STATUS OF THE J-PARC RING RF SYSTEMS

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Abstract

Due to the 11th March 2011 earthquakes, J-PARC was forced to stop operation. The restoration was as scheduled so that J-PARC was restarted in December. Before the earthquake, we had considerable success in accelerating the 400 kW equivalent proton beam in the RCS. Multi-harmonic RF feedforward was established, which contributes to the reduction of beam loss and stable acceleration in RCS. The MR synchrotron achieved stable 145 kW beam operation for the T2K experiment. In summer 2011, we installed two new RF systems in MR. Eight RF systems in total allow a more stable beam acceleration and flexible bunch shape manipulation. Also, we prepare the RF feedforward to compensate beam loading in MR. To achieve a beam power in excess of 1 MW in MR, it is considered to double the MR repetition rate. We developed an annealing scheme for large magnetic alloy cores while inside a DC B-field that results in higher core impedance, and have succeeded in producing large FT3L cores in the last summer, 2011. With such cores we can almost double the accelerating voltage without re-designing the existing RF sources. For the near future, we are planning to replace the existing RF cavities with upgraded cavities using the FT3L cores.

INTRODUCTION

J-PARC is a high intensity proton accelerator facility, which aims to produce MW-class high power proton beams. The facility consists of the Linac, the Rapid Cycling Synchrotron (RCS) and the 50GeV MR. On 11 March 2011, the J-PARC facility was heavily damaged by the TOHOKU earthquake. The facility was forced to stop operation. After that, the repair-work and restoration works and restoration of the infrastructure of the facility have been carried out steadily until December 2011. Especially, in the MR synchrotron, the whole lattice components along 1.5km circumference were re-aligned within a limited time. The RF cavities were also then re-aligned about 30 mm at maximum vertically. Fortunately, the RF systems for both RCS and MR were not damaged severely. We concentrated on the regular work such as core replacements and the installation of the new cavities. In the RCS, 12 cores in two cavities were replaced with new cores [1]. In the MR, three major tasks were completed. The first, the cavity cooling water system was separated from the cooling system for the magnet. Second, the cores for three cavities were replaced with the newly processed cut-cores [2]. And, third, two new cavities were installed.

In December 2011, the operation has been re-started smoothly on schedule. 200 kW continuous beam operation has started for the Material and life science facility (MLF) users of the RCS. On the other hand, in the MR, a strategy to shorten the MR cycle time is chosen for increasing the beam power. The original MR cycle was 3.64 seconds ling. The most recent cycle is 2.56 seconds, which is 30% shorter. The beam intensity reaches *100 Tera-protons per pulse* (*10^{14} ppp*) and stable 190 kW user operations have started for the T2K experiment. Figure shows the typical beam intensity by DCCT in the MR.

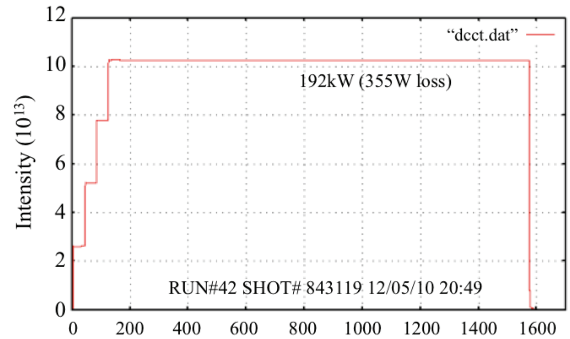

Figure 1: Typical MR operation for the T2K experiment.

RF SYSTEMS

J-PARC RF cavities each provide a high field gradient of > 20 kV/m. Magnetic alloy (MA) cores are the only materials to realize the required gradient in the available space. MA loaded cavities, therefore, had been designed for both J-PARC RCS and MR synchrotrons. The MA core itself is based on a low Q material. Nevertheless, since the magnetic permeability is high, the μQf-product, which is proportional to the shunt impedance of the cavity, becomes comparable or even higher under the high B_{rf} field than that of ferrite material.

$$R_{sh} \propto \mu Qf \qquad (1)$$

Also, the MA loaded cavity can be regard as a stable passive load. No tuning control is necessary. This is a great advantage, contributing to stable high power operation. A combination of the MA load and the high quality digital LLRF allows precise fine longitudinal control and reproducibility [3].

All 11 RF systems in the RCS are operational. The 12^{th} cavity system is under preparation with the aim to start operation at the end of FY2013.

The optimum Q-value of the RCS cavity is 2. The bandwidth of the RCS cavities is wide enough to cover the frequency ranges of both the fundamental and the 2^{nd} harmonics. The RCS systems are operated with a dual harmonic mode. The combined RF voltage allows longitudinal bunch shape manipulation as well as beam accel-

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eration. The multi-harmonic RF feedforward works properly to compensate beam induced voltages [4]. The impedance suppression seen by the beam reached 30 dB at maximum.

Table 1: Major RF Parameters

	3GeV RCS	MR Synchrotron
Kinetic Energy	181 MeV – 3 GeV	3 – 30 GeV
Cycle period	25Hz	2.56 s (FX) 6.00 s (SX)
No. of protons *1	1.3×10^{12} ppp	$1. \times 10^{14}$ ppp
Acc. Voltage *2	400kV	280 kV
RF harmonics	2	9
No. of bunches	2	8
Frequency range	0.938 – 1.67 MHz	1.67 – 1.72 MHz
Q-value	2	22
No. of cavities	11	8

*1: achieved value, unit is particles per pulse,
*2: fundamental/ Peak,
FX: Fast extraction, SX: Slow beam extraction

In August 2008, MR beam commissioning was started with four RF systems. In average one additional MR RF system has been installed every year to ensure enough accelerating voltage for a machine operation with a higher repetition rate. At present, 8 RF systems are operational and the (last) 9th system will be installed during this summer shutdown. So far, all 8 systems are used for acceleration. However, if requested, the MR RF systems can be easily switched to the 2nd harmonic operation by removing some of tuning capacitors. This is different from the RCS cavities due to the different Q-value.

The accelerating RF frequency in MR changes about 3% from 1.67 MHz – 1.72 MHz. Optimum Q-value is selected to be around 25 in consideration of transient beam loading. The cut core configuration was used to adjust the cavity Q-value. The RF in the MR operates at harmonic (h = 9). Beam current components of the three harmonics (h = 8, 9, 10) are taken into account for the loading compensation of the accelerating cavity. Like RCS, the beam loading compensation for the MR cavities also uses the multi-harmonic feedforward system. The multi-harmonic feedforward systems have been designed and developed in JFY2011. The preliminary beam test has been started [5].

MR Cavity Cooling Water System

In Autumn 2009, all MR cavities showed an impedance drop. The impedance drop attributes to insulation failure between ribbon-layers at the cut-core. The cavity cooling water was shared with the main ring magnets. The Cu-ions in the cooling water seemed to contribute to redox reaction [6]. To protect against cut-core corrosion in the cooling water, "Silica coating with perhydropolysilazane (PHPS)" and "Room Temperature Vulcanizing (RTV) rubber shielding" were developed. "PHPS" coating covers the cut-surface with a SiO_2 layer about 1µm thin. "RTV rubber shielding" can almost shut out cooling water from the cut-surface. Also, the RF cavity cooling system was separated from the magnet cooling system in December 2011.

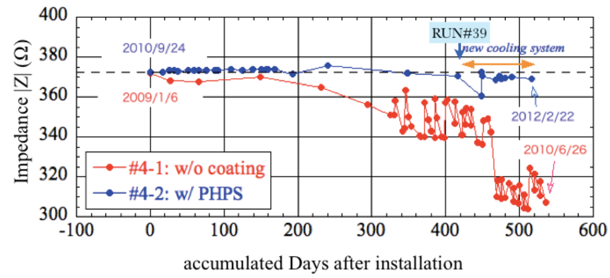

Figure 2: Cavity Impedance at MR station #4.

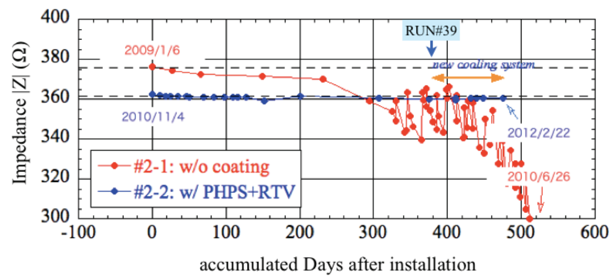

Figure 3: Cavity Impedance at MR station #2.

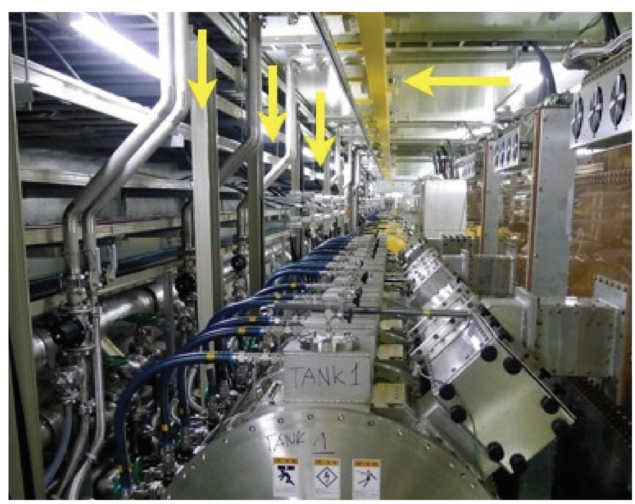

Figure 4: Separated cavity cooling system: Water Pipes are down from the ceiling (Flow rate: ~300 liters/min/station).

The cores at station#4 cavity were replaced with "PHPS" processed cores in September 2010 (see figure 2). And, the cores at station#2 cavity were replaced with "PHPS" and "RTV rubber" processed cores in November 2010 (see figure 3). The two figures 3 and 4 show the time variations of the cavity impedance after installation at station #2 and #4. The cavity impedances (blue line in figure) after core replacement are stable and do not shown any impedance drop. The surface protection processes seem to work fine. The "PHPS" coating + "RTV rubber" shield are robust and will be applied to all cut-cores at the 7 stations (#2, #3, #4, #5, #6, #7, #8). The new separated cooling system has been operated since RUN #39 (Dec. 2011).

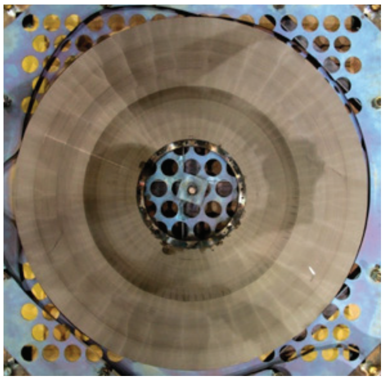

Figure 5: FT-3L core just after annealing under an axial magnetic field. (OD 800 mm × ID 245 mm × t 25 mm.)

FT-3L Cores

FT-3L cores have approximately twice the impedance compared to the present FT-3M cores. The cores are produced with annealing under an axial magnetic field. To manufacture large size cores suitable for accelerator application, we planned to process prototype FT3L cores at the J-PARC Hadron Hall by using the large magnet for a detector in last March 2011. Although the attempt was postponed due to the earthquake, We could successfully process a set of new cores in June 2011. The high power test of a FT-3L loaded cavity is planned for autumn 2012.

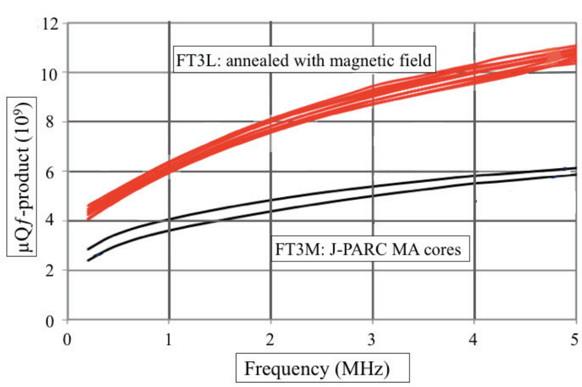

Figure 6: Comparison of FT-3L and FT3M. FT-3L cores achieve higher μQf-products.

FT-3L cores are made of 13μm thick ribbons, which are thinner than the 18μm-ribbons for the FT-3M cores. The electrical insulation between the wound ribbon surfaces is provided by SiO_2 coating. The quality of the coating as well as the thickness influences he core packing factor. This coating process is one of the issues to be solved. The FT-3L production at the J-PARC Hadron Hall had to be terminated, because the borrowed dipole magnet was given back to the original physics experiment. We are preparing the new experimental area in the building belong to the J-PARC neutrino experimental group. Further studies toward FT-3L mass production are planned in the end of JFY2012 [7].

OUTLOOK

In 2013, the J-PARC Linac energy will be upgraded to the 400 MeV original design value. And, the RCS injection systems will be upgraded to match the "linac energy recovery". The 12th RCS cavity will be installed in summer 2013. Preparation is going in into the direction of MW class beam operation. The ring RF systems run almost perfectly in both RCS and MR. Total run times in RCS and MR are exceeding 10000hrs. In the RCS, every year, the set of cores of two cavities will be replaced to eventually solve the issue of core buckling [1]. Core replacements for 5 of 11 cavities are finished and the replacements will be completed by JFY 2014. In the MR, the RF cavity cooling system was separated from the magnet cooling system. "Silica coating with PHPS" and "RTV rubber" processes were established and are applied to most of cut-cores. The impedance drop problem caused by corrosion might be solved this way. Large size FT-3L cores have been successfully manufactured at the J-PARC Hadron hall in collaboration with Hitachi-metal Company, NU-and HD-groups. The high power test of the cavity with FT-3L cores is planned for autumn 2012.

Design specification of the MR beam power is 750 kW with a designed 50 GeV proton beam energy. To achieve the goal with the present energy of 30 GeV, the high repetition scheme is considered in the MR synchrotron. High field gradient RF cavity with FT-3L cores will be the key for realizing the beam power upgrade in the MR synchrotron.

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