PERFORMANCE OF THE COMPENSATION KICKER MAGNET FOR J-PARC MAIN RING

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Abstract

A compensation kicker magnet (CKM) for the main ring (MR) of J-PARC has been developed to correct the large betatron oscillation of the circulating bunches which were deflected by the reflection pulses of an injection kicker magnet (IKM) for the MR. Two lumped-constant type kicker magnets which are designed as a window-frame with a ferrite yoke are employed. A ceramic vacuum duct which a thin TiN layer was spattered onto the inner surface were installed at the center of the magnet. The magnetic field was measured by using a small pickup coil and a long coil to evaluate the kick strength. The CKM have been installed at 80m downstream from the IKM on January 2016. The excitation timing and the current were optimized to minimize the betatron amplitude of the circulating bunches which were kicked by the residual field. As the result, the beam loss was decreased successfully. Since February 2016, the CKM has been operated for the user operation. In this paper, the basic design, the result of the standalone test and the beam test are discussed.

INTRODUCTION

J-PARC (Japan Proton Accelerator Complex) consists of three accelerators; a 400 MeV Linac, a 3 GeV Rapid Cycle Synchrotron (RCS) and a 30 GeV Main Ring (MR). The MR provides a high intensity proton beam to the long baseline neutrino experiment (T2K) and the hadron experiments. In 2016, the beam power of 390 kW with 2e14 protons per pulse (ppp) are provided for the T2K experiment in the cycle of 2.48 s.

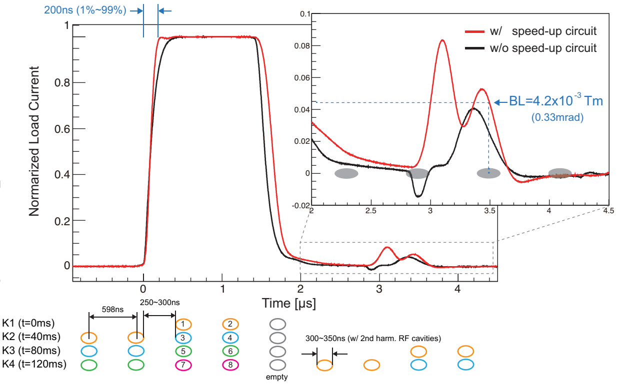

Figure 1: Pulse waveform of IKM.

Figure 1 shows the pulse waveform of the IKM for the MR. Four injection timing signals (K1-4, 40 msec interval) are synchronized to the extraction timing of the RCS. For each timing, the IKMs are excited to deflect two proton bunches into the circular orbit. While the rise time of less than 200ns (1%-99% of the full strength) was achieved after mounting additional circuits (so-called "speed-up circuit") to introduce the 2nd harmonic RF cavities which improve the bunching factor [1], two reflection peaks were appeared [2]. The circulating bunches (#1 bunch at K3, #2 and #3 bunches at K4) were kicked additionally by the residual field (approximately 4.2×10^{-3} Tm). It caused the coherent oscillation which induced the beam loss during the injection period [3]. Therefore, two CKM systems were required to compensate the extra-kick of the beam. Two independent magnets were developed to correct the #2 and #3 bunches deflected at K4 timing.

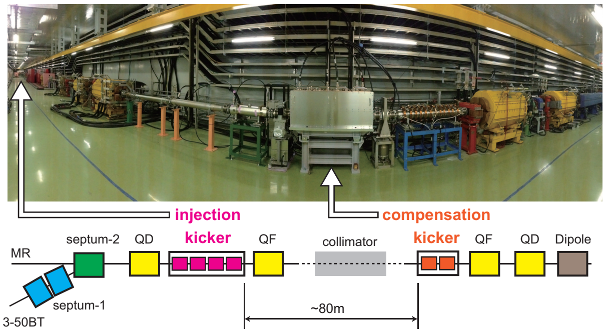

Figure 2: Picture and schematic drawing of the injection straight section of J-PARC MR.

The MR injection system is integrated into one of three long straight sections as shown in Fig. 2. No free space was left just behind the IKM to install a new device. Considering the vertical phase advance, the CKM has been installed at 80m downstream from the IKM.

KICKER SPECIFICATIONS

The main parameters of the CKM system are listed in Table 1.

SYSTEM DESIGN

Magnet

Figure 3 shows a cross section and a schematic drawing of the CKM. Basic concept of the structure of the CKM is similar to the IKM [4, 5]. Main difference is the ceramic vacuum duct installed at the center of the magnet. In case of the IKM, all components except for the matching circuit was installed in a vacuum chamber. On the other hand, all components of the CKM are placed in the air because of the lower applied voltage than the IKM. Inner diameter of the

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Table 1: Kicker System Parameters

Item	Design Value
Max. kick strength [Tm]	6.1×10^{-3}
Magnet length [mm]	470
Physical Aperture [mm]	$\phi 130$
Magnet inductance [nH]	450
Number of magnets	2
Termination resistance [Ω]	5
Max. charging voltage [kV]	40
Max. peak current [kA]	1.4
Pulse width [μs]	0.4

duct was decided as 130 mm which is the same size of the stainless beam pipe. The available free space for the CKM limits the duct length to 1560 mm. Two ceramic ducts with 700 mm length were brazed each other due to the restriction of the ceramic sintering furnace. Inner surfaces of the ducts were coated with a TiN (100 nm thickness) to suppress the secondary electron emission. Then titanium made sleeves were connected at the both end of the duct, and the TiN were spattered again onto the inner surface to connect electrically with the stainless beam pipe.

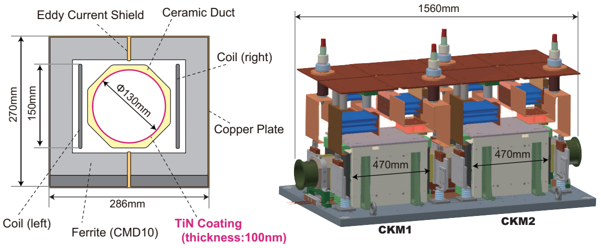

Figure 3: Cross section and schematic drawing of CKM.

Power Supply

The equivalent circuit of the CKM system is shown in Fig. 4. Two sets of the system were equipped to provide the pulse to each CKMs. Each system can be operated independently by controlling the charging and discharging trigger timing. Energy stored in one PFL is fed into the two coils which are comprised of the magnet. The length of the PFL was decided by a circuit simulation (LTspice) to fit the waveform to the reflection pulse of the IKM. To obtain the maximum current of 1.4kA with a smaller reflection pulse, the termination resistance of 5 Ω was determined by the simulation.

STANDALONE TEST

Standalone tests before installing to the beam line was carried out in the tunnel because of the availability of the power supply and the pulse transmission cables.

Pulse Waveform

Figure 5 shows the pulse waveform of the load current (I_{coil}) measured by a current transformer (Person Model.4779) attached at the end of the matching resistors. The CKM2 was excited after 300 ns from the CKM1 excitation.

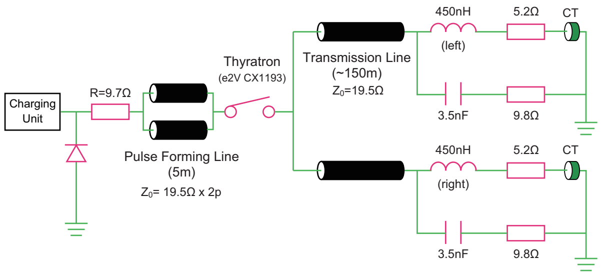

Figure 4: Circuit diagram of the CKM system.

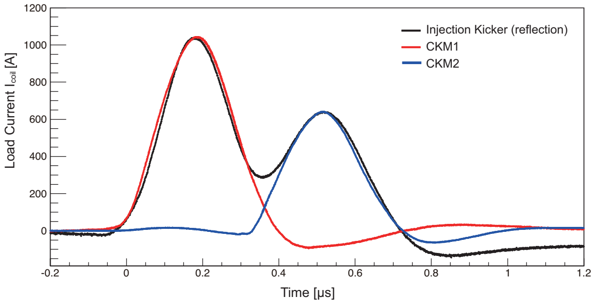

Figure 5: Pulse waveform for kickers.

Magnetic Field

Magnetic field was measured by two pickup coils. To scan the field distribution along the beam orbit, a short pickup coil (620 mm^2, single turn) was used. The output waveform of the pickup coil was recorded by a digital oscilloscope (LeCroy Waverunner model 66Zi). Time integration of the induced voltage of the pickup coil was performed by an offline analysis code (C++). Figure 6 compares the data and a numerical simulation (Opera3D). When one magnet was excited, the other was turned off. The data is in good agreement with the simulation for both CKMs.

A long pickup coil (5 mm × 2500 mm, single turn) was utilized to measure the integrated magnetic field (BL). Figure 7 shows the waveform of the BL and one of the I_{coil} measured by the CT. Second peak was shifted when the difference of the trigger timing for both CKMs (Δt) was changed.

BEAM TEST

Timing Adjustment

The discharge timing of the thyratron was scanned to find a peak of the horizontal betatron amplitude measured by the beam position monitors (BPM) [6]. Figure 8 shows the result of the 2nd bunch at K1 timing (see Fig. 5). The solid line indicates the excitation current waveform of the kicker. Both the CKM1 and the CKM2 were excited with $I_{\text{coil}} = 1.4$ kA and $\Delta t = 0$ ns. At the peak, the kick angle was evaluated as 0.96 mrad which corresponds to the BL = 12.3×10^{-3} Tm.

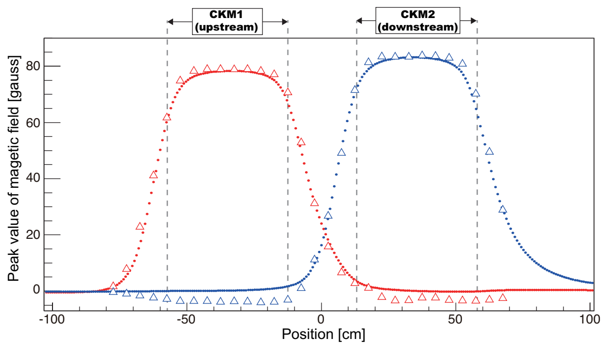

Figure 6: Magnetic field distribution at the center of the CKM (open triangle: measured data, closed circle: simulated data).

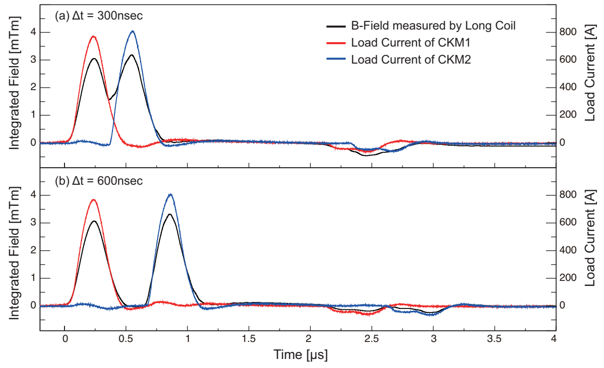

Figure 7: Waveform of long pickup coil and load current.

Beam Loss

Figure 9 shows the measured phase space plot of the #1 bunch at both K1 and K3 timing (see Fig. 5). While the betatron amplitude was sufficiently small at the K1 timing, it was increased at the K3 timing due to the residual field of the IKM. After optimizing the operation parameter (i.e. the applied voltage and the excitation timing) of the CKM2, the beam orbit was corrected successfully. The BL was evaluated as 4.3×10^{-3} Tm ($I_{\mathrm{coil}} = 993$ A, $V_{\mathrm{PFL}} = 28$ kV), which is consistent with the expectation. The kick angle was estimated as 0.34 mrad.

Figure 10 shows beam intensity which was measured by a DCCT equipped in the MR at the K3 timing. The beam intensity was recovered by utilizing the CKM. Beam loss was decreased from 170W to 51W for 160kW operation.

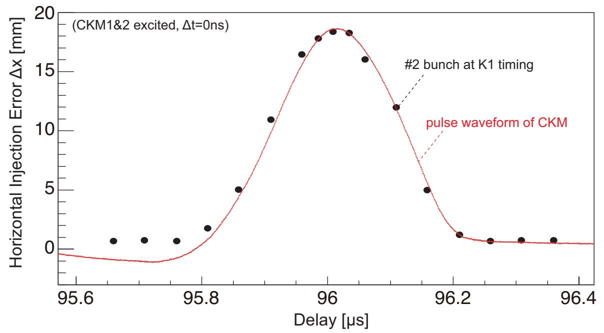

Figure 8: delay scan of kick angle.

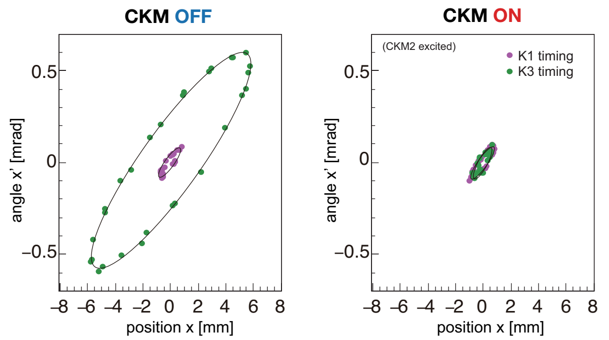

Figure 9: Phase space plot of #1 bunch at K1 and K3 timing. CKM2 was excited.

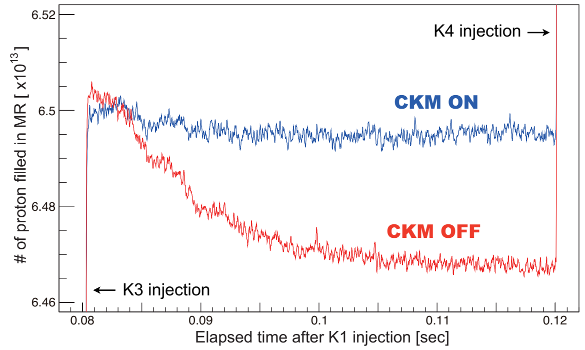

Figure 10: Beam Intensity measured by DCCT during K3 injection period.

CONCLUSION

The compensation kicker magnet of the J-PARC MR was installed and operated successfully to reduce the beam loss during the injection period. Since February 2016, the CKM has been operated for the T2K neutrino experiment.

REFERENCES

[1] Y.Sato *et al.*, “Recent commissioning of high-intensity proton beams in J-PARC main ring”, in *Proc. HB’12*, Beijing, China, paper THO1C06, p. 575, 2012.

[2] T.Sugimoto *et al.*, “Upgrade of the injection kicker system for J-PARC main ring”, in *Proc. IPAC14*, Dresden, Germany, paper MOPME069, p. 526, 2014.

[3] Y.Kurimoto *et al.*, “The bunch by bunch feedback system in J-PARC main ring”, in *Proc. DIPAC2011*, Hamburg, Germany, paper TUPD74, p. 482, 2011.

[4] K.Fan *et al.*, “Design and test of injection kicker magnets for the JPARC main ring”, in *Proc. IPAC12*, New Orleans, USA, paper THPPP004, p. 3728, 2012.

[5] K.Fan *et al.*, “Coupling impedance study of the new injection kicker magnets of the JPARC main ring”, in *Proc. IPAC12*, New Orleans, USA, paper THPPP003, p. 3725, 2012.

[6] S.Hatakeyama *et al.*, in *JPS Conf. Proc. 8*, p. 012001 (2015).