

UPDATE OF POWER SUPPLY CONTROL SYSTEM AT THE SAGA LIGHT SOURCE STORAGE RING

Y. Iwasaki[#], T. Kaneyasu, Y. Takabayashi, S. Koda, SAGA Light Source, Tosu, Japan

Abstract

The control system for the SAGA Light Source storage ring power supplies is being upgraded to increase the ramp-up speed and allow the stored beam energy to be easily changed. By replacing the CPU module in the PLC used to control the power supplies, the ramp-up time was reduced from 4 to 2 minutes in a test bench prepared for the upgraded system. Until now, the allowable beam energy has been restricted to certain fixed values during ramp-up operation due to the original specifications of the PLC ladder program. To operate the storage ring at an arbitrary energy, the algorithm used in the PLC program was changed. The resolution at which the energy can be changed is less than 1 MeV. The upper layer of the control system, which uses National Instrument LabVIEW and ActiveX CA, was also reconstructed to produce a flexible GUI. Preliminary measurements of the energy dependence of the beam size and lifetime were carried out using the updated control system.

INTRODUCTION

The SAGA Light Source (SAGA-LS) is a middle-scale synchrotron radiation facility, at which electrons from a 255 MeV injector linear accelerator are injected into a 1.4 GeV storage ring [1]. The electrons are ramped up to 1.4 GeV in the storage ring during a period of 4 minutes. The storage current is 300 mA. The storage ring lattice is a double-bend type with 8-fold symmetry (see Figure 1). The power supplies for the storage ring magnets are listed in Table 1.

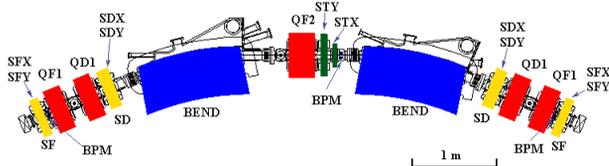


Figure 1: Unit cell of SAGA-LS storage ring.

The control system for the power supplies is constructed using personal computer (PC) and programmable logic controller (PLC) [2]. National Instruments LabVIEW is used for the graphical user interface (GUI). ActiveX CA [3], which provides EPICS channel access for Microsoft Windows, is adopted as the data communication protocol between server and client PCs.

Although the original control system worked stably, two problems existed with it. The first was the ramp-up speed. The ramp-up pattern file consists of 10,000 elements for each main power supply, and is stored in the internal register of a CUP module in the PLC. The ramp-up speed was limited by the performance of the CPU module. The second problem was a restricted accelerated beam energy. The allowable energy was fixed at certain values due to the original specifications of the PLC ladder program. We therefore replaced the CPU module: F3SP58-6S (YOKOGAWA Electric Corporation) with F3SP76-7S, and modified the algorithm of the ladder program slightly to allow arbitrary energy settings. The upper layer of the control system using LabVIEW and ActiveX CA was also reconstructed. Preliminary measurements of the energy dependence of the beam size and lifetime were performed using the updated control system.

In this paper, we describe the design of the control system for the power supplies at the SAGA-LS storage ring, the control algorithm and GUI, and the preliminary experimental results.

Table 1: Power Supplies for SAGA-LS Storage Ring Magnets

| Power Supply | Control Interface | Number |
|--------------|--------------------|--------|
| Bending | 16bit Digital | 1 |
| Quadrupole | 16bit Digital | 7 |
| Sextupole | 16bit Digital | 2 |
| BM-Corrector | Analogue , Digital | 16 |
| Q-Corrector | Analogue , Digital | 40 |
| Steering | Analogue , Digital | 80 |

CONTROL LAYER FOR POWER SUPPLIES

A schematic view of the control layer for the power supplies is shown in Figure 2. Local control of the power supplies is performed by PLC. The PLC consists of one CPU module, an Ethernet module, I/O modules, and optical link bus modules. One CPU module controls all the power supplies of the storage ring. Sub-modules of the PLC are connected to the main unit with optical link bus modules. At the SAGA-LS storage ring, synchronization among power supplies is important, since the electrons are ramped up from 255 MeV to 1.4 GeV in a short time. The PLC outputs 10,000 set points for each

[#]iwasaki@saga-ls.jp

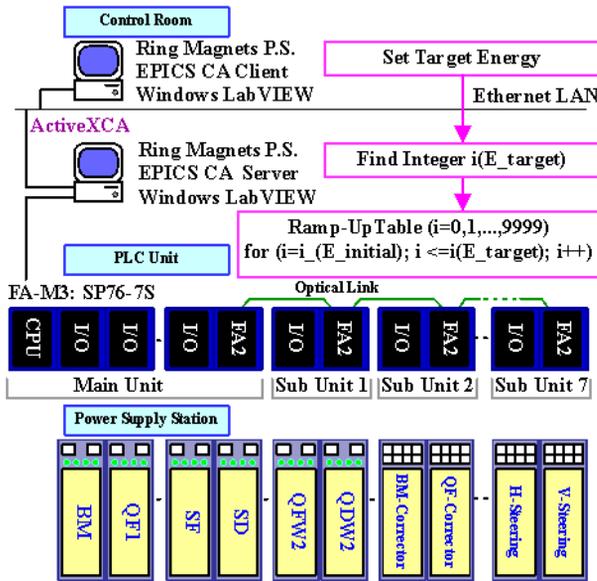


Figure 2: Control layer for power supplies.

of the main power supplies (bending and quadrupole magnets) during the ramp-up period. The configuration of the PLC (one CPU module, I/O devices, and optical linked sub-modules) ensures the synchronization among the power supplies.

Since the lattice of the storage ring is compact and the bending and quadrupole magnets are strongly excited (e.g., the maximum magnetic field produced by the bending magnet is 1.46 T and the maximum magnetic gradient in QF1 is 25 T/m), the ramp-up pattern for these power supplies is not linear. The sextupole and analogue controlled power supplies (BM-correctors, Q-correctors, and steering magnets) are excited in proportion to the QF2 power supply, because the magnetic field produced by the QF2 magnets, for which the maximum magnetic gradient is 18 T/m, increases in proportion to the excitation current. As a result, these magnets are excited linearly with the beam energy.

The server PC running ActiveX CA with the PLC acts as a PC IO controller (PC-IOC). The ActiveX CA client is used to access the server PC with the Process Values. The server and client applications are developed in LabVIEW.

In 2014, two new power supplies (QFW2 and QDW2) were installed for a second superconducting wiggler. The I/O and optical link bus modules for these power supplies were added to the existing PLC modules. An overview of the project for the second superconducting wiggler has been previously reported [4].

ALGORITHM AND GUI

The beam energy E in the storage ring is a function of the excitation electric current I in the bending magnet power supply,

$$E = f(I).$$

The function $f(I)$ is determined from magnetic field measurement data. The power supply current for the

bending magnets is determined by an integer i ($i = 0, 1, \dots, 9999$) stored in the internal register of the PLC,

$$I = g(i).$$

Thus, the beam energy is expressed in terms of i as

$$E = f\{g(i)\} \equiv E(i).$$

If the target beam energy E_{target} is given, then the integer

i_{target} is easily obtained as

$$i_{\text{target}} = E^{-1}(E_{\text{target}}).$$

Figure 3 shows the subroutine for finding i_{target} , which is estimated by linear interpolation of $E^{-1}(E_{\text{target}})$ and rounded off to the nearest whole number.

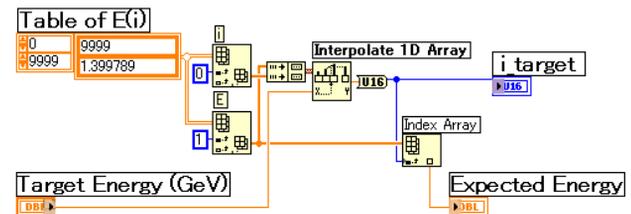


Figure 3: Subroutine for finding an integer for target energy (LabVIEW).

This calculation is performed in the server PC. When the button “Set Target Energy” is pushed on the client PC, the target energy value is sent to the server PC, which then calculates i_{target} and sends it to the PLC. During the ramp-up period, the PLC outputs the ramp-up pattern data for each main power supply from i_{initial} to i_{target} (see Figures 2 and 4). The accelerated beam energy can be easily changed using this PLC and PC based control system.

Because the ramp-up pattern consists of 10,000 set points for each main magnet for energies between 255 MeV to 1.4 GeV, the resulting energy resolution is less than 1 MeV. However, the absolute accuracy of the beam energy depends on both the precision with which the magnetic field produced by the bending magnets can be

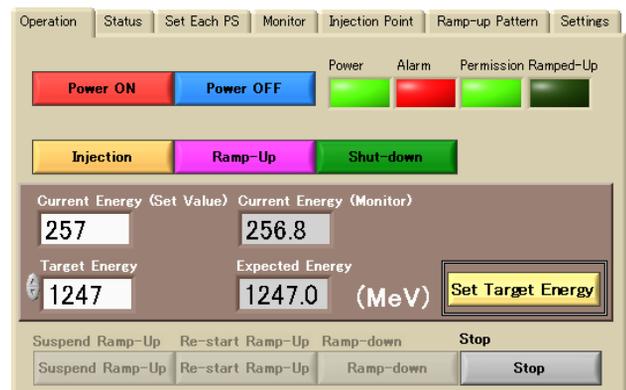


Figure 4: GUI of energy ramp-up client PC.

measured and the form of the function f in the formula $E = f(I)$. In addition, the stability and the setting precision of the bending magnet power supply influences the beam energy. The absolute energy should be calibrated using another method. At a nominal beam energy of 1.4 GeV, the actual energy was estimated to be 1417 ± 4 MeV by a laser Compton scattering experiment [5].

PRELIMINARY ENERGY DEPENDENCE EXPERIMENTS

Preliminary measurements of the energy dependence of the beam size were carried out using the synchrotron radiation (SR) interferometer system [6]. Figure 5 shows the transverse beam size for injection energies of 255 MeV to maximum energy of 1.4 GeV. Since the SR interferometer system was optimized to measure the beam size at 1.4 GeV, the results indicating horizontal and vertical beam sizes of greater than 800 and 1000 μm , respectively, are unreliable.

At the same time, the beam lifetime was measured. The product of the beam current and lifetime is shown in Figure 6. The peak at an energy of about 0.6 GeV may be

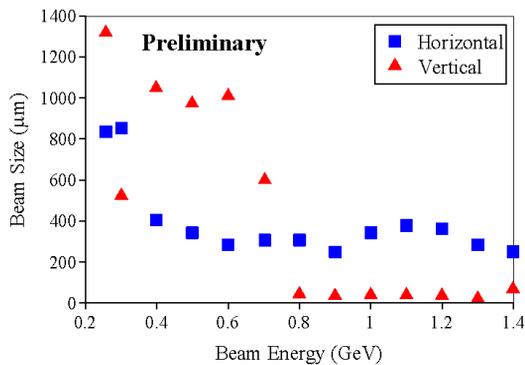


Figure 5: Dependence of transverse beam size on energy from 255 MeV to 1.4 GeV.

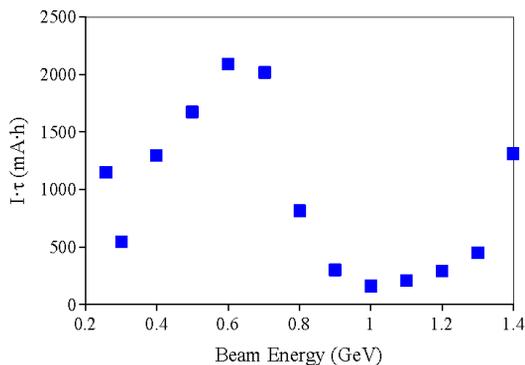


Figure 6: Energy dependence of product of beam current and beam lifetime.

related to the increase in the vertical beam size. Since the betatron tunes strongly vary during the ramp-up period (i.e., horizontal: 0.13, vertical: 0.11) at the SAGA-LS storage ring, quantitative estimation of the beam lifetime should take into account the optical modulation at each energy. Detailed measurements and quantitative estimations of the energy dependence of the beam size and lifetime have not been performed yet. However, energy-dependent experiments can be easily carried out using the updated power supply control system. In addition, we plan to investigate the beam energy dependence of ion trapping and intra-beam scattering (IBS) effects using this system.

SUMMARY

In order to increase the ramp-up speed of the SAGA-LS storage ring, we replaced the CPU module in the PLC. The ramp-up time was reduced from 4 to 2 minutes in a test bench prepared for the upgraded system.

The algorithm and the GUI for the control system were also modified to change the operating energy of the storage ring. The resulting energy resolution was less than 1 MeV. The accelerated beam energy can be easily changed using this PLC and PC based system.

Preliminary measurements of the energy dependence of the beam size and beam lifetime were carried out using the updated control system. The observed lifetime peak at about 0.6 GeV may be related to an increase in the vertical beam size. In a future study, we will investigate the beam energy dependence of ion trapping and IBS effects at the SAGA-LS storage ring.

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