BEAM COLLIMATION SYSTEM
FOR THE SPring-8 TOP-UP OPERATION

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Abstract

In the SPring-8, a beam collimation system was built for a continuous refilling of electrons to the storage ring, so called top-up operation, to keep the synchrotron radiation with fixed intensity. The system was placed on the beam transport line from the booster synchrotron to the storage ring to shape the beam profile in horizontal direction. This paper describes a preliminary result and discusses a future plan using this system.

INTRODUCTION

The SPring-8 booster synchrotron accelerates an electron beam up to 8 GeV and then ejects to stack into the storage ring [1]. Path length of a beam transport line from the booster to the storage ring (SSBT line) is 324.0 m. It has 13 dipole, 42 quadrupole and 21 correction magnets.

The top-up operations were already started at other light sources [2,3]. In the SPring-8, the operation has been tested from September in 2003. The operation requires that electrons are injected while the photon beam user are making their experiments. To prevent demagnetization of insertion devices, not only reduction of beam oscillation by off-axis injection is needed but also a particle loss should be minimized to nearly 0 %. A low-emittance injection-beam helps to reduce the losses because horizontal emittance of ejected beam from the booster is about two orders bigger than that of the storage ring [4,5]. Therefore, we installed a beam collimation system on the SSBT to shape the beam profile in horizontal direction.

INSTRUMENTATION

The collimation system consists of two pairs of scrapers. These were named SL1A_ss and SL1B_ss (Fig.1). SL1A_ss and SL1B_ss were located 23.4 m and 26.7 m downstream from the ejection point of the booster. These were placed on a dispersion-free section in the SSBT. Because of the negligible dispersion, the scrapers can only be used for betatron collimation. In order to limit x and x' in the phase space, horizontal phase difference between SL1A_ss and SL1B_ss were designed to be $\pi/2$ radians. Designed horizontal beam sizes at SL1A_ss and at SL1B_ss are 0.606 mm and 1.46 mm, respectively.

For both scrapers, two stainless-steel plates with 21.2 mm thick were prepared as left- and right-side blades (Fig.2). These blades are moved by stepper-motors. The step size is 1 µm. The operation ranges of the inside-edges of both blades were between 20 mm left and 20 mm right from the center of the beam pipe.
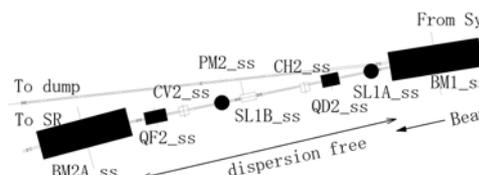
Figure 1: Arrangement of the scrapers in the SSBT line. From the side of upstream, two scrapers were named SL1A_ss and SL1B_ss. Blocks indicate the magnets.
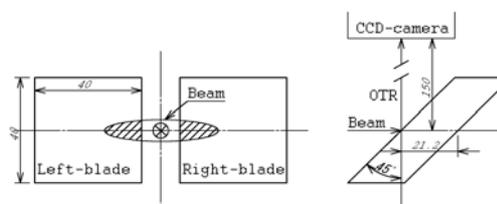
Figure 2: Detail of the scraper. Left- and right-side figures show an elevation view and a cross-section view, respectively.

Energy loss of the beam in the blade was calculated by Monte Carlo simulation using "EGS4". Samples of up to 10^6 electrons were tracked. A cleaning inefficiency was defined as the number of electrons injected into the storage ring divided by the number of electrons injected into the scraper under a condition that scraper fully closed. The inefficiency was obtained to be 1.7×10^{-4} under a condition that energy acceptance of the SSBT was 1 %.

An optical transition radiation (OTR) is generated when a charged particle crosses the interface of two media with different dielectric constants, in both backward and forward directions [6,7]. To observe an OTR on the surface of the blade, the surfaces were tilted 45 degrees with respect to the normal of the input face (Fig.2). The face was finished to a mirror surface. A profile of removed beam by the scraper was imaged with a 1/2" CCD-camera (Pulnix Inc., TM-1400CL, 1376x1024 pixels, 8 bits resolution). A close-up ring with 40 mm long was inserted between the camera and a lens (CANON Inc., VF75-1.8) to magnify the image. The image size a pixel was 8.1 µm/pixel. A divergence of the OTR was estimated to be 6 µm at the surface of the lens [4]. The lens-caliber of $\phi48$ is much larger than the divergence. After the image was digitized, it was transferred to a PC through a camera-link cable. Image data was integrated along vertical axis to obtain an intensity distribution of the removed beam in horizontal direction (Fig.3). A synchrotron radiation, which was emitted by BM1_ss (Fig.1), was piled up at right side of

the figure. The beam size and the beam position were obtained under a condition that the scraper fully closed.

A profile of the collimated beam was observed with a fluorescent monitor at the injection point to the storage ring. After the beam profile was imaged with a 1/3" CCD-camera (Takenaka Inc., FC-300M-T1), the image was captured using a PC with 640x480 pixels, whose resolution was 8 bits. The image size a pixel was 49 μm/pixel.
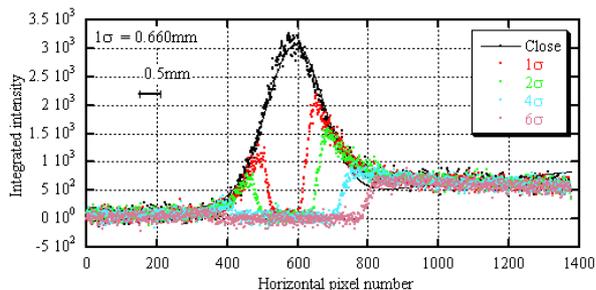
Figure 3: Integrated intensity in horizontal directions of the OTR at the surface of SL1A_ss. Colored dots indicate the intensities with various scraper gaps. Black dot indicates the intensity under a condition that the scraper fully closed. Black line indicates a result of the gaussian-fit.

MEASUREMENT

To calibrate the blade positions, transmission rates of the scrapers were measured with various blade positions. The rate was defined as number of electrons at downstream of the scraper divided by number of electrons at upstream of it. The rate was measured with a DC-CT at the storage ring and one at the booster. Measured rate was normalized to the rate without collimation.

Designed horizontal phase difference between SL1A_ss and the injection point is $8\pi+0.84\pi$ radians. If the phase is equal to the integral multiple of π radians, the horizontal beam size is minimum under a condition of same twiss-parameter. Consequently, the horizontal distance between injection orbit and stored-beam orbit can be minimized. Under the condition, intensity at the horizontal center of the collimated beam with only SL1A_ss is agreed with that of the no-collimated beam at the injection point. To adjust the phase, the profiles were observed at the injection point with various phases. The phase was varied using a quadrupole magnet, QF12_ss, which was located 35 m upstream from the injection point. The data were integrated along vertical axis to obtain an intensity distribution in horizontal direction. The scraper gap of SL1A_ss and SL1B_ss was separately set to be 2σ.

To determine the relation between injection efficiency and the scraper gap, the efficiencies with various scraper gaps were measured. The efficiency was defined as increment of number of electrons at the storage ring divided by number of electrons at downstream of the scrapers. The former was measured with a DC-CT at the storage ring. The latter was measured with a beam-charge

monitor. All the insertion devices of the storage ring were closed to their minimum values. The efficiency was measured also under the condition of the insertion-device free for comparison. Horizontal and vertical chromaticites of the storage ring were set to be +2 and +2, respectively.

RESULTS

The transmission rates versus blade positions are shown in Fig.4. We assumed that a beam intensity distribution had a gaussian shape. The transmission rate was fitted by a least-squares method with an error function. A position of an effective beam center was defined as the position, which gave a transmission rate of 0.5. The positions for all the blades were defined as the origins in this figure. An effective beam size was defined as one standard deviation of the error function.

The integrated intensity at the injection point without collimation was fitted with a gaussian function. For the collimated beam, the gaussian fit was performed using data of the range from -1σ to $+1\sigma$. A peak ratio was defined as the ratio of a peak of gaussian for the collimated beam to that of no-collimated beam. The peak ratio versus relative strength of QF12_ss is shown in fig.5. In the case of SL1A_ss, even if the field increased up to the present maximum field, the peak ratio did not amount to unity. In the case of SL1B_ss, the ratio amounted to unity if the field decreased. The field was decided to be -10 % for the top-up operation.

Injection efficiencies versus scraper gaps are shown in Fig.6. The efficiency increased as the gap decreased. The efficiency amounted to 81 % under a condition of the gap of 2σ even if all the insertion devices were closed to their minimum values. However, fluctuation in the efficiency shot by shot increased abruptly at the gap of 1σ. The gaps of both scrapers were decided to be 2σ for the top-up operation.
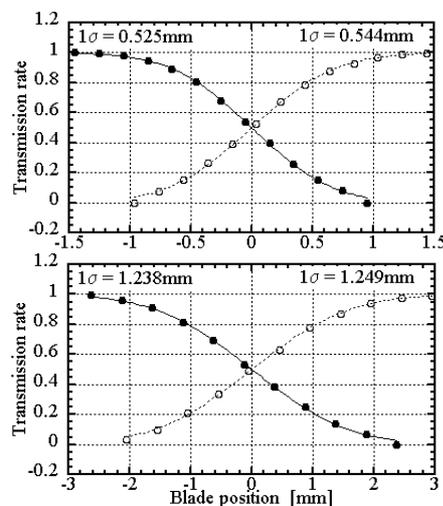
Figure 4: Upper and lower figure show the transmission rate versus blade position at SL1A_ss and at SL1B_ss, respectively. Closed and open circles indicate the rate for left- and right-blade, respectively. Solid and broken lines indicate the results of a least-squres fit with an error function.
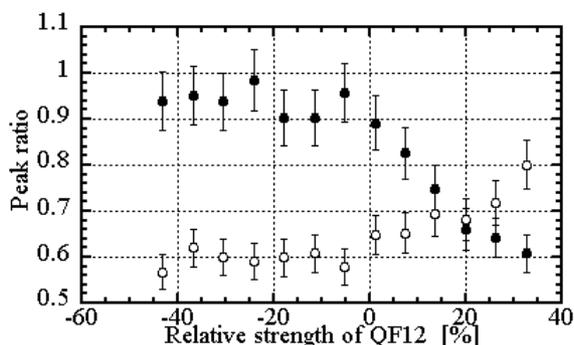
Figure 5: Peak ratio, which was defined as a ratio of the intensity at the horizontal center of the collimated beam to that of no-collimated beam, versus relative strength of QF12_ss. Black circle and dot indicate the ratio for SL1A_ss and that for SL1B_ss, respectively. Error bar indicates one standard deviation of the intensity fluctuation of the ejected beam from the booster.
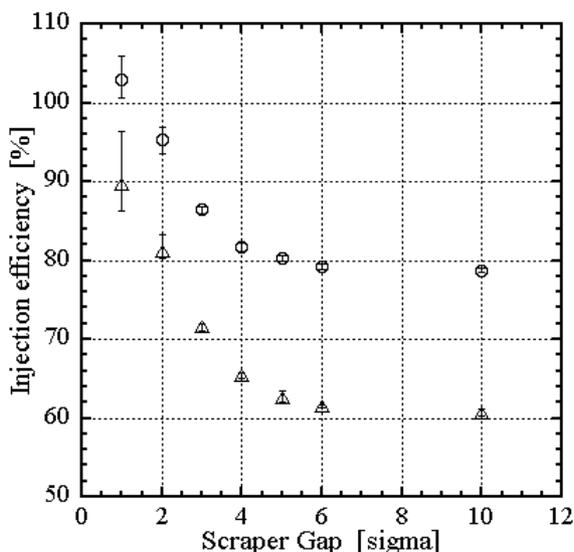
Figure 6: Injection efficiency versus scraper gap. All the gaps were set symmetrically from the position of the effective beam center. The gaps were normalized to the effective beam size. The gap of 10σ indicates a condition that the scrapers fully open. Triangle indicates the efficiency under a condition that all the insertion devices were closed to their minimum values. Circle indicates the efficiency under a condition of the insertion-device free. Error bars indicate fluctuations in the efficiency of five shots.

DISCUSSION

It became clear that the phase difference between SL1A_ss and the injection point differed from the designed one. It could be presumed that the phase advance was 0.29π radians smaller than designed one. The difference is explained by the field errors of the quadrupole magnets, which are located between the scrapers and the injection point. It is necessary to adjust again twiss-parameters of the SSBT.

Since the test of the top-up operation has been started, adjustment of the blade position was required. Changes in the position of the effective beam center at scrapers are shown in Fig.7. In the figure, the position at start point was defined as 0 mm. The changes at SL1A_ss and at SL1B_ss were equivalent to 2.3σ and 1.2σ, respectively. In the case of SL1A_ss, the change was larger than the scraper gaps. Therefore, it is necessary to trace a cause of the drift of the beam to operate the top-up injection with constant efficiency. Continuous measurement of the position of the beam center is also needed using OTR at the scraper surface.
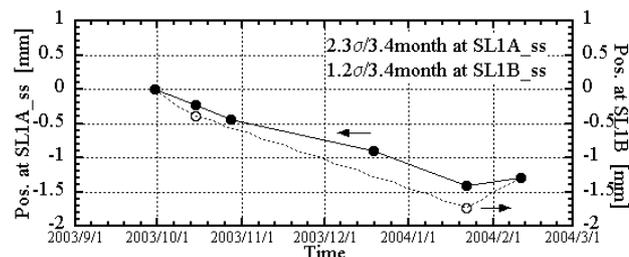
Figure 7: Long-term change in the position of the effective beam center at the scrapers. Closed and open circles indicate the changes at SL1A_ss and at SL1B_ss, respectively.

SUMMARY

We built a beam collimation system for the top-up operation. Injection efficiency was increased from 60 % to 81 % under a condition that all the insertion devices were closed to their minimum values. In the future plan, beam positions at the scrapers will be measured shot by shot using OTR. The data will be used to feedback the correction magnets in order to stabilize the beam orbit in the SSBT.

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