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TIME DOMAIN PHOTON DIAGNOSTICS FOR THE ADVANCED PHOTON SOURCE UPGRADE*

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Abstract

With swap-out injection and a third-harmonic bunch lengthening cavity, time domain diagnostics will be beneficial tools for optimisation of the Advanced Photon Source Upgrade electron storage ring. In the present work, we present plans for time-domain X-ray and visible photon diagnostics for the Advanced Photon Source Upgrade. Particular emphasis is given to implementation of visible light streak cameras and X-ray bunch purity monitors as time domain photon diagnostics.

INTRODUCTION

The Advanced Photon Source (APS) storage ring presently provides beams to user X-ray beamlines. The Advanced Photon Source Upgrade (APS-U) project is currently underway to increase the brilliance of photon beams to user beamlines [1–3]. Several user programs take advantage of the pulsed time-of-arrival of X-rays corresponding to the storage ring fill pattern. As these user programs are anticipated to continue during Advanced Photon Source Upgrade (APS-U) operations, we plan to provide temporal photon beam diagnostics for the optimisation and diagnostics of accelerator operations.

In the present work, we motivate time-domain photon diagnostics for the APS-U storage ring. We outline the time distribution of photons for beamlines at APS-U. Proposed techniques for time-domain photon diagnostics are summarised. Finally, we describe the proposed changes to the existing beamline configuration to employ these diagnostics.

FILL PATTERN AND BUNCH PROFILE

Fill patterns of the APS are controlled by the radiofrequency (rf) of the main rf cavities (352 MHz), and the storage ring circumference (1104 m). This accommodates 1296 buckets.

At present, the APS operates three fill patterns for routine user operations. Essentially, these are either bunches equally-spaced, or a camshaft fill ('hybrid mode', 1 + 8×7), with 1 bunch, and 8 trains of 7 bunches spaced at 2.84 ns [4]. For APS-U operations, a 48-bunch mode and 324-bunch mode are foreseen, with 324 bunches operating in bunch trains with ion-clearing gaps and guard bunches [5]. A camshaft fill pattern is not envisaged for future APS-U operations. These fill patterns and bunch lengths are summarised in Table 1 below.

Table 1: Temporal Structure Corresponding to Fill Patterns of APS and APS-U Storage Rings

Description	Bunch Spacing (ns)	Bunch Length (ps)	Ref.
APS Fill Patterns:			
324 bunches	11.4	25	[6]
24 bunches	153	40	[6]
Hybrid (1, 8×7)	2.84	50, 32	[4]
APS-U Fill Patterns:			
324 bunches	11.4	88	[2]
48 bunches	77	104	[2]

So for APS-U, the proposed bunch lengths to be measured are of the order ~100 ps, with a minimum bunch spacing of 11.4 ns. We propose to use bunch length measurements sensitive on the picosecond time scale [7].

TIME DOMAIN PHOTON DIAGNOSTICS

At present, the APS operates temporal diagnostics at the 35-BM bending magnet diagnostic beamline [8–11]. Specifically, this includes bunch length measurement and bunch purity monitoring. These two temporal diagnostics are outlined below.

Bunch Length Measurement

For the existing APS, the bunch lengths can be reasonably approximated as Gaussian in profile. However, for bunches in the future APS-U storage ring, the operation of the higher harmonic cavity to lengthen the bunch results in a bunch distribution that potentially departs significantly from a Gaussian approximation [12]. This motivates experimental techniques to measure the bunch temporal profile without assumption about the bunch shape.

For APS-U, bunch length measurements will be performed using a visible light streak camera [13]. Visible light streak cameras have been employed as a bunch length diagnostic at APS since its commissioning [14–18]. Synchronising the vertical (fast) sweep with the storage ring rf ('synchroscan') has been usefully employed in studies of longitudinal dynamics in the storage ring [19–23]. The streak camera can be synchronised with the third subharmonic of the storage ring main rf frequency (117 MHz), derived from the APS-U timing and synchronisation system [24].

Bunch Purity Monitor

Ensuring bunch purity in the fill pattern is essential to the operation of some user X-ray experiments at APS. At the

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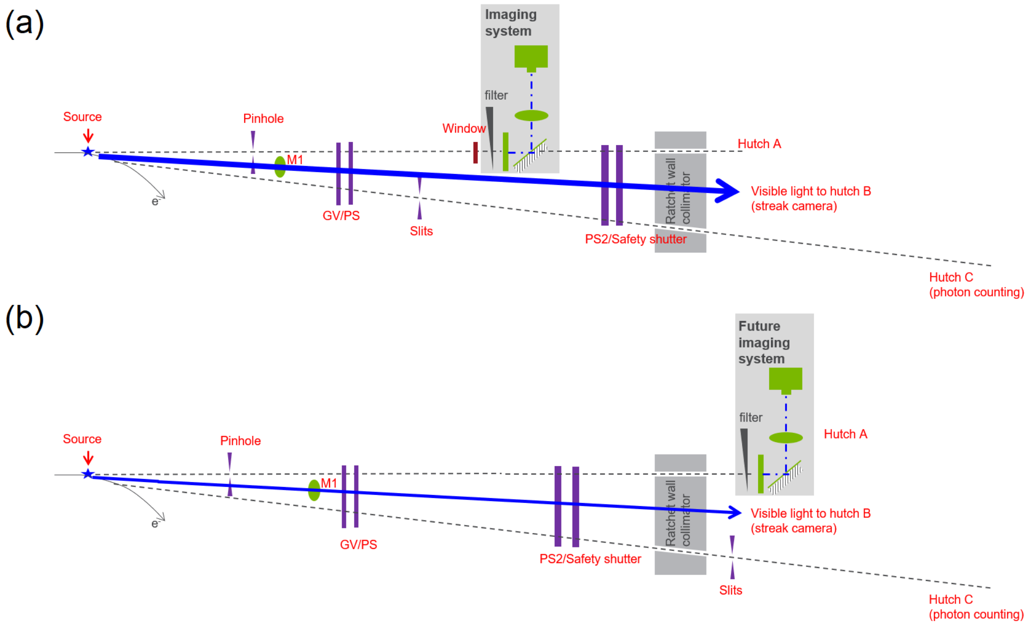

Figure 1: Schematic illustration of 35-BM beamline in plan view [25]. (a) Most common configuration of 35-BM beamline for APS operations. For daily operations, the outboard branch line serves a pinhole camera for imaging, with the pinhole located in the beamline front end, and the X-ray camera physically located within the storage ring tunnel. The placement of the M1 mirror allows visible synchrotron radiation to be present within hutch B independent of shutter status. Time-correlated single photon counting is performed in hutch C using the inboard X-ray branchline when storage ring photon shutters can be opened. (b) Proposed configuration of 35-BM for APS-U operations. Future capability for a pinhole camera will be allowed for on the outboard branch line in hutch A, visible light transport will be reconfigured to connect to hutch B, and the capability of photon counting for bunch purity monitoring will be preserved in hutch C.

APS, the electron bunch is cleaned in the Particle Accumulator Ring (PAR) to provide a single electron bunch, which is accelerated and accumulated in the storage ring [26]. A bunch purity monitor can provide a real-time diagnostic of the storage ring fill pattern, and at the APS the operation of bunch cleaning [27].

At the APS, time-correlated single photon counting of X-rays is employed to measure bunch purity [28–33]. This capability will be preserved in order to measure bunch purity of the APS-U storage ring. Clocks for the data acquisition system will be synchronised with the APS-U timing and synchronisation system [24].

BEAMLINE GEOMETRY

The principal features of the bending magnet radiation beamline at 35-BM are outlined. As illustrated schematically in Fig. 1 [25], in routine operation three photon beams are provided to three experimental areas, separated horizontally in angle. During APS operations, X-ray beams can be provided to either hutch A or hutch C (through a radiation-shielded transport pipe passing through hutch B), and visible light is provided via an optical transport line to hutch B.

For daily operations, the outboard branch line typically serves a pinhole camera, with the pinhole located in the beamline front end, and the X-ray camera physically located within the storage ring tunnel. For routine beam size monitoring, locating the pinhole camera detector within the storage ring tunnel is convenient because the electron beam dimensions can be observed independent while keeping X-ray (photon) and bremsstrahlung shutters closed.

An elevation view of the proposed changes to the beamline front end is illustrated in Fig. 2 [34]. An existing in-tunnel X-ray pinhole camera assembly is removed, as the principal emittance diagnostic for APS-U will be the 38-AM diagnostic beamline [35].

Visible Light

Calculations of the angular distribution of synchrotron radiation in the vertical plane for polarisations in both the horizontal (σ) and vertical (π) is illustrated in Fig. 3 [25]. The parameters used in the calculation of visible synchrotron radiation flux as presented in Fig. 3 are summarised in Table 2 [25].

Table 2: Parameters Used in Calculation of Visible Synchrotron Radiation Flux [25]

Parameter	Units	APS	APS-U
Beam energy	GeV	7	6
Electron beam current	mA	100	100
Bending magnet field	T	0.60	0.68

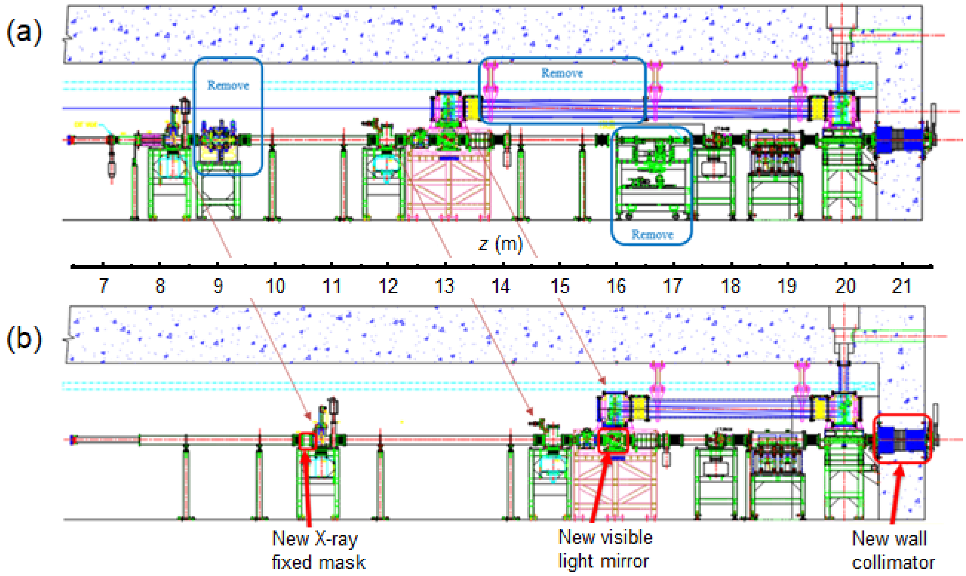

Figure 2: Profile of components in 35-BM front end [34]. The longitudinal coordinate z is with respect to the bending nominal bending magnet photon source point. (a) Existing components and assemblies in the 35-BM front end for APS storage ring operations. A section of the visible light telescope, the pinhole aperture assembly and pinhole camera will be removed. (b) Proposed configuration of beamline front end for APS-U storage ring operations.

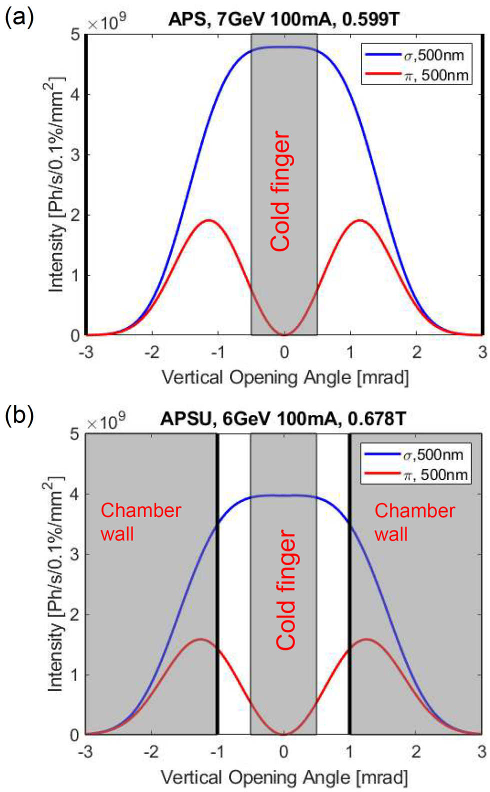

Figure 3: Calculated angular distribution of visible synchrotron radiation and angular apertures in the beamline in the vertical plane [25]. Beam parameters are summarised in Table 2. (a) Calculated flux at 500 nm for APS. (b) Calculated flux at 500 nm for APS-U. Implementation of a cold finger for the APS-U storage ring would significantly reduce the visible photon flux.

As illustrated in Fig. 2, the first visible light mirror will be relocated downstream, and a section of the visible light telescope will be removed from the beamline. Principally, the table supporting the mirror and telescope (beginning at $z = 12.5$ m in Fig. 2(a)) overlaps laterally with the anticipated footprint of a full-length insertion device in the adjacent 35-ID insertion straight. Furthermore, since it is not planned to use the visible light beamline to spatially image the electron beam size, the optical magnification of the existing telescope does not need to be preserved.

Vertical apertures in the vacuum system are shown in Fig. 3. The vertical aperture of the bending magnet vacuum chamber is ±1 mrad. The inclusion of a cold finger in the visible light photon transport (masking the central ±0.5 mrad core of the photon fan) for the APS-U configuration of the beamline would significantly further reduce the available photon flux at the beamline. To maximise visible photon flux, we are considering the use of a gold-coated diamond mirror, rather than a cold finger and metallic mirror as used in the present configuration.

Hard X-ray

The lateral shift of bending magnet source points 42.3 mm inboard between the APS and APS-U storage rings necessitates changes to the existing X-ray beamline [1]. The proposed X-ray beamline geometry is outlined in Fig. 1.

Initially, we envisage adapting the inboard-most branchline to provide X-ray beams to hutch C. As illustrated in Fig. 2, this necessitates the design of a new X-ray fixed mask, and a new wall collimator.

In the future, we envisage implementing a pinhole camera to image the electron beam source size. Owing to the horizontal dispersion at the location of the bending magnet front ends, the horizontal electron beam size in APS-U is dominated by the electron beam energy spread. Hence a pinhole camera at this location is anticipated to provide a complementary measurement capability to the proposed emittance monitor at 38-AM [35].

SUMMARY

Time domain diagnostics will be beneficial tools for optimisation of the APS-U electron storage ring. In the present work, we have presented plans for time-domain X-ray and visible photon diagnostics for the APS-U storage ring commissioning and operations. To the maximum extent possible, existing components are re-used.

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