Nonintercepting Imaging Diagnostics for the APS Injector during Storage Ring Top-Up Operations*

A. H. Lumpkin, W. J. Berg, and B. X. Yang

Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439

Abstract. The recently implemented top-up operating mode of the Advanced Photon Source (APS) storage ring has motivated an emphasis on nonintercepting imaging diagnostics in the injectors. We present the upgrades to the optical synchrotron radiation (OSR) monitors on the accumulator ring and injector synchrotron as well as the plans for a new OSR monitor on a chicane dipole in the linac and for an optical diffraction radiation (ODR) monitor for the 7-GeV transport line to the storage ring. Two key issues are signal strength for a single macropulse in the chicane and discriminating key transverse information from the visible light ODR, respectively.

INTRODUCTION

The Advanced Photon Source (APS) is a third-generation x-ray synchrotron radiation user facility [1]. We have recently implemented a top-up operating mode that involves single-shot injection into a targeted rf bucket of the fill pattern to maintain the 100-mA stored beam current. When the fill pattern is 23 singlets and a low-emittance (~3.5 nm rad) lattice is used, injection efficiency must be high on each shot (which occurs every two minutes). The sequence involves about 20 seconds of checkout time, which has been found to be impractical for tuning the injector between shots using intercepting beam profiling screens in the linac and transport lines. This scenario resulted in a plan to upgrade the existing optical synchrotron radiation (OSR) monitors on the accumulator ring (AR) and the injector synchrotron (IS) and to evaluate other nonintercepting (NI) diagnostic imaging techniques for the linac and various transport lines between the accelerators. In particular, we are exploring the addition of one OSR station using a dipole source in the chicane bunch compressor located at the 150-MeV point in the linac and an optical diffraction radiation (ODR) monitor on the 7-GeV transport line between the IS and the storage ring (SR). The status and feasibility aspects of these initiatives will be presented.

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EXPERIMENTAL BACKGROUND

The APS facility includes the three electron guns (two rf thermionic [2, 3] and one rf photocathode [4]), an S-band linac with acceleration capacity up to 600 MeV, the accumulator ring, the injector synchrotron that ramps the beam energy to 7-GeV, the 1104-m circumference 7-GeV storage ring, and the transport lines between these accelerators [5]. The facility is schematically shown in Fig. 1. There are rf beam position monitors (BPMs) installed in all accelerators and transport lines that provide the beam position noninterceptively. However, aspects of the beam transverse or longitudinal parameters are evaluated by both intercepting screens and nonintercepting imaging techniques during standard operations. In this case, the fill-on-fill interval may be 12 or 24 hours depending on the stored beam lifetime. There are OSR ports on both the AR and IS, and there are both an OSR port and an x-ray synchrotron radiation (XSR) port on the storage ring. The SR OSR is typically used for bunch-length measurements with a streak camera while the XSR is used with a pinhole camera to provide ~ 22 μm (σ) resolution beam size imaging [6].

In the linac, intercepting beam profile screens are used at a number of locations and several have been upgraded to utilize optical transition radiation (OTR) converters or YAG:Ce single crystals instead of the original Chromox scintillation screens [7]. For top-up mode, the single shot of charge is injected every two minutes. The rf beam is only available in the linac, transport lines, AR, and IS for about 20 seconds preceding the single shot. It has been problematic to tune the linac rf phase using intercepting screens to optimize injection into the AR in this time period. It is also useful to operations to be able to observe simultaneously the beam in all three rings of the facility and verify the basic injector functions. In support of these needs the upgrades to the suite of nonintercepting imaging diagnostics were planned as described in the next section.

DIAGNOSTIC UPGRADES

The initial upgrades and proposed upgrades on the injector will now be discussed. Since OSR is a major feature, Table 1 summarizes the expected signal strengths from various points in the machine, and Fig. 1 shows schematically where the sources are. In the case of the single-pass mode of the linac beam, signal strength is one of the challenges for a linac macropulse. In the rings, thousands of turns might be integrated into a 30-ms image.

TABLE 1. Estimates of Total Visible Photons per 1-nC Charge in a Single Pass (λ = 400-700 nm).

Accelerator	Beam Energy (GeV)	B – Field (T)	Angular Width	Integrated Flux
Linac OTR	0.20	Thin film	2 π solid angle	10.6×10^7
Chicane	0.15	0.6	20 mrad	4.1×10^7
Accumulator Ring	0.375	1.2	10 mrad	3.1×10^7
Injector Synchrotron	7	0.7	8 mrad (16mm @ 2m)	8.4×10^7
Storage Ring	7	0.6	3 mrad (35mm @ 12m)	4.4×10^7

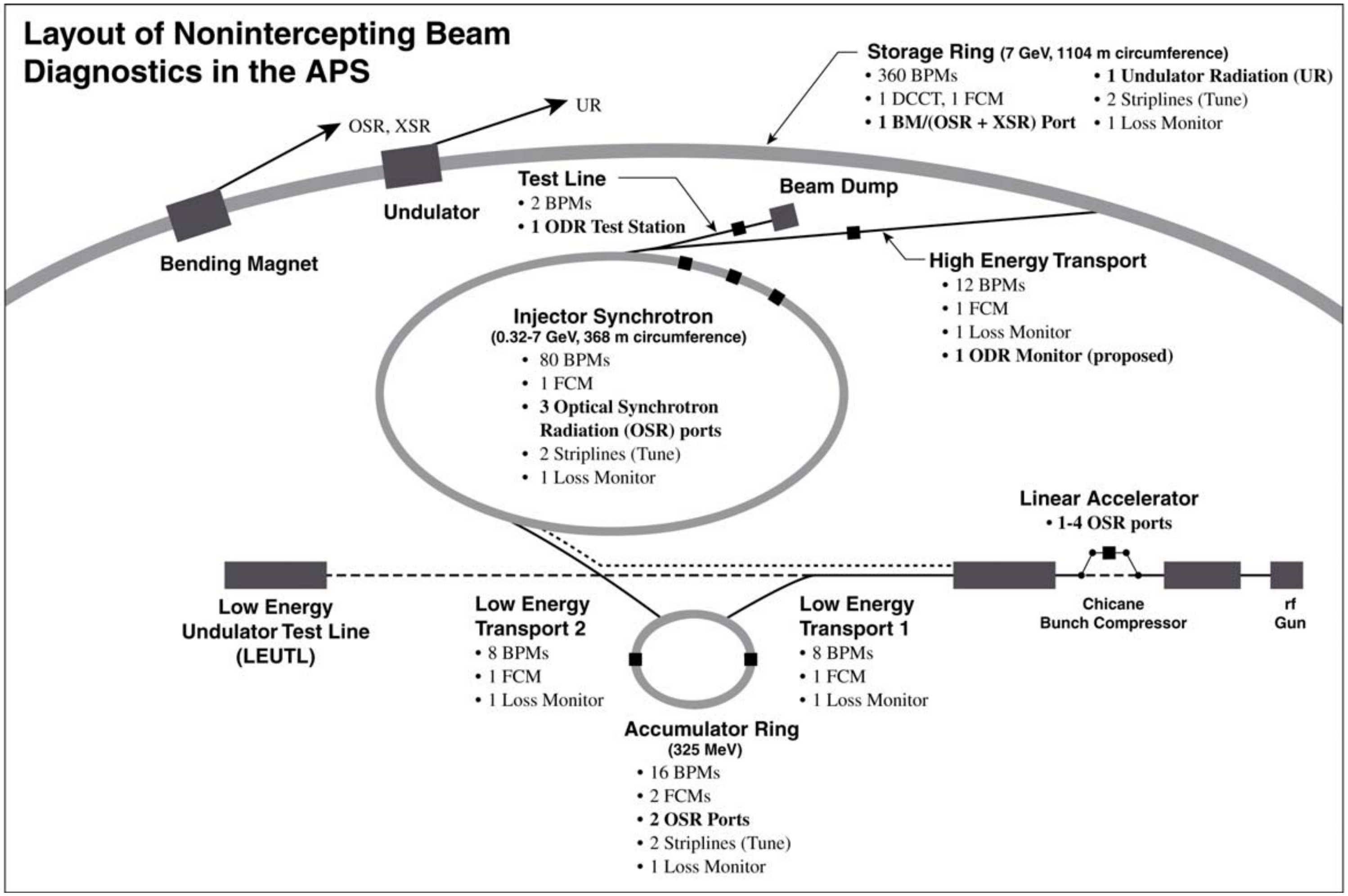

FIGURE. 1. Schematic of the APS injector facility and storage ring with list of the nonintercepting imaging diagnostics.

Linac

At the 150-MeV location, a four-dipole chicane has been installed to provide bunch compression of the rf photocathode (PC) gun beam [8]. We propose to add an OSR monitor after the second dipole, which would be a dispersive point in the lattice. Then transverse (horizontal) beam centroid and size measurements would yield relative information about beam energy and energy spread, respectively. These latter two parameters are directly related to the upstream rf phase and amplitudes for the accelerating structures. Operationally, this could be one of the key tuning aids since we have experienced rf phase shifts sufficient to impact injector efficiency in the past. The projected OSR strength is given in Table 1, and this may require some sensitivity boost with an intensified camera for successful imaging.

Accumulator Ring

Typically, the linac injects a 325-MeV, 8-ns-long macropulse consisting of 25 S-band micropulses. Although the two OSR ports have been functional and were used extensively during the commissioning period several years ago, they have been used in later years for machine studies. The video was selectable in the APS-wide video multiplexor. As a first phase, a dedicated fiber line was added that provides the video at all times to a dedicated quad view with monitor in the main control room (MCR). This will be followed by upgrades of the cameras and optical table components with EPICS control capabilities. The present video clearly shows the top-up sequence of injection of beam, storing of beam, damping of beam size, extraction, and then the absence of beam after the SR injection shot.

Injector Synchrotron

This ring is used to ramp the beam energy from the 325 MeV out of the AR to the full energy of 7 GeV. The ramping of the rf cavity power/phase and the power supplies for the dipoles, quadrupoles, sextuples, and correctors is a delicate balance that occurs over a 200-ms period at a 2-Hz repetition rate. The OSR images of the two-dipole sources reveal the damping of the beam transverse size, a centroid motion, and then the absence of circulating beam after extraction. The beam image centroid at the end of the ramp should be stable for top-up. A dedicated fiber line was also implemented to transport the images to the MCR, and the ramping phenomena are monitored. Ultimately, a dedicated video digitizer with video processing will be added to track the final beam centroid and size.

7-GeV Transport Line

The transport line between the IS and SR at 7 GeV provides another opportunity to track the beam quality. Besides the intercepting screens, we propose complementary information on transverse parameters may be obtained from an ODR monitor [9]. In this case of high gamma, a 1-mm aperture or slit will result in visible diffraction radiation (DR) being emitted. Basically, appreciable DR will be generated as the charged particle beam passes through the aperture when gamma times the reduced wavelength is equal to or larger than the aperture radius (a); i.e., $\gamma\ \bar{\lambda} \geq a$. Backward ODR will be emitted around the angle of specular reflection as in OTR. So slits placed at a 45° angle to the beam direction will result in ODR emitted around 90° to the beam direction as illustrated in Fig. 2. Our elliptical beam size should result in a contribution to the asymmetry of the angular distribution pattern. Calculated signal strengths for horizontal and vertical polarization components are about 25% and 80% of OTR for $R = a/\gamma\bar{\lambda} = 0.5$ but for a lower beam energy example [9].

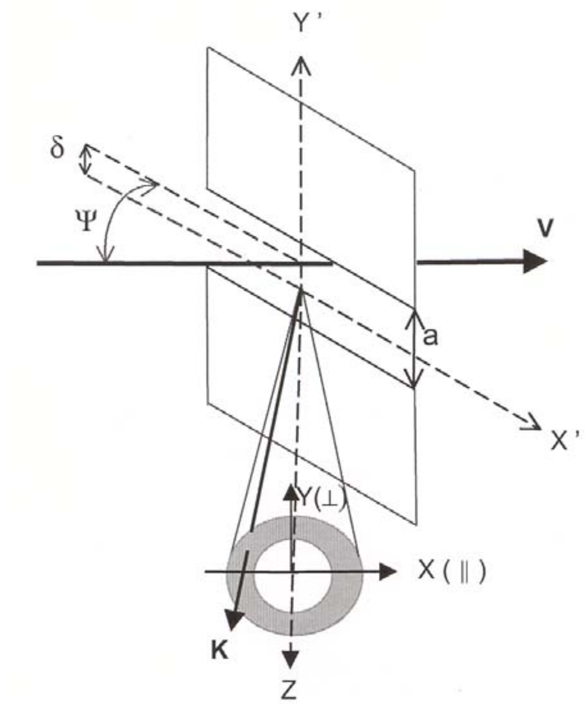

FIGURE 2. A schematic representation of the backward diffraction radiation emitted when a charged particle passes through a slit. The conducting plates are at 45° to the beam direction. (Based on Fig. 1 of Ref. 9).

SUMMARY

In summary, we are in the process of augmenting our NI imaging diagnostics at APS to support the top-up operating mode. In addition, we will be evaluating other locations to employ OSR or ODR imaging in support of interleaving operations where the linac will be used to inject another beamline for free-electron laser (FEL) experiments.

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