J-PARC ACCELERATOR COMPLEX CONSTRUCTION

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Abstract

The full beam commissioning of the J-PARC accelerator complex began in May of 2008, and then from December of 2008 the 3 GeV Rapid Cycling Synchrotron began providing beam to user runs while work continued in parallel to commission the 50 GeV synchrotron and the primary beam lines for the Hadron and Neutrino experiments. Physics runs of the Neutrino experiment began in January 2010, and the first neutrino event at the Super-Kamiokande was observed in February 24, 2010. This paper outlines the beam commissioning status, the current beam power upgrade scenario and issues around the long-term plan for the 50 GeV synchrotron.

INTRODUCTION

The J-PARC accelerator consists of a 181 MeV Linac (to be upgraded to 400 MeV in 2012), a 3 GeV Rapid Cycling Synchrotron (RCS, repetition rate 25 Hz), and a 50 GeV slow cycling synchrotron (MR: Main Ring, for the time being operating at 30 GeV with a repetition rate of 0.3 Hz). For scale, an aerial view is shown in Fig. 1. Most of the output beam from the RCS is delivered to the Materials and Life Science Experimental Facility (MLF). Every 3.5 seconds the MR receives the beam from 4 RCS cycles, this is determined by the MR cycle time (MR_{cycle}).

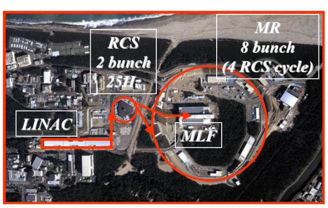

Figure 1: Layout of the J-PARC accelerator complex.

The MR accelerates the beam up to 30 GeV before it is extracted to either the Hadron or the Neutrino Experimental Facility. The MR beam power P_{MR} can be expressed as a function of the RCS beam power (P_{RCS}) and MR_{cycle}. A timeline for the expected beam power upgrade curves is shown in Fig.2.

$$P_{MR} = 1.6\, P_{RCS}/MR_{cycle} \quad (1)$$

In order to provide efficient and stable operation, we have set the beam energy to be 30 GeV instead of the original design spec of 50 GeV. The lowered beam energy is not disadvantageous when the goal is obtaining high-beam power, because the lower the energy, the shorter the MR_{cycle} needed. However, it should be noted that this formula only applies when the MR is able to accept the full RCS beam. The purpose of this paper is to outline the commissioning status, summarize issues in achieving the MR design power, and finally to propose a new MR operational scheme to realize the KEK road map (the red dotted curve marked with a star in Fig.2.)

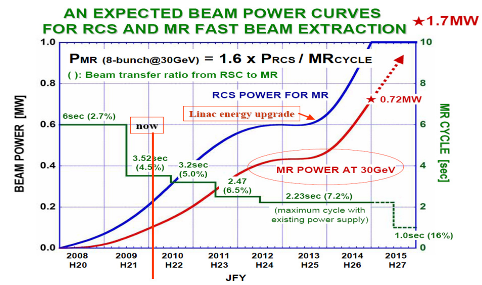

Figure 2: Expected beam power curves.

COMMISSIONING STATUS

Outline and RCS

The construction phase of the facility was completed in 2008 and user runs began step-by-step. While the design beam power of the RCS for the MLF is 0.3 MW with 181 MeV injections and 1 MW with 400 MeV injections, the current beam power for MLF user runs is limited to 0.12 MW. But a successful test run up to 0.3 MW has been carried out for beam loss studies. The authors are confident that routine operation at 0.3 MW can be realized by 1) improving the tune manipulation system to avoid resonances in the tune diagram, and 2) enhancing the beam halo collimation system at the beam injection area. We also expect to achieve a 1 MW output after implementing the 400 MeV RCS injection scheme. These expectations for the RCS are conditioned on a working full beam aperture design and a proper design of the beam halo collimator capacity.

MR

The current beam power for the Neutrino experiment is 70 kW and has been improved gradually. The beam power for the Hadron experiment is reaching the 5 kW-level; the limitation coming from issues in the beam spill control. The details of the MR commissioning status will be described elsewhere [1].

ISSUES IN COMPONENT DESIGN

We have solved many problems with the original design of the MR components to be able to bring the beam commissioning this far. The current status and schedule are summarized next.

Fast extraction kicker magnet

The pulse rise time of the MR kicker magnets in the fast extraction system is currently 1.8 μs, which is not short enough to accept 4 RCS cycles as originally designed and is therefore limited to only 3 cycles. New kicker magnets and power modulators, which should solve these problems are in preparation now and should be installed during this summer shutdown.

Septum magnets for the fast extraction

The aperture of the septum magnets in the fast extraction system was originally designed for extraction after the beam had been accelerated up to 50 GeV; but that aperture is not large enough for extraction of 30 GeV beam. New septum magnets designed for 30 GeV beam extraction using mineral insulated coils (MIC) are currently in the R&D process; but the expectation is that they can be installed next year.

Main magnet power supply and cabling

When the first beam commissioning was performed in May 2008, we found that the original main magnet power supplies and cabling configurations between the magnets and power supplies caused large ripple noise (~1 %) to be transferred to the beam and also poor controllability. Investigation revealed that the ripple was coming from a large common mode noise. In order to reduce this noise induction, the cabling was modified to maintain a symmetric configuration between the P and N terminals of the power supplies [2], and the circuit constants in the power supplies were modified and tuned to produce better controllability. In December of 2008 the first beam acceleration after these modifications showed that the ripple had been reduced to about 10^{-4}. We still need further improvements to reduce the ripple to the order of 10^{-6} for the required fine beam spill control for the Hadron experiment.

CHALLENGES AND ISSUES

The J-PARC design was premised on overcoming several new challenges to achieving high beam power in a constrained area site. One of the most important concepts was the adoption of imaginary transition γ optics for the MR, which is indispensable for high power beam acceleration. On the other hand, the missing bending magnet scheme necessary to implement this optics results in a longer ring circumference, which in turn requires higher accelerating RF voltage per turn. This was realized by using new materials for the RF cavities. In particular, magnetic alloys were employed as cores. In the MR now, 5 cavities are installed and together they generate an accelerating voltage of 225 kV. Accepting the challenge to work with new materials involves taking risks. As a matter of fact, we have experienced several kinds of serious core damage due to heating problems and/or inhomogeneous stresses in the cores. We will need further studies into the fundamental characteristics of the magnetic alloy and then new design ideas in order to find a way to overcome these problems. This will be crucially important to be able to deliver user operational time of more than 5000 hours per year. A new scheme for the core configuration and its cooling are investigated in [3].

MR EMITTANCE AND ACCEPTANCE SCENARIO

In addition to the problems in the previous sections, we have found several more essential problems with the MR design related to the RCS beam emittance, MR acceptance and collimator scenario. As shown in Fig. 3, two beam halo collimating systems are installed for the MR; one is in the beam transport line between the RCS and MR and another in the MR.

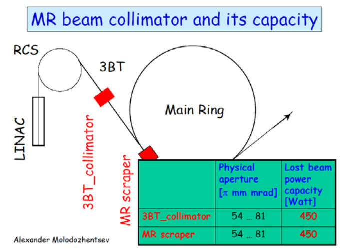

Figure 3: Two collimator systems for the MR [4].

As the beam power of the RCS increases, the space charge force working to disperse the beam also increases. To inject four RCS cycles into the MR, an injection time of at least 120 ms is necessary. This long accumulation time at injection energy is the main cause of emittance-growth. However, the capacity of the collimators is only 450 W; this design figure was based on an analytic estimation of the space charge force. In that calculation, it was assumed that the beam emittance would be adiabatically damped when the beam acceleration is started. More recently, further extensive numerical simulation studies of the space charge effect have been carried out (summarized in Fig.4), and it has become apparent that a capacity of 450 W is not even close to being enough [4].

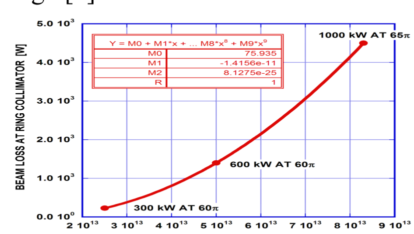

Figure 4: MR beam loss simulation.

We have decided to improve the capacity of the 3BT collimator from 450 W to 2~4 kW by installing additional steel shielding blocks in the accelerator tunnel during the summer shutdown this year. The design work on a method to increase the capacity of MR scraper is underway and the installation is projected to be next year. We have estimated that the maximum collimator capacity in the accelerator tunnel should be less than about 5 kW in order to satisfy realistic conditions for a hands-on maintenance scenario. As a result, as proposed below we will need another upgrade program for additional improvement of the collimator capacity.

SEMI-RAPID CYCLING MR

The basic concept of the MR design for achieving high-beam power is to receive as much beam as possible from the RCS and then to accelerate the beam as fast as possible.

Distributed magnet power supply

The current baseline approach to shorten the MR_{cycle} is to improve the magnet power supplies in use. But at best their design tops out at 2.2-second; this is the result of the original design concept where a central large power supply feeds many magnets. During the MR construction phase, we have already changed the power supply system for the bending magnets. Originally, all 96 magnets around the ring were connected in single series loop. We have now divided the magnets into six groups driven by six independent power supplies. The independent power supplies must be more stable and an increased repetition rate becomes possible. Therefore, we propose dividing all magnets, including the quadrupole magnets, into groups each of which should have moderate inductance. Then standardized 100 kW-class power supplies will be deployed as shown in Fig. 5. The most serious challenge to this method could be flicker noise induced in the primary AC line. Therefore the R&D for the new power supply should set a high priority on noise rejection to reduce the coupling to line power.

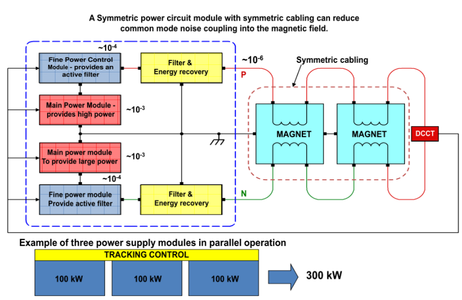

Figure 5: New power supply conceptual drawing.

Resonance type "AC" magnet power supply

To reduce flicker noise emitting to line power, a resonant type power supply such as currently used in the RCS is very desirable. If we set a constraint to keep the applied voltage to the bending magnets below 4 kV, then operation around 3 Hz is the upper limit. In the case of a pure resonant power supply, the beam injection from the RCS could be done in only one RCS cycle. So using a resonant power supply is an improvement, but not yet optimum for us. Therefore we consider the use of a semi-resonance type power supply. The output current waveform is shown in Fig. 6. This has a flat bottom for 4-RCS-cycle injection. Acceleration and recovery of the magnets is one cycle of resonant operation. This system will require a large capacitance to store the energy and a complex control system. But, if we are to achieve progress toward the KEK roadmap it seems an approach that is worth trying.

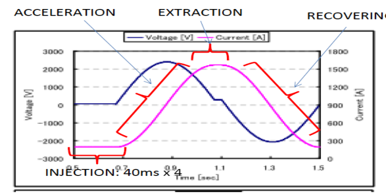

Figure 6: Semi-resonant cycle power supply waveform.

SUMMARY

Since the RCS design was based on a full beam aperture concept, as is essential for a high-power machine, the scenario for achieving the design beam power is straightforward. On the other hand, it was found that the MR aperture and the collimator capacities are not enough to achieve even the design beam power; there were fundamental problems with the original design. As a solution, we have decided firstly to increase the collimator capacity from 450 W up to 5 kW. Secondary, we have started R&D on the magnet power supplies to shorten the MR_{cycle}. Two alternative methods are under consideration and were proposed in this paper. Thirdly the RF acceleration voltage should be increased to shorten the MR_{cycle} time, either by improving the RF accelerating gradient or by installing as many cavities as possible in the ring. Unfortunately, due to space limitations, this issue could not be discussed in this paper.

ACKNOWLEDGEMENTS

The favorable results we have been able to present in this paper based were achieved by the great efforts of all the members of the J-PARC accelerator team. In particular we needed help from many hands to make the many difficult to implement modifications to the various accelerator components in a very tight time schedule. The authors are grateful for our colleagues efforts so far, and we are encouraged that with their help we will be able to realize the performance wished for in the KEK roadmap.

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