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INJECTION BEAM MEASUREMENT USING SYNCHROTRON RADIATION MONITOR AT THE SuperKEKB ELECTRON RING

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Abstract

We upgraded the diamond mirror of the SuperKEKB electron ring to extract the good quality synchrotron light in 2020 summer. As a result, the accuracy of profile measurement for each bunch using a gate camera has improved dramatically, and it has become possible to measure the incident beam for each turn. The electron beam was injected with single turn injection mode to measure the properties of the beam and measured turn by turn after injection. In order to convert the measurement results into beam size, convolution by diffraction effect and absolute value calibration using real images were performed. We report the behaviour of the injection beam during normal operation of SuperKEKB.

INTRODUCTION

SuperKEKB is a collider with 7 GeV electron and 4 GeV positron. Aiming for the highest luminosity in world, we have adopted a nanobeam scheme and have just recorded a peak luminosity twice that of KEKB [1].

Beam size measurement is very important for collision tuning to improve luminosity. SuperKEKB mainly uses synchrotron radiation X-rays for beam size measurement and visible light for beam size measurement and other behaviour measurements.

One example is the turn-by-turn measurement of the injection beam [2, 3]. For stable beam operation, the stability of the beam injection from the injector linac is significant. When the injection efficiency becomes unstable, it becomes difficult to accumulate the beam and the background to the detector increases, which hinders physics experiments. Therefore, it is important to observe how the injection beam turn in the ring usually and prepare for the measurement of difference with worth efficiency injection beam.

SYNCHROTRON RADIATION MONITOR

The setup of SuperKEKB visible light monitor consist of extraction mirror, optical window, transfer mirrors and optical system. An extraction mirror of visible light is made of diamond. Since it is a high current machine from KEKB, it was a problem to suppress the thermal deformation of the extraction mirror for visible light. At the beginning of SuperKEKB, we have developed a single crystal diamond mirror and made efforts to suppress the current dependence of thermal deformation, but the mirror had not only the current dependence of the deformation at high currents, but also some deformations made during manufacturing [4]. Therefore, we made a new thick polycrystalline diamond mirror that is not easily deformed by heat and installed it in 2020 [5]. Resistance to thermal deformation is similar to single crystal. In addition, the reflectance is high because the coating is changed from gold to platinum. At the result, it became possible to obtain a sufficient amount of light for beam profile measurement for each bunch, and it became possible to measure the injection beam for each turn.

A diamond mirror is inserted into the antechamber type light extraction chamber as shown in Fig. 1 and pass into the optical window made of silica quartz on the opposite side of the chamber. Extraction chamber is set up to downstream 23 m of source bend magnet. At the downstream of the chamber, five mirrors are used to relay light to the above-ground SRM hat about 30 m downstream. An optical system for beam measurement, a gated camera, streak camera etc. are installed in the SRM hat on the ground. Figure 2 is an incident optical system for measuring an injection beam. Object system which designed for corona graph is used to measure the injection beam [6].

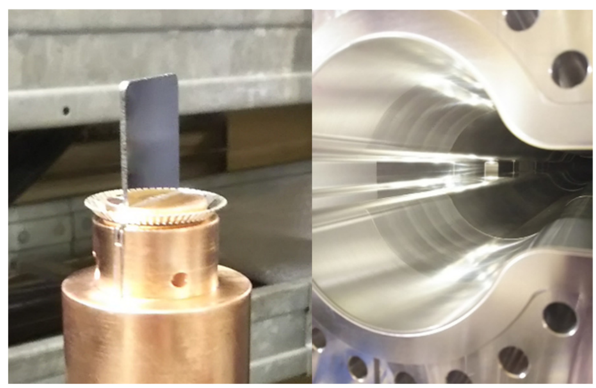

Figure 1: (Left) Diamond mirror mounted on the holder. (Right) Mirror inserted inside the chamber.

INJECTION BEAM MEASUREMENT

The standard injection beam measurement was performed with a single turn injection using stable injection parameters at electron ring. Each injection bunch kicks out the previous injected bunch. Then the ring always has only one bunch.

The gate width of the gated camera is one turn, in other words, 10μs. The trigger was applied at the injection timing, and after finding the first turn, the beam behaviour was observed turn by turn by shifting the timing. Figure 3 shows the examples of first turn to 10th turn after injection. It can be seen that the beam just after the injection repeatedly oscillation. Since SuperKEKB operating tune is close to a half-integer, it can be seen that the bunch moves left and right at every turn. The beam size does not shrink monotonically, but shrinks while repeating oscillation.

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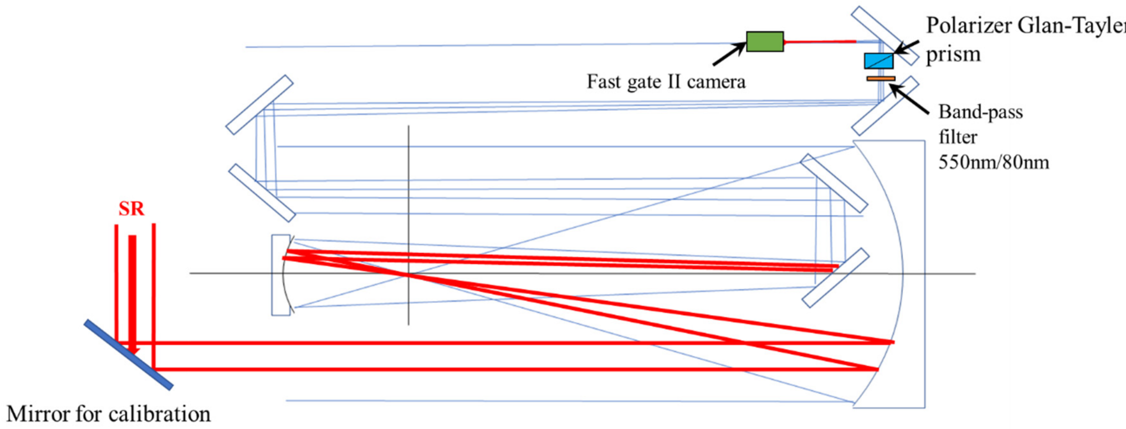

Figure 2: Gregorian objective for observation of injection beam f=7028mm.

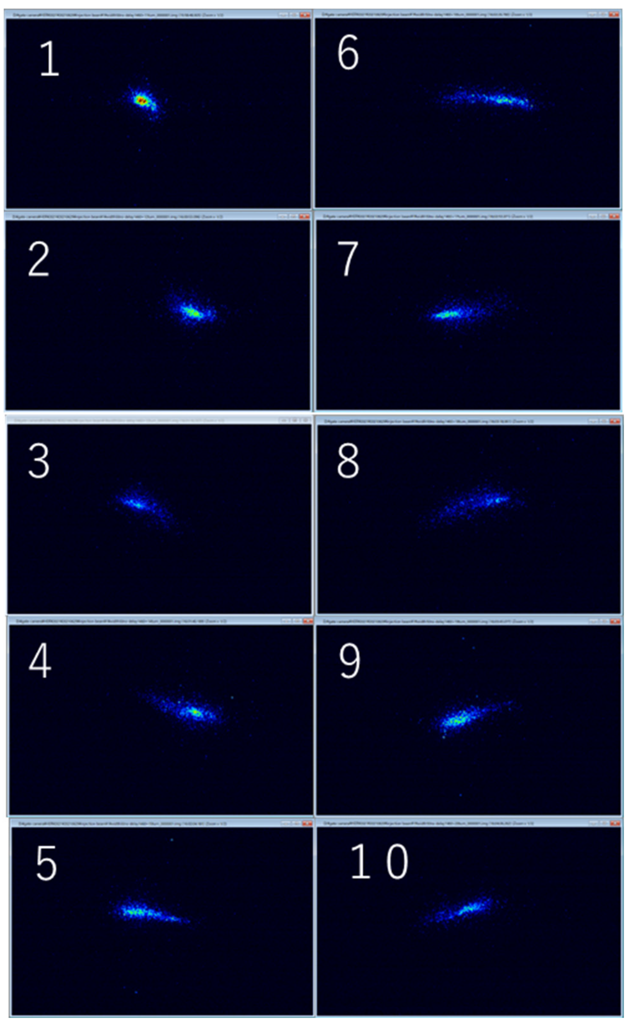

Figure 3: First turn to 10th turn after injection at SuperKEKB electron ring.

CALIBRATION

A simple calibration was performed to estimate the transverse scale. The most upstream mirror of Fig. 2 was placed on a cross roller stage equipped with a micrometer and moved horizontally by ± 15 mm to measure the position on the screen. This corresponds to moving the beam virtually. Figure 4 shows an example of the calibration result. Calibration was performed using a stored beam with the gate width of the gated camera reduced when the beam was stable. The error bars due to measurement variability are smaller than the plot, and the variability of circles at the same position comes from the displacement of the beam due to the difference in measurement time. No large distortion is seen on the photoelectric surface of the CCD camera.

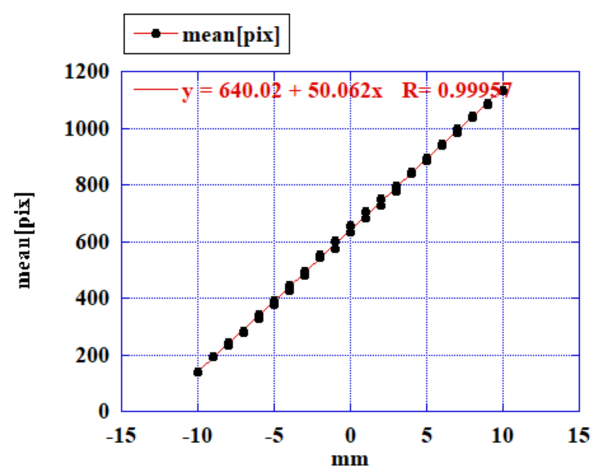

Figure 4: Calibration result of gated camera.

ANALYSIS

Transverse magnification of the focus system is 0.0204 and image size at imaging point of the beam σ_x=300μm is 6.13μm. Image size with diffraction is roughly given by Sqrt $(6.13^2 + 6.24^2)$=8.75μm. Then using transverse magnification, expected beam size with diffraction will be 8.75/0.0204=429μm. There is no correction of diffraction effects on the plotted beam sizes in Fig. 6.

Figure 5 (a) shows the horizontal beam size for each turn of the injection beam after calibration. The size plotted on turn 0.1 is the previously injection beam and corresponds after a complete dump for comparison. It can be seen that the injection beam repeatedly expands and contracts and damped after 10,000 turns (10 ms). The beam

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size including the diffraction effect does not contradict the calculated value. The injection beam oscillation is as shown in Fig. 5 (b), and it can be seen that the amplitude becomes stable while oscillate with a width of about ± 4.5 mm at the maximum. The correlation between the vertical and the horizontal oscillation width is as shown in (c) and (d).

CONCLUSION

SuperKEKB has prepared a system for observing the behaviour of the injection beam in the ring when the injection efficiency becomes unstable. By exchanging the light extraction mirrors for both the electron ring and the positron ring, the image of the beam can be clearly focused, and the injection beam, which has a smaller charge than the storage beam, can be measured every turn. It was observed that the injection beam size of HER was dumped while oscillating even when the beam condition was stable. Similar measurements were made with the positron ring, and the injection beam was successfully observed. The reference data was measured in the study mode, which can measure only the injection beam in a single turn incident, but by masking the accumulated beam, it is possible to measure some incident condition even during collision operation.

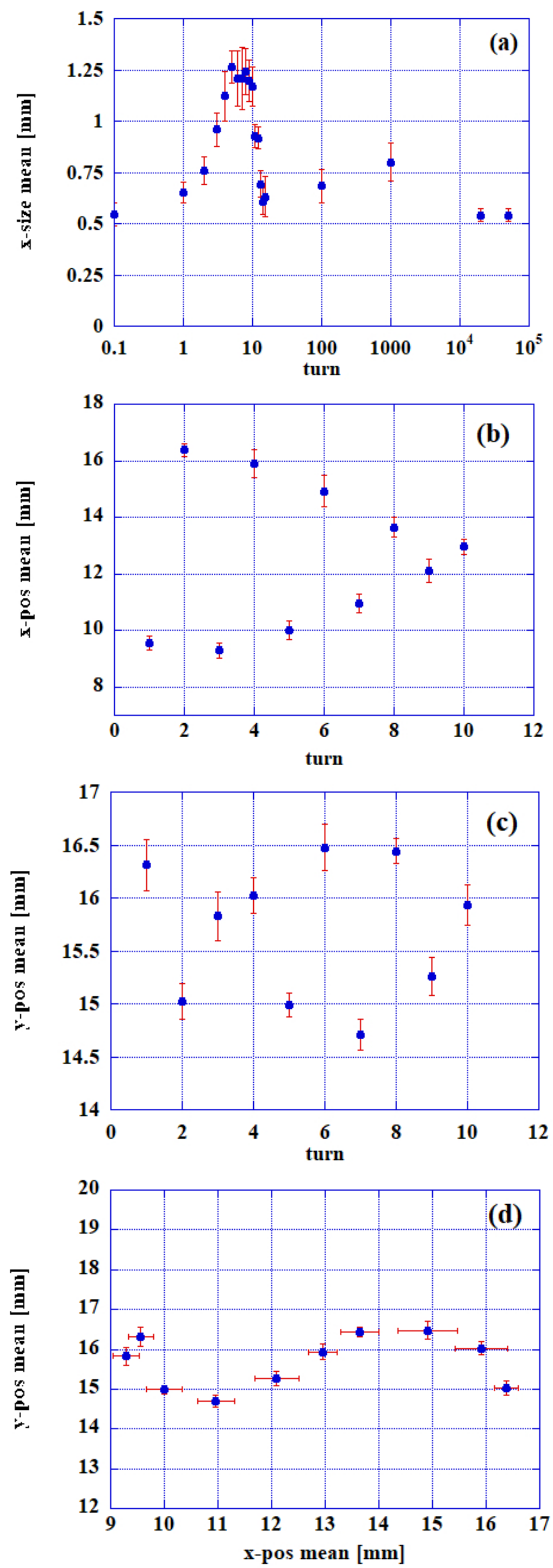

Figure 5: (a) Horizontal beam size, (b) horizontal beam position, (c) vertical beam position and (d) vertical vs horizontal position for each turn after injection.

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