Injection Section Upgrading with the Septum-Magnet Replacement in KEK-PF Ring

In 2015, a water leakage occurred in a cooling pipe of the in-vacuum septum magnet installed in the injection point. Since it was desired to replace the septum magnet with the out-vacuum type to facilitate maintenance, upgrading of the injection section was simultaneously planned to improve the injection efficiency. In this upgrade, the injection beam is closed to the stored beam more than before by adopting a thinner septum structure to improve the injection efficiency. Improvements were also made to part of the monitor and beam duct, such as a real-time beam monitor and thinner Inconel duct [1].

In the KEK-PF, upgrading of the injection section was scheduled to be carried out during the accelerator shutdown period in the summer of 2020 to renew the pulse septum 2 (Sep2). There are two in-vacuum pulse septum magnets in the ring injection section and the pulse Sep2 is placed furthest downstream in the beam transport line. Two approaches were proposed to solve the problems. One was to improve the cooling performance including heat dissipation by using an in-air type septum magnet to increase the ease of maintenance and operation. The other was to review the injection point parameters and to design the injection point to have the smallest physical aperture in the ring. This reduces the relative distance between the stored beam and the injection beam from 15 mm to 9.85 mm, and decreases the probability of injection beam loss. Additionally, the bump orbit height is also lowered from 19 mm to 12.5 mm. The distance of the chamber wall from the stored beam at the injection point is reduced from 21 mm to 16 mm. These two improvements are expected to improve the injection efficiency and also to suppress the horizontal oscillation of the stored beam during top-up injection since the bump height is reduced by about 6 mm due to the closer proximity of the injected beam to the stored beam. The theme of these improvements is to modify the injection section to ensure a stable supply of synchrotron light in regard to future upgrading of the PF.

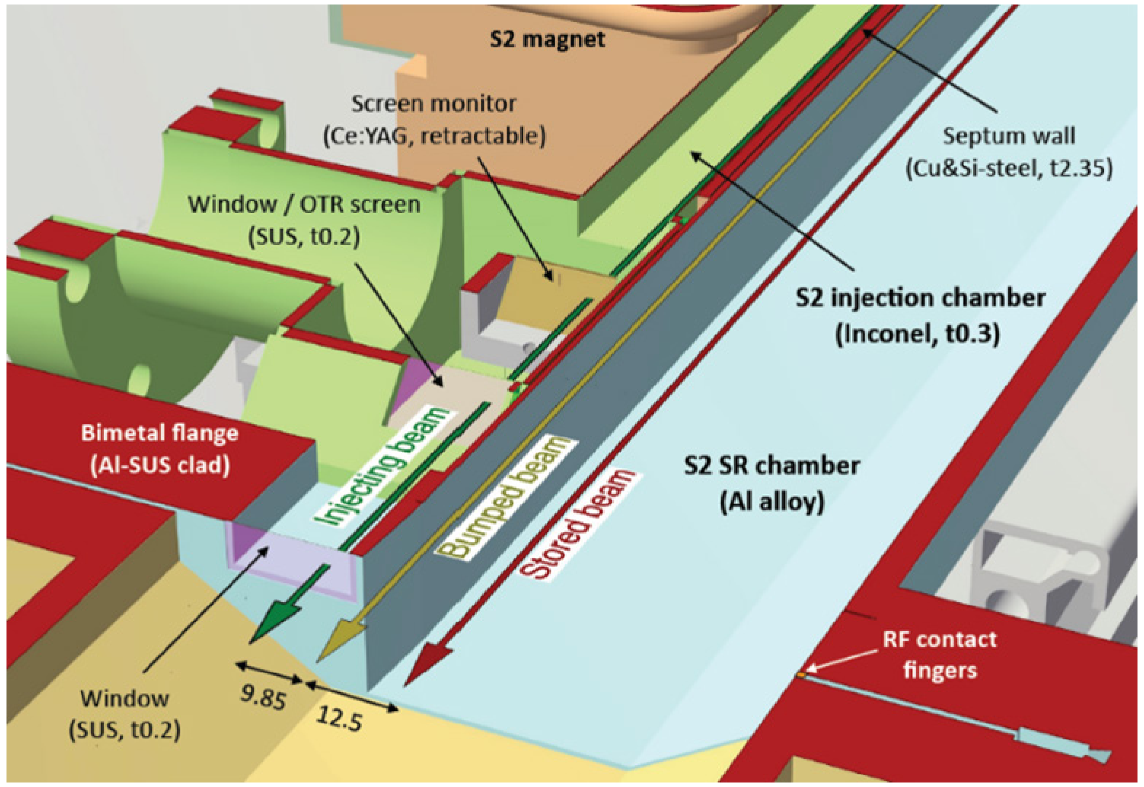

Figure 1: Configuration of the vacuum chamber at the PF ring injection area after modification.

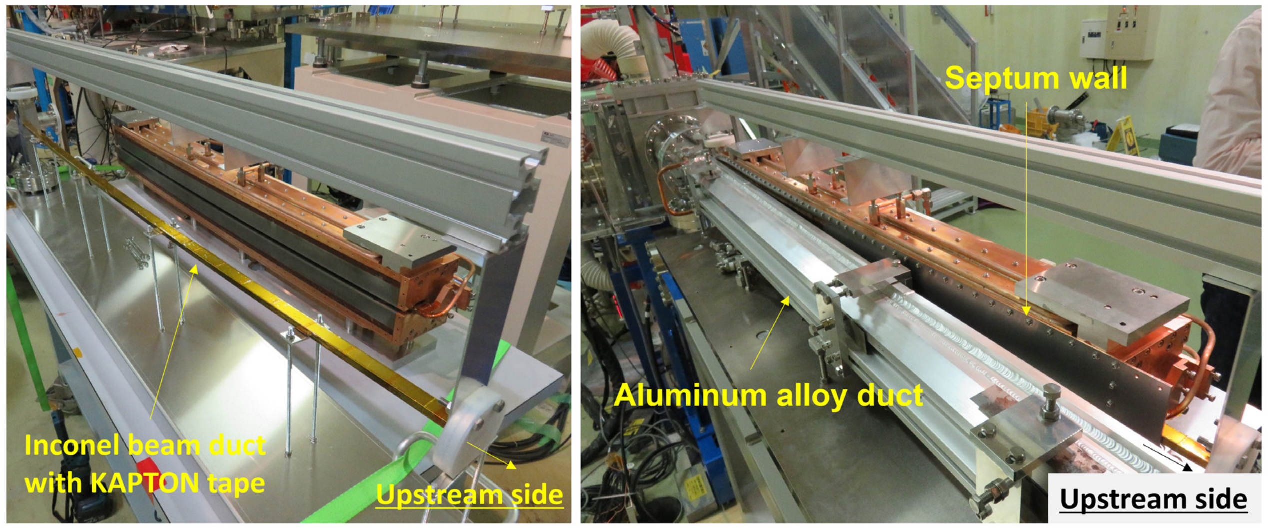

Figure 2: Installing the thin Inconel duct into the septum 2 gap (left picture). The final setting of beam chambers (right picture).

In the upgrade of the injection section, two new technical challenges were tackled. The first one was to reduce the shielding effect due to eddy currents in the pulsed magnetic field by using an Inconel chamber as thin as 0.3 mm. This enables us to adopt a simple in-air type septum magnet with a reduced vertical gap and to provide sufficient magnetic field strength even with the existing power supply. The second one was to utilize one of the 0.2 mm-thick stainless steel (SUS) windows facing the air gap as a full-time OTR monitor, which provides a complementary system of monitoring the position and profile of the injecting beam with GigE digital camera systems (see **Fig. 1**).

In the basic design of the new Sep2 vacuum chamber, we decided to follow the same concept as we adopted for the upgrade at PF-AR [2]: a 47 mm-long air gap is formed by two SUS foils each 0.2 mm thick, by which the ultra-high vacuum in the storage ring is isolated from the beam transport line. This is beneficial in cutting the eddy current loop induced by the pulsed magnetic field. This current loop can be a source of stray magnetic fields that cause horizontal oscillation of the stored beam [3]. To reduce the attenuation of the pulsed magnetic field due to eddy currents, the new chamber is made of Inconel-718, whose electrical resistivity is about 1.7 times higher than that of SUS304, and the thickness of the chamber is reduced to 0.3 mm. This reduces the magnetic field attenuation rate to 3.8% compared to 6.2% for SUS chambers of the same thickness, enabling operation at 1.3 kV with a margin of 0.2 kV for the rated voltage of the pulse power supply (the recharge time is also reduced by about 15% to 40 ms, but 25 Hz repetition is difficult). The new stored beam chamber is made of aluminum alloys, A6063 and A5052, with high thermal conductivity as in the other sections of the ring. The aluminum alloy chamber, which is about 2.1 m long, receives 322 W of synchrotron radiation (when 450 mA is stored) on its gradually tapered surface toward the injection point and removes heat through cooling water flowing in aluminum channels welded to the top and bottom outer surfaces of the chamber.

As soon as the accelerator was shut down in July, the alignment confirmation work to preserve the current status of the magnet was started. During September, the equipment was placed and assembled according to the design, and the construction was completed (see **Fig. 2**). User operation was started without any failures, then stable top-up operation at the new injection section was performed on schedule.

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