COMISSIONING RESULTS OF THE KICKER MAGNET IN J-PARC RCS

J. Kamiya#, M. Kinsho, M. Kuramochi, T. Takayanagi, T. Togashi, T. Ueno, M. Watanabe, and M. Yoshimoto, JAEA/J-PARC, Tokai, Naka, Ibaraki, Japan

Abstract

Installation of the kicker magnets in the extraction section of the RCS in J-PARC facility had been completed. They succeeded to extract the proton beams accelerated up to 3GeV in the first beam test in October in 2007. The operation parameters of the kickers agreed well with the parameters which were estimated from the magnetic field measurement and the current test of the each power supply. The stability of the power supply have been about ±0.2 % which is enough small to extract the beam stably. The rise time and jitter of the output current largely depends on the individual characteristic of each thyratron. They have been kept within the required value by adjusting the reservoir voltage at regular interval. The beam based measurement of the flattop of the kicker magnetic field was performed. Although the ringing structure which was measured by the search coil was also observed by the beam based measurement, the degree of the flattop distortion was able to be corrected by the timing adjustment of the output current.

INTRODUCTION

The Rapid Cycling Synchrotron (RCS) in Japan Proton Accelerator Research Complex (J-PARC) started its beam commissioning test in October 2007. At first, the beam test was performed with non-accelerated beam whose energy was 181 MeV. The beam was succeeded to go around the ring and extracted by the kicker magnets. Acceleration of the beam up to 3 GeV was successively achieved and the beam was precisely extracted to the downstream beam line. The specification of the kicker magnet was shown in Table 1. The detailed specification is reported in the past paper [1]. There are eight kicker systems in the extraction section. The charging voltage of about 60 kV, which was charged in the pulse forming lines, was discharged by the thyratron at the repetition rate of 25 Hz in the normal operation. There are three types of kicker magnets (L-, M-, S-type) corresponding to their vertical aperture sizes as listed in Table 1. The integrated magnetic field to extract the 3 GeV proton beam is 0.02 to 0.03 Tm per magnet.

In this report, the operation parameters of the kicker are first shown with the relationship between the setting voltage and the integrated magnetic field. The stability of the kicker power supply during the operation is also shown. Next, the operation status of the thyratrons, which is very important for the stable operation, is summarized. Finally, the degree of distortion of the flattop which was directly measured by the displacement of the beam position was shown.

Table 1: Specifications of Kicker System.

Power source	
Numbers	8
Output pulse shape	Rectangle
Maximum repetition rate	25Hz
PFN	Co-axial cable (~110m)
Switching device	Thyratron (CX1193C)
Load cable	Same as PFN (~133m)
Maximum charging voltage	80kV(~60kV at operation)
Maximum exciting current	8000A(~6000A at operation)
Characteristic impedance	10Ω
Magnet	
Numbers	8 (S:3, M:2, L3)
Equivalent circuit	Distributed constant type
Configuration	Twin-C distributed magnet
Vertical aperture size	186mm(S),206mm(M), 232mm(L)
Magnet core	Ni-Zn ferrite
Characteristic impedance	10Ω
Magnetic filed	230-310 gauss·m/magnet

OPERATION OF THE KICKER

Operation Parameters

There are two operation modes for the RCS beam study. One is non-acceleration mode, the other is acceleration mode. The setting voltages for the pulse forming lines in each operation mode are listed in Table 2. In the non-acceleration mode, only two of eight kickers have been used to kick the 181 MeV proton beams, while all eight kickers have been used in 3 GeV operations. Figure 1 shows the relationship between the setting value of the charging voltage and the integrated magnetic field, BL. The BL values were estimated by the measurement results by using the search coil in the whole range of the aperture [2]. The linear relationships are found in all kicker systems. It was found that there was no large spread in performance of the same magnet type. Using the setting values listed in Table 2, which were estimated by the relationship in Figure 2, the beam has been transported to the extraction septum magnets and the following beam line [3] without significant beam loss. This means the results of the magnetic field measurement was very reliable.

#kamiya.junichiro@jaea.go.jp

Table 2: Operation Parameters of Kicker System

	No.1(L)	No.2(M)	No.3(S)	No.4(S)	No.5(S)	No.6(M)	No.7(L)	No.8(L)
Non-acceleration mode		26.70kV				48.67kV		
Acceleration mode	58.86kV	58.48kV	59.41kV	59.84kV	59.57kV	59.21kV	59.37kV	59.16kV

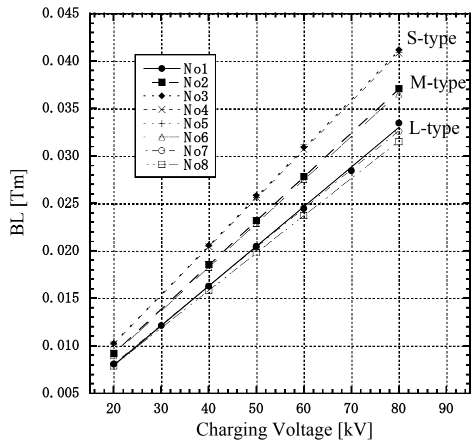

Figure 1: Relationship between the set value of the charging voltage and the integrated magnetic field.

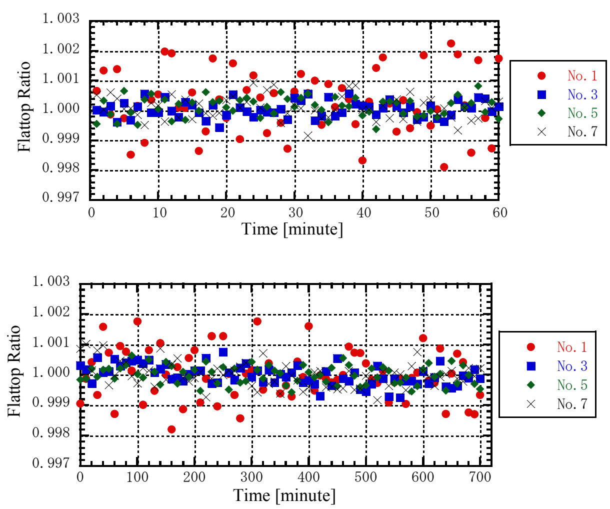

Figure 2: Stability of the output current during 1 hour (the upper panel) and 8 hours (the lower panel).

Stability

The stability of the output current of the kicker magnet determines the stability of the orbit of extracted beam. It is shown by the calculation that the beam position at the exit of the extraction septum magnet change by about 0.5mm if one of the kicker's magnetic field changes by 1 %. Figure 2 shows the time dependence of the output current of the kicker power supplies. The upper panel shows the stability during 1 hour, while the lower panel shows one during longer time range of 8 hours. The fluctuation is about 0.2 %, which is enough small to deliver the steady beam to the downstream line.

THYRATRONS

Thyratron CX 1193C, which are produced by e2V, has been used in our system. The detailed specification of this tube is omitted in this paper because it is described in its manual. The peak anode voltage and current of CX1193C are 130 kV and 10 kA, respectively with the modulator service operation. Total 16 thyratrons are used because 2 thyratrons are used in one power supply [1].

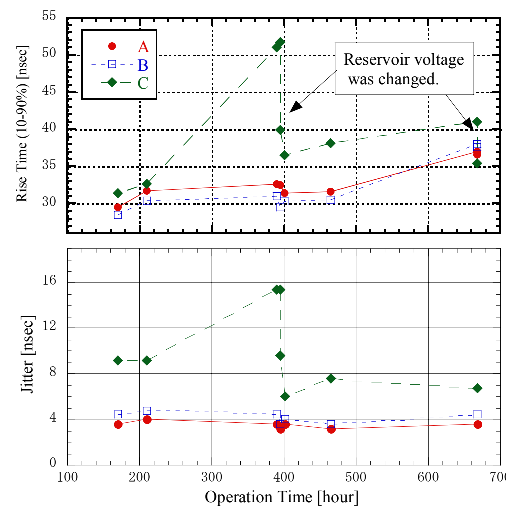

Figure 3: The secular change for the rise time and jitter in the case of three typical thyratrons.

The parameters, which are largely depending on specifications of the individual thyratrons, are the rise time, jitter, and delay time between trigger signals to output current. The reservoir voltage values, which critically affect the specification of the thyratrons, were set to the datasheet values at the first operation. So far, the operation time has been over 600 hours. The rise time, jitter, and delay time has been changing due to the secular distortion of the gas pressure in the thyratrons. We have made a practice of increasing the reservoir voltage when the rise time has become larger than 40 nsec. The degree of the change of the rise time and jitter largely depends on the individual thyratron. Figure 3 shows the record of the rise time and jitter change in the case of three typical thyratrons. In the case of thyratrons A and B, the reservoir voltages have not been changed because the rise time was less than 40 nsec at the moment, although their rise time has gradually become larger. The jitter of these tubes remains virtually unchanged until now. In the case of the thyratron C, the rise time and jitter had drastically changed. Therefore the reservoir voltage has been changed a few times during the past 700 hour operation.

The rise time sharpened when the gas pressure in the tube recovered by increasing the reservoir voltage.

When the reservoir voltage is changed, the delay time between the trigger signals to the output current is also changed because the delay time largely depends on the gas pressure in the tube. The delay time can be adjusted by the delay modules for all output current to be fired at the same time.

BEAM BASED MEASUREMENT

The flattop uniformity of the kicker magnetic field directly affects the profile and position of the extracted beam. The required flatness of the flattop is 2 % in the time length of 840 nsec, which is the case of 2 bunches operation. It was found that the disturbance of the flattop be caused by the two reasons [2]. One is the impedance mismatch between load-cables and a magnet. The other is the effect of the magnetic field induced by the penetrated magnetic flux from opposite ferrite core. As a result, the flat top of the kicker magnetic field formed a ringing structure. The degree of flatness distortion which was measured by the search coil was 6 %, while the requested value was 2 %. However, there was a comment that a pulse shape measured by a search coil was lack of reliability because it depended on the circuit constant of the measurement system. Therefore we decided to measure the degree of flatness by using extracted beam itself.

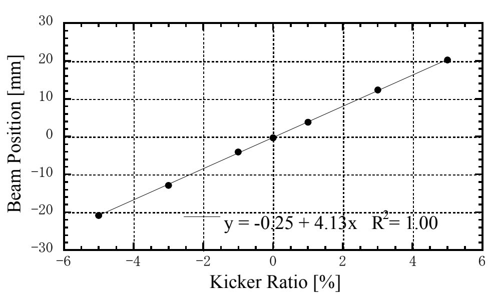

Figure 4: The beam position shift corresponding to the rate of kicker setting voltage.

Figure 4 shows the shift amount of the beam position corresponding to the rate of change of the set value of the kicker power supply. The beam position was measured by the Beam Position Monitor (BPM) installed at the downstream beam line. The relation is linear as a matter of course. Using this relationship, the degree of magnetic field flatness was measured as the shift amount of the beam position when the timing of the kicker pulse was changed step by step. In this measurement, the longitudinal beam width was chopped to be very short, about 25 nsec in full width at the extraction timing, in order to get better resolution. The measured magnetic field flattop is shown in the upper panel of Figure 5 with the result which was measured by using the search coil. The two measurement results are well consistent with each other. The degree of distortion is actually 6 % in total. Next, the timing adjustment of the each kicker magnet was attempted in order to decrease the distortion. The trigger timing of No. 2, 4, 6, and 8 kickers was delayed for about 130 nsec to cancel out the peaks and troughs of the flattop. The lower panel of Figure 5 shows the results. The flatness of 2 % was achieved in the time length of 850 nsec, which satisfies the requirement.

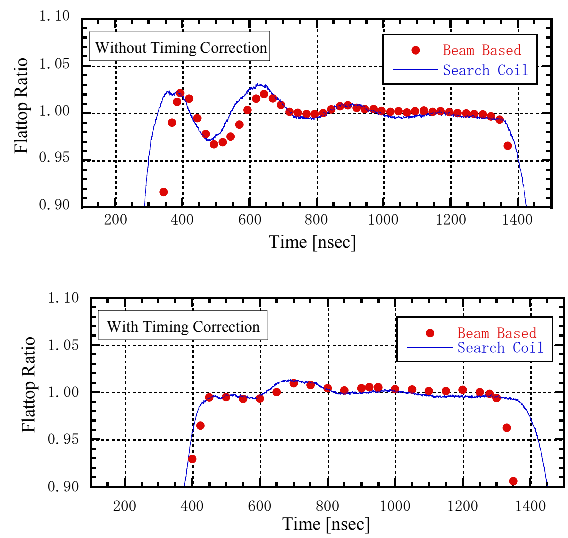

Figure 5: Flattop ratio measured by the beam position (closed circles) and the search coil (solid line). The upper panel shows the results without the timing correction, while the lower shows that with the timing correction.

CONCLUSION

The kickers in the J-PARC RCS facility succeeded to extract the non-accelerated and accelerated beams to the downstream line. The beam has been correctly extracted by the operation parameters which were derived from the magnetic field measurements. Although there are some individualities of thyratrons' characteristic change, the method of adjustment is being established. The beam based measurement of the kicker flattop was well agreed with the measurement result by the search coil. The ringing structure has been cancelled by correcting the timing of the output pulse.

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