CONSTRUCTION OF THE NEW KICKER 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 kicker magnet systems. The kicker magnets were designed as a window frame type ferrite core magnet.

The magnetic fields measured by a search coil method. We paid attention to evaluating eddy current losses of the metal coated ceramic duct. The impedance of the matching box was carefully adjusted minimize the undesired kick of the stored beam.

INTRODUCTION

The injector linac (LINAC) of the PF-AR is shared with other three storage rings, High Energy Ring (HER), Low Energy Ring (LER) of Super KEKB and Photon Factory storage ring (PF-ring). The LINAC can supply electron or positron beam simultaneously to these storage rings by pulse-by-pulse switching.

But only the injection to the PF-AR had been exclusive, because its BT line was shared with the HER with different injection energy. The PF-AR interrupted the other rings' injection for about 20 or 30 minutes during the injection at 3GeV and the acceleration of the accumulated beam to 6.5 GeV.

Such interruption will not be compatible with the future physics run of Super KEKB because its beam life time is estimated only 10 minutes, a continuous injection for HER and LER will be inevitable.

In order to solve this problem, we have constructed a new BT line and a new injection system compatible with a 6.5 GeV full energy injection. The BT line has connected the LINAC end to the new injection point of the PF-AR at an almost straight line. The simultaneous continuous injection of all four rings will be realized before a constant physics run of the Super KEKB will start.

In March 2017, the commissioning of the new BT line was finished successfully [1], [2], [3]. In this paper, we will report on the development a kicker system for the PF-AR.

LOCATION OF THE KICKER 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 the upstream half of the BT line had been shared with that of the KEKB HER.

On the other hand, the new BT line connects the LINAC end and the south-western part of the PF-AR in an approximately straight line, and it becomes a dedicated BT line for the PF-AR.

The layout of the new injection section of the PF-AR and the location of the kicker magnets are shown in Fig. 1.

Three kicker magnets (K1, K2, and K3) were installed around the injection point to form a pulsed bump orbit. Each kicker magnet has a maximum deflection angle of 1.8 mrad for 6.5 GeV electron beam.

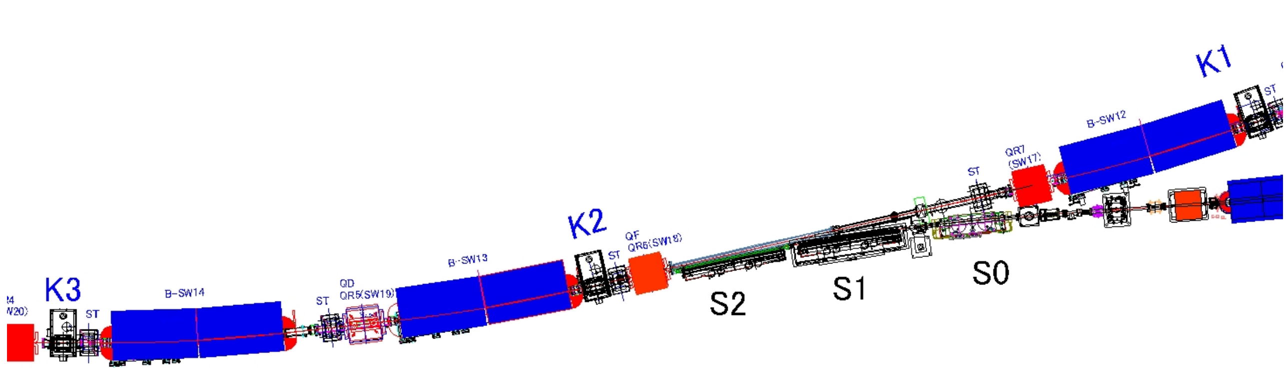

Figure 1: The new injection section at the south-western part of the PF-AR. There are two pulsed septum magnets (S1 and S2) at end of the BT line and three kicker magnets before and behind the new injection point.

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KICKER MAGNET SYSTEMS

We produced three sets of kicker magnet systems including a power supply, high voltage cables, a matching box, and a kicker magnet. The kicker magnets were designed as a window frame type ferrite core magnet and were installed on the matching box as a frame stand. Finally, it was covered by a shield box. (See Fig. 2).

The ceramic duct was installed in the gap of the kicker magnet. The inside of the ceramic duct was coated by titanium of 3 µm thick to sufficiently reduce the impedance for the electron beam.

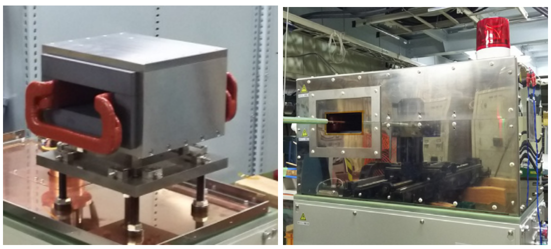

Figure 2: The kicker magnet. The main body (left) is covered with shield box (right). The search coil is insert in the magnet gap for magnetic field measurement and the XYZ stage is reflected in the shield box (right).

The kicker power supply output a half sine current pulse of the maximum peak current 3500 A. The pulse width was 2.4 µsec, and the maximum repetition rate was 12.5 pulses per second.

The power supplies were installed in the machine room on the ground level. The PF-AR ring tunnel is underground 5 m. The kicker magnet and the power supply were connected by using two parallel-connected 25-Ω coaxial high voltage cables via a matching box. We determined the impedance of the cable as 12.5 Ω to lower the power supply voltage [4].

Figure 3 shows the output waveform of the kicker power supply. The peak shape of the half-sine wave was distorted because of the impedance mismatch between the matching box and the cable. The reason why the impedance mismatch remained will be described below. There was a rather large undershoot, and the ringing continued after the main pulse.

The revolution time of the PF-AR is 1.257 µsec, so the magnetic field pulse of the kicker magnet should be less than 2.514 µsec. By taking into consideration that the pulse width of the magnetic field becomes slightly longer than that of the current due to the eddy current of the Ti coating inside the kicker duct, so we determined the current pulse width as 2.4 µsec.

The reason why the large undershoot and the ringing appeared was as follows. The multi-gap thyratron has a long recovery time; the recovery time of the E2V CX1175C (2-gap thyratron) was longer than 50 µsec. Therefore we had to use a high voltage diode to prevent the flow of reverse current. Since this diode had a reverse recovery time of 0.5 µsec, the reverse current flows in the circuit for 0.5 µsec caused the large undershoot and ringing.

The ringing after the main pulse possibly affected the stored beam. To minimize the undesired kick for the stored beam, the impedance of the matching box was adjusted as 25 Ω instead of the cable impedance of 12.5 Ω. Because of this mismatch, the main pulse was slightly distorted but nodes of the ringing synchronized with the arrival time of the circulating beam. The PF-AR is always operated by a single bunch, so the interference of the ringing wave can be well avoided. (See Fig. 6 and Table 2) Parameters of the kicker magnet systems are listed in Table 1.

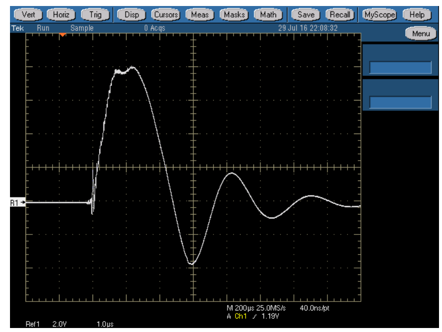

Figure 3: The current pulse shape of the kicker magnet. The large ringing wave is preceded after main pulse.

Table 1: Parameters of the Kicker Magnet Systems

Maximum peak current	3500 [A]
Maximum DC voltage	45 [kV]
Maximum repetition rate	12.5 [p.p.s]
Current pulse width	2.4 [µsec]
Magnetic field pulse width (with ceramic duct)	2.5 [µsec]
Magnet gap height	52 [mm]
Magnet length	250 [mm]
Magnet gap width	126 [mm]
Number of coil turns	2 [turn]
Inductance of the magnet	4.7 [µH]
Thyratron	E2V CX1175C
Material of the magnet	Ferrite : CMS10 Ceramic Magnetics

RESULTS OF THE MAGNETIC MEASUREMENTS

Decay of the Magnet Field with the Metal Coated Ceramic Duct

The magnetic fields of the kicker magnet were measured by using a search coil with and without the metal coated ceramic duct [5].

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Figure 4 shows the magnetic field pulse and the current pulse. The magnetic field waveform (red) accords with a current waveform (green) exactly without the ceramic duct. When the ceramic duct was inserted in the kicker magnet gap, the magnetic field pulse delayed and the pulse width became broad, due to an eddy current on the Ti coating of the ceramic duct. The pulse width of 2.386 μsec without the ceramic duct was extended to 2.546 μsec, and the pulse peak was delayed 0.059 μsec from the current pulse with the ceramic duct.

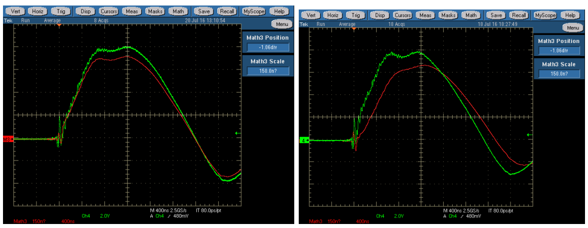

Figure 4: Kicker pulse measured without (left) and with (right) ceramic duct. Right wave form is warped by eddy current effect of the Ti courting.

The excitation curve of the kicker magnet and the magnetic field distribution along the beam orbit were measured with and without the ceramic duct (See Fig. 5).

The effective length was estimated 292 mm by the field distribution measurements. And from the measurement of the excitation curve, relations of the kick angle vs. current is determined as follows,

θ [degree] =6.21e-4 x I [A]-4.14e-2.

The attenuation of the magnetic field due to the eddy current of the Ti coating was estimated as 3.6%.

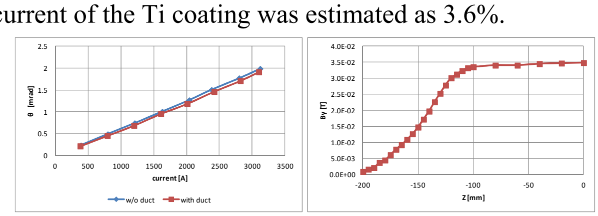

Figure 5: The excitation curve of the kicker magnet (left) and the magnetic field distribution along the beam line (right).

Beam Timings in the Kicker Pulse

As mentioned above, the ringing wave after the main kicker pulse interferes the stored beam at 1.26-μsec interval, because the PF-AR is operated by a single bunch.

Figure 6 shows the beam arrival timings in the kicker pulse. When the beam timing is adjusted to the zero cross at the point C, beam timings can be indicated by points A to E on the kicker pulse. If we assumed the peak of the magnetic field pulse (red) was 100% at the point B, the kick angle at each point is calculated as shown in Table 2. As a result, it is understood that the undesired kick angles on the stored beam can be suppressed less than 3.4%, so the influence of the ringing wave become no problem with the careful timing adjustment.

In the beam commissioning, the kicker timing was carefully adjusted while observing the oscillation of the injected beam. The injection efficiency of about 90% could be achieved [3].

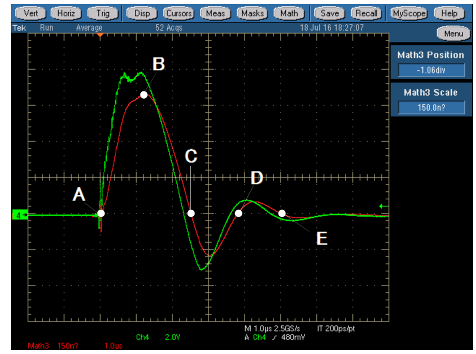

Figure 6: Beam timings in the kicker pulse.

Table 2: Kick Angle at Electron Beam Timings

A	B	C	D	E
3.4%	100%	0%	0.8%	2.3%

CONCLUSION

We designed and produced the new kicker magnet systems for the new BT line of the PF-AR. We evaluated the magnetic field with attention to the eddy current losses of the metal coated ceramic duct.

We determined the impedance of the matching box as 25 Ω . intentionally mismatched with the cable impedance of 12.5 Ω. The mismatch made the interval of nodes of the ringing wave synchronized with the revolution time of the stored beam. We could sufficiently reduce the influence of the ringing wave to the stored beam by the careful timing adjustment as the PF-AR was normally operated at single bunch mode.

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