OPERATION AND CURRENT STATUS OF INJECTION, EXTRACTION, KICKER MAGNET AND THE POWER SUPPLY FOR J-PARC 3 G V RCS

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Abstract

Stable operation is required for 3-GeV Rapid Cycling Synchrotron (RCS) at High Intensity Proton Accelerator Facility (J-PARC). In the kicker system at extraction section of RCS, there were many troubles for unstable operation of the thyratron switches of the power supply just after 25 pulses per seconds (pps) operation started in February 2009. However, the operation was improved by handling thyratrons in appropriate manner in October 2010. After the Great East Japan Earthquake on March 11, 2011, injection and extraction magnets, power supplies, cables and bus-duct were checked. The results of the measurements and the checks were all not in the problem. We have to accomplish extraction beam power of 1 MW in RCS in the near future. Kicker impedance is the most severe among other impedance sources. We adopt that the matching resistor and newly developed diode are connected at the power supply to reduce the impedance. From the beam test, it is found that induced voltages to the kicker are decreased by the diode and the resistor.

INTRODUCTION

The RCS has two roles, one is a proton driver for the MLF and another is an injector to the MR. The extraction energy of the RCS is 3.0 GeV. Stable operation is required by beam users. However, the Great East Japan Earthquake occurred on March 11, 2011. It forced operation of J-PARC to stop for a long time. In this paper, current status of stable operation of kicker system is described and checks of the magnet systems after the grate earthquake are described.

We have to accomplish beam power of 1 MW in the near future. Impedance of kicker magnet is expected to cause beam instabilities at the beam power beyond several hundred kilo-watts. In this paper, reduction method of the kicker impedance using resistor and diode is described.

OPERATION OF KICKER SYSTEM

Kicker system is shown in Fig. 1 [1]. The power supply unit is composed of charging units, pulse forming lines (PFLs), matching load resistors, diodes, and thyratrons (CX1193C, E2V Technologies Ltd.) as switching devices.

Stable operation is strongly demanded by the beam users. However, as thyratrons are gaseous discharge switching devices, they make misfire or break down. There were many troubles by the thyratrons in February 2009. Because reservoir voltage and cathode heater voltage were not adjusted in the appropriate values, respectively. From the many experience of the troubles, we have been handling it in appropriate manner [2]. Figure 2 shows failure rate for each RUN. Failure rate means the time when the kicker system is stopped in all the instruments concerned with the beam operation. Though it was 13.11 % in February 2009 (RUN 21), it became approximately 0.5 % in April 2010 (RUN 32) in the end. It keeps less than approximately 0.5 % after re-start of beam operation after the earthquake.

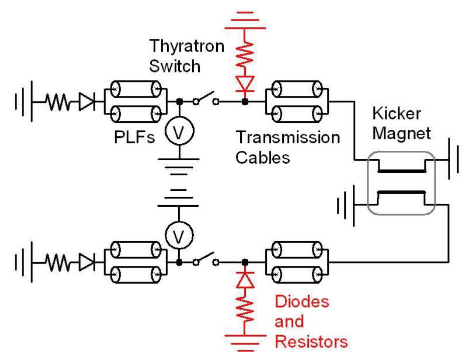

Figure 1: Schematic of the kicker system.

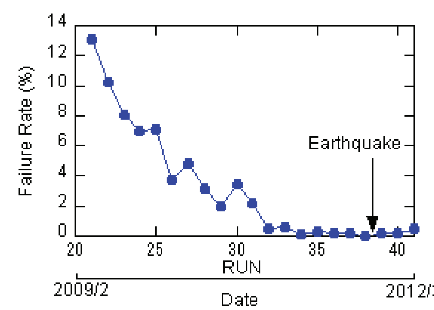

Figure 2: Failure rate of kicker system.

DAMAGE CHECK OF THE MAGNET SYSTEMS

Damage Check of the Injection and Extraction Magnet Systems

Beam operation was stopped by the Great East Japan Earthquake on March 11, 2011. After the earthquake, the injection and extraction magnets, power supplies, the cables and the bus-duct were checked. Insulation resistance tests, impedance test of the magnets were performed. The resistance of the each magnet are enough large (more than 0.2 kΩ), though a little cooling water is left in the cooling pipe.

The magnet systems are almost not damaged except for

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bus-duct of the extraction septum magnet system. Outside of the accelerator tunnel fell down at the expansion joint in comparison with the inside of it. The bus-duct at connection point fell down approximately 15mm. As flexible conductor was used at the connection point, it was enough to correct the height of the support base. Then, insulation resistance examinations are performed. The values indicate more than 10 MΩ at the 1000 V, which are normal values

Damage Check of the Kicker Magnets

Kicker magnet has ferrite and ceramic units which have possibility to be broken by the shock of the earthquake. First, inductance of the magnets were measured to check how much the kicker magnet was damaged or not. The indicated values were normal (approximately 1.4 μH). Next, visual check inside of the magnet using a fiber-endoscope was performed after the vacuum chamber of the magnet was vent with argon gasses. Figure 3 shows inside of the magnet. It was confirmed that the ferrite and the ceramic were not damaged.

Figure 3: Photograph of inside of the kicker magnet.

High Power Excitation Test of the Kicker

High power pulse excitation test with repetition rate was 25 pps of the kicker was performed. The current was measured by CT (Pearson Electronics, Inc, Model 110). Output and reflection current waveform are shown in Fig. 4. The waveform is the same as one before the earthquake.

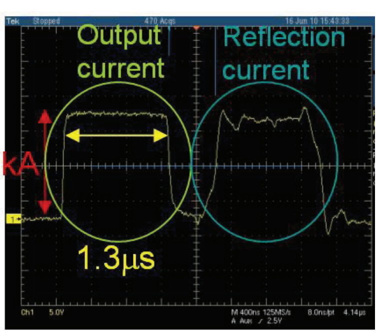

Figure 4: Measured current of kicker.

PSpice (Micro Cap 7) modelling of the equivalent circuit of the kicker system is made and calculated. Figure 5 shows the equivalent circuit and Figure 6 shows the calculated current. From calculation result, it is found that the inductance (400 nH) between the connection with magnet and the cables leads to large ripple at the flat-top of the reflection waveform. As the calculated current good agree with the measured one, therefore we conclude the kicker system is not any problem.

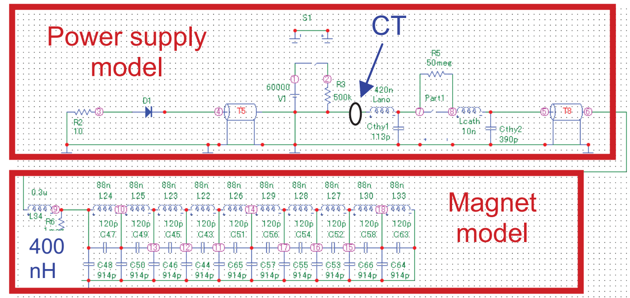

Figure 5: Equivalent circuit of the kicker system.

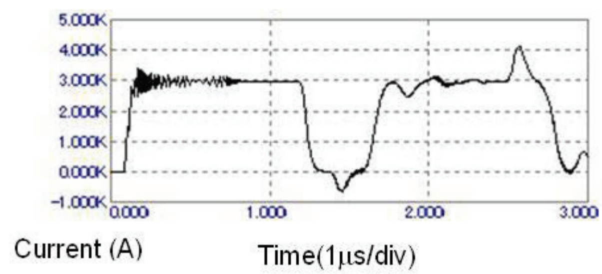

Figure 6: Calculated current of kicker.

IMPEDANCE OF THE KICKER

We have to accomplish beam power of 1 MW in the near future. Impedances of kicker magnets are expected to cause beam instabilities at the beam power beyond several hundred kilo-watts [3]. Basically, the impedances of the kicker can be reduced by connecting the matching resistor with 10 Ω.

First, we consider that resistor is placed either at the earth of the magnet side or at the output part of the power supply side. It is difficult to connect it at the end of the magnets, because not only there is no space but also output current must be twice, which means larger power supply must be developed.

We adopt that the matching resistor with a diode is connected between the anode of thyratron and transmission cables, which is drawn by red in Fig. 1. The diode needs to be isolated from output current of the power supply.

We need to confirm whether diode works. First, we adopt a diode (MDO65SN1K, Origin Co., Ltd.), which is used at the power supply drawn by black in left side of Fig. 1. Reversal breakdown voltage is 65 kV, and maximum current is 1kA. DC characteristic of the forward direction voltage is known by catalogue, however, there is no data at high frequency characteristics of it.

Proton beam circulates in RCS at approximately 1 MHz. Then, high frequency characteristics of the forward direction voltage and the current should be measured. The set up of the measurement is shown in Fig. 7. Since the input signal is sinusoidal function, the peak forward voltage and the peak forward current of the diode are measured, respectively. The measurement result is shown in Fig. 8. Measured frequencies are 1 and 0.5 MHz. DC Characteristics from catalogue is also shown in Fig. 8. In Fig. 8, *Vdi* and *Idi* are peak forward voltage and the current. When the voltage shows 100V, the current shows 2 A at 1 MHz. This means the impedance of the diode is 50 Ω. This value is too large.

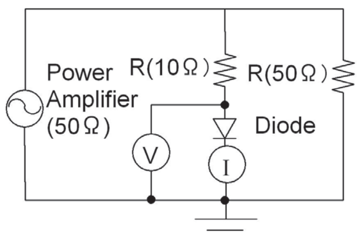

Figure 7: Schematic circuit diagram for measurement of diode characteristics.

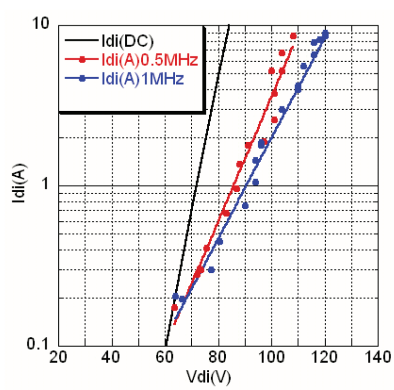

Figure 8: V-I characteristics of a diode (MDO65SN1K).

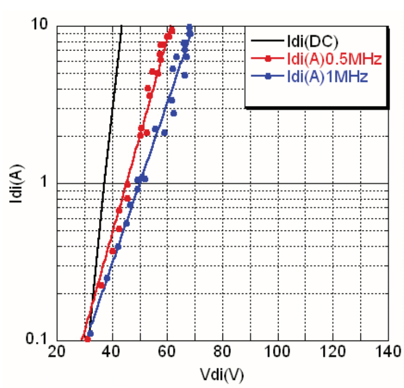

Figure 9: V-I characteristics of a new diode.

Then, we develop a new diode which is made by Origin Co., Ltd. The reversal breakdown voltage is 40 kV, the maximum current is 1kA. The measurement result is shown in Fig. 9. When the voltage shows 70V, the current shows 9 A at 1 MHz. This means the impedance is 7.7 Ω.

Induced voltages to the kicker by 3 GeV, 420 kW-equivalent intensity beam are measured. The chromaticity is corrected to zero only at the injection energy.

The diode and a resistor with 10 Ω are connected with all the transmission cables, shown in Fig. 1. The transmission cables were disconnected from the anode of the thyratron.

The measured voltages are shown in Fig. 10. In the figure, the waveforms shown by red and yellow are left and right sides of the kicker magnet among the beam direction. For a comparison, measured voltages without the diode and the resistor are shown in Fig. 11. Maximum voltage is approximately 240Vin Fig. 11. On the other hand, it is approximately 100 V in Fig. 10. From these results, it is found the diode with resistor reduce impedance of the kicker.

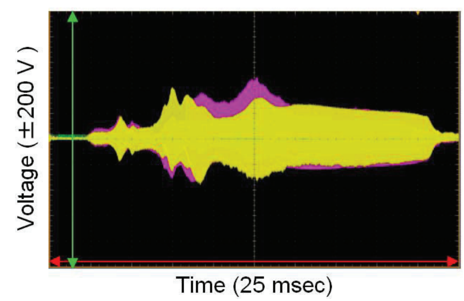

Figure 10: Induced voltages to kicker with diodes and resistor.

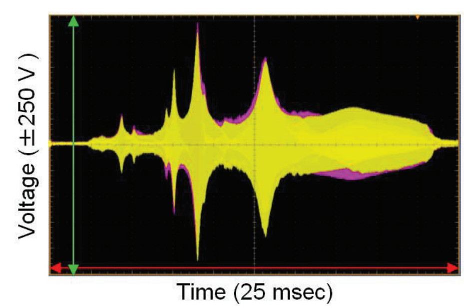

Figure 11: Induced voltages to kicker without diodes and resistor.

ACKNOWLEDGMENT

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