CONSTRUCTION OF THE NEW SEPTUM MAGNET SYSTEMS FOR PF-ADVANCED RING

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Abstract

A new beam transport (BT) line for the Photon Factory Advanced Ring (PF-AR) was constructed from July 2016, and the commissioning of this new BT line was finished in March 2017. For this project we designed and produced new pulsed septum magnet systems. The septum magnet was constructed as a passive type magnet, with a copper eddy current shield and a silicon steel magnetic shield, and the extended septum wall for reducing leakage field from the septum magnet gap.

The magnetic fields were measured using a search coil method. We paid attention to evaluating eddy current losses of the SUS beam duct in the magnetic field measurement.

INTRODUCTION

The PF-AR shares the injector linac (LINAC) with other three storage rings, High Energy Ring (HER), Low Energy Ring (LER) of Super KEKB and Photon Factory storage ring (PF-ring).

During the successful operation of the KEKB Factory, a simultaneous injection to these three rings had been completed. The LINAC became able to supply electron and positron of different energies by a pulse-by-pulse switching. But only the PF-AR was left behind from the simultaneous injection because the half of its BT line was shared with the HER which had injection energy different from the PF-AR. The PF-AR was injected at 3 GeV and accelerated to 6.5 GeV after the storage. On the other hand, the HER was a full-energy injection of 8 GeV. So the DC magnets of the shared BT line had to be reset, and the interlock system of the LINAC permitted only an isolated injection to the PF-AR as before.

The injection of the other rings was usually interrupted by PF-AR for about 20 or 30 minutes.

This interruption is never compatible with the future physics run of the Super KEKB, because their life time is estimated about as short as 10 minutes. A continuous injection without any interruption for HER and LER will be mandatory. In order to make the operation of PF-AR compatible with the future Super KEKB, we constructed a new BT line designed to transport the full energy 6.5 GeV beam directly from the LINAC to the PF-AR. The injection point has also been moved, and the new injection section including the septum and kicker magnets has been developed.

In March 2017, the commissioning of full energy injection of PF-AR using the new BT line was completed successfully. The simultaneous injection with the other three rings will be realized combined with the reinforcement of the LINAC before a constant physics run of the Super KEKB will start [1], [2], [3].

LOCATION OF THE SEPTUM MAGNETS IN THE NEW INJECTION SECTION

An old BT line of the PF-AR connected to the south-eastern part of the PF-AR and upstream part of the BT line shared with that of KEKB HER. On the other hand, the new BT line was connected from the LINAC end to the south-western part of the PF-AR in an approximately straight line, and it is a dedicated BT line for the PF-AR.

Layout of the new injection section at the PF-AR and location of the septum magnets are shown in Fig 1.

Two pulsed septum magnets (SI, SII) and a DC septum magnet (S0) are located on the end of the BT line. The deflection angle of each septum magnet is 3degrees.

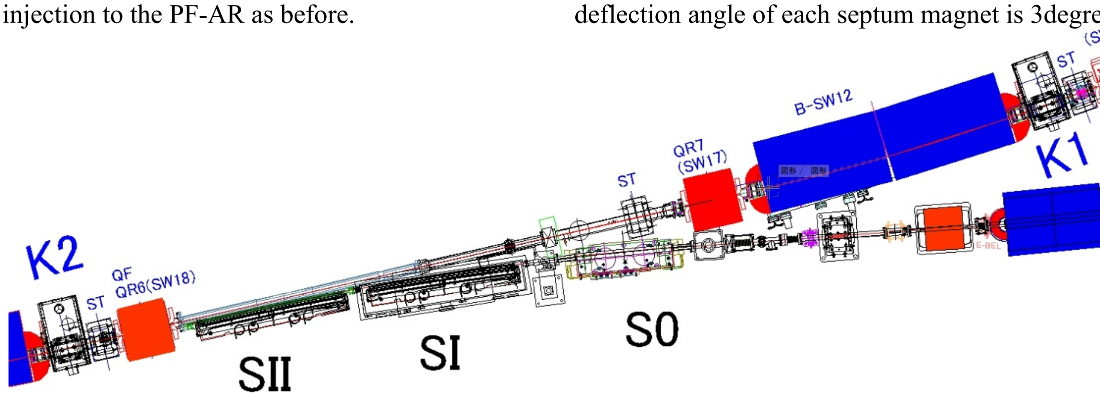

Figure 1: The new injection section at the south-western part of the PF-AR. There are two pulsed septum magnets (SI and SII) at end of the BT line and three kicker magnets before and behind the new injection point.

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SEPTUM MAGNET SYSTEMS

We produced two septum magnet systems including power supplies, high voltage cables, matching boxes, and septum magnets. The specifications of these two set of septums are almost the same. The difference between SI and SII is whether installed in the vacuum or not, and only SII has a 40-mm extended septum plate to reduce leakage fields affecting the stored beam. The SII magnet and the vacuum chamber containing the SI magnet are shown in Fig 2; it was an image taken before the installation of the vacuum ducts of the storage ring.

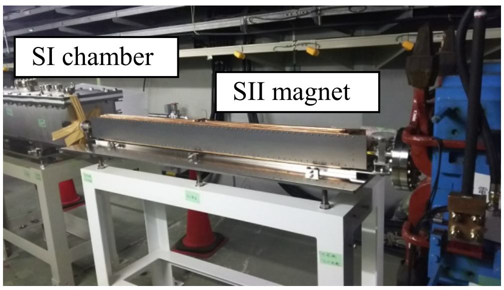

Figure 2: SII magnet and the vacuum chamber containing the SI magnet. The vacuum duct of the storage ring side has not yet been installed then.

The power supplies of the septum magnets produce a half-sine current pulse. The maximum peak current is 8000 A, a pulse width is 100 μsec, and the maximum repetition rate is 12.5 pulses per second. The power supplies were installed in the machine room on the ground. The current pulses are led from the power supplies to the septum magnets in the underground ring tunnel by using six parallel-connected 25-Ω coaxial high voltage cables via matching boxes placed in front of the septum magnets.

The SI and SII were a passive type magnet made of a laminated silicon steel core equipped with a 2-mm thick copper eddy current shield and a 0.35-mm thick silicon steel magnetic shield. The laminated silicon steel core was contained in a copper box, and the box was impregnated by polyimide resin insulating the cores and fixing an inner coil. The septum plates were fixed on the front of the copper box using screws [4]. The cross-section of the septum magnet and the appearance of the SII magnet are shown in Fig. 3. The SII magnet has a 40-mm extended septum plate, and 0.3-mm thick rectangular vacuum pipe are laid in the magnetic gap. Principal parameters of the septum magnet systems are listed in Table 1.

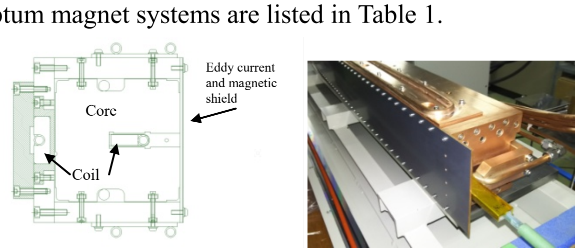

Figure 3: Cross section of the septum magnet (left) and SII magnet (right). SII magnet has an extended septum plate and tin vacuum pipe within the gap.

Table 1: Parameters of the Septum Magnet Systems.

Maximum peak current	8000 [A]
Maximum DC voltage	3 [kV]
Pulse width	100 [μsec]
Maximum repetition rate	12.5 [p.p.s]
Number of coil turns	1 [turn]
Magnet gap height	10 [mm]
Magnet length	1.5 [m]
Magnet gap width	23 [m m]
Inductance of the magnet	7 [μH]
Material of the magnet	silicon steel:35H600 NSSMC

RESULTS OF THE MAGNETIC MEASURMENTS

Decay of the Magnet Field with the Thin SUS Pipe

The magnetic fields of the septum magnets were measured using a search coil. The magnetic field pulse could be deduced by integrating the signal of the search coil [5].

The measurement results are shown in Fig. 4. The left photo shows current pulse (blue line) and magnetic field pulse (red line) measured without the vacuum pipe, and the right photo shows them measured with the thin vacuum pipe. The delay and decay of the magnetic field due to an eddy current effect of the thin vacuum pipe were determined at 9.1 μsec and 3.7%, respectively..

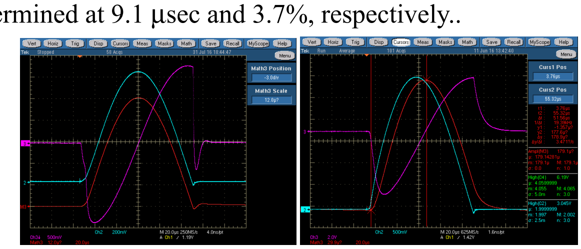

Figure 4: Septum pulse measured without (left) and with (right) the thin vacuum pipe. The blue line is a current pulse, the red line is a magnetic field pulse and the rose line is a signal of the search coil.

The excitation curve of the septum magnet and the magnetic field distribution along the beam line were measured with and without the vacuum pipe (See Fig. 5). The distribution of the magnetic field was recorded by moving the search coil along the beam direction and the effective length was estimated at 1506 mm.

The relations of deflections angle vs. current for the SI and SII were determined as follows,

θ [degree] = 4.92e-4 x I [A]-2.65e-2
(SI: in the vacuum)

θ [degree] = 4.74e-4 x I [A]-1.79e-2
(SII: using with the thin vacuum pipe)

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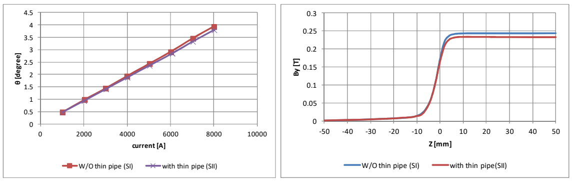

Figure 5: The excitation curve of the septum magnet (left) and the magnetic field distribution along the beam line (right).

The Leakage Field Caused by the Eddy Current of the Septum Plate

The passive type septum magnet is equipped with a copper eddy current shield to extinguish a leakage field outside of the septum plate. However a leakage magnetic field having a lower frequency component than the current pulse possibly occurs by the eddy current in the septum plate [6].

The measurement of the leakage filed beside the septum plate is shown in Fig. 6. The long leakage field pulse (red) was recorded behind the septum current pulse (green). To reduce the slow leakage field, we added a 0.35-mm silicon steel plate on the 2-mm copper shield.

The shield effect of the silicon steel is shown in the right plot of Fig. 6. The leakage field of about 250 Gauss in the case of single copper shield could be reduced to about 3 Gauss when the silicon steel shield was added.

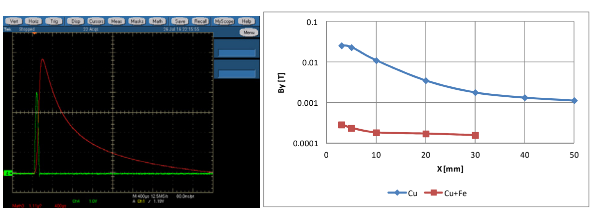

Figure 6: The left photo is the leakage field pulse shape (red) recorded after the septum current pulse (green). The right graph shows the reduction of the leakage field by adding 0.35-mm silicon steel plate.

The Leakage Field from the Septum Magnet Gap

The leakage field from the end of the septum magnet gap is also possible to influence the stored electron beam. To reduce this leakage field, the septum plate of the SII was extended by 40 mm toward the injection point (see Fig. 3).

We measured the leakage field along trajectory line of the stored beam. The measurement result is shown in Fig. 7. The left graph is in the case of a normal septum plate and the right graph is in the case of the extended septum plate. The horizontal axis is a path length along the beam trajectory and the origin is the edge of the septum core. The blue line expresses a leakage field at a distance of 15 mm apart from septum plate. The red line and purple line are at 20 mm (position of the kicker bump) and 45 mm (position of the sorted beam), respectively.

As show in Fig. 7, it was confirmed that the leakage field from the gap could be reduced effectively by the extended plate, and the leakage field was suppressed to less than 25 Gauss.

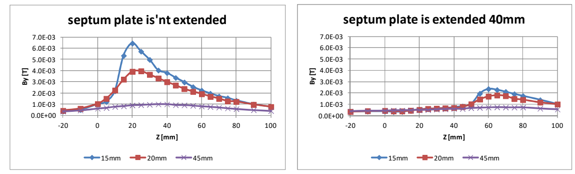

Figure 7: Leakage field from the magnet gap. The leakage field behind the septum magnet could be reduced by the extended septum plate.

CONCLUSION

We designed and produced new pulsed septum magnet systems for the new BT line of the PF-AR. We evaluated the magnetic field including eddy current losses of the SUS beam duct. And we measured and optimized a leakage fields caused by eddy current of the septum plate and from the septum gap. Both leakage fields could be reduced effectively by superimpose of 2-mm copper shield with 0.35-mm silicon steel shield and the extended septum plate.

In March 2017, the commissioning of the new BT line was over successfully.

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