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J-PARC: The path to 1 MW at J-PARC, including 400 MeV linac improvement, RCS improvements and front-end upgrades

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Abstract. An accelerator system of Japan Proton Accelerator Research Complex (J-PARC) operated since May 2008 for neutron experiments. The accelerator system consists Linac, Rapid Cycling synchrotron (RCS) and Main Ring. The original design of RCS injection energy is 400 MeV, but first operation was started by 181 MeV for budget reason. New acceleration cavities were installed in J-PARC linac summer shutdown of 2013, and user operation to Material and Life science Facility (MLF) by the injection energy of 400 MeV was started from February 2014. Owing to the beam commissioning of 400MeV injection energy, the amount of the beam loss was enough small and we established 300 kW continuous operation. In this paper, we report the present status and future plan of J-PARC linac and RCS.

1. Introduction

The Japan Proton Accelerator Research Complex (J-PARC) is facilities for the various physical experiments. The J-PARC facilities were constructed in the Tokai site of the Japan Atomic Energy Agency (JAEA). The accelerator complex consists of a 400 MeV linac, a 3 GeV Rapid-Cycling Synchrotron (RCS), and a Main Ring synchrotron (MR)[1]. RCS delivers 3 GeV, high power proton beam to the MLF, and MR delivers 30 GeV proton beams to Neutrino target and Hadron Experimental hall. The beam commissioning of the linac started in November 2006[2][3][4]. Construction of another accelerators and experimental facilities were continued afterwards, the RCS started to deliver proton beam to the MLF in May 2008[5]. The user operation for MLF started in December 2008[6], and the beam power was gradually increased. However, the great east earthquake caused many serious damages to all J-PARC facilities in March 2011. We completed the recovery work in only nine months and restarted user operation[7]. After the earthquake, we smoothly increased the output power and the user operation of 300 kW power was started at the end of 2012[12]. However, it was necessary to improve the linac and RCS to achieve more output power. Then, the acceleration energy of the linac was raised to 400MeV by installing a new acceleration cavity in the summer of 2013. The injection system of the RCS has also been increased simultaneously for 400MeV injection. In addition, the front end is replaced in the summer of 2014 to increase the beam current of 50 mA.

2. Linac energy upgrade in 2013

In order to increase the output power of RCS, the acceleration energy of the linac was increased from 181 MeV to 400 MeV at the first setout. This energy upgrade aims to mitigate the effect of the space charge in RCS injection process and to reduce the beam loss. Therefore, the ACS (Annular-ring Coupled Structure) cavity was developed[9][10]. 25 ACS modules have been fabricated in total. 21 modules are used to acceleration, and rest 4 are used for debuncher. The ACS cavities were installed in the summer shutdown period of 2013[11]. Figure 1 shows the linac accelerator tunnel after installation of ACS cavities.

Figure 1. The linac accelerator tunnel after installation of ACS cavities.

Aftre installation of ACS cavities, we started the high-power conditioning of the ACS cavities. Figure 2 shows a typical conditioning history of ACS cavity. In the conditioning sequence, we put short pulse RF (50 us) up to 2 MW at first. After that we put longer pulse RF (600 us) up to 2MW. The average conditioning time for one ACS cavity is 149h. The detail conditioning sequence is written in the reference[12].

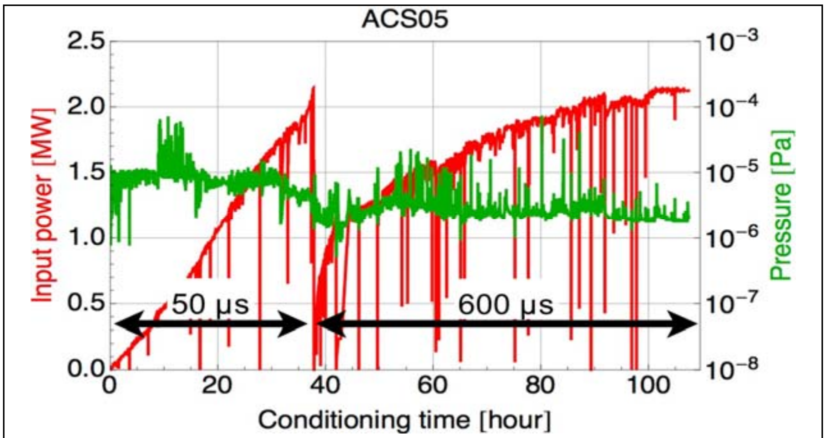

Figure 2. Typical conditioning history of ACS cavity.

A beam commissioning with new ACS cavities are carried out from December 2013 to January 2014. After the commissioning, we achieved acceleration energy of 400 MeV on January 17[13]. Then we started user operation at the acceleration energy of 400MeV, but we need more study time in order to clear next issues. The first issue is a halo formation in the ACS section. This halo brings about the beam loss in the RCS. Proper matching is needed by help of new additional longitudinal monitors. The other issue is higher radioactivity at some points of ACS section.

3. Accelerator improvements in summer shutdown 2014

In summer shutdown period of 2014, we improved many accelerator components of linac and RCS. Here we introduce some major improvements.

3.1. Linac

The most important improvement is replacement of the front-end system for higher peak current. Figure 3 shows a test bench of new front end system.

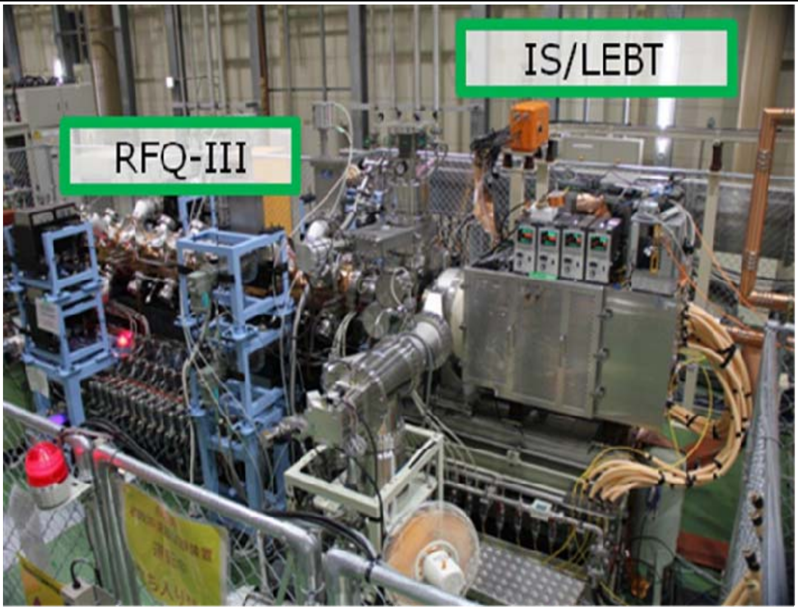

Figure 3. Test bench of the new front end.

The front-end system consists of new ion source, RFQ-III and some parts of the MEBT1. The old ion source used a filament to produce the ion plasma and it did not need Cs. On the other hand, new system adopts the Cs seeded RF-driven system[14]. RFQ-III is optimized for the beam current of 50 mA[15].

The rf-driven H^- ion source and RFQ-III were tested in a test bench, which was constructed in the J-PARC linac building. We checked various parameters of the test bench[16], and we tried long-term continuous operation of this system[17]. Figure 4 shows a test result of long-term operation. Finally, we achieved 683 hrs. (about 1 month) continuous operation. However, discharge of the RFQ frequently occurred during long-term operation test. Thus we decided to install additional pump in actual beam line and keep conditioning as possible.

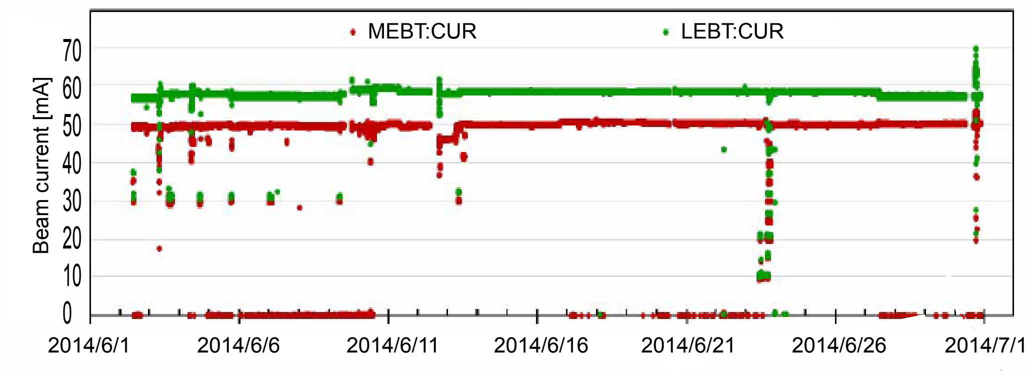

Figure 4. Result of the long-term operation test.

From the results of the first 400MeV beam commissioning, the linac beam had much halo than the lower acceleration energy(181 MeV) operation. In order to improve this condition, we need a beam monitor which can measure the longitudinal shape of the beam. Bunch Shape Monitor (BSM) was installed once for this purpose, but it was replaced due to its high outgas rate[13][18]. Therefore we bake BSM to improve its vacuum property and will install it again in summer 2014.

3.2. RCS

In RCS, a malfunction occurred to the power supply of the injection bump magnet that had been reinforced for 400MeV injection. The flattop region of the shift bump current had a slope due to the defect of the power supply system. This induced the beam orbit shift during injection. Figure 5 shows the magnetic field pattern defect of the shift bump magnet, and the orbit shift due to the defect is shown in figure 6.

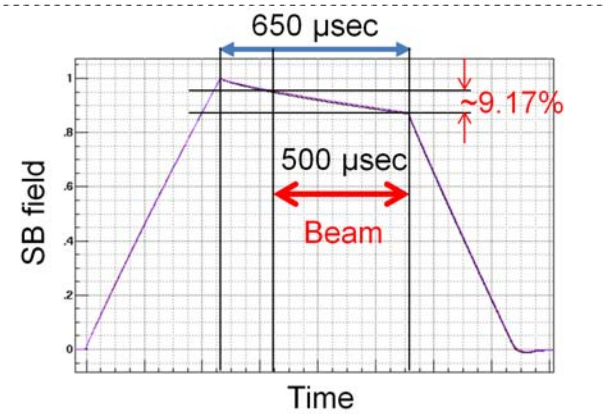

Figure 5. The magnetic field pattern of the shift bump magnet. When it's normal, the magnetic field during injection period has to be flat. However, it has a slope and decreases 9.17 % during injection period.

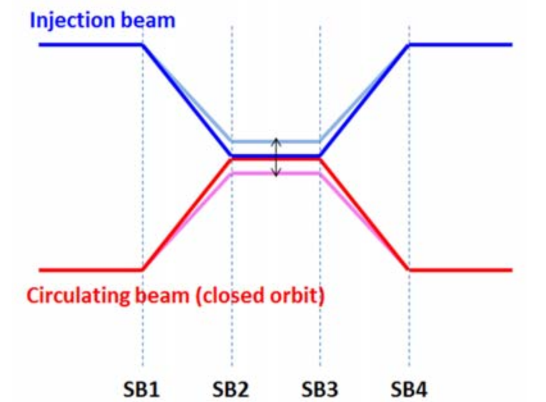

Figure 6. Orbit shift due to the defect of the shift bump field. Four shift bump magnets are excited the one power supply, and these magnetic fields make the injection and circulating orbit merge. Due to the slope of the magnetic field pattern, the injection and circulating beam are separated each other.

So far, we compensated this orbit shift by the other magnets(PBH1-4,PSTR1-2). Figure 7 shows the current waveforms of the injection magnets for compensation, and the injection orbit before and after correction are sown in figure 8.

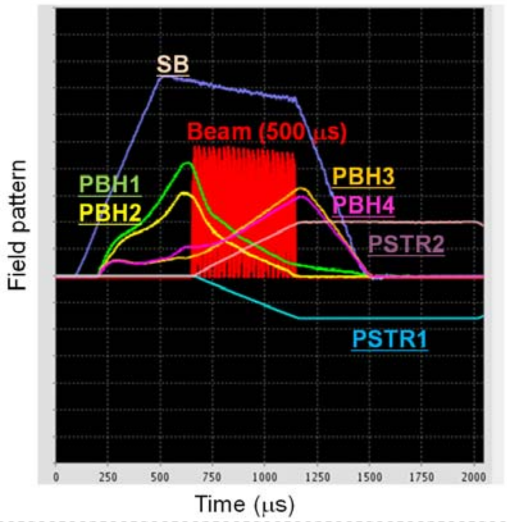

Figure 7 The current waveforms of the injection magnets for orbit correction.

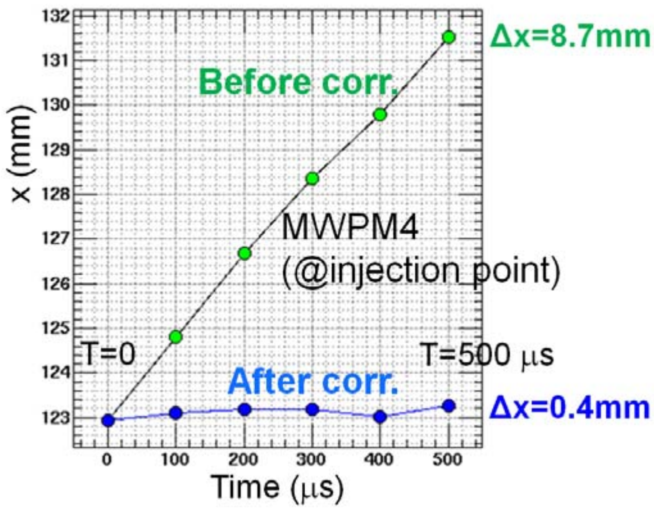

Figure 8 The injection orbit before and after correction.

We also improved the halo scraper system of Linac - 3 GeV RCS Bema Transport (L3BT) line. Previous results[19] showed the scraper system was able to remove the halo of injection beam, and the beam loss in the RCS was reduced. However, the frame of old scraper is too small and the radiation shield of the dump is not enough for continuous operation. We renovated the halo scraper of L3BT line and the dump line for scraped beam.

4. Conclusions and future plan

To achieve the 1 MW output power, the improvements of J-PARC linac and RCS were carried out. As a result, the linac energy was successfully upgraded to 400 MeV with the new ACS system. So far, achieved beam power in user operation is 300 kW for MLF users. The new front-end system will operate to increase the peak current from 30 mA to 50 mA, and the RCS will try to high power demonstration of 1 MW-equivalent beam in Autumn 2014. After that, if possible, we will gradually increase a delivered beam power from 300 kW. Finally, we plan to deliver the design beam power of 1 MW by middle of 2015. But there are some issues to achieve stable 1 MW operation. In the linac, we need to reduce the beam halo and decrease beam loss at ACS section. In the RCS, a countermeasure of the activation at the charge-exchange foil chamber is required. We will clear these issues by the beam commissioning and hardware improvements.

5. References

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