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A PRELIMINARY REPORT FROM LOUISIANA STATE UNIVERSITY CAMD STORAGE RING OPERATING WITH AN 11 POLE 7.5 TESLA WIGGLER

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Abstract

Louisiana State University installed a 7.5 T superconducting wiggler in May 2013 on the electron storage ring located at the Bennett Johnson, Sr. Center for Advanced Microstructures and Devices (CAMD). The wiggler's influence on betatron tunes and functions, orbit, lifetime, performance, and other relevant beam parameters are described. We further comment on device operations and modifications to ring operations that were necessary to provide light for both wiggler and dipole stations.

INTRODUCTION

Louisiana State University (LSU) operates the CAMD light source at the Center for Advanced Microstructures and Devices. This electron storage ring has been delivering synchrotron radiation (SR) regularly since 1992. The working energy of the storage ring is 1.3 GeV, and injection energy is approximately 180 MeV. CAMD has a circumference of 55.2 meters. There are 4 dispersion free straights and 8 dipoles operating at 1.48 Tesla. Each dipole chamber has two ports delivering SR with a critical photon energy of 1.6 keV. A 7 Tesla superconducting wavelength shifter installed in straight section 2 increased this critical photon wavelength to 7.95 keV for three x-ray beamlines. In 2007, a proposal was made to increase the amount of x-ray radiation being delivered to protein crystallography, x-ray absorption spectroscopy, and tomography experiment stations [1]. In May 2013, a 7.5 Tesla 11-pole multipole wiggler (MPW) with 4 additional fractional field poles was installed in CAMD's third straight section. This device has been delivering light routinely at 5.5 Tesla since October 2014.

The device was built by N. Mezentsev's group at Budker Institute for Nuclear Physics (BINP). Overall the layout is similar in design to SIBERIA-2's superconducting multipole wiggler. However, in terms of physical dimension and stored energy this device is the largest ever fabricated by BINP [2].

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GENERAL MPW PARAMETERS

The CAMD MPW supplies 3 x-ray beamlines with a critical photon wavelength of 8.53 keV. The 11 main poles are used to generate SR While the two twin outer poles control trajectory by introducing ¼ and ¾ field. Basic parameters are listed in the Table 1.

Table 1: General Parameters

Parameter	Value
Poles	11 full; 2 ¾ field pole; 2 ¼ field pole
Peak Field	7.5 Tesla
Wiggler Pole Period	193.4 mm
Pole Gap	25.2 mm
Beam Aperture	15 mm by 80 mm
Physical Length (Magnet)	1594 mm
Field Energy Stored	≈ 850 kJ
Power Output at 7.5 T	7.38 kW at 100 mA
Superconducting Currents	205 A (central coils), 143 A (side coils)

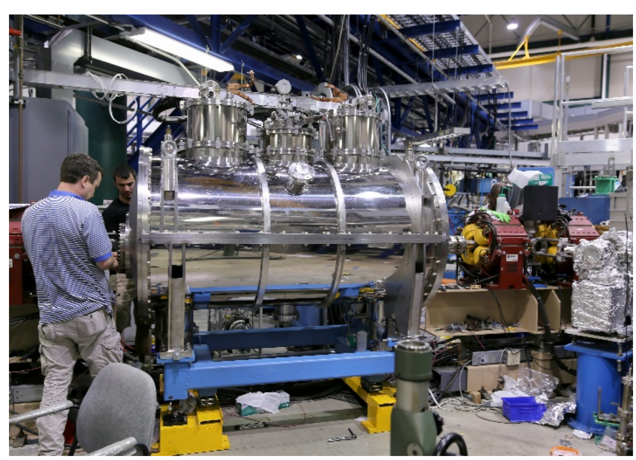

Figure 1: The MPW installed on the CAMD ring.

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Following the installation of the MPW, impacts to the stored beam were recorded. The most significant are shown below in Table 2.

Table 2: Wiggler's Influence on Ring

Parameter	**Value**
Betatron Tune Shift	+ 0.083 (vertical), - 0.004 (horizontal)
Injected Current	>250 mA (prior to install) 150 mA (post install)
RF Drive Voltage (using 1 of 2 RF drives)	319 kV @ 1.3 GeV 466 kV with MPW 5.5 T
Radiation Loss	73.76 keV
Momentum Compaction	0.0334 (estimated)

FACTORY TESTING

The Budker built MPW was originally scheduled to be delivered in January 2012. However, a series of complications resulted in delayed delivery. This delay allowed SIBERIA-2's design update to be implemented to CAMD's MPW. In 2013, a fully functional MPW was transported to LSU CAMD and assembled by BINP personnel. Initial tests to reach 7.5 Tesla were not conducted until the MPW was installed into the CAMD ring in straight 3.

The first tests trained the magnet and demonstrated the device's ability to reach 7.5 Tesla, the operating point. This level was achieved following several training quenches. Liquid helium (LHe) consumption following site acceptance testing has been recorded to be near zero for all magnetic field excitations and durations. We should point out that the MPW experienced a small number of magnetic field crashes from high field levels without impacting the LHe level.

During the factory acceptance tests, 1st magnetic field integrals were zeroed using two Danfysik 883's power supplies that feed the ¼ field (side) coils and the ¾ field (central) coil sets. These settings were determined under static conditions. Both unipolar supplies operate in a free running mode with respect to each other. The Figure 2 depict the power supply ramping profile. The 2nd magnetic field integral was measured and determined to be within tolerance.

It should be noted that the supplies had communication issues resulting in real current drops during positive and negative ramping. This is critical since the CAMD MPW begins operation at zero field and ramps to operating conditions. The accelerator group repaired the problem by changing communication protocols yielding a smooth ramp.

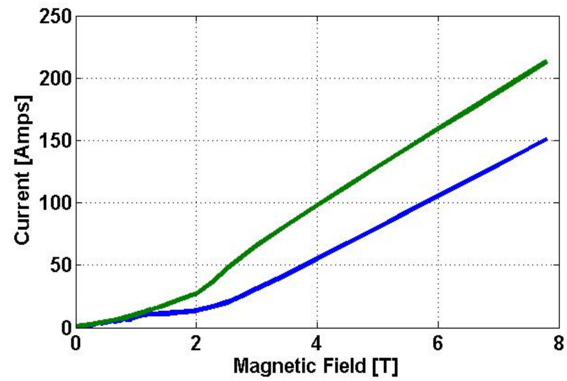

Figure 2: MPW Currents.
Green = Central; Blue = Side

MPW COMMISSIONING

Several hurdles needed to be cleared before standard operations could commence. These issues fell into the categories of vacuum and cryogenics performance, beam orbit compensation, tunes, power supply failures, and the new lattice optics effect on injection and high energy beam.

Hardware Modification

To successfully install the MPW, new sections of vacuum hardware were installed to connect the MPW to the ring. To convey the radiation out of the vacuum system, the fifth dipole chamber was replaced with one equipped with increased cooling and three additional x-ray ports. The new x-ray beamlines also required a modification to the shield wall to accommodate photon and bremsstrahlung shutters. The ring was not baked out prior to re-starting operations. Nevertheless, following two weeks of pumping, the storage ring's electron beam was re-established with only minor difficulty.

During extended testing and operations, cryogenic containment appeared to maintain liquid helium with insignificant loss. Regardless of magnetic field excitation, liquid helium consumption was not affected. This has been the case also during a pair of power supply failures at elevated field excitation.

Quad- ini Beta: Four Waists in Four traights

To negotiate the long and vertically narrow straight of the MPW, new magneto-optics settings were modelled and implemented [3]. The new lattice betatron functions are graphed below.

The new beam envelope places vertical waists in all 4 long straights, and allows CAMD to integrate quadrupoles that were previously devoted to the operation of the wavelength shifter into the two primary quadrupole families. Prior to the installation of the MPW the wavelength shifter straight possessed two focusing

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quadrupoles and two defocusing quadrupoles independent from the ring's quadrupole families.

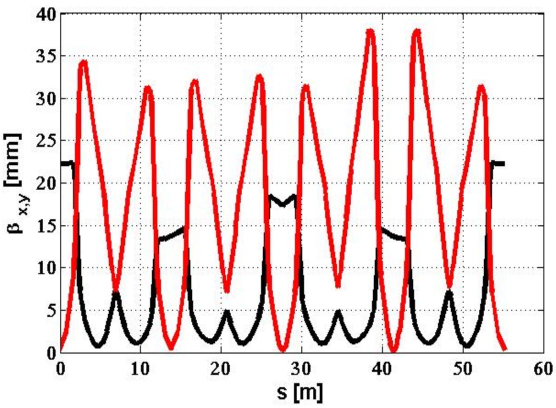

Figure 3: Betatron Function for CAMD with MPW at 7.5 T. Red = Vertical; Black = Horizontal.

Dynamic Aperture

As indicated, the new optics are applied to clear the vertical aperture of the MPW (15 mm). Present measurements indicate a current dependent dynamic aperture at injection energy of 4 mm at 30 mA to 1.2 mm at >100 mA. Currently, we believe induced local magnetic fields may be a significant factor. We also believe clipping at injection may be due to vertical offset in the electron beam. Characterizations of these dynamics are still in progress.

Tune Space

Due to the new optics, the accelerator team determined the old tune space had become more restricted. Therefore, a new region of tune space (3.3-3.37) called a "high-tune" region was examined. The differences between the two operating spaces are noted below. We should mention the new region permits the storage ring to inject with a greater flexibility. The new lattice produces a more tenuous beam at injection.

A portion of this tenuous-ness comes from the narrower quad-mini beta pattern and the residual MPW field at zero excitation. It has been our experience that prior to the MPW upgrade injected beams were more robust. We have observed that minor displacements in tunes will negatively impact beam stacking. As a minor demonstration of the impact of the MPW on the injected beam, we measured the displacement of the electron beam at injection energy with respect to applied current in the MPW. A 10 mA excitation in the central coils generated a 1 mm horizontal displacement in the injection and MPW straight.

Effects on Electron Beam

With respect to the high energy electron beam at 1.3 GeV, the dynamic effects of the MPW are just as pronounced. At present, the MPW is ramped from zero field to 5.5 Tesla. We do not ramp to 7.5 Tesla since the storage ring is not yet optimized for this condition. Top field will be enabled once protein crystallography's beamline is operational. As the MPW increases field density, the electron beam shows perturbations in vertical and horizontal tunes.

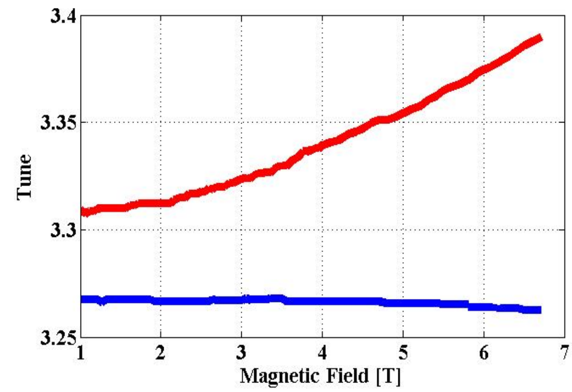

Figure 4: Uncorrected Tune Shift.
Blue = Horizontal Tune; Red = Vertical Tune

The measured vertical tune shift produced by the MPW follows a parabolic dependence on MPW's field, exactly as expected [2]. The horizontal tune shift arises due to orbit changes, which arise because the MPW first integral is not perfectly corrected due to dynamic effects. CAMD minimized this effect by making live measurements during the MPW ramp process.

CONCLUSION

LSU CAMD's 7.5 T MPW has been generating synchrotron radiation since late 2012. Routine operation commenced in October 2014. An insignificant rate of helium consumption has been observed since installation. Characterization of the MPW and its effects on the CAMD storage ring continues. Parameters have been measured, and the effort continues to increase injected and ramped ring current. Following optimization of the CAMD ring and experimental beamlines, we expect to operate the MPW at 7.5 T routinely in the near future.

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