ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME062

STATUS OF THE J-PARC RING RF SYSTEMS

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Abstract

The high intensity proton accelerator complex (J-PARC) consists of the Linac, the 25Hz rapid cycling synchrotron (RCS) and the 50GeV main synchrotron (MR). During the long shutdown of 2013, the Linac energy was upgraded from 181MeV to the design value of 400MeV. In the RCS, we have installed the last 12th RF system. In operation from January 2014, beam commissioning aimed at 1 MW operation was started. In the MR, the upgrade plan of the beam power, realized by raising the repetition, is now going on. For this reason the accelerating voltage must be increased, and all MR RF systems will be replaced with more efficient systems. A new magnetic alloy material (FT3L) was developed. Manufacturing of the FT3L accelerating cavities has been proceeding. It becomes possible to increase the accelerating voltage from 280 kV to 560 kV, using the new cavities in combination with the existing RF power supplies. We have started the developments of a 2nd harmonic system loaded with air-cooled FT3L cores and a high-Q VHF cavity system, too. The VHF system is used for longitudinal dilution and the 2nd harmonic system increases the bunching factor of the circulating high intensity proton beam.

INTRODUCTION

The RCS is a compact synchrotron with a repetition rate of 25Hz, and a circumference of 348.333m. 2 proton bunches are accelerated from 181 (former)/ 400MeV (present) to 3 GeV. The twelve accelerating cavities are designed to generate the total 440 kV peak accelerating voltage.

In the summer of 2013, the linear accelerator output energy was upgraded to the design value of 400 MeV from 181 MeV. Then, in November 2013, the last RCS cavity (#12) was installed. The RCS beam commissioning using a 400MeV Linac beam was carried out with the twelve sets of RF systems in January 2014. The longitudinal painting and acceleration in the RCS proceeded well with the RF parameters given by a particle tracking like before with the 181MeV proton beam. The RCS has succeeded in the proton acceleration of a 550 kW equivalent proton beam. The operation with a beam power of 300 kW started for the MLF users from the middle of February.

The MR has a circumference of 1567.5m, which is exactly 4.5 times of the RCS circumference. 8 bunches from the RCS are accelerated from 3 GeV to 30 GeV with the h = 9 RF harmonics. MR cycles are 2.48 s and 6 s for the fast beam extraction (FX) and the slow beam extraction (SX), respectively. The nine cavities are operated as 8 accelerating systems and one dedicated 2nd harmonic system.

The J-PARC operation has been stopped for about one year due to the accident, which happened at the Hadron experimental hall in May 23rd 2013. The MR user operation was restarted with 200 kW beam for the neutrino experiment in May 26th 2014.

The replacement of the RCS cores has been carried out on schedule since March 2010. This is for preventing from impedance reduction of the cavity due to core buckling inside. The present status is briefly reviewed in the following section.

The FT3L core is a new magnetic alloy material. The μQf -product value is twice high compared to the present FT3M core. The production of a large FT3L core was initiated at the J-PARC site collaborating with the company. After successful development of the large FT3L core, the setup moved to the company site for mass production, which started in JFY2013. The 4 or 5-gap FT3L cavities are designed and manufacturing of the nine sets of cavities is in progress. Four sets of the cavities were delivered in the end of last March. One of the new cavities (5-GAP) has been tested with high RF power [1].

MAGNETIC ALLOY CAVITY

The RF systems for the J-PARC RCS and MR require a high accelerating gradient (more than 20 kV/m). Magnetic alloy (MA) cores were the only material able to achieve the required voltages in the available space. A magnetic alloy core is made by rolling a thin metallic ribbon. The ribbon has a thickness of 18μm and is 35 mm wide. The size of core is 850 mm O.D. and 375 mm I.D. for the RCS cavity and 800 mm O.D. and 245 mm I.D. for the MR cavity. A cavity has three acceleration gaps, then 6 cores are loaded per gap, and the accelerating voltage is 15 kV/gap. The dissipated power reaches several kW/core. When applying a magnetic alloy core to the acceleration cavity of J-PARC, the development of efficient cooling was the biggest technical issue. Finally, we selected the direct cooling method with purified water. The coating process aiming at preventing cores from corrosion of a core became important as well as making a cut-core for the MR application. In case of the MR, the cores are cut in half with an air gap so that the effective quality factor Q can be changed to around 22. The key manufacturing process is summarized below,

1. Low-viscosity resin impregnation
2. Epoxy coating with thin glass cloth

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3. Cutting in half
4. Polishing the cross-section
5. Antirust coating finish.

On the other hand, the RCS cavities require a wide RF frequency range of 0.938 MHz to 1.67 MHz. The Q-value should be around 2 to cover the wide frequency span. The RCS cores were adopted without cutting.

RCS Un-cut Core Issue

The biggest issue in the RCS RF system was the impedance drop caused by the compression buckling of the cores. Since the impedance drop was observed first in January 2009, such impedance drop has happened 5 times until August 2012. The buckling phenomenon is caused by compressive force due to internal thermal stress. Because the magnetic flux density (B_{rf}) is inverse proportional to the centre distance inside an (un-cut) core, the heat density at the inside of the core becomes 5 times or more than at the outside. And, the compression stress by thermal expansion exceeds 100 MP in calculation of a simple model [2].

We re-investigated the manufacturing process in detail and traced the cause by induction. As a result, we concluded that the processes of 1 and 2 in the cut-core production were influencing the core elasticity.

The coating process for an un-cut core was modified so that the core can retain the elasticity. Manufacturing of the improved cores was started from the beginning of 2010. Exchange of the old cores was advanced from March 2010. The cores in nine systems were already replaced until now. Replacement will be completed by 2015.

When an impedance drop occurs, the accelerating gap is electrically short-circuited by remote control and later the bus-bars are rearranged. We minimize the downtime by 2-gap operation of the affected RF cavity (Fig. 1).

BEAM COMMISSIONING

The beam commissioning of J-PARC RCS was started in January 2014. At the beginning of the commissioning, we focused on the optics tuning with 400 MeV DC-mode, because the whole magnets were re-aligned during the maintenance period. The acceleration to 3 GeV was started with the peak current of 25 mA and the macro pulse width of 100 μA ~ 500 μA from February 2014. The longitudinal accelerating parameters such as a frequency and amplitude patterns were recommissioned. And also, the gain/phase parameters for the multi-harmonic feedforward were readjusted using a high intensity beam. The full longitudinal painting during the injection was applied

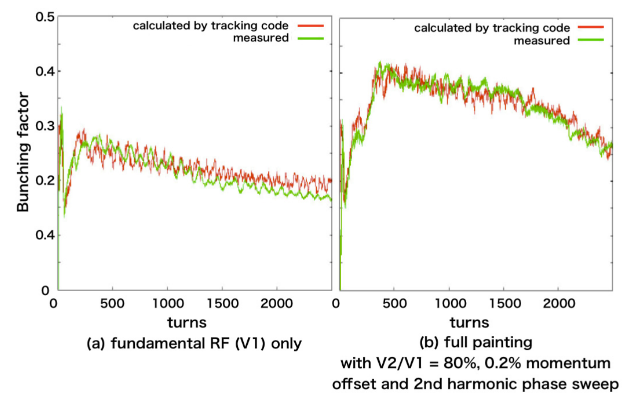

Figure 2: Full longitudinal painting with a 400 MeV Linac beam during the RCS injection (1000 turns ~ 1.63 ms).

and agrees with the parameters based on the particle tracking [3] as shown in Fig. 2.

The beam intensity of 4.66 x 10^{13} protons per pulse (corresponding to 550 kW with a 25 Hz repetition) has been successfully achieved in a trial operation. The user operation re-started from the end of February with a full beam power of 300 kW.

The beam commissioning of J-PARC MR was started

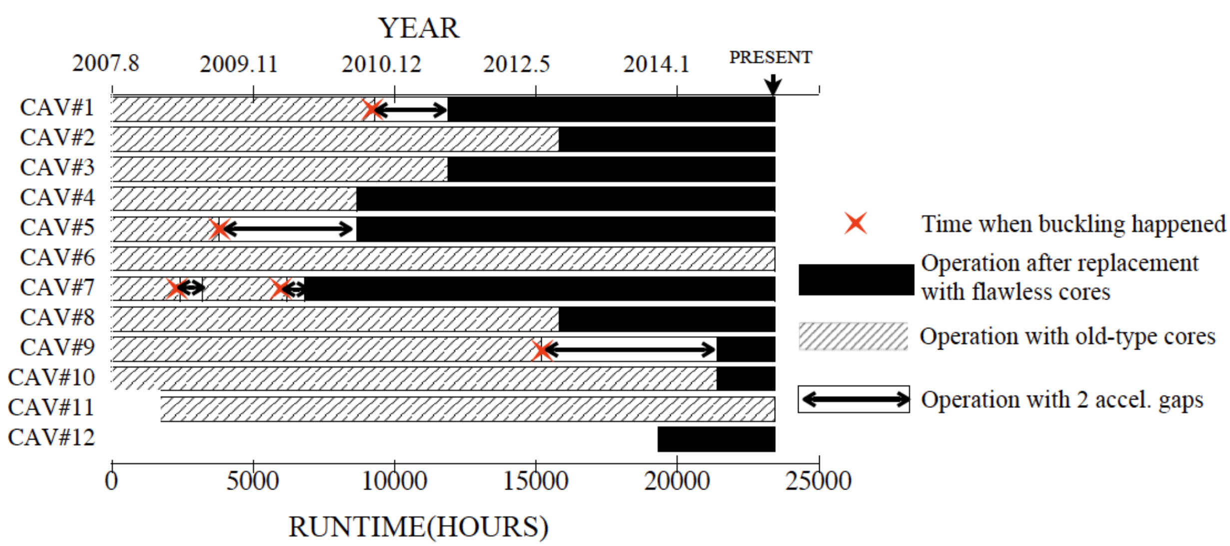

Figure 1: History of the replacement of the cores for each RCS cavity with an operation time.

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in March 2014. The longitudinal emittance from the RCS is slightly larger in case of the 400 MeV proton beam acceleration. Since the extracted bunch length is limited below150 ns for the MR injection, the RF voltage had to be increased from 60 kV to 150 kV at the RCS extraction. The RF voltage at the MR injection also had to be raised in connection with it. It is an important issue to increase the bunching factor and to keep it high during the MR injection. In the trial beam study using 2nd harmonics, we have checked that it was effective in improving the bunching factor to set the 2nd harmonics voltage to 70% of the fundamental RF voltage.

Typical user operation for the fast beam extraction has started with a beam power of 200 kW and a repetition rate of 2.48 seconds. Total beam loss is kept below the order of a few hundred watts.

BEAM POWER UPGRADE FOR MR

The design beam power is 0.75 MW for the FX user operation. To realize this output power with 30 GeV, 1 Hz high repetition rate operation scenario is considered and two critical R&D are in progress. The development of a high field gradient cavity is one of the key pillars of the upgrade scenario. The existing nine RF cavities are going to be replaced with the high impedance cavities with FT3L cores. The production of the FT3L accelerating cavities (two of 4-GAP and seven of 5-GAP cavities) is now going on. And, four sets of cavities have been already delivered. In the test area at the J-PARC site, the test operation of one of 5-GAP cavities (Fig.3) was started from May 2014. The RF test parameters are the peak RF voltage of 80 kV per cavity, the RF frequency of 1.725 MHz and a duty of 47%.

Longitudinal manipulation is necessary to alleviate the space charge effect or to keep the stability criterion for longitudinal microwave instability. A 2nd harmonic system is effective to make fast bunch lengthening during the injection period. The dedicated 2nd harmonic system with air-cooled FT3L cores is designed. We made the single cell proto-type cavity to verify the technical issues [4].

Figure 3: FT3L 5-GAP Cavity at the RF High Power Area.

For the SX in the MR, the extracted beam power of 24 kW was achieved with a high extraction efficiency of 99.5% so far. During the debunching process, the longitudinal coupled impedances consume the momentum of the circulating beam. Because of the chromatic effects, the momentum deceleration would affect the extraction efficiency [5]. To increase the SX beam intensity while keeping the high efficiency, a fast longitudinal debunching and a controlled emittance blow-up are necessary. We are considering the 50 MHz VHF cavity to provide a controlled longitudinal emittance blow-up.

SUMMARY

We report that the replacement of the old cores of the RCS cavities has smoothly been carried out on schedule. We are convinced that the core-buckling issue was solved. Probably, the more quantitative analysis and understanding about a production method are necessary in the other application.

Production of the high impedance cavity with FT3L core is now going on. In the RF high power test examination, the highest accelerating field gradient of 31 kV/m is achieved with a new F3L core. This success is an important milestone in the upgrade scenario. Replacement of new nine cavities will start in this summer and will be completed by JFY2017. The proto-type single cell cavity with air-cooled FT3L core was designed/manufactured for the dedicated 2nd harmonic system and the test operation with high RF power is prepared in the near future. The high-Q VHF cavity is in the design phase now. Manufacture of a cold model and the design of a radio-frequency source are planned in this fiscal year.

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