COMMISSIONING AND OPERATION OF WIGGLER SWITCHYARD SYSTEM FOR DUKE FEL AND HIGS *

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Abstract

To enable the Duke storage ring FEL to operate in VUV with adequate gain, a major storage ring upgrade was carried out in 2012 to install two additional helical FEL wigglers with a wiggler switchyard system. Using the switchyard, a quick changeover can be made between two planar OK-4 wigglers and two helical OK-5 wigglers in the middle of the FEL straight section. This system preserves the linear polarization capabilities of the Duke FEL and High Intensity Gamma-ray Source (HIGS), while enabling VUV FEL operation with a higher gain using a longer FEL with up to four helical wigglers. The switchyard upgrade was completed in Summer 2012, followed by a rapid and successful commissioning of the Duke storage ring, FEL system, and HIGS. In this paper, we describe the development of the wiggler switchyard, its installation and commissioning, and its impact on the research program at the HIGS.

INTRODUCTION

The High Intensity Gamma-ray Source (HIGS) [1] is a premier nuclear physics research facility at Duke University. Driven by the Duke storage ring Free-Electron Laser (FEL) [2], an intense, nearly monochromatic Compton gamma-ray beam has been produced with variable polarization in a wide energy range from 1 to 100 MeV.

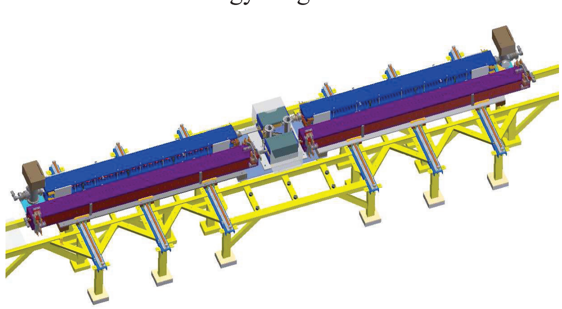

Figure 1: The wiggler switchyard in the middle of the FEL straight section. Electrons travel from the left to the right.

To extend the HIGS operation first above 100 MeV and then above 150 MeV (beyond the pion-threshold energy), a longer FEL system with up to four helical OK-5 wigglers is required to increase the FEL gain for VUV lasing below 200 nm with substantial FEL cavity losses. To preserve the HIGS user capabilities with linear polarization associated with the planar OK-4 FEL, a wiggler switchyard system has been developed to allow the use of two OK-4 wigglers or to bring two more helical OK-5 wigglers into the middle of the FEL section, in addition to two existing OK-5 wigglers [3]. The wiggler switchyard is the most cost-effective solution to extend the HIGS energy range with four OK-5 wigglers by employing the existing FEL straight section and FEL cavity system, and using the existing gamma-ray beamline and downstream target rooms for nuclear physics experiments. More information about the accelerator physics and light source research at the Duke FEL lab can be found in [4].

WIGGLER SWITCHYARD PROJECT

The FEL wiggler switchyard is designed to switch between two OK-4 planar wigglers and two OK-5 helical wigglers. With this system, the Duke FEL and HIGS can be operated in two different configurations (see Fig. 1): (1) the mixed wiggler configuration of two planar OK-4 wigglers and two helical OK-5 wigglers; and (2) the helical wiggler only configuration with four OK-5 wigglers.

In the mixed wiggler configuration, two OK-4 wigglers are brought to the middle of the FEL straight section. In this case, the setup of FEL wigglers is practically identical to that before installing the switchyard, with small changes of the location of the quadrupoles adjacent to the OK-4 wigglers. Using these wigglers with different polarizations, the switchyard preserves all existing gamma-beam capabilities before the switchyard upgrade – the production of high intensity gamma beams with either linear or circular polarization below 65 MeV.

In the four OK-5 wiggler configuration, two additional OK-5 wigglers are brought to the middle of the FEL straight section to replace the OK-4 wigglers. In this configuration, the OK-5 FEL can be operated with different numbers of wigglers. For example, for FEL operation at 240 nm or 190 nm, two middle wigglers can be used. To produce gamma-rays in the energy range of 100 to 150 MeV, the first three or all four OK-5 wigglers can be used to produce FEL lasing at 175 nm, or as short as 150 nm.

Project Milestones

The FEL wiggler switchyard was first proposed around 2004 as an incremental upgrade of the HIGS accelerator facility to produce higher energy gamma-ray beams. While a preliminary design of the system was developed from

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2006 to 2007, a change of funding sources, and the consequent need to operate the HIGS facility extensively for nuclear physics research put the project on hold for several years. The project was restarted in 2010 in order to meet the demand of nuclear physics experiments to have gamma-ray beams at higher energies. By realigning efforts in the lab in Fall 2010, we were able to move the project forward in parallel with the user operation, overcoming a number of challenges, including very limited personnel resources. The switchyard system was successfully commissioned in June 2012. The timelines and major milestones of this project are summarized in Table 1.

Table 1: Timelines for the Wiggler Switchyard Project

Timelines	Milestones
2004 – 2005	Physics concept
2006 – 2007	Preliminary mechanical design
Aug. 2010 – Feb. 2012	Magnetic lattice design Design of mechanical, vacuum and electrical systems Fabrication, assembly, testing
Feb. 27 – Jun. 7, 2012	Wiggler switchyard installation
Jun. 8, 2012	Acc. equipment power-up and injector system recommissioning
Jun. 14, 2012	Storage ring commissioned with stored electron beam
Jun. 18, – Aug. 24, 2012	Vacuum scrubbing, FEL mirror tests, and short shutdowns for facility upgrades
Aug. 16, 2012	HIGS user test run
Aug. 27, 2012	HIGS user operation resumed

Magnetic Lattice

The magnetic lattice of the Duke storage ring was designed and optimized to achieve a high level of performance, including flexibility in lattice tuning and a large dynamic aperture using effective nonlinear compensation schemes [5]. The wiggler switchyard lattice maintains the high performance of the storage ring, while realizing a higher level of flexibility necessary to operate the storage ring with a number of different configurations of FEL wigglers. To make this possible, the magnetic lattice outside the FEL straight section is kept unchanged, while the FEL straight is redesigned to accommodate various FEL wigglers. In this design, important characteristics of the lattice, including the tune work point, injection scheme, orbit compensation, and nonlinear dynamics compensation scheme, are preserved to help reduce the effort for the lattice design and storage ring commissioning [6].

Overall, a total of seven magnetic lattices of the FEL straight section were developed with built-in betatron compensation schemes and betatron tune knobs. In Fig. 2, two magnetic lattices are shown, one with two OK-4 wigglers, and the other with two OK-5 wigglers for FEL lasing at 450 nm with a 500 MeV electron beam.

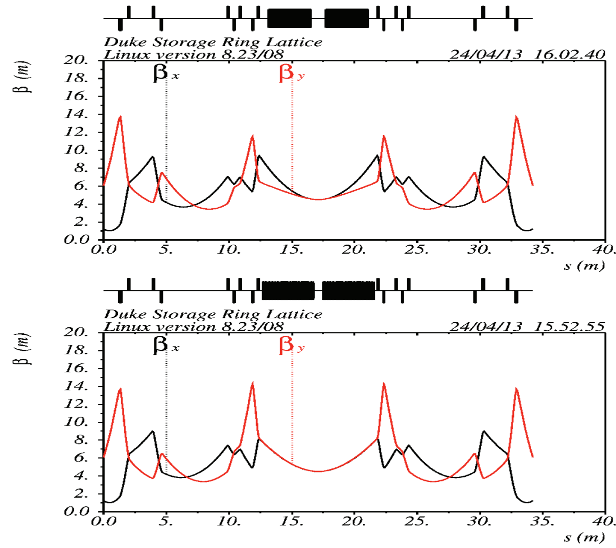

Figure 2: FEL straight section lattices with two different FEL wiggler configurations. Upper: with two planar OK-4 wigglers. Lower: with two helical OK-5 wigglers. In both cases, the central wavelength of the wigglers is set to be 450 nm with a 500 MeV electron beam.

Switchyard Design and Development

The wiggler switchyard system is developed with several important features. First, using a special rolling slide system, the wiggler platform can be rolled smoothly in the horizontal plane and then parked at designated locations with high precision. Second, the same set of magnets and beam diagnostics are used in the straight section for the operation of either wiggler system. Third, several designated vacuum valves are used to isolate various sections of the vacuum system. To enable rapid vacuum recovery, during the switchover, only part of the vacuum chambers in the FEL straight section are exposed to dry nitrogen for a short duration (an hour or so). The switchyard is developed and optimized to minimize the time for wiggler switching and for the subsequent vacuum recovery in the storage ring.

Switchyard Installation

The final design of the wiggler switchyard was completed in late Fall, 2011. During the same period, mechanical components were procured, fabricated, and tested. New vacuum chambers were welded, assembled, and processed for use in ultra-high vacuum (UHV). The shutdown for the wiggler switchyard upgrade started on February 27, 2012, and the installation of the switchyard went smoothly and was finished ahead of schedule. Over the next three and half months, we carried out the following major tasks for the project: (1) dismantling the old 15 m long OK-4 beamline, including two OK-4 wigglers, a number of quadrupoles and correctors, and modifying cooling-water and electrical infrastructure; (2) installing new strongback supports with a series of linear sliding tracks topped by a wiggler platform; (3) installing and aligning two OK-4 wigglers, two OK-5 wigglers, and two buncher magnets on the sliding platform; (4) installing and aligning adjacent quadrupole magnets, and restoring cooling water to all magnets; (5) installing new vacuum chambers and connecting these with the existing storage ring chambers; and (6) connecting power bus bars to OK-5 and OK-4 wigglers and cables to various magnets.

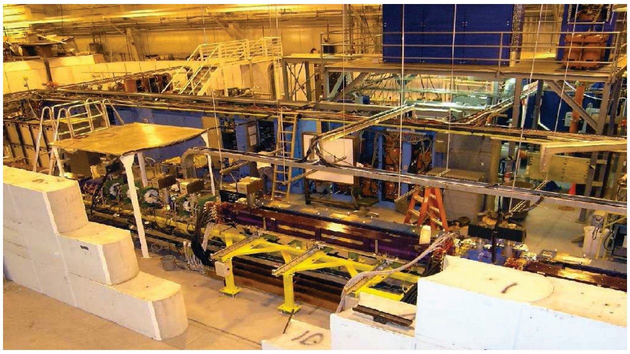

Figure 3: A picture of the completed wiggler switchyard system in June, 2012 before restoring the shielding wall.

Switchyard Commissioning

With two additional OK-5 wigglers installed (see Fig. 3), the main equipment of the storage ring was first powered up on June 8, 2012, followed by restarting and testing the linac pre-injector and booster injector. On June 14, 2012, we started to commission the storage ring with the switchyard. This went extremely smoothly and the first electron beam was stored in the storage ring (see Fig. 4) in just a few hours after the first injection.

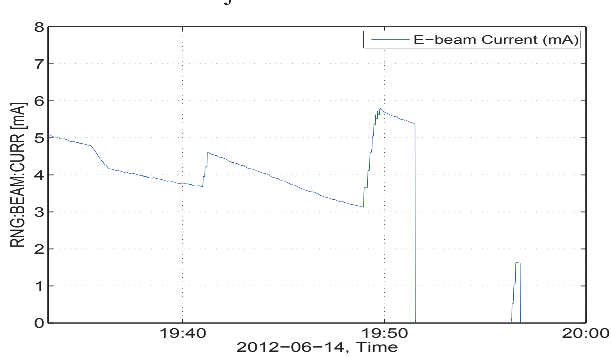

Figure 4: The electron beam current in the Duke storage ring during the first day of commissioning the wiggler switchyard on June 14, 2012.

The vacuum in the center of the FEL straight section, (including two new OK-5 chambers and a new chamber for the buncher magnet), was poor initially due to chamber outgassing, especially under the illumination of intense off-axis wiggler radiation. Following the initial commissioning, from mid June to mid September, 2012, substantial time was devoted to vacuum scrubbing/conditioning by operating a multiple-bunch beam at 1 GeV with the beam current raised gradually to 200 mA. The magnetic field in the OK-5 wigglers was varied systematically to allow wiggler radiation to illuminate different parts of the vacuum chambers. In early June after about two weeks of vacuum scrubbing, the vacuum recovered enough to start a program to test and condition a number of new FEL mirrors. The first gamma-beam production was a test run to produce an 80 MeV beam using a set of new 193 nm mirrors on July 18. On August 16, a gamma-ray beam was produced for a test experiment to calibrate new detectors. Following this, on August 24, routine gamma-ray beam production was established to allow the resumption of the HIGS user program.

IMPACT TO HIGS USER PROGRAM

Since June 2012, the switchyard has been used three times, and a summary of these wiggler switch events is provided in Table 2. Following the first two wiggler switches, substantial vacuum scrubbing was needed in order to condition the new vacuum chambers. In April, 2013, the wiggler switch was carried out for the third time, but without a need for extensive vacuum conditioning afterward. With this experience, it is projected that wiggler configurations can be switched in about 5 to 6 working days in the future.

Table 2: Recent Wiggler Switch Events with the Switchyard

Dates	Change of Wigglers	Vacuum Recovery
Jul. 20 - 27, 2012	OK-5 to OK-4	4 weeks
Jan. 8 - 10, 2013	OK-4 to OK-5	3 weeks
Apr. 8 - 9, 2013	OK-5 to OK-4	4 days

In February and March, 2013, the switchyard enabled the production of a high intensity, circularly polarized gamma-ray beam at about 87 MeV for the first experiments in the nuclear Compton scattering program at the HIGS.

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