A TRIAL TO REDUCE THE KICKER IMPEDANCE OF 3-GeV RCS IN J-PARC

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Abstract

At the 3GeV RCS in J-PARC, the kicker impedance has been theoretically considered to be the most dominant source to cause beam instabilities. Recently, experimental studies have demonstrated that reducing the kicker impedance can stabilize beams. In this report, the present status of a trial to reduce the kicker impedance is reported.

INTRODUCTION

The J-PARC [1], which is composed of the 181MeV linac, the 3 GeV RCS and the 30 GeV main ring, is the proton accelerator facility, that aims to accomplish MW-class proton beams in the future. Nowadays, about 300kW beam is routinely operated in the RCS. Besides, about 500kW-equivalent beam has been accomplished in the RCS when the chromaticity is corrected only at the injection energy.

Nevertheless, in order to achieve 1MW beam in the future, it is very important to understand the impedance sources in the RCS, because beam instabilities occur when the chromaticity is fully corrected during the acceleration [2]. Theoretically, the kicker impedance has been considered to be the most dominant in the RCS [3]. However, it has been unclear until now whether the beam can be stabilized by reducing the impedance, and whether the other impedance sources are negligibly small in the real machine[4, 5].

In this report, it is experimentally demonstrated that reducing the kicker impedance can stabilize the beam in the RCS. And, the present status of a trial to reduce the kicker impedance is reported.

A DEMONSTRATION OF BEAM-STABILIZATION BY THE REDUCTION OF KICKER IMPEDANCES

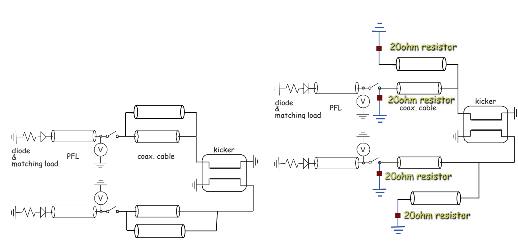

Figure 1: Schematic pictures of the kicker magnets.

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First of all, it is necessary to know the structure of the kicker magnet to discuss the kicker impedance [6]. Then, let us explain the present kicker system of the RCS.

The left figure in Fig.1 is a schematic picture of the present kicker system. The system is composed of the pulse forming line(PFL) and the magnet parts. Combining two C-type magnets makes the kicker magnet. Since the respective C-type magnets have two ports, the kicker magnet has four ports in total. Two ports among four are grounded.

The characteristic impedances of the C-type magnet and the cable in Fig.1 are about 10 Ω and 20 Ω, respectively. Thus, by connecting two cables to the respective ports in parallel, the mismatch at the connection points is mitigated and the reflection waves are suppressed. The inner conductor of the coaxial cable from the PFN is connected to the short plate after the kicker, and then is connected to the outer conductor of the coaxial cable.

The short plates are beneficial when beams are extracted from the RCS, because a doubled excitation current is realized, due to the superposition of the forward and backward currents, when the kicker is activated [7]. However, the same short plates cause the sharp resonance peaks in the kicker impedances (refer to the black dashed lines in Fig.6). It is 10 times larger than that of SNS kickers [8]. This may be a significant constraint to increase beam intensities.

Measurements of beam positions for 500 kw-equivalent beams are done for a case that the chromaticity is fully corrected to zero during the acceleration. The measurement results are shown in the left figure in Fig.2. The beam instability can be observed.

Theoretically, the kicker impedance has been considered to be the most dominant source of RCS. The best way to demonstrate it is to show that a reduction of the impedance can suppress the beam instability. Since beam-induced voltages in the coaxial cable are the impedance source, damping the voltages in the cable can reduce the impedance. As shown in the right figure in Fig.1, resistors with matched impedance (20 Ω) are temporarily inserted between the cable and PFN. Since there are four cables for one kicker, 32 resistors are connected at the ends of all cables, because eight kicker magnets are installed in the RCS. The red line in Fig.6 is the impedance of kicker with matched resistors. The resonance peaks described by the black dashed line in Fig.6 diminish in the red line in Fig.6. Thus, the kicker impedance is drastically reduced.

Let 500 kW-equivalent beams accelerated and pass through the modified kicker. The horizontal beam positions are measured. The measurement results are shown in the right figure in Fig.2. The horizontal beam positions do

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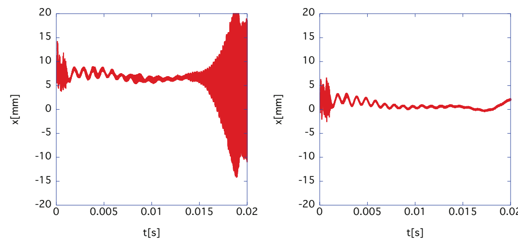

Figure 2: Measurement results of horizontal beam position for 500 kW-equivalent beam. The chromaticity is fully corrected to zero. The left and the right figures show the results for the left and the right kickers in Fig.1, respectively.

not increase, even when the chromaticity is fully corrected during the acceleration. Consequently, it is experimentally confirmed that the kicker impedance is the most dominant source of RCS.

In the experiments, it is remarkable that the beams are not extracted from the RCS and all particles are lost inside the ring. In order to realize the reduction of kicker impedance in routine operations of the RCS, some ideas are necessary.

A REDUCTION METHOD OF KICKER IMPEDANCE

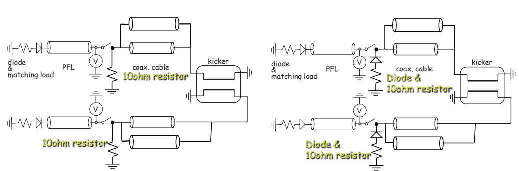

Figure 3: The terminal conditions of kicker cables.

In the previous section, it is experimentally found that reducing the kicker impedance can stabilize beams. The main idea to reduce the impedance is to insert matched resistors between the coaxial cable and PFN, as in the left figure in Fig.3 (when two cables are connected in parallel, the matched resistors are 10 Ω.). However, the resistors have to be isolated from PFL to ensure doubled excitation currents due to the superposition of the forward and backward currents to extract beams, while they need to be seen by the beams to absorb beam-induced currents. A mechanism is needed to isolate the damping resistors from pulse currents from PFL. From a mechanical point of view, the easiest way is to insert diodes in front of the resistor, as in the right figure in Fig.3.

In a practical point of view, the diodes must have the high reverse voltage (which means that the resistors have to be isolated from PFL when the kicker is activated) and the low forward voltage (the resistors need to be seen by the beam.). Requirement to real diodes is that the reverse voltage must have 40 kV, while it is better that the forward voltage is as low as possible.

Recently, new diodes are developed by ORIGIN Ltd [9, 10]. After connecting the diodes with 10 Ω resistors to the ends of coaxial cables, let us measure the induced voltages at the ends and the currents of the resistors. The intensity is 300kW-equivalent beam. An oscilloscope and a current transformer measure the voltages and the currents, respectively. For comparisons, measurements are done for three types of terminal condition (open, the diodes + 10 Ω resistors and the 10 Ω resistors). The measurement results are shown in Fig.4. The beam induced voltages and the currents are shown in the left and the right figures, respectively. The horizontal axis shows the acceleration time. The red, the green and the blue points show the cases that the terminal condition is open, that the diodes + 10 Ω resistors and that the only 10 Ω resistors are connected to all terminals, respectively. Figure 5 is a scaled figure of the induced voltage around 6.739 ms. When the matched resistors are connected, the beam-induced voltages are absorbed at the terminals. When the terminals are open, the reflection waves are superposed and, the voltages become maximum. When the diodes are inserted in front of the resistors, the matching conditions are not perfectly satisfied. Consequently, the induced voltages exist between the cases that the terminals are open and that the matched resistors are connected.

Since the voltages and the currents are measured independently, the terminal impedances may be evaluated. When the terminals are open, or the matched resistors are connected to the terminals, the impedance can be accurately found, and the beam impedances can be accurately evaluated. On the other hand, when the diodes with matched resistors are connected, it is difficult, because diodes are non-linear devices, such that the impedance depends on beam conditions. Thus, the beam impedance, especially for the diodes + 10 Ω resistors, is effectively evaluated for the 300 kW-equivalent beam.

The evaluated impedances for one kicker are shown in Fig.6. When the terminals are open, the sharp resonance peaks appear in the impedance, because the beam-induced voltages go back and forth between the ends of cables and the short plates in the magnet. When the matched resistors are connected, the sharp resonance peaks diminish, because the induced voltages and currents are absorbed at the resistors.

When the diodes with resistors are connected to the terminals, the resonance peaks do not diminish, because the matching condition is not perfectly satisfied. However, the resistors with the diodes successfully reduce the impedance by factor two, compared to the impedance in the case that the terminals are open.

Though the resonance structure still remains, the structure can be effectively cancelled by randomizing the length of 8-kicker cables, because the interval of the resonance peaks is approximately evaluated as $1/2(\sqrt{L_k C_k} L + \sqrt{L_{cable} C_{cable}} l_{cable})$ [6], where L_k is the inductance of kicker magnet, C_k is the capacitance of kicker magnet, L is the length of kicker magnet, L_{cable} is the inductance of

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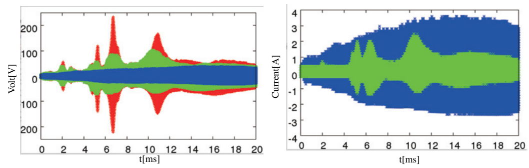

Figure 4: Measured beam induced voltages (left) and currents (right) for 300 kW-equivalent beam. The red, the green and the blue points represent the open, the diodes with 10 Ω resistors and the 10 Ω resistors cases, respectively.

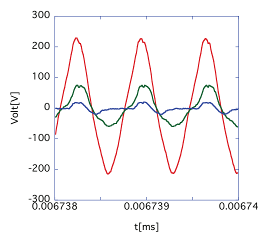

Figure 5: The beam induced voltages around 6.739 ms.

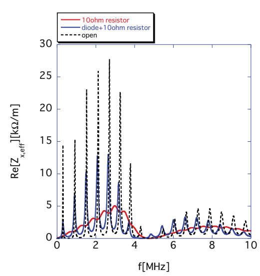

Figure 6: Effective kicker impedances for the different terminal conditions.

coaxial cable, C_{cable} is the capacitance of coaxial cable and l_{cable} is the length of coaxial cable.

The cable length of the present kicker is identical for all eight kicker magnets, and it is equal to 130 m. Let us consider three cases that the differences of the cable length are 100 m, 40 m or 15 m, where the diodes with 10 Ω resistors are connected to the terminals of the cables. The effective impedances for one kicker for the respective cases are shown in Fig.7. Even when the difference of cable length is 15 m, the impedance is much smaller than that in Fig.6. When it is longer than 40 m, the cancellation of cable resonances is remarkably done. Beside, when the difference is longer than 100 m, the kicker impedance can be minimized.

Nevertheless of this merit, there is a possibility that the randomization of the length of kicker cables disturbs to extract beams. This is because the resistance R_{cable} and the conductance G_{cable} of coaxial cable depend on frequency. In other words, too long coaxial cables fail to make an appropriate flat top on the kicker waveform. Further investigations should be necessary to know how long the difference of cable length can be lengthened. Present target is to let the difference of cable length to be longer than 15 m. The numerical simulation studies are now progressing.

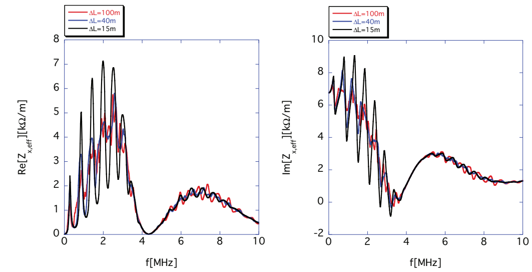

Figure 7: The dependence of the effective one kicker impedance on the difference of cable length, where the diodes with 10 Ω resistors are connected to the terminals.

SUMMARY

It is experimentally confirmed that beam instabilities at the RCS are caused by the kicker impedance. A reduction of the kicker impedance is very important to accomplish 1MW-class beam at the RCS in the future.

Insertions of diodes with matched resistors at the ends of coaxial cables can reduce the kicker impedance. The diodes with resistors successfully reduce the kicker impedance by factor 2 effectively, though the resonance structure still remains.

Randomization of the length of 8-kicker cables in the RCS can reduce the total impedance along the ring. However, it is necessary to investigate whether 8 kickers with their different cable length can work or not, when beams are extracted from the RCS. This is because the coaxial cable has frequency dependent resistance and conductance. Simulation studies are under way.

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