at extraction window. ○ : OK, △ : There's a mark but not bulged, × Damaged.

# Ti Plate	Radiation Length(Fe)	Energy Deposit	δX	Relative Charge Density	Ti Alloy (1mm)	Ti (1mm)
	0	4.9	1.17	0.5	○	○
0	0.5	11.4	1.17	1.3	○	○
1	0.75	18.7	1.17	2.1	○	○
2	1.0	28.6	1.17	3.3	○	○
3	1.25	41.2	1.17	4.8	○	△
4	1.5	56.5	1.17	6.5	△	×
5	1.75	74.5	1.17	8.4	△	×
6	2.0	95.2	1.17	10.9	△	×
7	2.25	118.5	1.17	21.2	△	×
8	2.5	144.6	1.17	25.8	△	×

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Table 4: Atomic and Nuclear Properties of Ti

Z (Atomic Number)	22
A (Mass number)	48
ρ (Density)	4.54 (g/cm3)
Melting point	1941 K
Boiling Point	3560 K
Phase transition	1153K
Minimum ionization	1.477 MeV/(g/cm2)
Radiation Length	35.6 (mm)

From this experiment, the breakdown limit of pure Ti extraction window is between 3.3 to 4.8A operation in KEKB. For the current larger than this limit, electron beam left a trace on the Ti plate. The plate surface was bulged. Figure 6 shows the bulged surface of Ti plate. The unevenness of the surface is larger than 25μm.

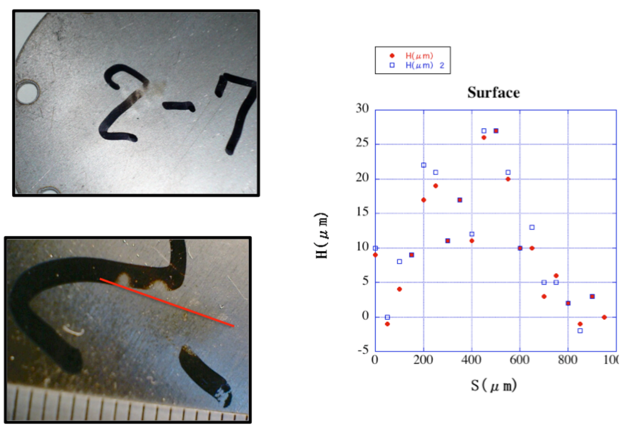

Figure 6: Damaged Ti plate surface unevenness.

The temperature rise of Ti plate is estimated from the following formula.

$$\Delta T = \frac{N}{C}\left(-\frac{1}{\rho}\frac{dE}{dx}\right)\frac{1}{\sqrt{2\pi}}\frac{1}{H\sigma_x}$$

N: Number of electron, ΔT: Temperature rise, ρ:Density, dE/dx: Stopping power, H:vertical sweep height, σx:Horizontal spot size, C: Specific heat

The Ti plate damage seems to occur around the Ti phase transition temperature. Figure 7 and Table 5 shows Thickness dependence of Ti plate damage. For same amount of beam, damage of 0.5 mm thickness plate was minimal.

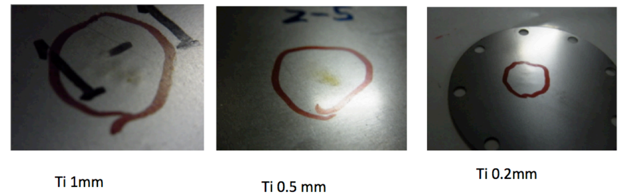

Figure 7: Thickness dependence of the damage in Ti plate.

Table 5: Thickness Dependence of Ti plate Damage
○ : OK, △ : There's a mark but not bulged, × Damaged.

# Ti Plate	Ti Alloy 1	Ti Alloy 0.5	Ti Alloy 0.2	Ti Alloy 0.1	Ti 1	Ti 0.5	Ti 0.2	Ti 0.1
	○	-	-	-	○	-	-	-
0	○	-	-	-	○	-	-	-
1	○	-	-	-	○	-	-	-
2	○	○	△	△	○	○	○	○
3	○	○	-	-	△	△	-	-
4	△	○	×	×	×	△	×	×
5	△	-	×	-	×	-	×	×
6	△	△	-	-	×	△	×	×
7	△	-	-	×	×	-	-	×
8	△	△	×	×	×	△	×	×

CONCLUSION

With 8 GeV electron beam, the breakdown limit of Ti window was investigated. In the KEKB, the extraction window breakdown limit is between 3.3 and 4.8A. For the design of SuperKEKB abort system, the current density at the window must be lower than this condition. The damage of Ti plate seems to have plate thickness dependence. A bulge is observed in the damaged Ti plates. Ti alloy Timetal 110 has excellent characteristics at the high temperature.

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