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UPGRADE PLAN OF J-PARC MR - TOWARD 1.3 MW BEAM POWER

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Abstract

The Main Ring synchrotron (MR), a 30 GeV slow cycling proton synchrotron, delivers intense proton beam to a long-baseline neutrino oscillation experiment, T2K, by fast extraction (FX) and to an experimental facility, which is called hadron hall, by slow extraction (SX). The maximum beam intensities for routine operations are 495 kW for the FX and 51 kW for the SX. In order to increase the beam intensity, a plan to replace the magnet power supplies is now in progress for operation with a higher repetition rate. After the replacement, the cycle time will be shortened about a half and increase beam intensities two times larger for the FX. In addition, a further upgrade, which is mainly reinforcement of the rf system, is planned for the FX. The goal of the upgrade is reaching 1.3 MW beam power for the neutrino experiments.

INTRODUCTION

The J-PARC facility comprises an H^- linac, a Rapid-Cycling Synchrotron (RCS), the MR, and related experimental facilities. The RCS provides 3 GeV proton beam to the Materials and Life Science Experimental Facility (MLF) at a repetition rate of 25 Hz. A part of the beam extracted from the RCS is injected into the MR, which accelerates the beam up to 30 GeV and delivers the beam to the hadron hall using the SX system and to the T2K experiment using the FX system.

Figure 1 shows a beam power history of the MR as of the end of April 2018 [1]. For the FX operation, the maximum beam power for T2K experiment is 495 kW, 2.55 x 10^{14} protons per pulse (ppp) with a repetition time of 2.48 s. The achieved ppp is the world highest extraction intensity in synchrotrons. For the SX, third integer resonance extraction is adopted in the MR. The maximum beam power for user is 51.1 kW, 5.53 x 10^{13} ppp with a repetition time of 5.20 s. It is also the highest-class beam intensity of the SX in the world.

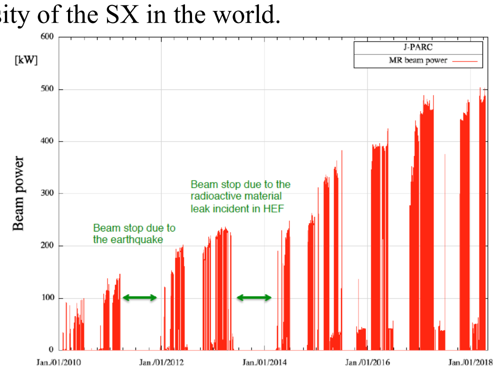

Figure 1: History of beam intensity for the MR.

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BEAM POWER UPGRADE PLAN

The T2K experiment discovered electron neutrino appearance in a muon neutrino beam in 2013 [2]. After the achievement, T2K started the oscillation experiment also using antineutrino beams to study CP symmetry violation in neutrino sector. In the latest results based on beam exposure of 2.65 x 10^{21} POT (protons on target), 34 % of approved statistics, the T2K experiment rejected the hypothesis that neutrinos and antineutrinos oscillate with the same probability at 95% confidence level (2σ) [3]. For further improvement in sensitivity of the CP violation study, higher beam intensity of the MR is necessary.

We adopt a scenario of higher repetition rate operation for reaching the beam power larger than 750 kW, the original design value [4]. To realize the scenario, upgrade plans of magnet power supplies, rf system, ring collimator system, beam injection and FX systems are now in progress. The cycle time will be shortened from the current value of 2.48 s to 1.32 s or less after the upgrade.

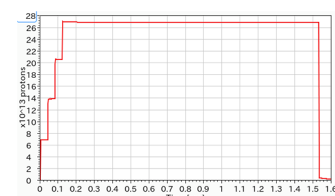

Figure 2: Circulating beam intensity in the high power demonstration.

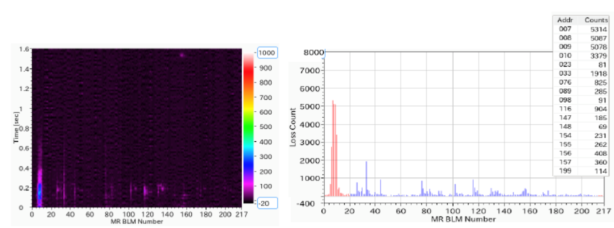

Figure 3: Distribution of beam loss monitor signal in the high power demonstration; mountain plot of one shot (left) and integrated counts (right). The sensitivity of the blue part in the right figure is eight times larger than that of the red part.

Figures 2 and 3 show the most recent results of demonstration of high power beam extraction for the FX. The betatron tune is (21.35, 21.43), the same as that of the routine operation in the FX mode [1]. The circulating beam intensity measured by DC current transformer is shown in Fig. 2. The extracted beam intensity is 2.7x10^{14} ppp, which corresponds to 520 kW beam power at a 2.48 s cycle time. The total beam loss in the MR was estimated

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to be ~1 kW. The distribution of the beam loss monitor signals around the whole ring is shown in Fig. 3. The most of the beam loss occurs during the injection and the beginning of acceleration. The beam loss is well localized in the collimator section, the red part in the right figure.

When we consider that the MR will be operated with the 1.3 s cycle after the upgrade, the extracted beam of 2.7x10^{14} ppp corresponds to beam power of ~1MW. Therefore, the demonstration shows that the MR has a feasibility to reach the beam power of 1MW with the well-localized beam loss in the collimator section less than ~2 kW in total.

Figure 4 shows the power upgrade plan of the FX, which was revised in March 2018. The plan until JFY2020 is based on a conservative funding scenario. The operation of 1.32 s cycle will be started in the end of 2021 in this plan. However, it will start earlier if we can succeed to get supplemental budget for manufacturing the magnet power supplies.

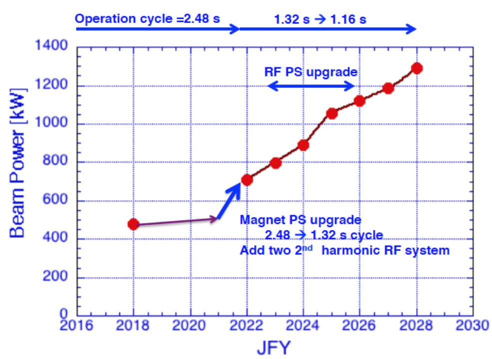

Figure 4: Power upgrade plan of the MR.

The operation of 1.3 MW beam power is the goal of the MR until the latter half of the 2020s. The 1.3 MW beam will be achieved by 3.33x10^{14} ppp at 1.16 s cycle. Required injection beam from the RCS is 8.33x10^{13} ppp, the design intensity of the RCS and corresponds to 1 MW at 25 Hz. Main parameters for 750 kW and 1.3 MW operations in the MR are summarized in Table 1. The required rf voltages in the table are determined by a particle tracking simulation study [5].

Table 1: Parameters of 750 kW and 1 MW Operation in the MR

	750 kW	1.3 MW
Protons per pulse	2.06 x 10^{14}	3.34 x 10^{14}
Required equivalent beam power of RCS	619 kW	1 MW
Repetition time	1.32 s	1.16 s
Acceleration time	0.65 s	0.58 s
Accelerating voltage	510 kV	600 kV
2nd harmonic voltage	120 kV	120 kV

In 2016, the T2K collaboration has proposed a project of run extension program, which is called T2K-II [6], to collect data of 20x10^{21} POT. The main purpose of the T2K-II is CP violation observation with 3σ sensitivity.

Furthermore, after the T2K-II, the next generation large water Cherenkov detector Hyper-Kamiokande is expected to start the neutrino oscillation experiment [7]. The Hyper-Kamiokande project is assuming the 1.3 MW beam power of the MR from the start.

In such situations, the power upgrade plan from the original design power 750 kW to the new target power 1.3 MW was selected as the first priority in future projects of KEK by "Project Implementation Plan (KEK-PIP)" which was issued in 2016 [8].

STATUS OF HARDWARE UPGRADE

Magnet Power Supply

Figure 5 shows a circuit diagram of power supply (PS) for main dipole magnets [9]. The PS has serially connected six choppers, each of them is connected to a large condenser bank module (CBM) which has a capacitance of 480 mF. The most of the power is transfer between the CBMs and the magnets in each cycle and the only dissipated power is supplied by electric power line. CBM3 and CBM4 are connected to the electric power line, and the other CMBs are not connected to the power line. The CBM not connected to the power line is called "floating capacitor". The design adopting floating capacitors can reduce the number of rectifiers/convertors in the PS and reduce the total cost.

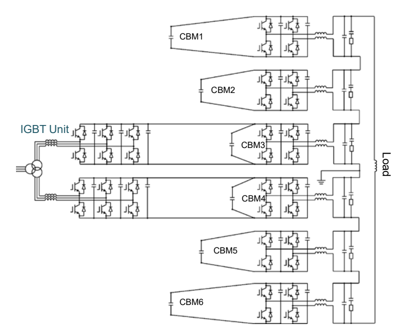

Figure 5: Circuit diagram of the dipole magnet PS.

The budget for manufacturing the new PS's and new three buildings for the PS's have been approved by the Japanese government. The construction of the buildings has been finished in JFY2017 as shown in Fig. 6.

Figure 6: The newly constructed three buildings for the magnet PS's.

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Figure 7 shows the first manufactured dipole magnet PS installed in one of the building (D4). The output current and voltage are 1.6 kA and 6 kV, respectively. One dipole magnet PS has three containers. Two CBMs are installed in one container. Figure 8 shows photographs of three containers set in a yard of D4 and two CBMs installed in one of the containers. System performance test of the PS is now in progress.

Figure 7: New dipole magnet PS in D4.

Figure 8: Three containers in the D4 yard (left) and two CBMs installed in one of the containers (right).

RF System

We developed a new type of magnetic alloy (MA) core to achieve a larger accelerating gradient than that of the original MA loaded cavity using the FT3M core. The new core material, which is called FT3L is produced by annealing with transverse magnetic field, whereas the FT3M is annealed without magnetic field [10]. The FT3L core has two times larger shunt impedance than the FT3M core. All of nine rf cavities with FT3M cores in the MR have been already replaced with new cavities with FT3L cores until 2016. In the user operation with beam power larger than ~400 kW, seven rf system are used for acceleration and two rf systems are used for applying 2nd harmonic rf voltage to control the bunching factor during the beam injection.

As listed in Table 1, the accelerating time is 0.65 s and the required accelerating voltage is 510 kV for the 750 kW beam operation. All nine FT3L cavities in the MR will be operated as the accelerating system. Two FT3M cavities will be recycled for the 2nd harmonic system. For the 1.3 MW beam operation, the accelerating time is 0.58 s and the required accelerating voltage is 600 kV. To produce the required accelerating voltage, all rf anode power amplifiers will be reinforced by installation of additional four inverter output units. In addition, two more FT3L cavity systems are planned to install. Details of the upgrade scenario for the rf system are described in Ref. [5].

Collimator, Injection and FX Systems

Configuration of the MR collimator section is shown in Fig. 9. The present collimator system has a beam loss capacity of 2 kW. The capacity will be increased up to 3.5 kW by installing three additional collimator units as shown in the lower figure.

Figure 10 shows an injection septum magnet system, which was developed for the high repetition rate operation and was installed in summer of 2016 [11]. Since then, it has been operating very stably for two years.

The newly manufactured low field FX septum for high repetition rate operation is shown in Fig. 11. It is an induced eddy current type magnet, which has a larger beam aperture and a lower leakage field on the circulating beam than those of the present septum The field measurement of the magnet and operation test of its power supply are now in progress.

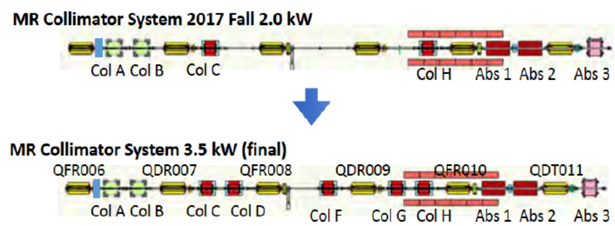

Figure 9: Configuration of the MR collimator section: present system, which has a 2.0 kW loss capacity (upper), and final system with a 3.5 kW capacity (lower).

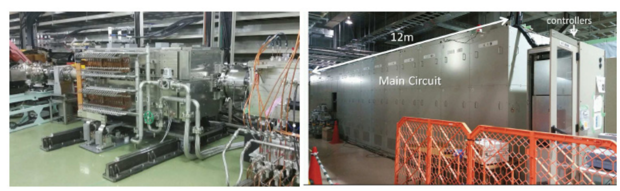

Figure 10: The injection septum magnet system developed for the high repetition rate operation: magnet in the ring (left) and power supply (right) [11].

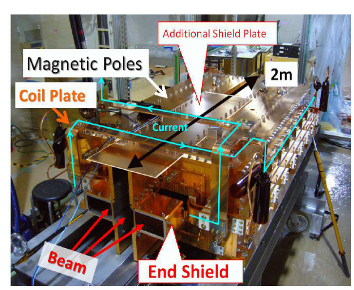

Figure 11: New low field FX septum magnet [12].

SUMMARY

Beam study and hardware upgrade based on high repetition rate scenario are now well in progress in the MR. To achieve the beam power of 1.3 MW for the long baseline neutrino oscillation experiments is the goal of the MR until the latter half of the 2020s.

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