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PMQ RADIATION TESTING AT THE NSLS-II IFE

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Abstract

A new lattice for NSLS-II upgrade is likely to use high strength (> 100 T/m) Permanent Magnet Quadrupoles (PMQs). An ID beam exiting through these quadrupoles will place highly intense x-rays very close (~ 1mm) to the permanent-magnet material. In these tests the PMQs will be placed in the IFE (Instrumentation Front End) front end to assess any degradation of their field strengths and field quality due to long term exposure to an ID beam. The IFE beamline was recently commissioned at NSLS-II and is dedicated for testing mechanical properties of accelerator materials and components. The description of the source and experimental setup will be given.

INTRODUCTION

NSLS-II is based on the well-established double-bend achromat, commissioned with first light in 2014, it was the last synchrotron based on this lattice. Since then, new and upgraded synchrotrons have moved towards various forms of multi-bend achromats in an effort to reduce horizontal emittance. The goal of NSLSII-U is to select a lattice with world-leading emittance and brightness. To realize this goal, lattice designs using the complex-bend principle are being investigated. A promising lattice is the triple complex-bend achromat (TCBA) which utilizes three bending regions in each cell comprised of PMQ focusing and defocusing regions with magnetic aperture as little as 16mm. These constraints will impose significant radiation challenges to the permanent magnets from both synchrotron radiation at absorber and extraction regions as well as radiation generated from electron beam loss and gas interaction. Furthermore, the machine upgrade will be accompanied by a boost in beam energy from 3GeV to 4GeV and the anticipated vacuum chamber material will be thin ~2 mm wall aluminium providing little shielding. The small aperture (11 mm ID) vacuum chamber and close proximity (0.5 mm) to the permanent magnets, are seen in the recently completed full-scale complex-bend prototype (Fig. 1).

Demagnetization of Nd-Fe-B rare-earth magnets used within insertion devices have been observed at numerous third generation light sources such as ESRF and APS [1]. However, reduced field strength in magnets used to preserve electron orbit have far greater implications. Investing in such a design requires strong confidence in long term stability of the field strength and magnetic fidelity of the Sm_2Co_{17} permanent magnets. While it has been shown Sm-Co magnets have superior thermal stability and radiation resistance over Nd-Fe-B magnets, quantitative measurements are an important undertaking to gain confidence [2,3]. Installing the PMQ in close proximity to the circulating -e beam was not an option due to aperture and beam influence. However, the recently commissioned IFE at NSLSII is an excellent alternative to make long-term radiation hardness assessment of the PMQ prototype.

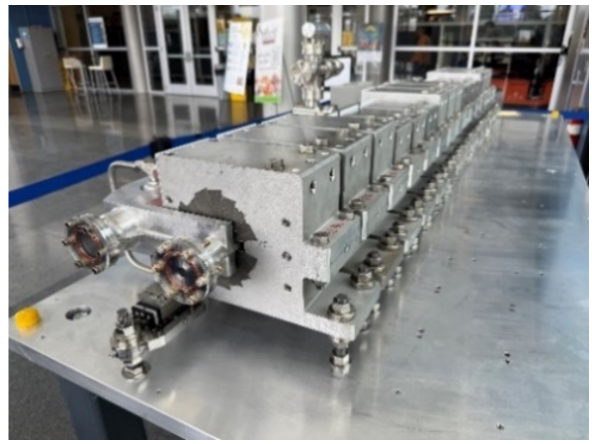

Figure 1: Full-scale complex-bend assembly.

EXPERIMENTAL

The IFE is dedicated to the study of accelerator materials and advanced diagnostics development for existing and future synchrotrons shown in Fig. 2.

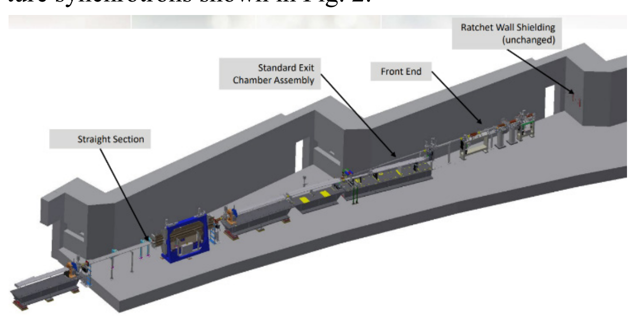

Figure 2: General arrangement of the IFE.

This tool, commissioned in 2023, has been used extensively to test and characterize thermal properties of CuCrZr absorber materials and configurations. The source, shown in Fig. 3, is the U68 Undulator acquired from Argonne National Lab and refurbished. It is capable of providing ~16 kW/mrad^2, with a total power of ~5.2 kW at 500 mA of beam. While low power compared to modern IDs, it is quite sufficient for thermal fatigue testing accelerator materials.

The beamline Instrumentation and Control system runs on EPICS architecture with comprehensive PV (process variable) monitoring and logging.

The IFE consists of a fixed mask, X-Y slits with prototype XBPMs, x-ray flag and endstation. There is also a fast-valve as well as drift pipe region(s) for additional testing

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such as new XBPM designs. High resolution (0.01°C) 4-wire RTD thermowell temperature sensors and calibrated flow meters allow for precise heat transfer calculations. To date the IFE has successfully tested the thermal fatigue properties and validated the design criteria for CuCrZr absorber material at 40° and normal incidence at both low and high power over 20,000 cycles. This was followed by successful testing of 3D printed CuCrZr absorbers for Soleil. This testing has defined the upper temperature and fatigue limit of this novel material in various forms of construction which is critical for future synchrotron designs. Full comprehensive results of these tests will be presented in Ref. [4].

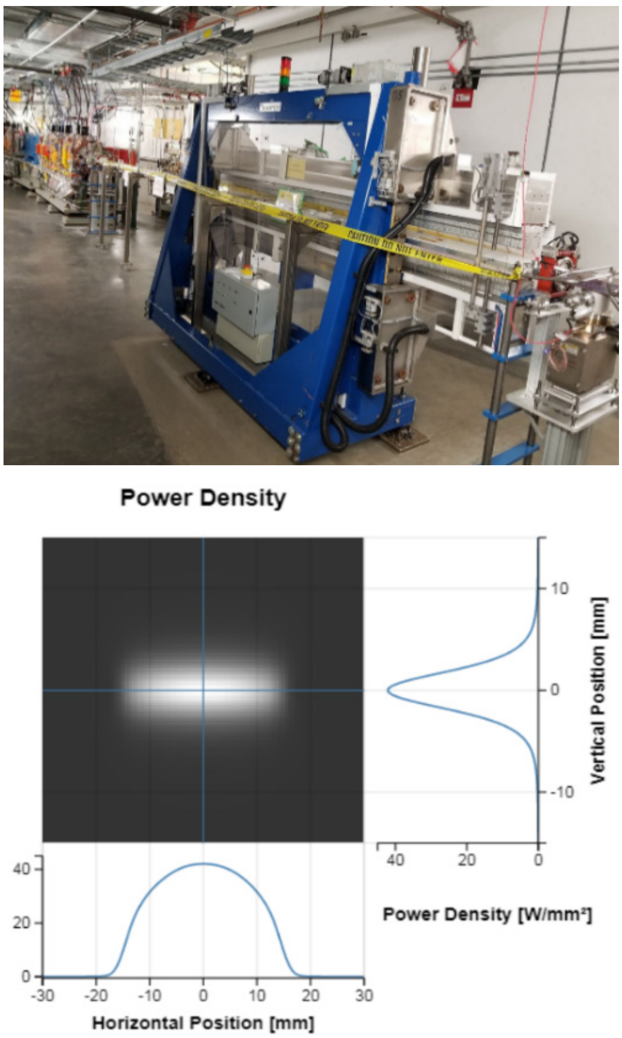

Figure 3: U68 Undulator installed in the storage ring.

With thermal characterization of CuCrZr complete, the FE has been reconfigured for the PMQ radiation testing. The installation layout is shown in Figs. 4 and 5, with the PMQ located at the end of the beamline in between upstream and downstream water-cooled CuCrZr flange masks. The upstream absorber (ABS1) has an open beam aperture of 12.2 mm x 3.5 mm. Whereas the downstream absorber (ABS2) acts as a beam stop.

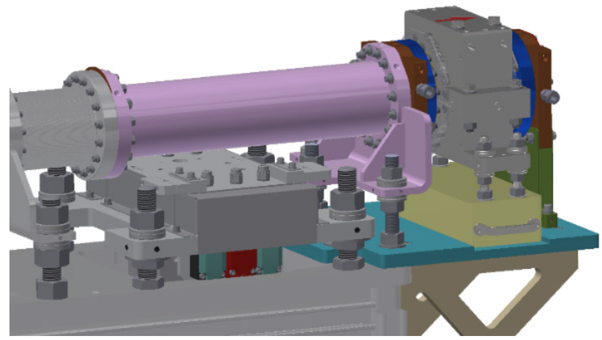

Figure 4: Assembly of PMQ at the end of IFE.

The fan exiting the fixed mask is trimmed by the upstream mask, thereby showering radiation onto the PMQ. Beam also passes through a thin aluminium vacuum chamber and strikes a downstream water-cooled CuCrZr mask where radiation is backscattered onto the PMQ assembly. The explosion bonded aluminium to stainless steel CF flanges were machined to remove stainless steel that would otherwise partially shield the PMQ from a cosine distribution of scatter.

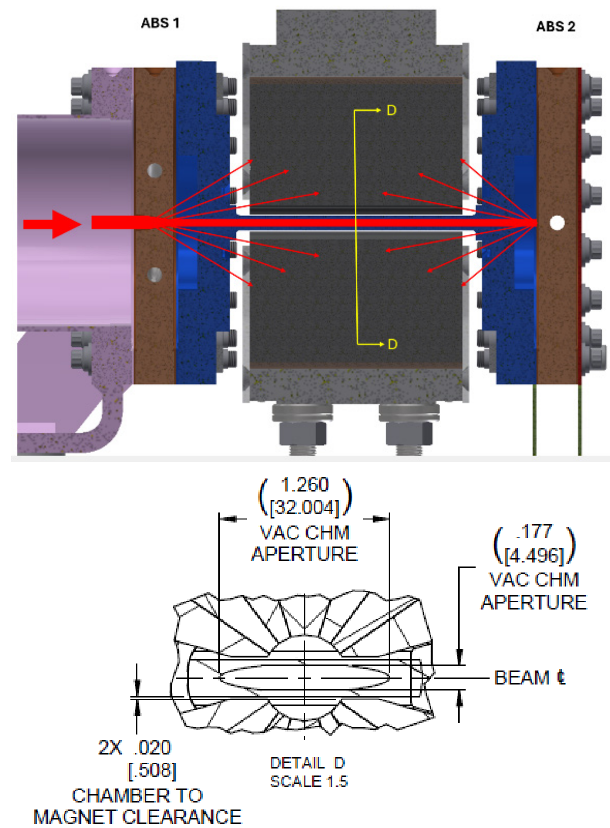

Figure 5: Cross section of PMQ and absorber assembly.

The total flux and energy spectra of x-rays striking the absorbers bracketing the PMQ is shown in Fig. 6.

The total power striking the assembly is 2121 W (500 mA), with 705 W on ABS1 and 1416 W on ABS2. Power density is shown in Fig. 7.

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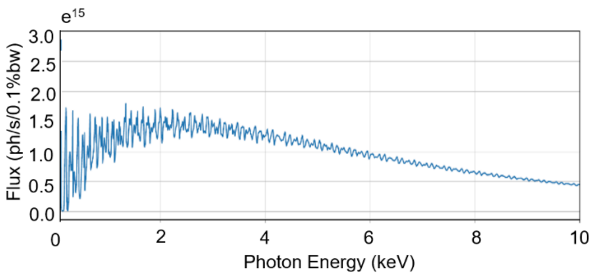

Figure 6: U68 Flux passing through the upstream slits (12.2 x 7.8 mm) and striking the PMQ/absorber assembly 20.8 m from source.

To measure radiation dose to the PMQ, FWT-60 film was chosen for its wide range of charged-particle energy down to 5 KeV or lower and high integrated dose rates.

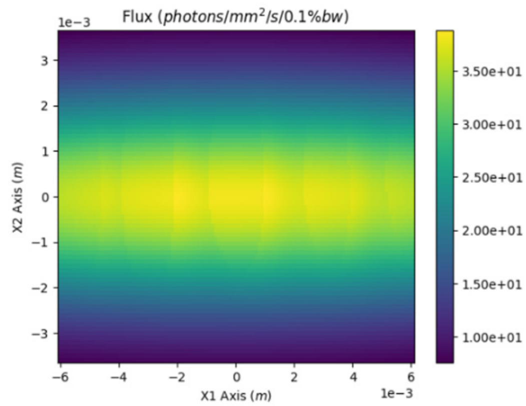

Figure 7: Total power density incident on downstream PMQ assembly (OSCARS [5]).

It was initially planned to install the thin film within the gap of the vacuum chamber and the PMQ, however, the film is sensitive to temperature and humidity and should not exceed 50°C for accurate measurement [6]. Temperature measurements of the vacuum chamber were measured at 400 mA. A plot of the temperatures is shown in Fig. 8 with a maximum temperature of 47°C. Installing the PMQ and raising beam current to 500 mA would overheat the film.

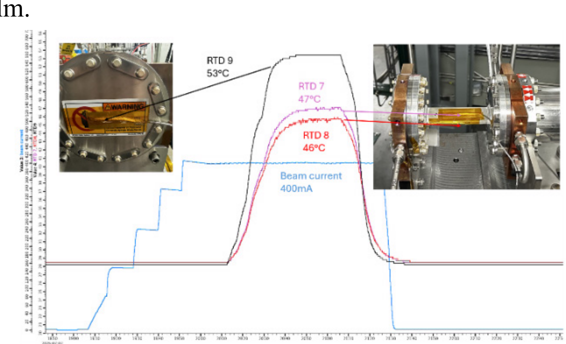

Figure 8: Vacuum chamber temp at 400 mA.

Instead, the film will be installed on a holder in close proximity to, but not in direct contact with the vacuum chamber and dose rates will be measured without the PMQ installed. Temperature testing of the fixture is shown in Fig. 9.

Once dose rates are calibrated with respect to beam current and exposure time, the PMQ will then be installed for extended time (~2 years) radiation exposure. The PMQ will be periodically removed and the magnetic field harmonics measured to evaluate any changes as a function of integrated dose.

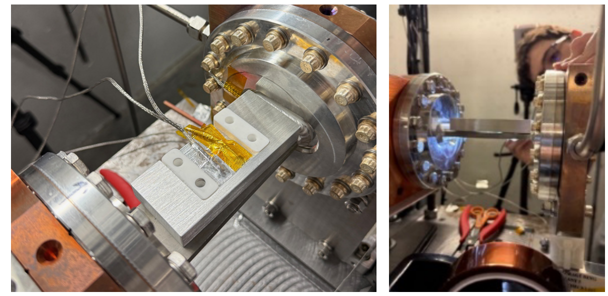

Figure 9: Temperature testing and placement of film holder close to surface of vacuum chamber.

CONCLUSION

Collection of radiological data will take some time. We anticipate having the dosimetry film installed in the August 2025 shutdown. We will collect dosimetry data and calibrate with accumulated A-hr of beam current by the end of 2025. With this data, total dose can be extrapolated for extended exposures up to several years. We anticipate installation of the PMQ to occur potentially in the winter shutdown in January 2026. The storage ring undergoes three major shutdowns a calendar year (January, April, August) so the PMQ will be removed for magnetic measurements starting in 2026.

ACKNOWLEDGMENTS

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