OPERATION OF KICKER SYSTEM USING THYRATRON OF THE 3 GEV RAPID CYCLING SYNCHROTRON OF J-PARC

M. Watanabe#, J. Kamiya, K. Suganuma, T. Takayanagi, N. Tani, T. Togashi, T. Ueno, Y. Watanabe, JAEA, Ibaraki, Japan

Abstract

3 GeV rapid cycling synchrotron of J-PARC accelerates proton beams from the 181 MeV up to 3 GeV. The RCS injects the beam to the Main Ring and transports it to the muon production target and neutron production target in the Materials and Life Science Experimental Hall. Proton beams in the RCS are fast extracted by kicker magnets at the repetition rate of 25 Hz. 16 thyratrons are used in the eight power supplies of the kicker system. Stable operation is strongly demanded by the beam users. However, thyratrons are gaseous discharge switching devices, they make misfire or break down. In this paper, present status of operation, "conditioning" and "ranging" methods of the thyratron are described.

INTRODUCTION

Japan Proton Accelerator Research Complex (J-PARC) is a high intensity proton beam accelerator facility. The J-PARC consists of a 181 MeV linac, a 3 GeV rapid cycling synchrotron (RCS), a 50 GeV main ring synchrotron (MR) and experimental facilities (a materials and life science experimental facility; MLF, a hadron experimental hall, and a neutrino beam line to Kamioka) [1].

The RCS has two roles of a proton driver for the MLF and an injector to the MR. The extraction energy of the RCS is 3.0 GeV in order to achieve a pulse of 0.6 MW with approximately 5 x 10^{13} protons at a repetition rate of 25 pulses per second. In the near future, the 181 MeV linac will be upgraded to 400 MeV. The extraction energy of RCS will reach 1 MW [2].

The beam commissioning of RCS started in October 2007 and accelerated successfully to 3 GeV on October 31. The extracted RCS beam has been delivered to the MR and MLF since May 2008. Repetition rate is normally 1 Hz or 1 shot because the beam studies were performed until January 2009. 25 Hz operation was started from February 2009. The operating times of the RCS are approximately 5000 hours from 25 Hz operation was started.

In order to extract the high power beam with emittance of 486 πmm mrad, the apertures of the kicker magnets are large. Required current to kicker magnets is approximately 6 kA. The magnetization current can be attained by adding the reflection current [3]. Then, the power supplies provide output current of 3 kA. The rise time of the magnetic field from the beam is required to be less than 400 ns. Therefore impedance matching from the power supply to the magnets is very important. The magnet structures are the distributed parameter type in order to match the impedance (10 Ω). Two parallel coaxial cables (20 Ω) with length of approximately 130 m are used to connect between the magnets and power supply. And also two parallel coaxial cables (20 Ω) with length of approximately 102 m are used to make pulse forming lines (PFLs) to charge the voltage of approximately 60 kV. Output voltage is approximately 30 kV because of the impedance matching.

In order to obtain fast rise time, selection of switching devices is also important. The allowable rise time of the output current from the PFLs is approximately 40 nsec when loss of the transmission cable and ripple of magnetic fields are taken into account [3]. In order to obtain such a fast rise time, thyratrons (CX1193C, E2V Technologies Ltd.) have been used as the switching device.

Stable operation is strongly demanded by the beam users. However, thyratrons are gaseous discharge switching devices, they make misfire or break down. The almost all troubles are caused by the thyratrons in the kicker system. In this paper, present status of operation, "conditioning" and "ranging" methods of it are described.

KICKER POWER SUPPLY SYSTEM

The power supply systems of the kickers are briefly described. There are 8 kicker magnets, and there are power supplies. Two thyratrons are used for each power supplies. Therefore, 16 thyratrons are used in a kicker system. The thyratrons are mounted in a silicone oil bath for insulation and cooling. And the their mount structure has low inductance to keep the fast pulse rise time. The power supply unit is composed of a charging unit, two pulse forming lines (PFLs), two matching load resistors, a thyratron, and two load cables [3]. The charging time is set to 30 ms and the hold time is 6 ms.

The thyratron and the driving circuits are briefly described. The trigger module MA2709A, which was made by e2V Ltd. is used. Trigger signals with different timing are pass through the two each trigger grids (G1 and G2) of the thyratron. The circuits of it and the trigger system are shown in Figure 1 and Figure 2.

OPERATION OF THYRATRON

The thyratron tube, CX1193C, is filled with deuterium gas. The gas pressure is very important which corresponds to the rise time of the current. Titanium hydride is used for the reservoir system. The gas pressure is kept by the reservoir heater.

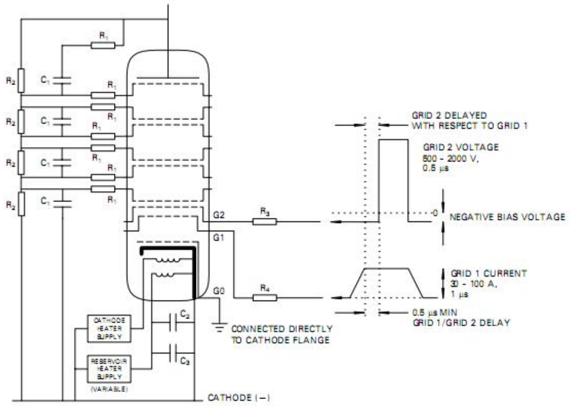

Figure 1: Thyratron (CX1193C)

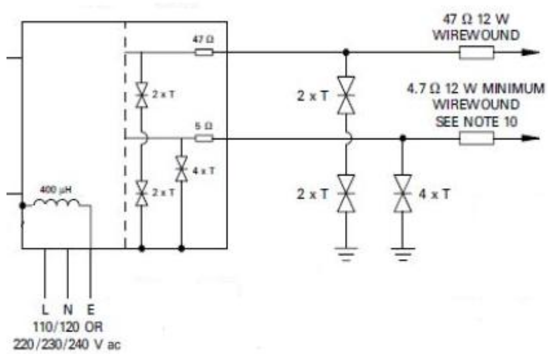

Figure 2: Trigger module (MA2709A)

Before using thyratrons in beam operation of the kicker system, we need to know a proper value of the reservoir voltage. Moreover, new thyratrons can not be used for beam operation; because break down are often occurred by maybe long charging time (30 msec). Therefore, we perform a "conditioning" of the new one. The conditioning method is as follows. First the reservoir voltage was set at a value from the data sheet (about 4.2-4.5 V). It starts operation at 25 Hz from charged voltage of 30 kV to keep the rise time smaller than approximately 35 ns. It is gradually increased up to 60 kV. Then the "ranging" are performed. (The ranging method is written in following). The reservoir voltage at break down is called $V_{r\,(max)\,60kV}$. It re-starts operation from 30 kV at the reservoir voltage of $V_{r\,(max)\,60kV}$ - 0.3 V. It is gradually increased up to 80 kV. Then the "ranging" at 80 kV are performed as well. The reservoir voltage at break down is called $V_{r\,(max)\,80kV}$. It re-starts operation from 30 kV at the reservoir voltage of $V_{r\,(max)\,80kV}$ - 0.3 V. Finally charged voltage is gradually increased up to 80 kV and the operation is continued 10 hours in a row.

Adjustment of the gas pressure to a proper value is called "ranging". The ranging method is as follows. At 60 kV or 80 kV, the reservoir voltage is changed in interval of 0.1 V and then is kept in 5 minutes at each reservoir voltage to stabilize the gas pressure. When the break down occurred within the 5 minutes, the reservoir voltage is regarded as the $V_{r\,(max)\,60kV}$ or $V_{r\,(max)\,80kV}$. Typical result of the ranging is shown in Figure 3. Around the $V_{r\,(max)\,60kV}$ - 0.3 V, the rise time is almost constant (27 nsec). We consider that proper range of the reservoir voltage is around the here.

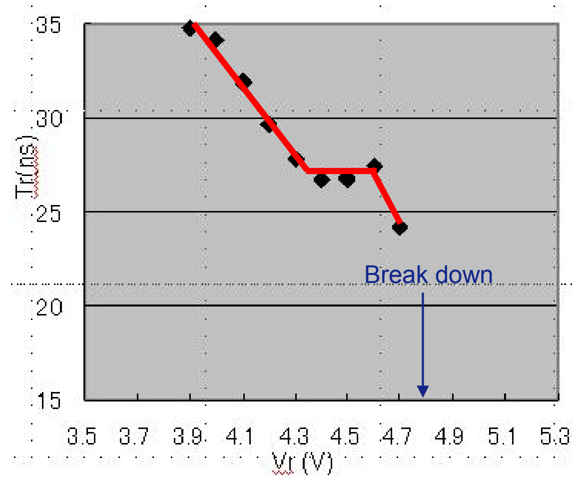

Figure 3: Typical result of ranging.

These "conditioning" and "ranging" methods are started from February 2009. Until then, the rise time were set about 40 ns in beam operations. However, they are almost 1 Hz or 1 shot, there were a few troubles by thyratrons. We did not find that the rise time of 40 ns was too low and resulted in short life time of tubes. Some thyratrons were disabled 500 - 2500 hours. (Nominal life time is 5000 hours at 25 Hz.) The inside of the tubes was investigated. Cathode surface was heavily damaged by an arc discharge [3]. The jitter of several damaged thyratrons were increased up to several tens nsec. We found that they were suppressed to less than 10 nsec by increasing the cathode heater voltage. When we had no-replace new one, we had used the old ones by increasing it up to 7.5 V. (It is generally set at 6.5 V.)

DAILY DATA TAKING FOR STABLE OPERATION OF THYRATRON

Past one year and a half, we have experienced many troubles about thyratrons. On the basis of the experience we didn't desire, we had begun to take several data (rise time and jitter (drift) of output current, reservoir voltage and cathode voltage) for the stable operation. The data were taken by two methods.

First, we take rise time and jitter by oscilloscope in four times a day. The times of data taking are 1:00 AM, 5:00 AM, 11:00 AM and 5:00 PM. The rise time is average and the jitter is the maximum of 500 pulses. Typical waveform of the current rise is shown in Figure 4, and typical accumulated data is shown in Figure 5. If increase of rise time was observed more than approximately 32 nsec, we would increase the reservoir heater voltage.

Second, we take rise time and time delay every two seconds. Typical waveforms of them are shown in Figure 6. In the figure, there are six waveforms. Characteristics of two thyratrons in a power supply are shown. They are distinguished by the colour in blue and red. In each colour, the upper waveform shows the time delay, the lower waveform shows the rise time (Tr) and the center waveform shows "input delay". The input delay means input trigger timing of a power supply.

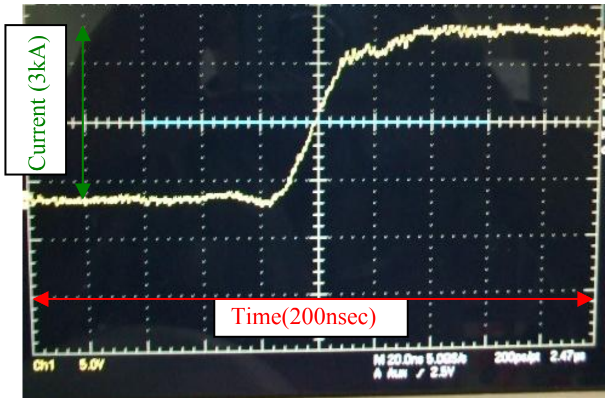

Figure 4: Typical waveform of the current rise.

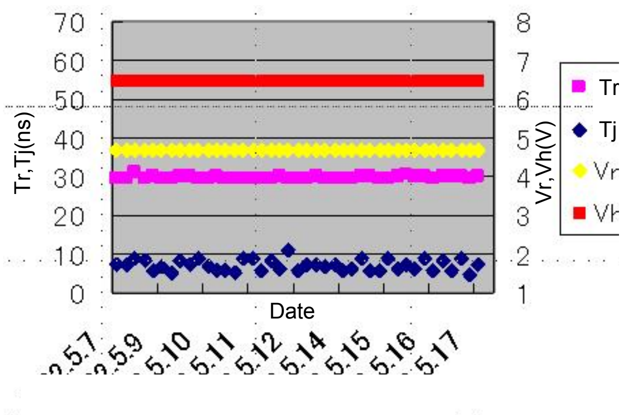

Figure 5: Typical accumulated data.

This data taking system has roles of correction of input delay by a programme as well. When the time delay is changed, which means the drift, more than +- 30 nsec, the programme corrects it to the proper value. The "input delay" shows the change of corrected time delay.

The jitter and the drift are essentially the same data (change of time delay), but the taking frequency of the data are largely different, therefore we have defined different parameters. The jitter is successive 500 pulses. On the other hand, the drift is discontinuous pulse every 2 seconds.

In the figure 6, slightly drift is observed (green circle). However, the input delay is not corrected. The large drift result in extracted beam loss and finally the beam can not be extracted. If large drift was observed as much as time delay was corrected, we would increase the cathode heater voltage to suppress it. The thyratron is near end of life. (Even so, it has more than one month in our experiences.)

In these ways, we have been checking the data and adjusting the reservoir voltage and cathode voltage.

The record of failure (beam stop) time rate in beam operation is shown in Figure 7. It is 13.11 % in January 2009 (RUN 21). On the other hand, after the "conditioning" and "ranging" methods are established, it gradually decreases and finally was reached 0.52 % in April 2010 (RUN 32).

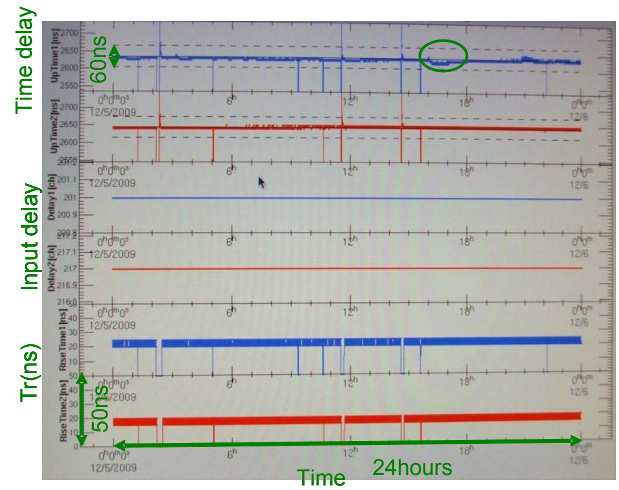

Figure 6: Typical accumulated data of rise time (Tr) and time delay of output current.

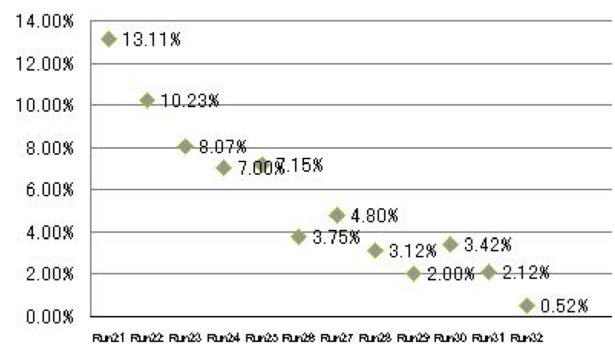

Figure 7: Failure time rates in beam operation.

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