# LOW IMPEDANCE MOVABLE COLLIMATORS FOR SUPERKEKB

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*Abstract*

Low impedance collimators for SuperKEKB have been designed to fit an antechamber scheme in the vacuum system and will be operated to suppress backgrounds in the particle detector named Belle-II. We have developed two types of collimators; a horizontal and vertical collimator. The collimator has a pair of horizontally or vertically opposed movable jaws with RF shields. The two horizontal collimators installed in the positron ring for a test functioned well without any problems during the first (Phase-1) commissioning up to a beam current of approximately 1 A. Following the promising results, the six collimators with almost the same structures are planned to be manufactured and installed by the second (Phase-2) commissioning. In this paper, the latest design, results of impedance calculations, a threshold of a transverse mode coupling instability and a future plan are presented.

## INTRODUCTION

SuperKEKB, which is an upgrade project of KEKB, is an electron-positron collider with extremely high luminosity. The design currents are 2.6 A and 3.6 A in the electron ring (HER: High Energy Ring) and the positron ring (LER: Low Energy Ring) respectively. In most of LER and part of HER, beam pipes have antechambers to reduce the impedance and the synchrotron radiation power density [1].

We had designed new type collimators to fit the antechamber scheme. The collimator is one of the vacuum components to cut off beam halo and suppress background in Belle-II detector. The collimators also work as one of machine protection systems from the storage beam. There are two types of collimators; a horizontal and vertical one. The former and latter have a pair of horizontally and vertically opposed movable jaws as shown in Fig. 2(a) and (b), respectively. The two horizontal collimators were installed and operated in an arc section of LER for the phase-1 commissioning as shown in Fig. 1. In HER, 4 horizontal and 4 vertical collimators, which had been manufactured and operated for not SuperKEKB but KEKB operation, each for the two arc sections were reused during the commissioning. The operation was no big trouble such as a rise of temperature and a damage on the collimator's tip up to approximately 1 A in the storage beam current.

## DESIGN

Schematic drawing of the horizontal and vertical collimator for SuperKEKB is shown in Fig. 2. We referenced collimators for PEP-II in SLAC for the basic design [2]. The cross section at the end of the collimator chamber (i.e., a beam chamber equipped with a pair of movable jaws) is same as the beam pipes of the up/downstream [3]. The collimator chamber is tapered from the end to the center in order to avoid trapped Higher Order Mode (HOM) electromagnetic field excited by beams. Because a part of each movable jaw of the horizontal collimator is inside an antechamber, the impedance is lowered compared to that of the conventional collimators. In the vertical collimator, the top and bottom region to where the movable jaw is inserted, 14 mm in the width, are not tapered, thus part of vertical jaws is also hiding from beam channel and this decrease the impedance as with the horizontal collimator.

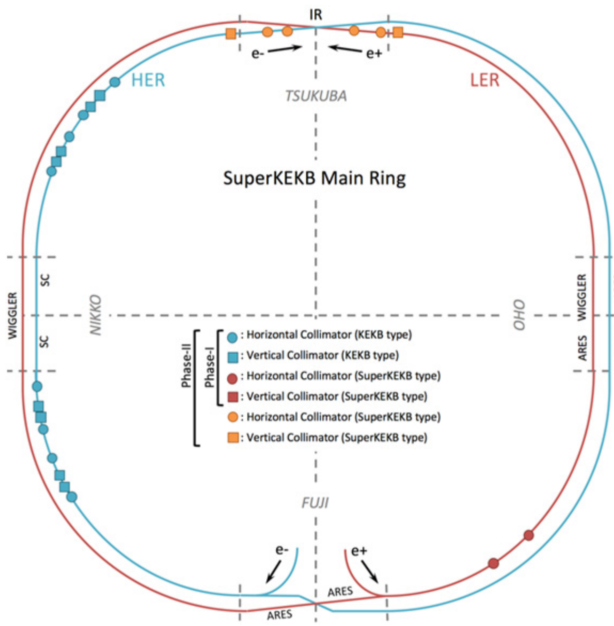


Figure 1: Collimators location in the phase-1 and -2 commissioning.

The chamber and jaws are made of oxygen free copper mainly. The MO type flanges and the race track shaped flanges, to where the jaws are inserted, are made of chromium copper and stainless steel, respectively. The jaw has a cooling channel inside it and a tungsten plate at the tip because of the high melting point and the short radiation length. These components are jointed with Hot Isostatic Press (HIP). Then, the halved chambers are machined and vacuum brazed. Since there is a cavity structure behind the jaw, the finger-type RF shield is attached on the top and bottom of each jaw to prevent the intrusion of HOM, as shown in Fig. 3. The RF fingers is made of silver-plated Inconel. The contact surface on the chamber is made of rhodium-plated stainless steel. We conducted an endurance test for the RF fingers and the contact surface, and a tiny amount of silver dusts were observed. Contact-less comb type RF shield, which is also used in bellows

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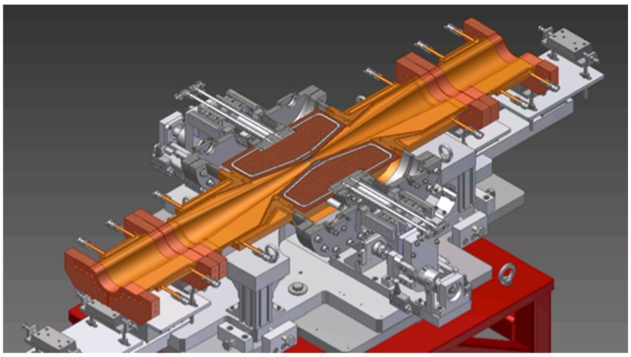
chambers in SuperKEKB, is adopted between the longitudinal end of the jaw and the facing surface on the chamber.

When we replace the damaged jaw to new one, for example, it is difficult to do it for the bottom one in the vertical collimator. Therefore, two rotatable circular disks are prepared at the outer side of the collimator chamber of vertical-type. In order to avoid trapped HOMs around the jaws, the inside of the antechamber in the horizontal direction is also tapered to the center of the vertical collimator.


(a) horizontal collimator

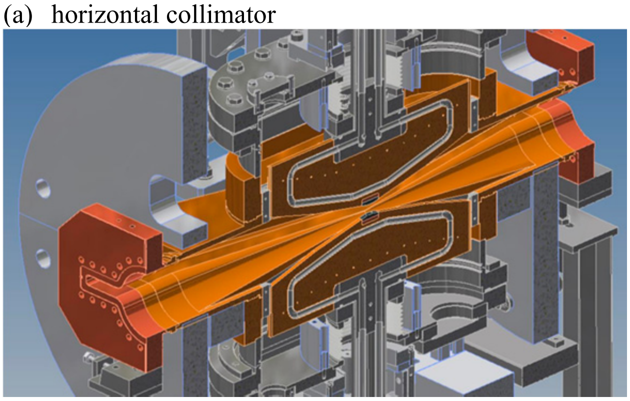

(b) vertical collimator

Figure 2: Collimators for SuperKEKB.

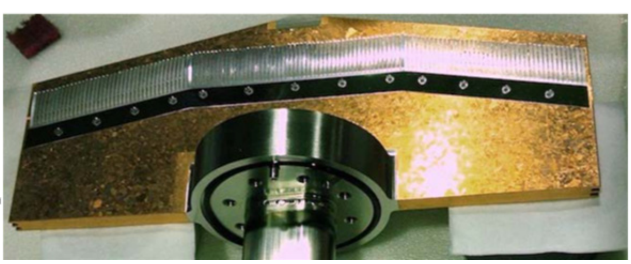
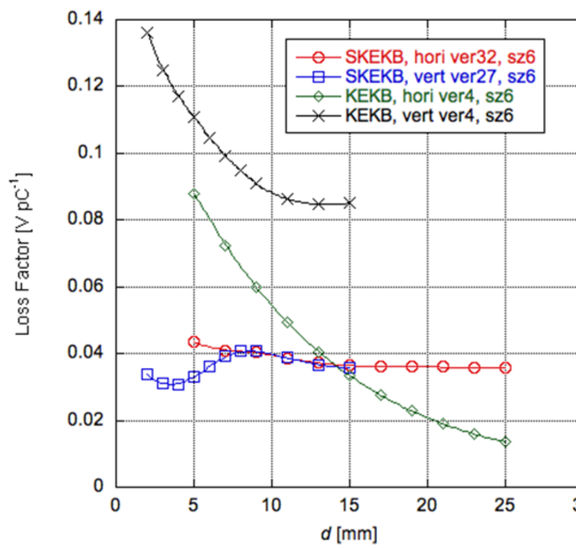


Figure 3: Moveable jaw with RF fingers.

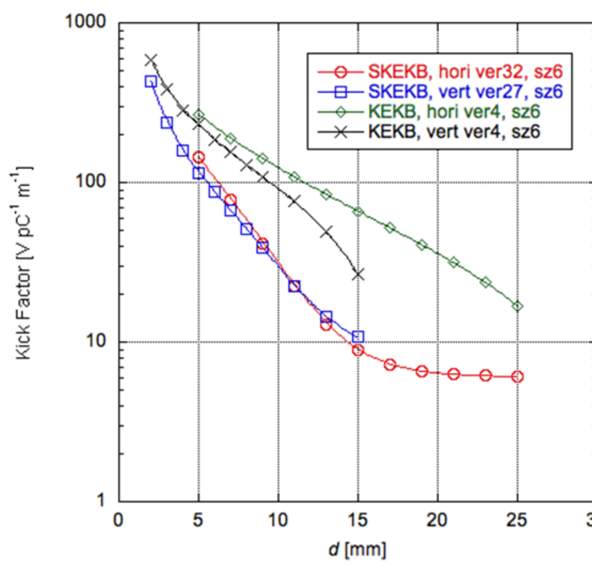
## IMPEDANCE

We estimated the impedance of the collimators for SuperKEKB and KEKB using GdfidL [2]. The KEKB-type collimator has one movable jaw (i.e., a chamber with a curved aperture) [4]. Figure 4 shows loss factors and kick factors in a bunch length of 6 mm, which is the design value of SuperKEKB LER. The kick factors are calculated with beam offset of 1 mm in horizontal or 0.5 mm vertical direction.

The loss and kick factors of the SuperKEKB collimators are less than those of the KEKB ones except for loss factors in the aperture of 15 mm or wider for a horizontal collimator of KEKB. In the third (phase-3) commissioning, we have a plan to operate up to 10 horizontal and 3 vertical collimators in LER. If we operate them with minimum apertures, which refer to 5 mm and 2 mm in $d$ for the horizontal and vertical collimator respectively, the total loss factor is approximately 0.6 V/pC. This value is acceptable in terms of the RF system in SuperKEKB [5, 6].



(a) loss factor



(b) kick factor

Figure 4: Loss and kick factors for collimators with a bunch length of 6 mm. Horizontal axis refers the distance between the beam orbit and the tip of jaw. For SuperKEKB collimators, the two movable jaws are moved simultaneously in this estimation. SKEKB or KEKB in the legend refer to factors for SuperKEKB or KEK collimator respectively. Hori or Vert in the legend refer to horizontal or vertical collimators.

Figure 5 shows a real and imaginary part of the collimators. There is no resonance in this structure to 16 GHz. Although there arises a step structurally between the movable jaw and the collimator chamber when the aperture becomes wider, no trapped modes is found in Fig. 5. This should be a benefit of the design that the jaw is embedded in the antechamber.

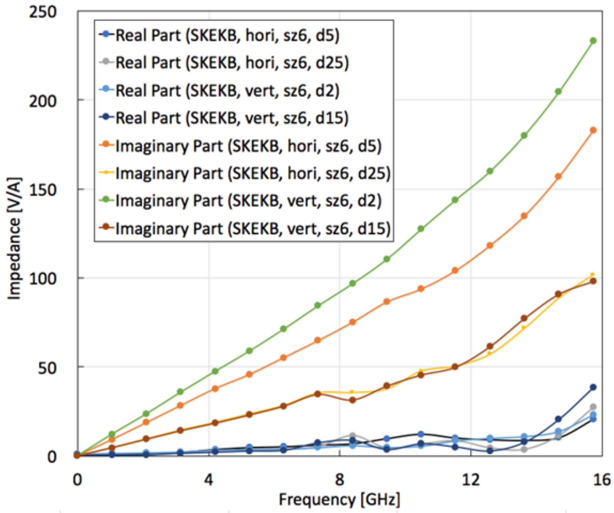



Figure 5: Real and imaginary parts of the impedances of collimators for a bunch length of 6 mm. $d$ refers to an aperture.

## TRANSVERSE MODE COUPLING INSTAVILITY (TMCI)

TMCI is one of factors which could limit the bunch current, and its threshold is given by

$$I_{thresh} = \frac{C_1 f_s E/e}{\sum_i \beta_i \kappa_{\perp i}(\sigma_z)},$$

where $C_1 \approx 8$, $f_s$: synchrotron frequency, $E/e$: beam potential, $\beta_i$: beta function in each collimator, $\kappa_{\perp i}$: kick factor in each collimator and $\sigma_z$: bunch length [7].

The calculated thresholds of the bunch currents in LER is approximately 1.67 mA/bunch and 10.43 mA/bunch in the vertical and the horizontal directions, respectively, for a bunch length of 6 mm and for the default aperture settings. Here the default aperture settings mean the optimized apertures in the collimators expected from a simulation to minimized the background in the Belle-II detector for the phase-3 commissioning [8]. This background simulation uses 9 horizontal and a vertical SKEKB-type collimator, and the minimum apertures of them are 8 mm in horizontal and 2 mm in vertical. Since the design bunch current in LER is 1.44 ma/bunch, it is found that the safety margin in the vertical direction is small. The low threshold in the vertical direction derives from a huge kick factor of approximately 430 V/pC/mm in a vertical collimator with $d = 2$ mm.

The threshold in HER is approximately 1.94 mA/bunch in vertical and 2.34 mA/bunch in horizontal direction with the default aperture setting and the bunch length of 5 mm, which is a design value for HER. In the background simulation, 8 horizontal KEKB-type, 5 horizontal SKEKB-type and a vertical SKEKB-type collimator are used, and the minimum apertures of them are 7 mm in horizontal and 2 mm in vertical. Since the design bunch current in HER is 1.04 mA/bunch, the safety margin is large enough compared to the case of LER. The threshold of HER in horizontal direction is lower than that of LER because the kick factor in the KEKB-type horizontal collimator is higher than that in the SKEKB one.

## BACKGROUND SUPPRESSION IN PHASE-1

We observed a background suppression derived from stored or injected beam by one of the horizontal collimators in one of Beam Exorcism for a Stable Experiment-II (BEAST-II) studies, which refer to a project to measure and characterize beam backgrounds for a safe roll-in of Belle-II.

Figure 6 shows a result of BEAST-II studies using a collimator named D06H03 in LER. CsI is one of detectors in BEAST-II, and the hit rate indicates the amount of background in Fig. 6. In this study, the beam current was accumulated to approximately 0.5 mA, then we closed the aperture of the collimator in a step-by-step manner. The number of beam trains and bunches are 1 and 1576 with 3.06 RF bucket spacing. The CsI hit rate is decreased when the aperture is closed as shown at green arrows in Fig. 6, therefore this is evidence that the collimator suppresses background derived from the stored beam.

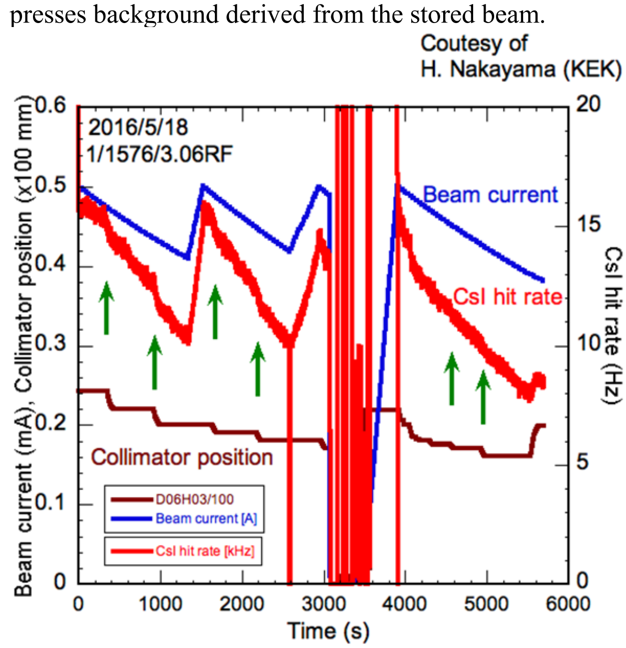



Figure 6: Background suppression using a collimator named D06H3 in LER. Collimator position refers to the aperture of the collimator in an outside axis of the ring.

## FUTURE PLAN

On the base of the prospective results during the phase-1 commissioning, the same design was adopted for collimators in the phase-2 or later commissioning. We have a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plan to install a vertical and two horizontal SKEKB-type collimators upstream of the interaction point additionally in each ring by the beginning of the phase-2 commissioning as shown in Fig. 1.

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