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INJECTION SECTION UPGRADING WITH THE SEPTUM-MAGNET REPLACEMENT IN KEK-PF RING

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Abstract

The injection section of the KEK-PF ring was upgraded in 2020. The main purpose of the upgrade is to recovered the reduced injection efficiency caused by the water leakage trouble which was happened at the cooling pipe of the in-vacuum septum magnet installed into the injection point in 2015. Because the water circulation was stopped permanently, and accordingly, the light absorber was installed upstream in the storage ring to prevent the synchrotron light of the bending magnet from coming to the septum wall. With the desired replacement of septum magnet to maintainable out-vacuum type, the injection section upgrading was simultaneously planned. In this upgrade, the injection beam is brought to the stored beam more than before by adapting the thinner septum structure. In addition, some new technical challenges are introduced in the part of monitor and beam chamber, for example, fulltime OTR beam monitor of beam window and thin Inconel out-vacuum septum chamber.

INTRODUCTION

In KEK-PF, the upgrading of the injection section was scheduled to be carried out during the accelerator shutdown period in 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 most downstream in the beam transport line. The old vacuum vessel and water-cooling pipes had been used since 1988. In April 2015, the water-cooling pipe in the Sep2 vacuum vessel leaked due to degradation over many years of machine operation and user operation had to be suspended. In 2017, the water-cooling piping was closed and an absorber was inserted in the storage ring side upstream of the injection point to 15 mm from the stored beam orbit to prevent the temperature rise due to the heat input of direct synchrotron radiation from the bending magnet of storage ring. As the result, the continuous user operation was secured, but the injection efficiency was deteriorated to less than 30% due to the loss of a part of the injection beam by the absorber. This low injection efficiency was detrimental to the stable supply of synchrotron light to user beam line and urgently needs to be improved.

UPGRADINGS OF INJECTION SECTION

Two treatments were proposed to solve the problems. One is to improve the cooling performance including heat dissipation by using an in-air type septum magnet in order to increase the maintainability and operability. This allows us to remove the absorber as an additional measure. The other is 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, which has been opaque since the Tohoku earthquake, and decreases the probability of the 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 stored beam at the injection point is reduced from 21 mm to 16 mm, and the existing storage ring chamber downstream having a horizontal aperture of 45 mm completely enclose both the new injection and storage beam chambers. There are some waist points of the physical aperture in the PF ring. One of the reason of beam loss in the ring is that the relative distance between stored beam orbit and injection beam orbit is larger than the waist points. Another one is that general parallel bump orbit which is made by four bump kickers could not be obtained because the three bump kickers were used to make a triangle bump orbit to prevent the stored beam from hitting to the inserted absorbers. This condition had been loosing controllability of either an angle or height in bump orbit tuning. As a result, this loss of operability made it difficult for the injection beam to pass simultaneously through the multiple waist points without loss. These two improvements are expected to recover the injection efficiency and also to suppress the horizontal oscillation of the stored beam at the 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 ”The modification of the injection section for stable supply of synchrotron light” in a point of view of the future upgrading of the PF.

PARAMETERS AT INJECTION POINT

Any changes were not adopted on lattice design in this injection section upgrading. The horizontal dispersion and beta function are preserved 0.6 m and 9.5 m respectively at injection point. Only the renewals of the beam chamber and equipment accompanied with the replacement of Sep2 magnet were carried out. Figure 1 shows the parameters at the injection point. Standard deviation of injection beam and stored beam sizes were 0.5 mm and 0.7 mm respectively, and each vacuum chamber is so designed as to keep a tolerance of 5 σ of beam sizes. The surface of septum wall at the storage-ring side was placed at 16 mm from stored beam orbit so that the physical aperture became minimum in the

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injection section of PF ring. The septum wall consists of the aluminum alloy chamber of 1 mm thick for stored beam, the silicon steel of 0.35 mm thick, the copper plate of 2 mm thick for eddy current shielding, Kapton insulation sheet of 0.2 mm thick, and Inconel chamber of 0.3 mm thick for injection beam. The whole thickness of septum wall is 3.85 mm. The injection beam was arranged far away from the inner surface of Inconel beam chamber by 5 times standard deviations of injection beam size. The bump orbit on stored beam was also risen up to 12.5 mm, where the stored beam on the bump orbit was placed from the septum wall by 5 times standard deviation of stored beam size.

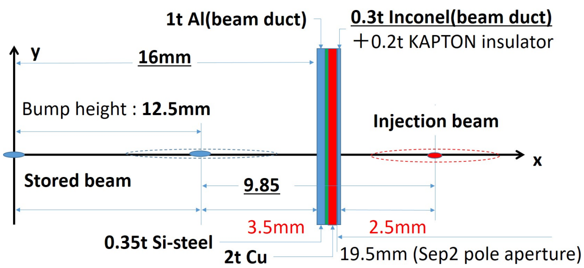

Figure 1: The beam arrangement and septum wall structure at injection point.

TECHNICAL CHALLENGES WITH UPGRADING

In the upgrade of the injection section, two new technical challenges are adopted. The first one is to reduce the shielding effect due to eddy currents on the pulsed magnetic field by using the 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 is 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. The window at the end of the injection chamber tilted at 45 degrees so as to detect the OTR emission through a view port at the bottom of the monitor chamber. The vacuum surface of the SUS window is buffed to a mirror condition to observe the OTR. This utilization of SUS foil added new value to the air gap. An actuated YAG screen monitor is also installed in the same chamber for precise monitoring. In order to mitigate the heat input to the septum wall, the septum wall of the storage beam chamber is thin at the injection point, but thickness of that toward the upstream is increased to enhance the structural strength, and a tapered aperture is spread in the space between the septum wall and Sep1 which is placed upstream of Sep2 to accept the synchrotron radiation widely. New stored beam chamber is made of aluminum alloy in order to dissipate the input heat and water cooling pipes are installed to remove the heat input. This structural modification contributes to the improvement of the injection efficiency by reducing the insertion depth of absorbers upstream of injection point to 37 mm from the stored beam orbit. There were some issues which should be considered when the new technical challenges were proposed. The first point is the radiation control problem of beam loss due to the air gap of 48 mm by using SUS foil separator. According to the calculation results of the beam loss, the production ratio of allowable radionuclides to the limit of air concentration is 10^6, which is very small and only about 4% increase from the current level. The second point is the consistency of the beam orbit in the existed beam transport line when the Sep2 are moved closer to the storage ring to bring the injection beam closer to the stored beam. The injection beam orbit can be connected from the junction with the beam line to the PF dump point to the injection beam point nearest the septum wall with a small realignment of the downstream magnets. The Fig. 2 shows the designed view of completion in the injection section upgrading.

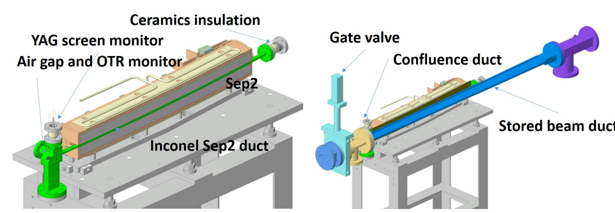

Figure 2: Overview of the injection section upgrading.

DESIGN OF THE VACUUM CHAMBERS

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 [1]: 1) in-air type septum magnet and 2) air gap structure between injection and storage ring chambers. The former has an advantage in simplicity and solves a longtime problem of the previous in-vacuum Sep2 magnet; high operating pressures caused by large outgassing from laminated electrical steel sheets of the magnet and by constant leakage or gas permeation through a large Viton O-ring gasket. The 47 mm long air gap is formed by two SUS foils of 0.2 mm thick each, by which the ultra-high vacuum in the storage ring is isolated from the beam transport line and the maintainability of the vacuum system is improved. The latter is beneficial in cutting an eddy current loop induced by the pulsed magnetic fields and in the maintainability of the injection section vacuum system. The current loop can be a source of stray magnetic fields that cause horizontal oscillation of the stored beam [2, 3]. For complete suppression of the loop current, the downstream side of the Sep2 injection chamber is insulated by a short ceramic pipe and the entire chamber supports are isolated from ground by inserting fiberglass laminate (G-10) blocks. The configuration of the new vacuum chamber is shown in Fig. 3. The features of the two types of new beam chambers are summarized below.

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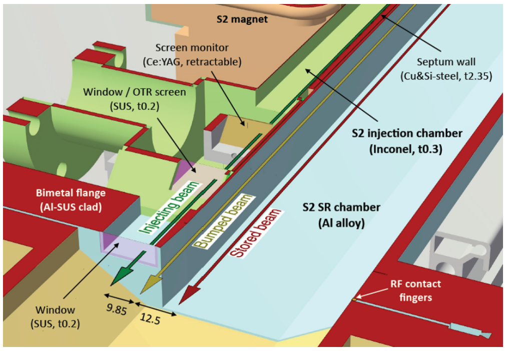

Figure 3: Configuration of the vacuum chamber at the PF ring injection area after modification.

Injection Beam Chamber

In the case of the in-air type septum magnet, the beam chamber must have high permeability to the pulsed magnetic field. In order to reduce the attenuation and delay of the pulsed magnetic field due to eddy current, 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 Inconel chamber which has an 8.0×16.4 rectangular cross-secion is installed inside the Sep2 magnetic pole, insulated with Kapton sheets. The 0.3 mm thick SUS304 chamber has been used for the PF-AR injection beam chambers [1], and this time, the solid solution hardened Inconel-718, which has about twice the tensile strength of SUS304, is used to improve the robustness. We have succeeded in manufacturing the thin Inconel chamber using fiber laser welding. This technology is expected to be applied to narrow chambers for such as fast corrector in the future. The SUS chamber for the two types of beam profile monitors is welded directly downstream of rectangular Inconel chamber.

Stored Beam Chamber

Since the injection beam is injected from the outside of the ring, the synchrotron radiation irradiates on the Sep2 magnet side. 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. In order to bring the injection beam to the stored beam as close as 9.85 mm, the aluminum chamber wall on the Sep2 side is placed as close as 16 mm from the stored beam orbit and machined to have a thickness of 1 mm. After traveling through the air gap of 47 mm, the injection beam enters into the storage ring through a 0.2 mm thick SUS304 foil which is laser-welded to the SUS flange surface of Al-SUS cladding material.

CONSTRUCTION PROCESS

The design plan, which took six months to develop in the second half of fiscal year 2019, was materialized the fiscal year 2019, and fabrication was carried out in parallel to meet the construction period in summer of 2020. As soon as the accelerator is shut down in July, the alignment confirmation work to preserve the current status of the magnet was started. Preparations for installation of new equipment were done such as pre-baking of vacuum equipment and opening of vacuum atmosphere, excitation test using injection beam prototype chamber, measurement of magnetic field leakage from septum wall in middle of August. In September, we started dismantling the site to meet the delivery date of the main components. During September, the equipment was placed and assembled according to the design, and the construction was be completed and a comprehensive operation test will be conducted 10 days before the start of the PF ring accelerator start-up and tuning on October 14. The construction work was progressing smoothly as if to make up for the delay of almost a month, thanks to the careful preparations made before the summer, such as the assembly drawings, sufficient material prochamberion, easy-to-handle assembly jigs., An Inconel thin chamber with a monitor box was inserted into the narrow gap of the Sep2 and installed at the designed injection point at -50 μm horizontally toward the storage ring, -2 mm longitudinally upstream of the beam transport line, and -200 μm vertically. In the vertical and longitudinal directions, the installation errors due to the fabrication errors of the chambers were allowed. These errors will be absorbed by the beam operation tuning. Figure 4 shows the scene before the installation of Inconel thin chambers in the Sep 2 magnet and a close view of the injection section after the septum magnet has been moved. Only Inconel chamber fabrication was delayed more than one month because of production difficulty, but the user operation was started without any failures, then the stable Top-Up operation at the new injection section was succeeded on schedule.

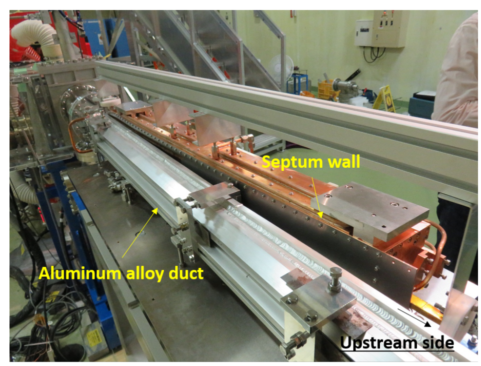

Figure 4: The final setting of beam chambers.

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