UPGRADE PROJECT ON TOP-OFF OPERATION FOR HEFEI LIGHT SOURCE*

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Abstract

Hefei Light Source has successfully finished a major upgrade project and has been officially opened to users since January 2015. The upgrade project mainly includes increasing the linac injector energy from 200 MeV to 800 MeV which is the same as the ring energy, changing the ring lattice structure from TBA to DBA in order to provide more straight sections for insertion devices while keeping the circumference unchanged, and lowering the beam emittance to obtain higher photon brightness. Before the upgrade project, decay mode is the only choice for the operation of Hefei Light Source.This is because the injected beam from the linac injector needs to be ramped up to 800 MeV after injection. At prensent we have the conditions to operate Hefei Light Source with top-off mode since the linac can perform full-energy and bunch-by-bunch injection. The main challenge for the top-off operation is to control the radiation dose for personal and equipment safety, and to maintain high stability and reliability of the injector. In this paper, we report our work on the top-off operation project for Hefei Light Source.

INTRODUCTION

Hefei Light Source (HLS) has undergone a massive upgrade which greatly improves its performance and started user operation in 2015 [1]. The main parameters of HLS and HLS-II storage rings are compared in Table 1. While remaining the same circumference, the lattice type is changed from TBA to DBA in order to provide more straight sections for insertion devices. The HLS storage ring has 4 straight sections, among which only 2 can be used for insertion devices and 2 are reserved for injection and RF cavity. The HLS-II storage ring has 8 straight sections and 6 straight sections can be used for IDs. In the HLS-II storage ring, there are 32 sets of correctors which are combined with the 32 sextupoles in order to save installation space for the straight sections. Those correctors together with 32 sets of beam position monitors (BPMs) are used to build the orbit feedback system of the HLS-II storage ring [2]. A state-of-the-art digital bunch-by-bunch feedback system is installed in order to stabilize the beam both longitudinally and transversely through suppressing the coupled-bunch instabilities [3]. A 4th harmonic cavity is also installed to the HLS-II storage ring to lengthen the electron bunch in order to obtain a higher beam life time [4]. The higher harmonic cavity also acts as a longitudinal Landau damping cavity which can help mitigating beam collective effects.

Table 1: Main Parameters of HLS and HLS-II Storage Ring

Parameter	HLS	HLS-II
Beam energy (MeV)	800	800
Circumference (m)	66.13	66.13
RF frequency (MHz)	204	204
Harmonic number	45	45
Beam current (mA)	250	>300
Magnet lattice	TBA	DBA
Beam emittance (nm·rad)	160	38
No. of straight sections	4	8
Injector energy (MeV)	200	800

These upgrades have greatly improved the light source performance, yet the operation mode still remains as usual—the decay mode. The former injector is a linac with an energy of 200 MeV and therefore the electron beam needs to be ramped up to 800 MeV before user operation. In that case, the decay operation mode is the only choice. After the upgrade project, the energy of the linac injector is raised up to the same as the storage ring. What is more, the bunch length of the linac is only 1 ns which provides bunch-by-bunch injection capability. Based upon the upgrade of the linac injector, we are able to operate Hefei light source with top-off mode.

TOP-OFF OPERATION MODE VERSUS DECAY MODE

Decay mode refers to operating the light source with decay of the beam current. When beam current decays to some degree, the injection is resumed. For radiation safety reason, the experimental hall needs to be evacuated during injection, therefore user experiments usually have to be suspended. Top-off operation aims at delivering quasi-constant photon flux to beamlines with quasi-constant beam current. This operation mode requires injecting while user experiments keep going with photon shutters open. The difference between top-off operation and decay operation is illustrated in Fig. 1. The top-off injection mode was first put into operation at Advanced Photon Source (APS) in 1998 [5], and Swiss Light Source (SLS) is the first one which is designed to be operated with top-off mode in 2001 [6]. Top-off operation can greatly improve the flux stability of the photon beam

* Work supported by Fundamental Research Funds for the Central Universities of China (WK2310000048) and Maintenance and Upgrade Projects for Large-scale Scientific Facilities of CAS.
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ISBN 978-3-95450-182-3

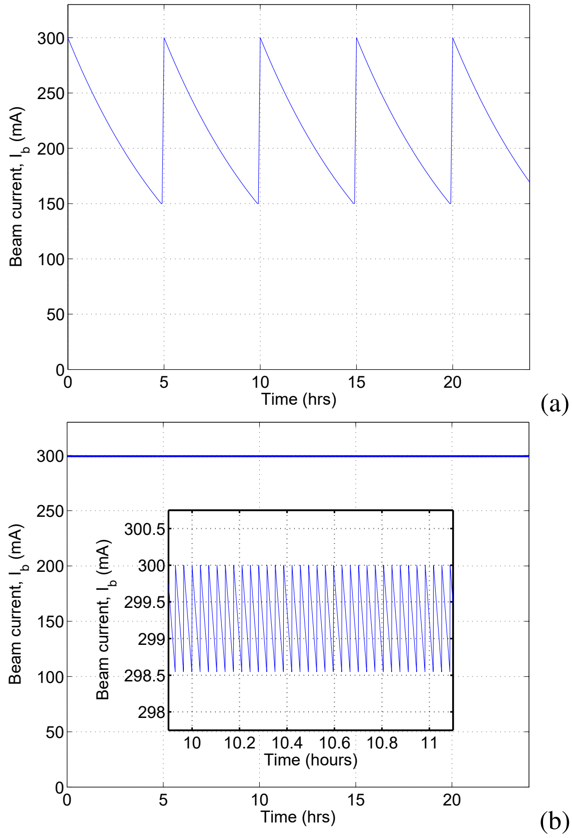

Figure 1: Decay operation v.s. top-off operation. Comparing with decay mode, top-off mode can provide more integrated beam current (i.e., beam lifetime) and more constant photon flux.

because of the constant heat load on the beamline optics. It also reduces the machine drifts due to the constant beam current, which can eliminate current dependent effects of beam diagnostics such as the ring BPMs. As a result, top-off operation becomes a standard operation mode for modern synchrotron light sources.

IMPROVEMENT OF RADIATION SAFETY

The most important thing for top-off operation is to keep the radiation dose level in a safety range so as to protect the personnel and equipment. Therefore it is critical to optimize the radiation monitoring system and lower the dose level as much as possible.

Radiation Monitoring System

The radiation monitoring system for the HLS-II experimental hall is comprised of 11 sets of dosimeters including gamma and neutron detectors. The dose data are sampled from the dosimeters and saved to a data server through Windows Labview. This system does not have enough reliability to provide interlock signal to the safety protection system. Another problem is that this system cannot easily share data with the light source control system which is based on Experimental Physics and Industrial Control System (EPICS). We

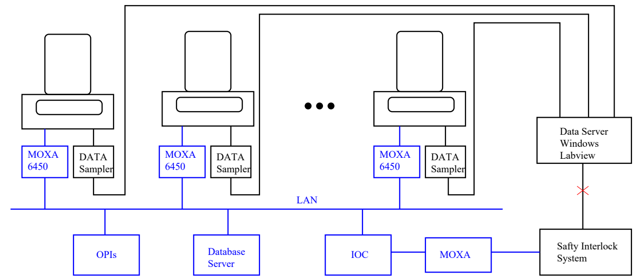

Figure 2: Development of a new radiation monitoring system. Different from the present one, the new system is based on EPICS, which is more reliable and is much easier to share the dose rate data.

plan to develop a new data acquisition and storage system for dose rate monitoring based on EPICS, shown in Fig. 2. The dosimeters are connected to local area network (LAN) through secure terminal severs. Dose data are acquired via EPICS input/output controller (IOC) and saved to the HLS database server for sharing.The real-time radiation dose rate measured by the dectors are monitored by an extensible display manager (EDM) based control panel, which can run on any operator interface (OPI) computer in the control network. . The new system can also provide reliable interlock signal to the safety protection system.

Radiation Dose Control

For top-off operation, the most concerned safety issue may be whether the injected electrons can exit the beamlines, causing a radiation hazard. Fortunately careful analytical and tracking studies show that the injected electrons cannot been extracted to beamlines while the stored beam survives [7, 8]. Therefor the safety interlock can be simplified as this: top-off injection only takes place when there is stored beam in the storage ring if the photon shutters are open. During top-off injection, the in-vacuum undulator (IVU) may be close with a small gap as the user experiment continues. Therefore the injected electrons may loss on the IVU magnets, inducing strong radiation dose which could lead to demagnetization of the undulator. The available physical aperture of the HLS-II storage ring is plotted in Fig. 3. The green horizontal line in y-direction shows the minimum aperture along the whole ring, where the IVU is located. The green vertical lines show the location of the scrapper. By adjusting the scrapper gap, we can limit the possible trajectories of the injected electrons which may hit the IVU. However a small scrapper gap may reduce the beam life time and injection efficiency. Simulation and experimental studies need to be carried out to optimize its performance.

INJECTION CONTROLS

The linac injector produces a single bunch with a length of 1ns and a maximum charge of 1 nC at 1 Hz. With optimized timing and injection system, the upgraded linac is capable of performing bunch-by-bunch injection, which makes top-off operation possible for HLS-II. The injection control logic

ISBN 978-3-95450-182-3

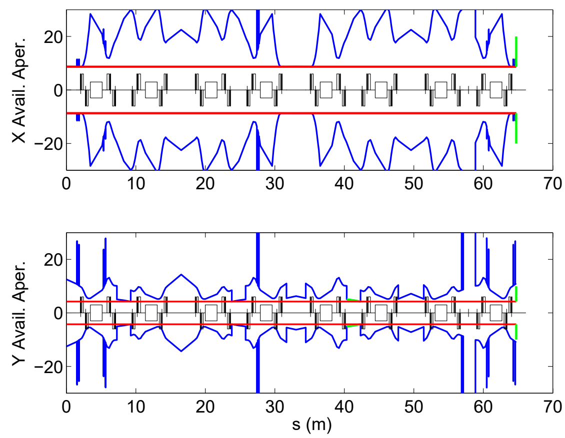

Figure 3: Available physical aperture of the HLS-II storage ring. A scrapper is installed during its upgrade, which can be used to protect the IVU from being demagnetized by the injected electrons.

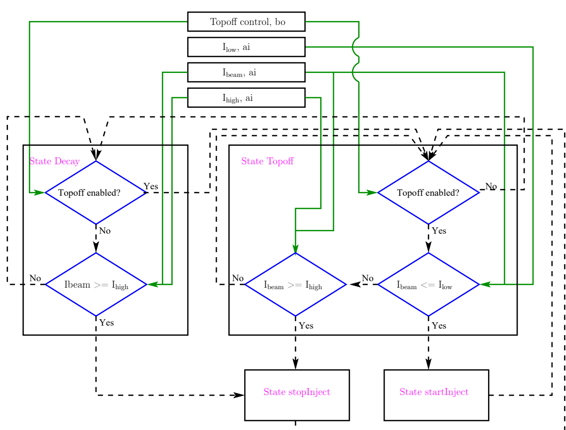

Figure 4: Control logic of top-off injection for HLS-II.

needs to be carefully designed. A sequencer, written using notation language, runs in an IOC to switch between top-off and decay mode and to control injection procedures based on a number of criteria as shown in Fig. 4.To ensure the top-off safety, we need to keep the injection efficiency at a high level. A scraper is installed at the end of the injector transport line to maintain good energy stability for the injected beam. During injection, the injected beam always goes to the bucket which has the lowest bunch current, so as to maintain a uniform beam distribution.

INJECTOR STABILITY AND RELIABILITY

The HLS-II injector is a linac with 8 accelerating structures which can energize electron beam to 800 MeV. To increase the injector reliability, we plan to insert one more accelerating structure as a standby which can substitute the failure one in a short time. The energy stability and energy spread is mainly determined by the klystron amplitude and phase. The measurement shows that some solid-state amplifiers cannot supply sufficient input powers to drive the

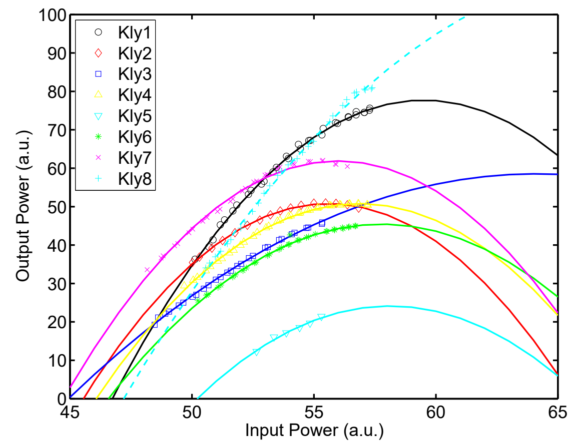

Figure 5: Input drive power and output power of the 8 klystrons of the injector linac.

klystrons to saturated output (see Fig. 5). Power amplifiers with higher output power are needed to stabilize the klystron amplitude. We also adopt digital low-level Radio Frequency (LLRF) controllers to overcome noise perturbation of the amplifier outputs for maintaining a good phase stability of the klystrons.

SUMMARY

In this paper, we present a project on upgrading Hefei Light Source to top-off operation mode instead of present decay mode. To ensure top-off safety, the radiation monitoring system are optimized and a scrapper will be used to avoid the IVU from being demagnetized by the injected beam. The injection control is carefully designed which can switch between top-off and decay mode and keep a designated filling pattern. Measures are also taken to improve the injector stability and reliability so as to reduce machine down time and to obtain a high injection efficiency.

ACKNOWLEDGMENT

The authors would like to thank all scientists and engineers at NSRL for their hard work on the top-off project. We are also grateful to the operators who help us preparing for our machine study.

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