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A COMPARISON OF FRONT-END DESIGN REQUIREMENTS

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Abstract

Front ends of the NSLS-II storage ring have numerous design requirements to ensure equipment and personal safety aspects of their designs. These design requirements, especially many pertaining to raytracings, have gradually become overly stringent and a review is underway to simplify them for building future front ends. As a part of this effort, we have assembled the front-end design requirements used in several other light sources. In this paper the assembled design requirements are discussed in comparison with those currently in use at NSLS-II.

INTRODUCTION

Front ends are used to control the size of photon and gas bremsstrahlung beams traversing from the storage ring to the users' beamlines. At NSLS-II there are presently 17 front ends for insertion device (ID) beamlines and 6 front ends for BM (bending magnet or 3-pole wiggler) beamlines. A typical ID front end [1] is shown in Fig. 1. Its main components are, (1) XBPM, (2) fixed aperture mask (FM), (3) lead collimators (LCO), (4) a pair of XY slits, (5) photon shutter (PS), (6) safety shutters (SS), and (7) ratchet wall collimator (RCO). The components that trim or stop the bremsstrahlung beam, namely, LCO, SS and RCO, are classified as PSS (personnel safety system) components and the remaining as EPS (equipment protection system) components.

The design of NSLS-II front ends is deemed to be too conservative, in part due to a very stringent approach to raytracings involving PSS components, and to the requirement of minimizing the size of bremsstrahlung beam. For the new front ends, presently in the planning stage, some simplified design criteria are being evaluated. As a part of this evaluation, front end design criteria collected from several light source facilities (APS-U, ALS-U, CLS, DLS, ESRF(EBS), HEPS, SOLEIL, SSRF and TPS) are compared with those used at NSLS-II. The focus of this comparison is on source definitions of photon and bremsstrahlung beams, and thermal fatigue design criteria.

FRONT END CONFIGURATIONS

Front-end configurations of different facilities mentioned above are quite similar except that XBPMs, XY slits and LCOs are not considered to be required components. XBPMS are not installed in ALS-U and most of the NSLS-II ID front ends to save space and/or cost. XY slits are not available in APS-U, ESRF(EBS) and SSRF front ends. In general, LCOs (to trim the bremsstrahlung beam) are not installed in the front ends of DLS, ESRF and TPS. A second SS for redundancy is used only at NSLS-II, APS-U, CLS and DLS. Vacuum pressure gages in the front ends of all facilities are interlocked to dump the stored beam. Thermal sensors are also used at ALS-U, HEPS, SSRF, Soleil, and DLS, although they are not interlocked in some cases. Trimming of un-interlocked photon beams by burn-through devices (explained below) is done only at NSLS-II and APS-U front ends. Only one of the facilities, (ALS-U), employs a sweeper magnet as safety against accidental entry of the injected e-beam into the front end.

RAYTRACINGS

Raytracings for both the photon and bremsstrahlung beams are critical part of the front-end design process at NSLS-II and a considerable design effort is devoted to generating formal raytracing drawings. The drawings are usually revised iteratively in order to optimize the apertures, lengths, and locations of the various front-end components.

Photon Beam Sources

Source definitions for raytracings consist of 3 parts, namely, (1) e-beam deviations, (2) location of the source in Z (along the beam) direction, and (3) fan angles of the device (defined by K and γ parameters) at the source point.

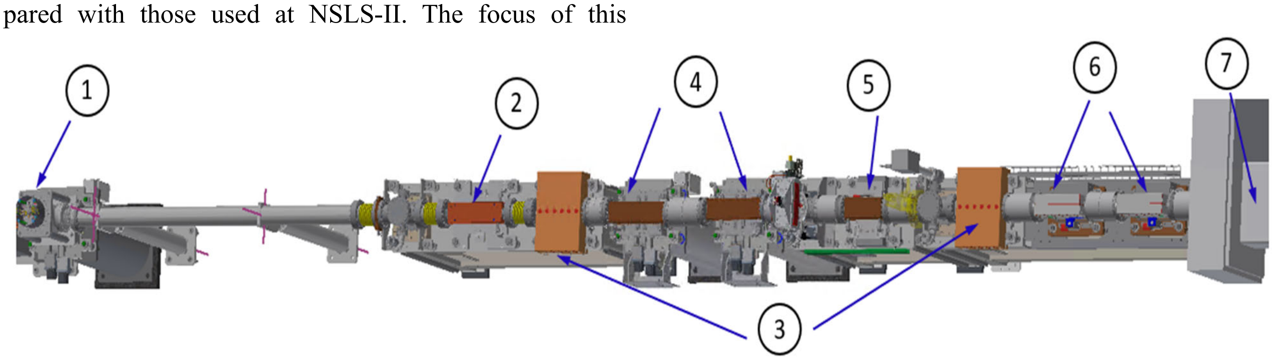

Figure 1: A typical NSLS-II ID front end; (1) XBPM, (2) fixed aperture mask (FM), (3) lead collimators (LCO), (4) XY slits, (5) photon shutter (PS), (6) safety shutters (SS), and (7) ratchet wall collimator (RCO).

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E-beam deviations are controlled by active interlocks that use RF-BPMs installed at the upstream (US) and downstream (DS) ends of the ID straight sections. The displaced positions of the beam at the two ends determine its angle when it is not specified explicitly. Interlock specifications are carried over to BM source locations in some facilities whereas in other facilities, including NSLS-II, they are assumed to be inapplicable. In the latter case the beam is constrained by the geometry of the vacuum chamber (geometric envelope, GE). For photon beam raytracings the e-beam deviations used at different light sources are summarized in Table 1.

Table 1: E-beam Deviations for Photon Beam Raytracings

Facility	**ID front end**		**BM front end**	
	Position ± (mm)	Angle ± (mrad)	Position ± (mm)	Angle ± (mrad)
NSLS-II	0.5	0.25	GE	GE
ALS-U	1.0	0.2	1.0	0.2
APS-U	1.5 (H) 1.0 (V)		GE	GE
CLS	2.5 (H) 1.6 (V)		1.6 (H) 2.5 (V)	
DLS	1.0		2 (H) 4 (V)	3 (H) 0.5 V
ESRF	1.0		3 (H) 2 (V)	
HEPS		0.1		0.1
SOLEIL	0.8		0.5	0.5
SSRF		0.5 (H) 0.2 (V)	5 (H) 2 (V)	
TPS	1.0 (H) 0.2 (V)		GE	

For personnel safety components (vacuum chambers of LCO, SS and RCO), e-beam is assumed to be not interlocked at NSLS-II and APS-U in order to provide additional margin of safety. Geometric envelopes (GE) are then used to determine e-beam deviations. The resulting large angles are stopped by burn-through devices in the case of interlock failure. At NSLS-II burn-through flanges (BTF) are used upstream of LCOs and RCO. The basic concept is shown schematically in Fig. 2. The photon beam outside the interlock limits will first strike the thin wall of the BTF (in the case FM has failed) causing local melting and a beam dump due to air leak.

The source location for ID front ends is the center of ID straight. At NSLS-II and TPS, the ends (US and DS) of the ID straight are also used to determine the worst conditions of beam interception. For the BM frontends the source location is tangent intersect of the beamline to the e-beam trajectory, usually several mrads inside the dipole.

Source fan angles and mechanical tolerances are included in raytracing drawings at TPS and NSLS-II. Moreover, this is shown by separate rays in the NSLS-II drawings which, consequently, consist of a large number of lines.

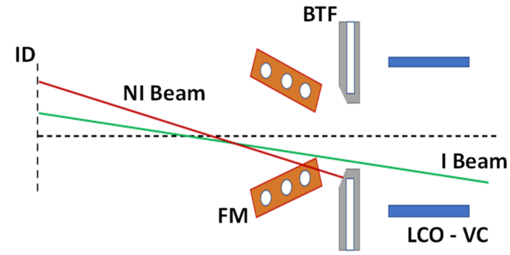

Figure 2: NSLS-II burn-through flange (BTF) concept. BTF stops photon beam outside the interlock limits (NI beam) to protect LCO vacuum chamber (VC). Upstream FM shadows BTF from interlocked beam (I beam).

Bremsstrahlung Radiation Sources

Transversely the entire cross-section of the storage ring vacuum chamber aperture (excluding antechamber) is specified to be the source size for gas bremsstrahlung. At NSLS-II and APS-U an exception to this source size is used in the radially inward direction in that the bremsstrahlung source is extended to the entire storage ring. In both the facilities LCOs (in addition to RCO) are then used to trim the resulting large angles of bremsstrahlung rays.

For ID front ends, the bremsstrahlung source is located at the center of the ID straight (APS-U, SSRF, Soleil, ESRF, DLS), or at the end of the ID straight (NSLS-II, HEPS), or at the US end of the first downstream bending magnet (ALS-U, CLS, DLS). For the BM front ends the bremsstrahlung source location is at the upstream end of the dipole with some exceptions, namely, at the BM source point (APS-U, CLS, DLS), and at the center of drift space after a specific magnet, DQ2 (ESRF).

The designs of SS are generally based on tungsten blocks, which are placed inside vacuum vessels (in-vacuum design), acting as bremsstrahlung beam stops. A second SS for redundancy is used at NSLS-II, APS-U, CLS and DLS. There are two exceptions to this common design: (1) lead bricks (instead of tungsten) are used at ESRF and NSLS-II as bremsstrahlung stops, (2) lead bricks are placed outside the vacuum chamber (out-of-vacuum design) in the NSLS-II design (Fig. 3). The NSLS-II design is passively safe in the sense that photon beam power cannot strike the lead block without first breaching upstream bellows which would result in a beam dump.

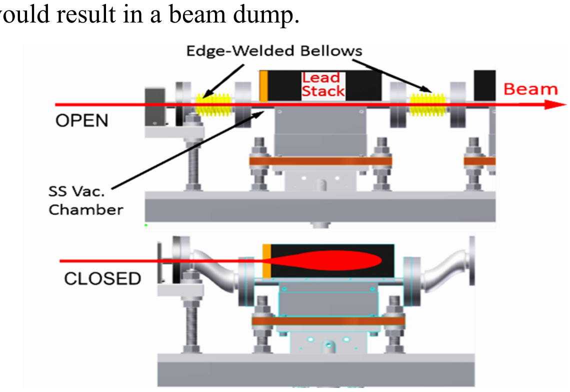

Figure 3: NSLS-II out-of-vacuum design of SS. In the closed position the bremsstrahlung beam is stopped by a stack of lead bricks.

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DESIGN CRITERIA FOR FRONT-END EPS COMPONENTS

In some earlier designs [2], the EPS components (FM, and PS) were placed inside vacuum vessels. With some legacy exceptions (PS in the ID front ends of ALS and in the BM front ends of ESRF), all facilities are using out-vacuum designs for FM, PS and XY slits. Recently a new design was proposed [3, 4] based on CuCrZr flanges (or Conflat® knife-edges) integrated into the main body as shown in Fig. 4. Two of the main advantages of this design are: (1) elimination of the brazing step, and (2) wide availability of CuCrZr compared to GlidCop.

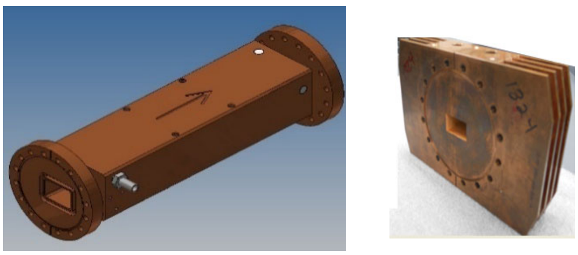

Figure 4: A high-power CuCrZr mask with integrated flanges (left), and an air-cooled, low-power, CuCrZr mask with integrated knife edges (right).

The new CuCrZr design is now used for essentially all new front ends at NSLS-II. GlidCop is used only for beryllium windows which require high-temperature diffusion brazing. CuCrZr has also been partially adopted at several other facilities, often with more conservative design criteria. In Table 2, design criteria for different Cu alloys, specified as maximum allowable values of temperature (T), von Mises stress (σ_y), or plastic strain (ε_p), are compared. The specified values differ significantly due in part to a lack of experimental data. Recently some thermal fatigue tests and analyses [5-7] have been performed to address this for GlidCop.

Table 2: Maximum Allowable Values of Temperature, von Mises Stress and Plastic Strain

Facility	Copper Alloys		
	OFHC Cu	GlidCop	CuCrZr
NSLS-II		300 ºC + T_{amb}	300 ºC + T_{amb}
ALS-U	300 ºC 300 MPa	400 ºC 430 MPa	
APS-U	200 ºC	375 ºC	250 ºC
CLS	150 ºC	300 ºC	200 ºC
DLS	400 ºC $\varepsilon_p < 0.5\%$	400 ºC $\varepsilon_p < 0.5\%$	
ESRF-EBS	200 ºC	200 ºC	250 ºC 280 MPa
HEPS		400 ºC	
SOLEIL	0.75 σ_{yield}	0.75 σ_{yield}	
SSRF	150 ºC 340 MPa	300 ºC 400 MPa	
TPS	150 ºC	300 ºC	200 ºC

CONCLUSION

Front end design criteria for several light source facilities have been compared with those used at NSLS-II. Uninterlocked e-beam deviations for PPS components (LCO, SS and RCO), and expanded source locations for photon and bremsstrahlung fans have resulted in more conservative but elaborate designs at NSLS-II. The new design for EPS components (FM, PS and XY slits), based on CuCrZr bodies with integrated flanges, has been adopted at several facilities. A comparison of thermal design criteria for three copper alloys (OFHC Cu, GlidCop and CuCrZr) shows a wide range in maximum allowable values of temperature and stress.

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