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

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Abstract

Recent machine studies at the Advanced Photon Source (APS) showed that at a beam current of about 140 mA, the storage ring (SR) injection-area components experienced unacceptable elevated temperatures. Heating of these components is related to several factors, namely: aperture discontinuity, poor contact between the rf fingers and the solid sleeve liner, 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

1. Introduction

The storage ring (SR) at the Advanced Photon Source (APS) operates in top-up mode where beam is injected into the SR every two minutes to maintain an average beam current of 102 mA. Future operating requirements are to have stored beam with an average current of 300 mA. At present some components in the injection area of the storage ring show unacceptable elevated temperature levels when beam current is increased to approximately 140 mA. The components that showed the most significant increase in temperatures were the kicker magnet chambers, the attached bellows with liners, and flanges. An analysis of this problem involved, in part, examining the design of all the components in this section to determine the design changes that would alleviate the overheating and allow us to operate at higher beam currents. On examining ray tracing drawings of this area, we took note that the transition absorbers did not provide adequate protection for some of these bellows and vacuum chambers. Further analysis showed that the sudden change in chamber aperture at some locations and the lack of adequate rf continuity between mating flanges were also contributing factors to localized heating. Another deficiency in the injection area was the inability to constantly monitor the injected beam size and position. It was determined that modifications to the mini-flag and flag chamber would allow for better monitoring of the injected beam.

2. Injection Area

Beam from the booster is injected into the SR via the high-energy transport (HET) line. A thick septum magnet at the end of the HET bends the beam, bringing it close to the stored beam in a parallel trajectory inside the thin septum magnet. Four kicker magnets symmetrically arranged about the injection section are used to bump the stored beam inwards, towards the thin septum during injection [1]. Located between the two kicker magnets in the injection area are: a fluorescent screen, a section of storage ring vacuum chamber, and the thin septum magnet. Another fluorescent screen, a mini-flag located at the end of the thick septum magnet, is for measuring the injected beam size and position. The vacuum chamber system is made complete with various designs of flexible bellows assemblies joining these components together. The current configuration is shown in Figure 1.

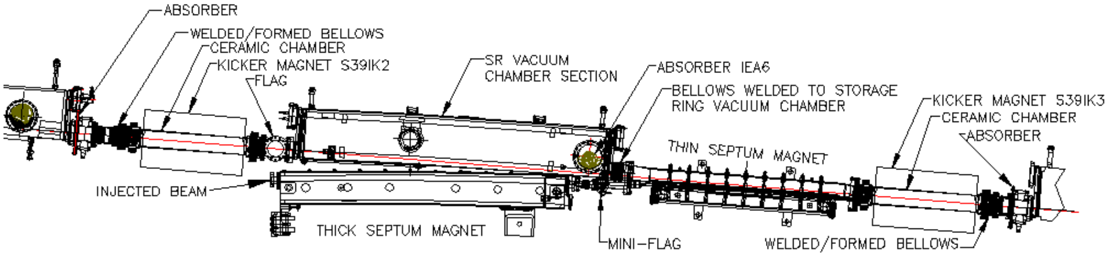

Fig. 1: Layout of SR injection area with existing components.

The existing SR vacuum chamber section was designed with a formed bellows welded to one end. Any leak in this bellows assembly would necessitate replacing the entire vacuum chamber section.

The following changes were made to the injection area and are shown in Figure 2.

- A bellows assembly was designed, detached from the chamber for installation as an independent component.
- Additional single bellows assemblies were designed to replace the arrangements that had separate and adjacent bellows assemblies, where one was of the welded type and the other of the formed type.
- A transition absorber was added immediately upstream of the second kicker magnet (S39IK3), providing more adequate x-ray shielding for the ceramic chamber.
- Several changes were made to the kicker magnets, which are discussed in more detail in section 3.

The physical design of the transition absorbers used in the injection area was not changed. The absorbing material, however, was changed from oxygen-free high-conductance (OFHC) copper to GlidCop AL-15 since GlidCop is more stable at higher temperatures. GlidCop is alumina dispersion strengthened copper, with electrical and thermal properties almost two times better than Beryllium-Copper (Be-Cu), and is resistant to softening due to annealing at temperatures close to the melting point of copper [2]. The elliptical aperture was also reduced by 8.0 mm and 4.0 mm, respectively, on its major and minor axes. This aperture is approximately 17 mm smaller all around than the ceramic vacuum chamber and 12 mm and 16 mm smaller, respectively, on the minor and major axes of the SR vacuum chamber. Based on new ray tracing drawings, this absorber will adequately protect downstream components from x-rays.

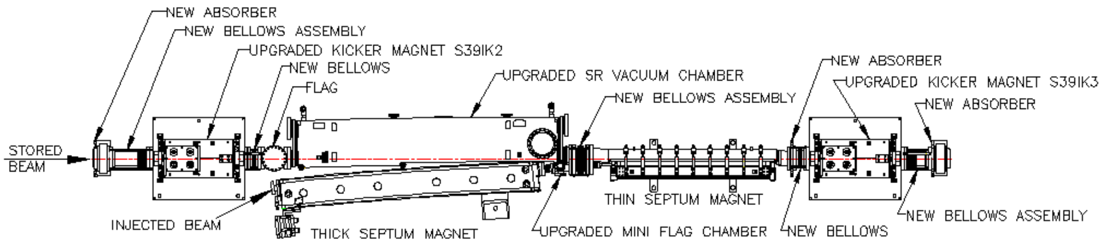

Fig. 2: Layout of SR injection area with new upgraded components.

The fluorescent screen in the existing mini-flag is inserted vertically, which limits its detection of the injected beam within a narrow trajectory. By adding a port to the inside of the arc of the beam trajectory from which the screen is to be inserted horizontally, it would be possible to image the beam at any trajectory.

3. Kicker Magnets

The kicker magnet shown in Figure 3 is typical of the design of all SR kicker magnets having a solid ferrite core, C-shaped in design. When assembled, the ferrite blocks that make up the core create a rectangular aperture in which the vacuum chamber and coils are inserted. The single-turn coil is made in two halves from OFHC copper, insulated with mica tape and an epoxy-potting compound. When assembled, one end of the coils is joined with a copper jumper bar and the other ends connect to the power leads. The ferrite housing is made from G-10 laminate.

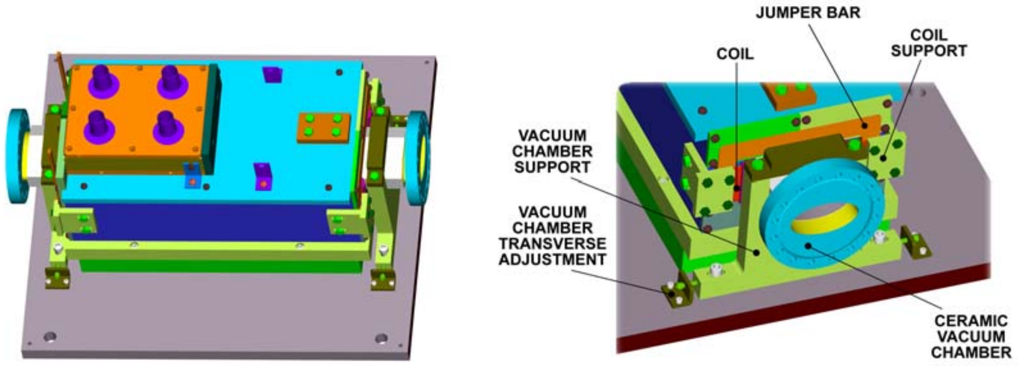

Fig. 3: Assembled storage ring kicker magnet.

The following were some of the guidelines considered in modifying this design.

- All surfaces of the ferrite must be aligned both vertically and horizontally when the magnet is assembled.
- The coil should be centered lengthwise inside the ferrite and held in place since it, along with the ferrite, affects the uniformity of the magnetic field.
- The assembly of these two components should be repeatable when the magnet is installed in the SR.
- The vacuum chamber should be centered within the aperture of the ferrite.

With these guidelines, the ferrite support base was machined to within 0.005-inch flatness tolerance to ensure that all surfaces of the ferrite are in the same vertical plane when assembled. The ferrite was aligned, surveyed, and pinned with 0.125-diameter brass dowel pins allowing for repeatable positioning of the ferrite after reassembly. This was also fiducialized to the base plate to ensure a more accurate placement to the beam orbit when installed in the SR. The ceramic vacuum chamber was independently supported from the ferrite and ferrite housing so that it could be adjusted both vertically and horizontally. Its position was surveyed and locked within 0.003-inch of the ferrite aperture center. L-shaped brackets made in two pieces with slots for adjustment were added to the side of the ferrite housing to support and hold the coil in a fixed position.

3.1 Ceramic Vacuum Chamber

The existing ceramic vacuum chambers shown in Figure 4, were designed with welded-bellows assemblies welded to both ends. The inside surfaces of the chambers are coated with a low-resistance conductive material, which adequately conducts image currents without significantly shielding the kickers' magnetic field [3]. Elevated temperatures are, however, measured on the flanges, vacuum chambers, and attached bellows during operation. Resistance measurements of this coating indicate that the coatings were inadequate or damaged, which lead to the increase in temperature [3].

Improvements in this design included detaching the bellows from the ceramic chamber. The chamber aperture, elliptical in shape, was reduced by 12.09 mm on the major axis and 2.65 mm on the minor axis, bringing it closer to the aperture of the SR vacuum chamber. The inside surfaces of the ceramic chambers were metallized with moly-manganese (Mo-Mn) to an average thickness of approximately 10 μm.

4. Bellows and Liners

All bellows assemblies installed in the SR beam path are shielded from beam image currents and rf energy with finger-type spring contacts or a combination of spring contact fingers and rigid sleeve liners. These liners span the bellows convolutions, making contact with the mating rigid sleeve into which it slides as the bellows extends or compresses during bake-out. Various arrangements of liners are used to suit each type of bellows assembly. Figure 5 shows one type of bellows assembly where all surfaces of the contact finger and rigid sleeve are enclosed inside the SR vacuum. In comparison, the mating rigid sleeve for the contact spring fingers shown in Figure 6 is an integral part of the bellows assembly. The force generated by the deflection of the spring fingers creates the necessary contact between the rigid sleeve and the spring fingers. The design of the bellows and liners in the current kicker magnet chambers are such that they could not be hardened after they were brazed and they made very poor contact with the mating sleeve.