BEAM TEST OF MOVABLE COLLIMATOR (MASK) WITH LOW BEAM IMPEDANCE

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Abstract

A movable collimator (mask) with low beam impedance for future high-intensity colliders has been investigated in KEK. The metal head of the mask is supported by a dielectric material in order to reduce the interference with beams. The present second test model had a head and a support made of graphite and artificial diamond, respectively. Graphite is a conductive material with high thermal strength, and diamond is a dielectric material with high thermal conductivity as well as the strength. The test model was installed into the KEK B-factory (KEKB) positron ring, and tested with real beams to prove the principle.

INTRODUCTION

Most particle colliders with high beam intensities usually have a movable collimator (mask) system to cut off spent particles around a nominal beam orbit, decreasing the particle detector's background noise [1–7]. Conventional movable masks, however, has high beam impedance [2–4, 7], which causes beam instabilities and also excessive heating of the adjacent vacuum components due to the HOM (Higher Order Modes) excited by the mask [8, 9]. Another problem is damage to the mask head due to the direct impact of intense beams [5]. The development of a novel movable mask with low beam impedance and a higher resistance against intense beams has been a key issue in realizing higher-intensity colliders [6, 10].

Recently, a new structure for movable masks with low beam impedance was proposed in KEK [1, 11]. A conceptual drawing of the new-type mask is presented in Fig. 1 (a). The mask consists of a head (mask head) made of a conductive material, which obstructs passing spent particles, and a dielectric support for this head. In the simulation, this combination can reduce the interference between the mask and beams, and thus reduce the impedance [1]. In contrast, the existing old-type mask for the KEK B-factory (KEKB) [9, 12] is a kind of bent beam chamber, with a part of the chamber playing the role of a mask head, as shown in Fig. 1(b) [3, 4, 8]. The trapezoidal structure of the mask head with ramps at both sides is a typical for conventional masks [2, 8]. The calculated loss factor of the new-type mask was found to decrease by several factors compared to that of the old-type mask [1].

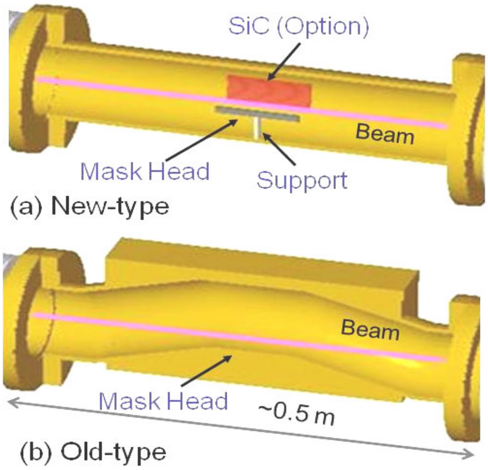

Figure 1: Conceptual structures of (a) a new-type and (b) an old-type movable mask.

Reported here are the results of experiments on the new-type movable mask, which were performed utilizing an intense positron beam of the KEKB. The positrons had an energy of 3.5 GeV, and the maximum stored beam current was about 1700 mA with 1585 bunches (about 6 ns intervals). The bunch length was about 6 mm. Two test models were installed into the ring, and were tested with beams stored up to a beam current of around 1300 A (1585 bunches).

TEST MODEL

The test model used here is the second one, which was redesigned based on the experience gained from a preliminary experiment with the first test model. The first model had unfortunately damaged at the initial stage of the beam test [11]. The second test model is presented in Fig. 2. The whole structure is basically the same as the first one, but the materials used were changed. The mask

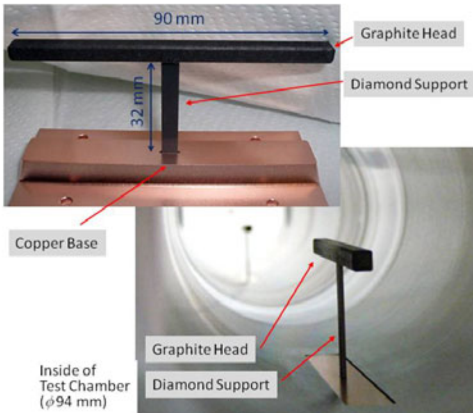

Figure 2: Test model of a new-type mask, where a graphite mask head is supported by a diamond support.

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head is made of commercially available graphite, of which the conductivity is about 3 × 10^5 Ω^{-1} m^{-1}. The height, width, and length are 5 mm, 5 mm, and 90 mm, respectively. A graphite bar with a length of 90 mm corresponds to a half radiation length. On the other hand, the support is made of artificial diamond, with a height, width, and thickness of 35 mm, 5 mm, and 1.2 mm, respectively. The diamond is not a single crystal but has a thermal conductivity larger than 1,000 W $mm^{-1}K^{-1}$ at room temperature. The dielectric constant is about 6, and the loss tangent (tanδ) is said to be typically lower than that of alumina ceramics. The input power into the head and support will mainly flow through the diamond support rather than as radiation to the outside beam chamber, which is quite different from the case of the previous first model. A simulation indicated that the maximum temperature of the head should be around 460 °C even at a beam current of 1700 mA (1389 bunches) [11].

The head (graphite), support (diamond), and copper base were connected by silver brazing. The mask was set to a beam chamber as shown in the lower portion of Fig. 2. The copper base was fixed to the beam chamber to plug the insertion slot for the mask head. The head position was normally set to a position at 10 mm apart from the beam orbit. The diameter of the beam chamber was 94 mm. The beam chamber was made of aluminum alloy, and cooled by water.

BEAM TEST

The two beam chambers with the test models were installed into the KEKB positron ring, replacing the existing old-type masks. Both masks were set vertically (see Fig. 2). The former and latter masks are called V1 and V2 here, respectively. The mask V1 was at the upstream side of V2, and the distance between them was about 2 m. The temperatures of the bellows chambers [13] and cooling water of the HOM absorbers [14] near the masks were continuously monitored during the beam test.

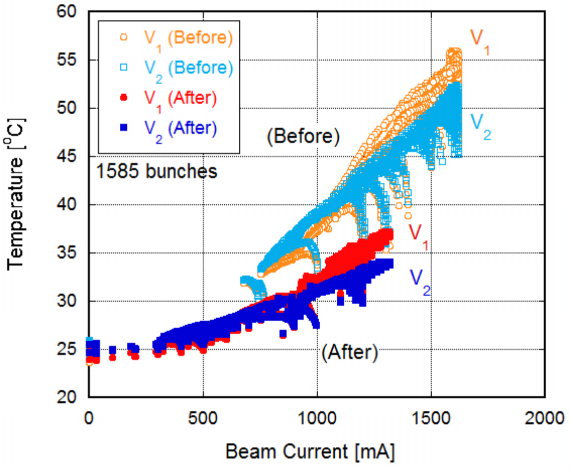

Figure 3: Dependences of the average temperatures of four bellows chambers located close to vertical masks (V1 and V2) on the beam current before and after installing the new-type masks.

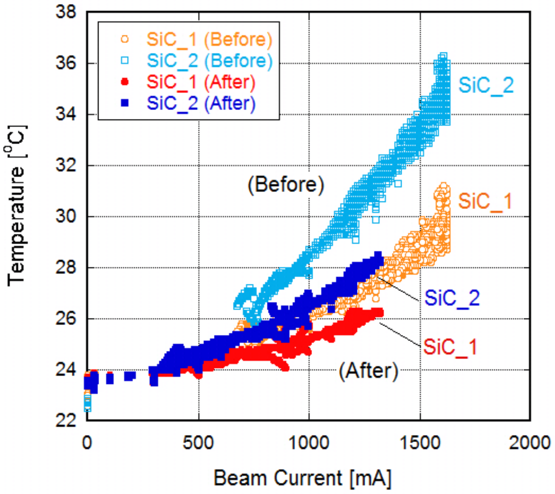

Figure 4: Dependences of the cooling water temperatures of HOM absorbers (SiC_1 and SiC_2) near the masks on the beam current before and after installing the new-type masks.

Temperatures of the Bellows Chambers

Figure 3 shows the average temperatures of the four bellows chambers located to either side of the masks V1 and V2 before and after installing the test models. The temperature rises after installing the test models clearly decreased by a factor of two, where the base temperature was around 26 °C at a beam current of about 1200 mA. The temperatures of the bellows chambers at about 10 m downstream from the masks V1 and V2 were also found to decrease at the same time. Since the heating of the bellows chamber is attributed to the TE-mode like HOM excited by the masks [3, 4, 8], the decrease in the temperature indicated a decrease in the excited HOM power.

The average temperature of the four bellows chambers located close to both sides of a horizontal mask, which is placed about 5 m upstream of the mask V1, also decreased by about 30%, although the horizontal mask was still an old type. This means that some portion of the HOM excited by the masks V1 and V2 was propagating there, and was decreased by using the new-type masks.

Temperatures of HOM Absorber

In order to absorb the intense HOM excited by the existing movable masks, a wing-type HOM absorber was developed and installed close to them [14]. The HOM absorber is a beam chamber with two SiC rods inside (SiC_1 and SiC_2), which are set vertically. The HOM absorber was located at about 24 m downstream of the mask V2. The SiC rods were cooled by water.

Figure 4 shows the temperatures of the cooling water at the outlet side of SiC_1 and SiC_2 before and after installing the test models, where the cooling water of the

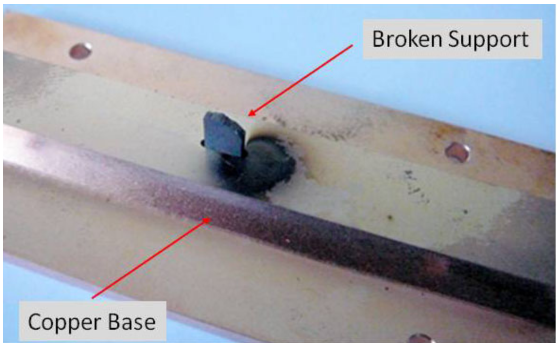

Figure 5: Damage to V1 mask found at a beam current of about 1300 mA (1585 bunches). The diamond support was broken just near the base.

two SiC rods was arranged in series. The temperature rise decreased by 40% for the case of the test models. This fact directly indicated that the excited HOM power decreased by using the new-type masks.

Damage at High Beam Current

One of the test models suffered serious damage at a beam current of about 1300 mA (1585 bunches). The inside of the beam chambers was inspected, and a break in the support for the V1 mask was found, as shown in Fig. 5. The support was broken at a position close to the bottom (copper base). Obvious traces of discharge were recognized on the surface of the copper base just close to the support. These facts indicated that extra-heating had occurred close to the bottom of the support. On the other hand, the other test model, V2, did not suffer damages regardless of the same test conditions.

The damage to the V1 mask should be attributed to a discharge around the base of the diamond support under an intense electromagnetic field. The peak electric field at the bottom of the support for a bunch with a bunch current of 1 mA is about 4×10^5 $\mathrm{Vm^{-1}}$. Possible reasons for this discharge are as follows; (1) Initial defect of the diamond support. (2) Defect at the brazing point between the diamond support and the copper base. (3) Surface discharge due to electrons emitted from the bottom of the support, that is, a triple junction of diamond (dielectric material), copper (metal), and vacuum.

FUTURE PLAN

The experiment here proved the principle of the new-type mask that the excited HOM power can be reduced by using the new-structure proposed by a simulation for the first time. The present test model, however, cannot withstand a higher beam current. Improvement of the present design is underway. The diamond will be upgraded to the optical grade from the mechanical one. The structure of the brazing point will be changed to ensure the brazing and relax the electric field at the triple junction. An experimental test using a microwave waveguide in vacuum is planned to verify the discharge and heating before installing them into the real ring.

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