Novel Designs of Accelerator and Beamline Components

The Canadian Light Source: Status Report

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Abstract

The Canadian Light Source, CLS, is presently in the final phase of construction and has begun commissioning of subsystems. The CLS comprises four main systems: a 250-MeV linac, a 2.9-GeV full energy booster, a 2.9-GeV storage ring, and a series of beamlines serving interests ranging from infrared light to hard X-rays. Commissioning of the injection system up to and including the booster ring is expected to be complete in September 2002. The storage ring has a compact lattice consisting of 12 double bend "achromats" sectors, incorporating twelve 5.2-m straights. Three straights will be used for injection, rf, and diagnostics, and the remaining nine will be used for insertion devices (IDs). The initial set of beamlines will include two IR (bend magnet) and five ID sources supplying light to seven beamlines and up to ten experimental end stations. Construction and commissioning of the storage ring and initial phase of beamlines is scheduled to be complete by the end of 2003.

Keywords: Canadian Light Source, linac, booster, storage ring, insertion devices, beamlines

Presentation: Oral

A Compact Back Face Cooled Slotted Infrared Mirror and Mechanism for the IR 13 Beamline at the SRS, CLRC Daresbury Laboratory

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Abstract

We report on the design and performance of a back face cooled slot relieved infrared mirror and mechanism for the IR 13 beamline at the Daresbury Laboratory SRS. The slot through the mirror allows the 12W/mRad heat load to pass straight through, avoiding severe distortion and damage to the optical face.

A compact fine resolution tilt mechanism and mirror is mounted on a bellows sealed long travel extraction mechanism. The installation position is close to the electron beam and very inaccessible. The extraction mechanism (which allows installation without venting the accelerator) needs to provide maximum stability. The coaxial tilt mechanism must permit extraction past the metal gate valve isolating the accelerator vacuum without disturbing the mirror setting.

Keywords: infrared, flexure, extractable

Presentation: Oral

Storage Ring Injection Area Upgrade at the Advanced Photon Source (APS)*

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Abstract

Recent machine studies at the APS showed that at a beam current of about 140 mA, the storage ring (SR) injection-area components experienced unacceptable temperature rises. Heating of these components is related to several factors, namely, aperture discontinuity, poor rf fingers' contact, inadequate x-ray shielding, and nonuniform conductive coating on the kicker ceramic chambers. To address these deficiencies, we have developed design upgrades for the injection-area kicker magnets, vacuum chambers, transition absorbers, and bellows-liner assemblies. In this paper we discuss important features of the new designs and their impact on machine operation at high beam current.

Keywords: storage ring, kicker magnets, ceramic chambers, bellows rf fingers

Presentation: Oral

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An Optimized Design for the NSLS 53-MHz RF Cavities and the Ancillary Components

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Abstract

The rf cavities are among the most complex components of a particle accelerator. They perform optimally when all electrical, mechanical, and vacuum requirements are fully integrated. This paper focuses on the mechanical design features of the new 53-MHz room-temperature rf cavities (including their ancillary components) for the X-ray ring at the National Synchrotron Light Source (NSLS). Differences between the new and previous designs of the rf cavities, input couplers, higher-order-mode (HOM) dampers, cooling and vacuum systems are reviewed. Thus far, two out of four units have already been constructed, tested, and installed into the X-ray ring, and two additional rf cavities are planned. The incorporated features in the new design have already demonstrated superior performance over the original design. The operating performance results along with some of manufacturing challenges will be presented.

Keywords: rf cavity, tuner, coupler

Presentation: Oral

Development of the Low Return Loss 340-Size Ceramic Window for the APS Linac *

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Abstract

The Advanced Photon Source (APS) linac high-power switching system makes use of 340-size waveguide components. These components include vacuum-grade furnace-brazed transitions, pressurized-grade aluminum 340-size switches, and more recently 340-size ceramic windows. The fabrication of these 340-size windows proceeded with brazing of ceramic membrane to thin walled copper sleeves and real-time network analyzer testing performed by the ASD (Accelerator Systems Division) RF (Radio Frequency) Group. Initially it was thought that this real-time testing of prototype hardware would be necessary in the investigative stage to establish required dimensions and physical geometry satisfying the 40-dB return loss criteria. However, producing four windows now installed involved real-time network analyzer testing during production of each window conducted in parallel with adjustments of tuners designed into each 340-size ceramic window.

Keywords: radio-frequency, vacuum, brazing

Presentation: Oral

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

A Variable-Focus X-ray Compound Lens*

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Abstract

Design and fabrication of an x-ray lens assembly for focusing x-ray beams is described. The assembly consists of a number of precisely stacked and aligned aluminum parts. These parts are cut from a long extruded section having sixteen parabolic cavities along its length. The thickness of the wall between adjacent cavities is 0.2 mm. By cutting the assembled parts diagonally as shown below, a variable-focus lens system can be made. Moving the lens horizontally allows the incident beam to pass through fewer or more cavities collimating or focusing the emerging beam at a desired distance downstream.

The variable-focus aluminum lens has been used at the Advanced Photon Source to collimate a monochromatic, 81-keV undulator beam to increase downstream crystal monochromator throughput. Results indicate collimation consistent with theoretical expectations.

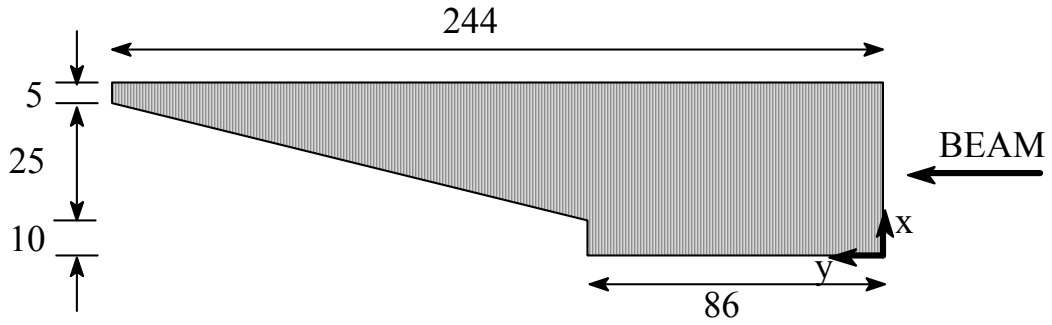

Figure: Cross-section of a typical variable-focus x-ray lens: the assembly focuses the beam in the z-direction (into the paper). Moving the assembly horizontally along the x-axis will vary the focal distance. Dimensions are in mm.

Keywords: x-ray, optics, lens, compound lens, variable focus, aluminum extrusion

Presentation: Oral

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Monolithic Two-Axis Flexure-Joined Mirror Support

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Abstract

At BESSY an infrared beamline was designed and built. In order to fulfill the stringent requirements a basically new mirror moving mechanism was developed (Figure 1). This unit is based on a monolithic body that contains two independent segments of rotational symmetric flexure hinge patterns [1,2]. The design provides two rotational axes that intersect the midpoint of the mirror surface normal to each other and parallel to the mirror surface. The flexure hinge patterns interpenetrate in two orthogonal directions. The monolithic body additionally includes the elastically loaded kinematic mirror mount. Its motion is driven by two linear feedthroughs.

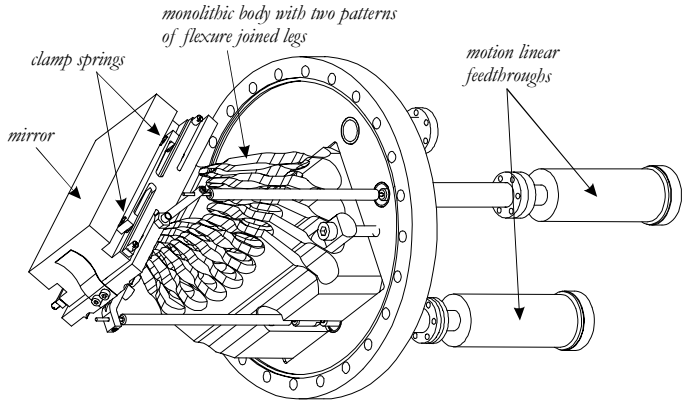

Figure 1: Two-axis rotational flexure-joined mirror moving mechanism, complete assembly.

Advantages over classical mirror moving mechanisms are that it: requires only minimal space, works very smoothly, producing a high positioning accuracy, and is vibrationally stiff. Because of the monolithic design, the UHV compatibility is good.

The presentation includes design parameters and the motion behaviour of the assembly as well as other particular features of the infrared beamline.

References

[1] Stuart T. Smith, *Flexures, Elements of Elastic Mechanisms* (Gordon and Breach Science Publishers) 2000.

[2] D. Shu, "Ultraprecision Motion Control Technique for High-Resolution X-Ray Instrumentation" Proc. of the 1st Int'l. Workshop on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation, Paul Scherrer Institute, Villingen, Switzerland, July 2000.

Keywords: mirror support, weak link mechanism

Presentation: Oral

Beam Stability: Vibration and Thermal Effects

Investigation of Passive Vibration Damping Methods for the Advanced Photon Source Storage Ring Girders*

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Abstract

Beam stability is a major concern for the operation of the APS. One of the many contributing factors to electron beam instability is mechanical vibration of the accelerator components, especially the focusing magnets. The electron beam should be stable to 5% of its rms size to maintain the specified photon beam stability. The APS utilizes steel girders to support the conventional magnets and vacuum chambers in the storage ring (SR). Three pedestal and jack assemblies support the girders. Damping pads are presently installed between the pedestals and the jacks. It has been shown that these damping pads are very effective in reducing the fundamental girder vibration mode. The horizontal vibration levels of the SR quadrupole magnets are presently within specification at between two and four times the ground motion, i.e., 50-100 nm rms (4-50 Hz). Future improvements to the APS beam quality would require a further reduction in girder vibration. Several options for reducing the vibration of the girders and magnets are discussed, and the measurement results are presented.

Keywords: vibration, beam stability

Presentation: Oral

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Measurement of Thermal Effects on the Advanced Photon Source Storage Ring Vacuum Chamber*

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Abstract

From the start of operations of the Advanced Photon Source storage ring, we have observed small thermally related dipole sources appearing soon after filling. Because there are many like sources occurring at about the same time, it has been difficult to locate them. Some sources have recently been located with a specially configured orbit correction running while the vacuum chamber temperature is changed. Vacuum chamber motion, seen as an apparent orbit change, can also be estimated from the results.

Keywords: orbit stability, thermal stability

Presentation: Oral

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Observation of Beam Orbit Fluctuation with Forced-Vibrating Magnets and Vacuum Chambers

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Abstract

Fluctuations of the beam orbit have been observed quantitatively when the quadrupole magnets and vacuum chambers are vibrated by external force. The vibration frequency spectra, amplitudes, and phases of each component are measured individually at the same time. The calculated spectra of closed orbit distortions, which were reconstructed from vibration spectra of each component with involving eddy currents in the vacuum chamber, were well agreed quantitatively with those of observed orbit fluctuation. At the frequencies of 1 to 100 Hz, contribution of the vacuum chamber vibration to the beam fluctuation was found to be greater than those of quadrupole magnet vibration at SPring-8. Vertical beam position stabilization at frequencies from 10 to 50 Hz was dramatically improved by reducing vacuum chamber vibration with minimizing the flow rate of its cooling water. These results show that reducing vibration of vacuum chambers, as well as quadrupole magnets, is essential for the stabilization of beam position, or improving effective transverse emittance. It will give us a new guideline of component design for future accelerators.

Keywords: beam stabilization, vibration, beam position, emittance, vacuum chamber

Presentation: Oral

Mechanical Stability Studies at Taiwan Light Source

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Abstract

Thermal and mechanical effects on the stability of beam orbit and beam size were investigated at the Taiwan Light Source (TLS). Most of the sources and routes that vary the beam orbit and beam size were identified. The outdoor temperature, cooling system capacity, device linearity, control parameters, and even electrical line voltages influence the stability of air temperature, water temperature, and/or mechanical structures. The stability of the beam orbit and beam size, as well as the reliability of the monitoring system were improved after reducing the thermal and mechanical fluctuations. A beam orbit fluctuation of < 1 μm (rms) and a drift of < 5μm/8hr (one shift) were achieved without using an orbit feedback system. A beam size fluctuation of < 0.3μm was estimated from an intensity fluctuation of ~ 0.2% of the photon beam through an aperture in the photon beamline.

Keywords: beam stability, temperature, mechanical, electrical

Presentation: Oral

Thermal Deformation of the Magnet Girder and its Solution at the SRRC Storage Ring

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Abstract

The thermally-induced deformation of the magnet girder has been observed to induce positional changes of the magnet and the beam position monitor (BPM) on the order of microns. This work investigates the deformation mechanisms. Methods for reducing the deformation are also proposed and applied in the storage ring. The improvement reduced the deformation of the girder by more than five times. A sensitive beam position and intensity monitor in the beamline was also used to verify the improvement.

Keywords: thermal deformation, magnet girder

Presentation: Oral

High Precision Positioning Mechanisms

The Mechanical Design of High Precision Positioning Instruments Used for X-ray Microscopy at the ESRF

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Abstract

The ESRF has built for six years, microscopy beamlines, on which various instruments like high precision sample scanners, micro-beamstop, zone-plate positioners, and Kirkpatrick-Baez optics have been developed. This design area covers vibrational stability, high level of reproducibility, micro-stiffness, compactness, and no lever arm. Thus, samples are exposed to X-ray beam spot sizes between 0.1 µm to 0.5 µm, which requires less than 50 nm vibration peak to peak, and step size in "zap-scan" mode less than 100nm.

According to the required accuracy, stiffness is a permanent improvement concern. Pico-motors against micro-jacks are alternative solutions, which imply from the instruments, a rather high degree of evolution.

This presentation should review the instruments design for ID21, ID22, Kirkpatrick-Baez optic, and other existing solutions, when micro-focus is required for some other ESRF beamlines.

Keywords: micropositioning, microscopy, high precision

Presentation: Oral

Optimal Dynamic Performance for a High-Precision Stage System*

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Abstract

Scientists at the Advanced Photon Source (APS) are continually stretching the limits of x-ray measurement techniques. To this end, mechanical structural dynamic stability is of primary importance. System dynamic performance of multidimensional stage groups, such as those found in optical instrument positioning systems, is dependent upon both individual component behavior and the system configuration. Experimental modal-analysis techniques have been implemented to determine the six-degree-of-freedom stiffnesses and damping for individual stages and groups. The key to the approach is a combination of experimental measurements and numerical simulation. Experimental dynamic-performance data, such as displacement, dynamic stiffness, and damping, are used in computer models to home in on problem areas faster than either a computational approach or experimental approach alone would allow.

In this paper, two recent examples of this methodology are presented: the diagnosing of a multiaxis goniometer installed in the 2-ID-D experimental station, and the investigation of actuator/stage group optimization for multiaxis positioning systems.

Keywords: high-precision, dynamic stability, actuator, stage, goniometer

Presentation: Oral

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Progress of the High-Precision Positioning Mechanism Development at the Advanced Photon Source*

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Abstract

There are many challenging tasks in the design of beamline instrumentation that relate to high-precision positioning mechanisms for users at third-generation synchrotron radiation sources, such as the 7-GeV Advanced Photon Source (APS). Over the last two years, progress has been made in the development of novel mechanisms with high positioning resolution and high stability at the APS. Applications include: high-energy-resolution monochromators, x-ray microprobe scanning stages, and a sample-exchange automation system for x-ray cryo-biocrystallography.

In this paper, the particular design upgrades, as well as the new mechanism design specifications, are summarized.

Keywords: high-precision, high-resolution, positioning mechanism, actuator, stage

Presentation: Oral

* Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences under Contract No. W-31-109-ENG-38.

Recent Advances in Nano-Precision Motion Technologies Address the Resolution/Speed Tradeoff

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Abstract

Mechanical and controls advancements have long been sought to address the needs for many industrial and optical applications for higher resolution and higher process throughput—or, ideally, both. But traditionally these goals are at cross-purposes, since the time to settle to a given positional tolerance rises exponentially with the inverse of the tolerance, all else being equal. Given the rapidly diminishing dimensional tolerances in a wide spectrum of industrial processes versus the "time is money" truism for any manufacturing or research endeavor, recently marketed advances that address both needs at the same time represent fundamental breakthroughs of keen interest to industrial engineers and researchers. In this session we will present parallel advancements in the fields of flexure-based nanopositioners, multi-axis, low-inertia, parallel-kinematics mechanics designs and high-bandwidth controls engineering with application to nano-scale positioning and active optics:

- Integrated, parallel-kinematics mechanics with up to six degrees of freedom
- Advancements in flexure designs that improve nanometer-scale bidirectional passive trajectory control, often allowing bidirectional processing for the first time
- Multi-axis, high-bandwidth active trajectory control, allowing out-of-plane motions in scanning applications to be controlled to Ångstrom levels
- Cost effective, industrial-class implementations of momentum compensation (also known as Frahm damping) for low-order cancellation of inertial inputs to supporting structures, which is of particular applicability to structures with low natural resonance frequencies such as telescope optics and biotech scanners
- Input Shaping®, a patented controls technique developed at the Massachusetts Institute of Technology, which provides effective cancellation of structural resonances in arbitrary actuation
- Input Preshaping™, a technique realized in both *a priori* and self-learning implementations, which substantially eliminates following errors in repetitive actuation.

The author reviews applications of each of these, alone and together, in a comprehensive overview of state-of-the-art industrial nanopositioning techniques.

Keywords: nano-precision motion control, flexural designs, multi-axis, high-bandwidth, Frahm damping

Presentation: Oral

Insertion Devices and Vacuum Chambers

The Flexible Taper Transitions for an In-Vacuum Undulator

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Abstract

In a joint project between SPring-8 and PSI, an in-vacuum undulator U24 was installed in the SLS storage ring during 2001. In this frame, cooled flexible taper transitions were developed to provide a smooth transition between the vertical aperture of the adjacent fixed taper sections and the vertical gap of the undulator, thus minimizing any impedance discontinuity. After a numeric optimization of the shape of the tapers, these were manufactured via electro-discharge machining (EDM) from a Be-Cu sheet. Subsequent fatigue tests, as well as the operational experience so far, have proven the validity of the adopted concept.

In a further development step, two in-vacuum undulators covering an energy range 5-18 keV and with a gap range of 4-40 mm are currently being designed. These will require an upgrade of the flexible tapers allowing a longitudinal degree of freedom based on a parallel spring translator mechanism. In this way the danger of incurring into buckling due to a bake-out-induced differential thermal expansion of the vacuum chamber with respect to the in-vacuum beams supporting the magnet arrays will be minimized.

In this work the results on a nonlinear finite element optimization of the resulting flexible taper assembly will be presented, together with the set-up being developed for the in-vacuum fatigue tests of the whole structure. Depending on the outcome of the experimental assessment, the same concept could then be adopted also for a scraper device.

Keywords: in-vacuum undulator, flexible taper, finite element analysis, fatigue tests

Presentation: Oral

Installation Aspects of the Third Harmonic Cavity and Superconducting Wiggler at Elettra

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Abstract

New cryogenic devices are going to be installed in the Elettra storage ring during the summer of 2002. The third harmonic cavity will increase the performance of the storage ring by increasing the beam lifetime, while the superconducting wiggler has been designed for a new high-energy high-flux diffraction beamline. Both of these devices are cryogenically cooled at 4 K, requiring liquid He circuits. In this contribution solution of problems related to installation (layout, vacuum chambers, cooled masks, cryogenic plants, etc.) will be presented.

Keywords: cryogenic instrumentation, rf cavity, wiggler

Presentation: Oral

First Prototype Undulator for the LCLS Project – Mechanical Design and Prototype Lessons*

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Abstract

The design of a new hybrid-type undulator with a fixed gap of 6 mm, a period of 30 mm, and a length of 3.4 m is presented. The undulator line, consisting of 33 such units, is a critical part of the LCLS project, which is one step toward the design of a fourth-generation synchrotron radiation source. Magnetic uniformity of all 33 undulators, as well as the corresponding mechanical uniformity, is a major challenge. A ridged C-shape design with a titanium housing of 12" diameter was chosen to provide easy access to the gap area for magnetic measuring and tuning. Lessons we learn while working with this prototype are very important and critical for successful project execution. Results of the assembly and tests and possible design changes are presented.

Keywords: hybrid undulator, synchrotron radiation, SASE

Presentation: Oral

*Work supported by the U.S. Department of Energy under contract W-31-109-ENG-38.

Mechanical Design of NSLS Mini-Gap Undulator (MGU)

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Abstract

The mechanical design considerations are discussed with respect to the currently installed X-13 and future X-29 MGU. Comparisons to the previous two generations of variable small-gap undulators in the NSLS X-ray ring are made and design improvements are noted. The design requirements and mechanical difficulties for holding, positioning, and driving the magnetic arrays are explored. The structural, thermal, and electrical considerations that influenced the design are then analyzed. The mechanical performance of the MGU currently installed at X-13 is examined, and future installations and enhancements are presented.

Keywords: undulator, in-vacuum, small-gap, magnet-arrays

Presentation: Oral

High Heat Load Analysis and Design

ESRF Thermal Absorbers: Temperature, Stress and Material Criteria

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Abstract

A great amount of thermal absorbers have been used to protect the ESRF storage ring vacuum vessels. These copper made thermal absorbers are cooled by water and have to remove very high power density heat load. For instance, a crotch absorber removes up to 8.16 kW of power at 200 mA current, with a peak linear power density of 72 W/mm or 177 W/mm^2 on the absorber. These thermal absorbers should be designed to withstand the temperature and thermal stress induced by the high heat load. The criterion of the thermal stress in the thermal absorber smaller than elastic limit of the material was mostly used in the design. Various experiences at the ESRF and tests made on the thermal absorbers show that this criterion is too conservative for the synchrotron radiation thermal absorber. This paper presents the design of some of the thermal absorbers made either of Glidcop or OFHC copper, the temperature and stress of the absorbers from finite element analysis, test results and operation experience with absorbers made of Glidcop or OFHC copper. Some points concerning the criteria to be considered in the absorber design will be discussed.

Keywords: storage ring, absorber, heat load, stress, criteria

Presentation: Oral

Thermomechanical Analysis of High-Heat-Load Components for the Canted-Undulator Front End*

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Abstract

With the canted undualtors operating at 200 mA at closed gap at the Advanced Photon Source in the future, the front end will receive 20.4 kW of total power and 282 kW/mrad^2 of peak power density. Thermal analysis of the front-end high-heat-load components becomes an essential part of the front-end design. An extensive study has been conducted in the thermal design of the photon shutters and fixed masks. A unique dog-bone-shaped cross-section design for the photon shutters is derived to relieve high stress in the corners. The dual-undulator x-ray beams are simulated at several locations on the fixed mask to ensure the worst possible case is considered. Stress analysis on the fixed mask revealed the maximum stress occurs when beam hits the intersection between the horizontal surface and the corner surface. The details of the analysis procedure are presented, and the failure criteria are discussed.

Keywords: front end, canted undulator, fixed mask, photon shutter, high heat load

Presentation: Oral

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An Evaluation of Enhanced Cooling Techniques for High-Heat-Load Absorbers*

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Abstract

Many components of the storage ring and front ends in the third-generation of light sources are subjected to high heat loads from intense x-rays. Temperature rises and thermal stresses in these components must be kept within acceptable limits of critical heat flux and low-cycle fatigue failure. One of the design solutions is to improve heat transfer to the cooling water either by increasing water velocity in the cooling channels or by using turbulators such as porous media, twisted tapes, and wire springs. In this paper we present experimental and analytical results to compare various enhanced cooling techniques for conditions specific to heating from an x-ray fan.

Keywords: heat transfer, high heat load, enhanced cooling, absorbers

Presentation: Oral

* Work supported by the U.S. Department of Energy under Contract No. W-31-109-ENG-38.

Enhanced Heat Transfer Utilizing Wire-Coil Inserts for High-Heat-Load Applications*

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Abstract

Enhanced heat transfer techniques, used to significantly reduce temperatures and thermally induced stresses on beam-strike surfaces, are routinely used at the APS in all critical high-heat-load components. A new heat-transfer enhancement technique being evaluated at the APS involving the use of wire-coil inserts proves to be superior to previously employed techniques. Wire coils, similar in appearance to a common spring, are fabricated from solid wire to precise tolerances to mechanically fit inside standard 9.5-mm-diameter cooling channels. In this study, a matrix of wire coils, fabricated with a series of different pitches from several different wire diameters, has been tested for heat-transfer performance and resulting pressure loss. This paper reviews the experimental data and the analytical calculations, compares the data with existing correlations, and interprets the results for APS front-end high-heat-load components.

Keywords: heat transfer, high heat load, wire coil, front end

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