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BEAM LOSS REDUCTION DURING ENERGY RAMP-UP AT THE SAGA-LS

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Abstract

The accelerator of the SAGA Light Source (SAGA-LS) consists of a 255 MeV injector linac and a 1.4 GeV storage ring. The energy of the electrons is ramped up to 1.4 GeV in 4.5 minutes in the storage ring. The electron beam current stored in the storage ring is about 300 mA. At the begging of the energy ramp-up, the electron beam was lost like step function. To understand the beam loss mechanism, we developed simultaneous image logging system of beam profile in addition to the beam current, the magnets power supplies, and the beam positions using National Instruments PXI. It was found that the vertical beam size was growing in the step-like beam loss process. The small perturbation of the output currents of the quadrupole power supplies caused the vertical beam size growth. By optimizing the ramp-up pattern of the quadrupole power supplies, sextupole power supplies, and the steering power supplies for the orbit control, we have achieved the reduction of the step-like beam loss and total time of the ramp-up.

INTRODUCTION

The accelerator of the SAGA Light Source (SAGA-LS) consists of a 255 MeV injector linac and a 1.4 GeV storage ring [1, 2]. Figure 1 shows the schematic view of the SAGA-LS accelerator. There are two 4T super-conducting wigglers [3], a planar undulator, and an APPLE-II undulator in the storage ring. The maximum electron beam current of the storage ring is about 300 mA. The energy of the electrons is raised up to 1.4 GeV in 4.5 minutes in the storage ring. The two 4T super-conducting wigglers are excited after beam acceleration. In the early stage of beam acceleration (the beam energy is lower than 400 MeV), the electron beam is lost like step function. The amount of beam loss is normally about 5 mA to 30 mA. In rare cases, total loss of the beam may occur. Although there is no clear threshold of the beam current, such step-like beam loss does not occur less than 200 mA of the beam current. In order to provide stable user operation, it was necessary to investigate the loss mechanism and reduce the amount of the beam loss.

It is expected that investigating the relationship between the growth of beam sizes and beam loss will lead to the identification of the cause of beam loss, since the blow-up of the beam sizes and beam loss occur only at low energy and high beam current. Therefore, we developed simultaneous measurement system of the images of the beam profiles and output values of magnet power supplies, which can be the cause of beam profile changing and beam shapes during ramp-up, and we performed time-series analysis of the beam shape changing and the output values of magnet power supplies during beam loss using National Instruments PCI eXtension for Instrumentation (PXI) based measurement system. The optics analyses of the storage ring from the measurement values of the power supplies were also performed using beam tracking code TRACY2 [4].

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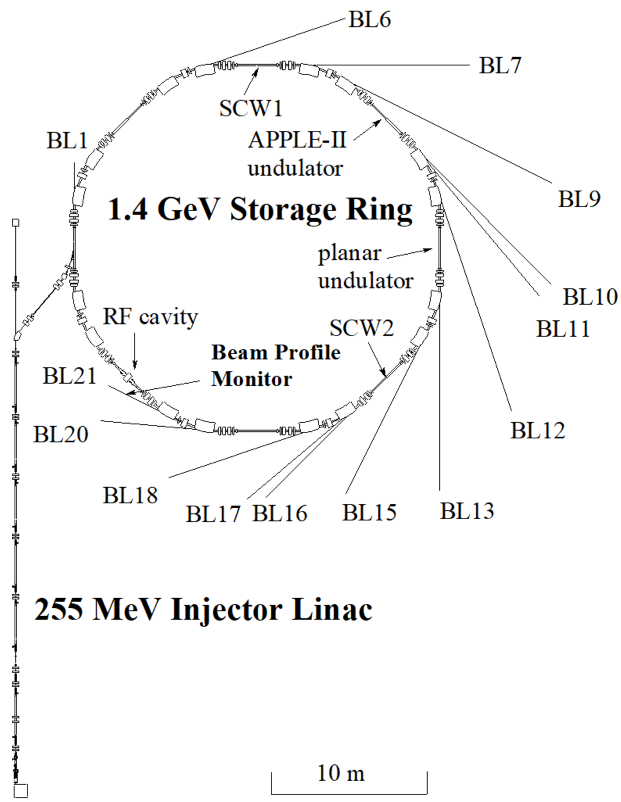

Figure 1: Schematic view of the SAGA-LS accelerator.

IMAGE AND DATA ACQUISITION SYSTEM

PC-based control system with the off-the-self remote I/O production, e.g., National Instruments Fieldpoint, YOKOGAWA PLC, are commonly adopted at the SAGA-LS accelerator [5]. The typical sampling rate of the monitoring system is from 0.5Hz to 2Hz. Originally, the beam loss occurred at the ramp-up was measured as a step like process by using this PC-based slow monitoring system. To analyse this phenomenon detail, we developed high-speed logging system of 250 kHz (PXIe-4300, 16bit ADC) for monitoring the beam current, beam positions, and output currents of the major power supplies of the storage ring magnets, using National Instruments PXI. In addition to acquiring these analogue parameters, image acquisition device (PXIe-1435, Frame Grabber) was set on this PXI system. Figure 2 shows the analogue data and image acquisition system for investigation of the beam loss. The typical sampling rate of the images is 60Hz. Beam profile images captured at accelerator beamline by CCD camera were translated to

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digital data via analogue digital convertor of STAC ACLD400. Images and measured data are displayed at remote PC in real time and the logged data with timestamp are saved on hard disk of the PXI controller.

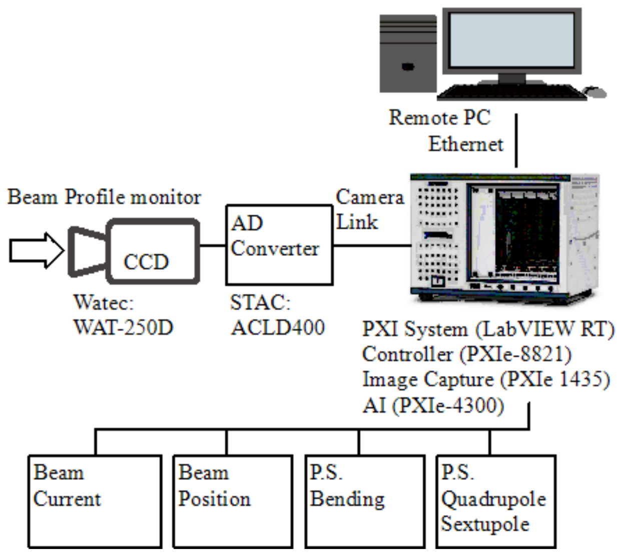

Figure 2: Image and Data acquisition system.

To calculate tunes and beta functions by using measured output values of the power supplies, orbit response matrix analysis method [6, 7] was adopted to estimate the effective K-value of quadrupole magnets. Beam tracking code of TRACY2 was implemented in the Labview based optics analyzation environment.

BEAM LOSS ANALYZATION

The beam current, output currents of the major power supplies (bend, all quadrupoles, and sextupoles), and beam positions were simultaneously measured with the beam profile by using PXI system. Figure 3 shows the beam loss and the output currents of the power supplies of QF1, QFW2, QDW2 during beam acceleration. The K-value of the quadrupole magnet should be constant to keep the betatron tunes at fixed values in the acceleration. As can be seen in Fig. 4, small perturbation of about 2% of QFW2 power supply was measured at the beam loss. On the other hand, the output currents of QF1 and QDW2 and another power supplies omitted from the figure didn't show such strange behaviours. In rate case, such small perturbation of QDW2 power supply was measured. Such perturbations were measured only at the beam acceleration, and the magnitude of the perturbation and the time occurrence changed with each trial. It was found that the at the beam loss the perturbation of output currents of both QFW2 or QDW2 power supplies were occurred.

Figure 4 shows the calculated beta functions derived from the measured value of the power supplies before and after the beam loss respectively, of which calculation were performed by using beam tracking code of TRACY2 and National Instruments LabVIEW. Figure 5 is the beam profile before and after the beam loss. The figures illustrating the beam shape in Fig. 5 below were obtained by noise removing and contour processing from the original images. The beta modulations and the vertical beam size growth induced by the small perturbation of the QFW2 power supply were confirmed.

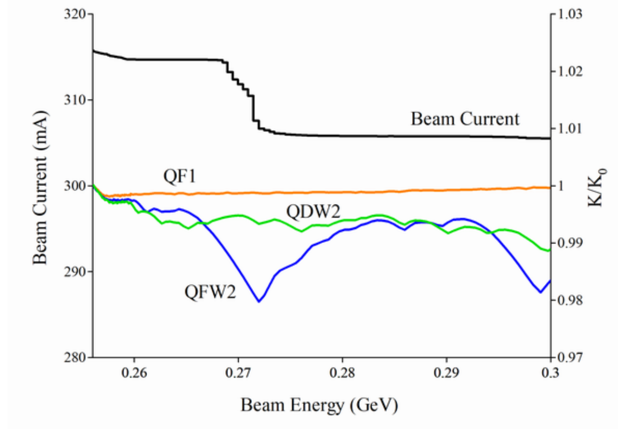

Figure 3: A case of beam loss and perturbation of the output current of QFW2 quadrupole power supply.

The vertical beam size of high beam current at the injection energy is more than 3 times larger than that of 1.4 GeV beam at the SAGA-LS storage ring, which is probably caused by ion trapping effect or another beam instabilities. Although the beta modulation and the beam size change were small, the beam size growth near injection energy would affect significant effect to the stored beam current. Because the vertical beam size will has increased to the limit. The beam loss would be a result of electrons exceeding the physical acceptance.

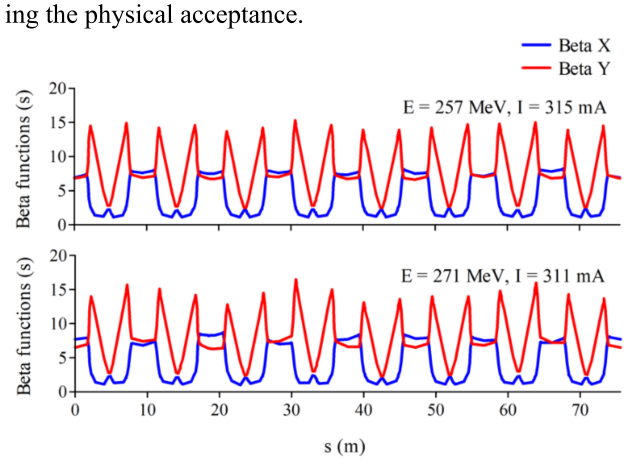

Figure 4: Beta functions before beam loss and at the beam loss.

RAMP PATTERN OPTIMIZAION

Since the perturbation of the power supplies occur at high-speed excitation, we built the ramp-up pattern of the power supplies as slow as possible near injection energy. In contrast, the effect of the perturbation of the power supplies is reducing as the beam energy is increasing, since the vertical beam size shrinks rapidly as the beam energy increasing. Therefore, the speed of the ramp-up pattern near 1.4 GeV was increased. Finally, the total ramp-up time has been reduced from 4.5 minutes to 1.5 minutes.

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For stable ramp-up, it is necessary not only to keep betatron tunes constant, but also to properly control chromaticities. The increasing dipole field during ramp-up gives rise to eddy currents in the vacuum chamber of bending magnet which produces a sextupole field. The sextupole strength generated by eddy currents in the rectangular vacuum chamber can be approximately written as [8]

$$\partial^2 B_y / \partial x^2 = 2\mu_0 \sigma_c \frac{h}{g} \frac{dB_y}{dt}$$

where g is the gap hight of the bending magnet, h is the thickness of the vacuum chamber, and the σ_c is the electrical conductivity. For the typical ramping speed of the bending magnet in the SAGA-LS storage ring, the maximum sextupole strength generated by the eddy current is about 0.123 m^{-3}, and the chromaticity change caused by the sextupole field are approximately $\Delta\xi_x \approx 0.067$ and $\Delta\xi_y \approx 0.512$ respectively, which gives not negligible effect to the storage beam at high beam current operation. Thus, the ramp-up pattern of the sextupole power supplies were determined by considering the eddy current effect. Furthermore, the power supplies of steering magnets were controlled to keep the beam orbit constant positions. Figure 6 indicates the histogram of beam loss amount during the beam acceleration before and after the ramp pattern optimization.

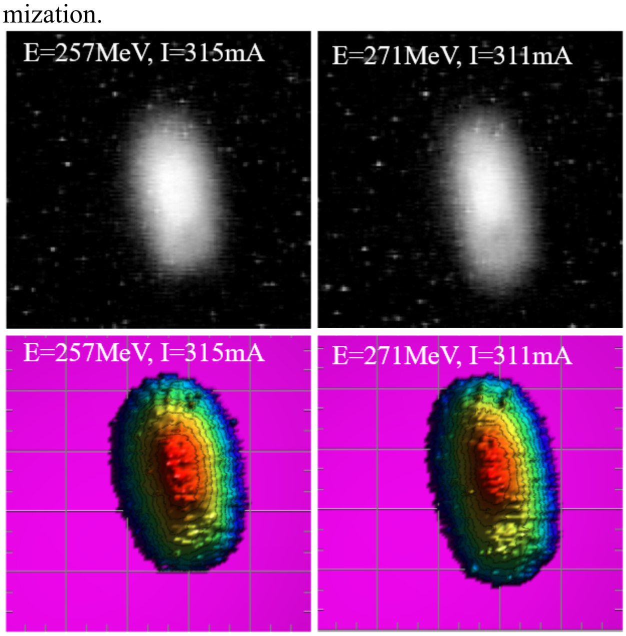

Figure 5: Beam profiles before beam loss and at the beam loss. Figures above are the original images, and the figures below are the images of which noise being removed and contour processed.

CONCLUSION

Small perturbation of the output current of quadrupole magnet power supplies were found at the moment of step-like beam loss during beam acceleration. The beta modulations and vertical beam size growth caused by the perturbation was measured by using PXI based image and data acquisition system. In addition to proper treatment of sextupole field caused by eddy current and beam position control, by optimizing the ramp pattern of the quadrupole power supplies, the amount of the beam loss was clearly reduced. The total ramp-up time has been reduced from 4.5 minutes to 1.5 minutes.

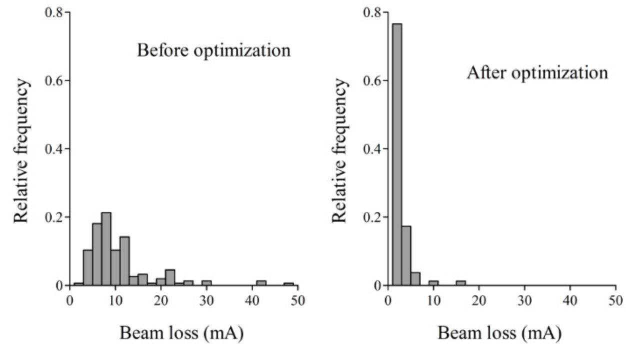

Figure 6: Histogram of beam loss during the beam acceleration.

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REFERENCES

[1] T. Tomimasu *et al.*, "The SAGA Synchrotron Light Source in 2003", in *Proc. Particle Accelerator Conf. (PAC'03)*, Portland, OR, USA, May 2003, pp. 902-904.

[2] Y. Iwasaki *et al.*, "Lattice Design of SAGA Synchrotron Light Source", in *Proc. Particle Accelerator Conf. (PAC'03)*, Portland, OR, USA, May 2003, pp. 3270-3272.

[3] S. Koda *et al.*, "Design of a Superconducting Wiggler for the SAGA Light Source Storage Ring", *IEEE Trans. Appl. Supercond.,* vol. 21, p. 32, 2011.

[4] H. Nishimura, "TRACY, A Tool for Accelerator Design and Analysis", in *Proc. European Particle Accelerator Conf. (EPAC'88)*, Rome, Italy, June 1988, pp. 803-805.

[5] H. Ohgaki *et al.*, "PC-LabVIEW Based Control System in SAGA-LS", in *Proc. Particle Accelerator Conf. (PAC'05)*, Knoxville, TN, USA, May 2005, pp. 3976-3978.

[6] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements", *Nucl. Instr. and Meth. A* vol. 388, pp. 27-36, 1997.

[7] Y. Iwasaki, "Analysis of the Orbit Response Matrix and Correction of Beta Function at the SAGA Light Source", in *Proc. Particle Accelerator Conf. (PAC'09)*, Vancouver, BC, Canada, May 2003, pp. 2291-2293.

[8] D. A. Edwards and M. J. Syphers, "An Intruduction to the Physics of High Energy Accelerators," John Wiley & Sons, New York, 1993, p. 113.