STATUS OF THE J-PARC 3-GEV RCS

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Abstract

The J-PARC 3-GeV rapid cycling synchrotron (RCS) has been beam commissioned since October 2007 and it has been able to provide downstream facilities, the 50-GeV synchrotron (MR) and the Materials and Life Science Facility (MLF) with stable beam required from them. After beam deliver operation to the MR and MLF, while the priority has been given to their beam tuning, the RCS also continues further beam studies toward higher beam intensity. On September 18th, 2008, the RCS achieved the beam power of 215kW to beam dump with 25Hz.

INTRODUCTION

The J-PARC 3-GeV rapid cycling synchrotron (RCS) is located in a 348 m long tunnel and will provide proton beam to a high power neutron spallation target as well as to the 50 GeV Main Ring (MR). With a beam intensity of 8.3×10^{13}protons per cycle, a repetition rate of 25 Hz and an injection energy of 400 MeV, the RCS can deliver 1 MW beam power at the 3 GeV extraction energy. The lower injection energy of 181 MeV, which is part of the present Phase I construction project, reduces the beam power of the RCS to 0.33 to 0.6 MW [1]. At the upper end of this range the beam loss is likely to exceed beam loss limits in the RCS and in the transport lines to the neutron spallation target and the Main Ring.

The RCS beam commissioning in September, 2007 and we accelerated the 181 MeV beam injected from the linac to the designed beam energy of 3 GeV via the RCS, and extracted it to the beam transport to the muon and neutron production targets on October 31st, 2007 [2][3]. The RCS has been operated for the neutron and MLF users program and beam was delivered to the MR for the successful commissioning of first acceleration to 30 GeV and first slow extracted beam to the hadron experimental hall [4]. The RCS operated for up to one hour at 100 kW and for 70 seconds at 215 kW with 25 Hz repetition rate. Present continuous operation is limited by the front end to about 20 kW [5].

This paper concentrates itself on the J-PARC RCS status, including the discussion on the issues of the high-power and stable operation.

RCS STATUS

The RCS operations in support of the MLF were initiated in December and were providing beam to support commissioning of the MR. In parallel we are challenging to realize higher beam power operations with better stability. Achieved parameters of the RCS are summarized at table 1.

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Table 1: Summary of Achieved Parameters of RCS

Parameter	Unit	Design	Achieved to data
Injection energy	MeV	400	181
Output energy	GeV	3	3
Number of bunches		2	2
Repetition	Hz	25	25
Output power	kW	1000	20*
Particles/bunch		$4.2\text{x}10^{13}$	$0.9\ \text{x}10^{12*}$
Injection scheme (painting)		Transverse and longitudinal	Transverse to reduce foil-hits **
Tune excursion during acceleration		<0.005	~0.025
COD	mm	<1	<2
Chromaticity		0 ~ 20ms w/AC p.s.	at injection w/DC p.s.
Stability of extracted beam orbit	mm	<±1 atQX3	~±0.5 atQX3
Extracted beam emittance (un-normalized in full)	πmm mrad	54 for MR, 81 for MLF	~14[x]/14[y] measured

*Consecutive 100 kW (for 1 hour) and 215 kW (for 70 sec) operations at 25 Hz were well demonstrated.

**Full painting injection in both transverse and longitudinal planes was well demonstrated with 200-300 kW equivalent intensity beam in single-shot operation.

The RCS has been operated for the neutron and MLF users program and beam was delivered to the MR for the successful commissioning of first acceleration to 30 GeV and first slow extracted beam to the hadron experimental hall. The RCS operated for up to one hour at 100 kW and for 70 seconds at 215 kW with 25 Hz repetition rate. Note that duration of 70 seconds was limited by the authorized beam dump capacity at that time. Present continuous operation is limited by the front end to about 20 kW.

User Program Operation

The RCS has been operated for the neutron and MLF users program from December 23rd, 2008. Not only beam power but also beam stability is important for user program operation. In order to appreciate beam quality for users, the position difference of 2 bunches and the stability of the beam for each pulse has been measured by beam position monitors located at the beam transport line.

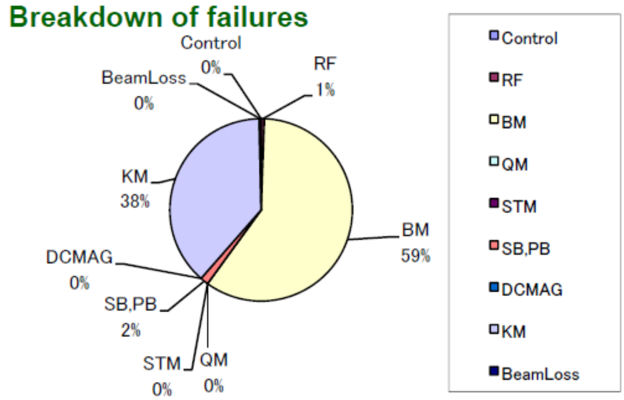

Figure 1: Breakdown of failures of RCS after user operation. Failures were mainly caused as follows, RF:"OC/UV" interlock of the screen grid, KM: pre-fire of Thyratron for extraction kicker magnet, SB&PB: power supply was down by the noise, and BM: troubles.

The position differences of 2 bunches, which was about 5 mm for horizontal and less than 1 mm for vertical were enough small for 3NBT line. The stability of the beam for each pulse was recognized to be smaller than 1mm [6].

Total programmed operation time was 858 hours from December 23rd, 2008 to February 28th, 2009, and the operation was stopped about 85 hours. The availability, then, was about 90 % during this period. Figure 1 shows breakdown of failures for the RCS after user operation. Failures were mainly caused as follows, RF:"OC/UV" interlock of the screen grid, KM: pre-fire of Thyratron (hot-cathode gas-filled tube) for extraction kicker magnet, SB&PB: power supply was down by the noise, and BM: troubles. There were 2 troubles for dipole magnet during this period. One was interlocking signal indicated high temperature, the other was it indicated high voltage of a rectifier of DC power supply for dipole magnet. The reason why the interlock worked was that a crimp contact was not properly connected to a temperature interlock cable of dipole magnet in that case, and feedback cable of rectifier was not properly connected to terminal block in this case.

Residual radiation levels for the accelerator components have been surveyed every beam run, where their radiation level is measured with contact on the vacuum chamber typically a half day after the beam shutdown. In RUN#20 (December'08), high power operations for about 130 hours at 20 kW in the middle of the RUN and at 4.5 kW for about 120 hours in the end were done. The highest level of 430 µSv/h was observed at the branch to the injection dump after the stripping foil. No other significant loss was however found anywhere else, and it looked most of particle losses were well localized on the collimators [7]. This high loss may be related to large angle scattering of beams with the stripping foil. Because the injection orbit was at the center of the RCS acceptance, this is so-called center injection, the number of the hit was estimated 150.This was 8 times larger than the design, and its resultant beam loss rate

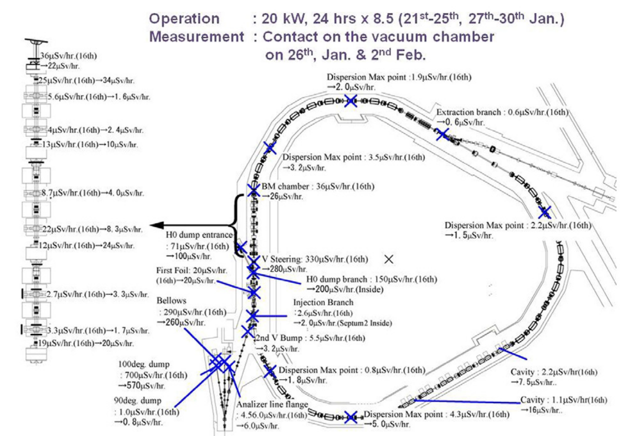

Figure 2: Distribution of residual activities whole the RCS. These were surveyed 6 hours after RUN#21.

during the injection was calculated to be 1.5 % considering both Coulomb and nuclear scattering [8]. Most of the lost particles should be localized on the collimator, but some of them with large scattering angles, which were mainly from the nuclear scattering and estimated to be 0.5 % of the lost particles, lead to uncontrolled beam losses downstream of the first foil. Most of the residual activities observed downstream of the first foil probably came from such a large-angle foil scattering.

In RUN#21 (January '09), user program operations for about 240 hours at 20 kW were done. The pant injection was adopted in this time and also the position of the foil was modified to reduce the number of hits [9]. Figure 2 shows distribution of residual activities whole the RCS. These were surveyed 6 hours after RUN#21. The radiation level was 100 µSv/h before beam operation and it became 200 µSv/h after beam operation at the branch to the injection dump after the stripping foil.

We still do not have enough data on the residual activities for long term operations, and can't yet make a reliable extrapolation for the machine activation, because we have only 3 times user program operations and beam operation time was totally 858 hours from December 23rd to February 28th, 2009. We must hereafter proceed with a careful beam power ramp up plan including monitoring and trending the residual activities.

High Power Demonstration

The RCS is in transition from the first commissioning phase to the next challenging stage and our efforts hereafter will be focused on higher beam power operation. High intensity operation of the RCS was tested in detail using single pulse mode. Transverse phase space painting was studied using orbit analysis and turn-by-turn profile measurements. The measurements show excellent agreement with expectations. Longitudinal painting and set-up of the 2nd harmonic rf was successfully tested and improved the bunching factor from 0.2 to 0.4 [10][11].

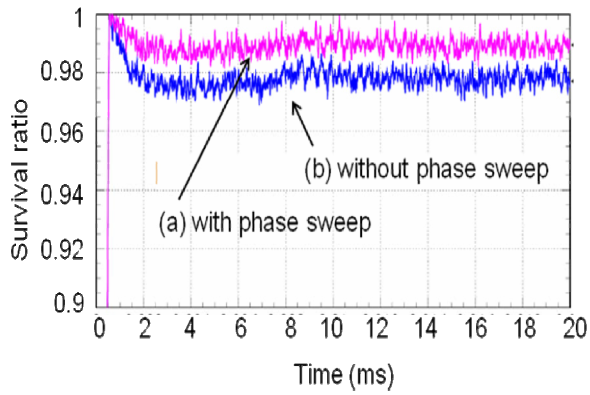

Figure 3: DCCT signal in high power demonstration. The beam condition is as follows, H- peak current is 15 mA, pulse length is 0.5 ms, intermediate-pulse width is 600 ns , bunch number is 2, transverse painting is done with 15 π mm mrad for both horizontal and vertical, and also longitudinal painting is done with 80% of 2nd harmonics is added and -0.1 % momentum offset. (a) phase-sweep from -80 to 0 degree, (b) without phase-sweep.

Figure 3 shows DCCT signal in high power demonstration. The beam intensity loss over the first few milliseconds for various conditions of longitudinal and transverse painting and various injected intensities compared quite well with multiple particle tracking calculation that includes space charge as well as the multi-pole components and field and alignment errors of the dipoles, quadrupoles, and sextupoles, and the measured power supply tracking errors. With optimum painting and optimum parameters for the 2nd harmonic rf the beam loss, as measured with the beam current transformer, was about 1% for a beam intensity of 2.6x10^{13} protons per pulse. This would correspond to about 310 kW for continuous operation at 3 GeV and 25 Hz repetition rate. All the loss occurred during the first 1.5 ms of the acceleration ramp. Note that this would correspond to 180 W of lost beam power, well within the 4 kW limit of the RCS beam collimation system.

ISSUES

Significant degradation in the shunt impedance of one out of three gaps of rf cavity # 7 was measured starting at about August, 2008 [12]. The cavity had to be run with only two gaps from January, 2009. Later inspection found that all six Magnetic Alloy (MA) cores corresponding to this gap show some damage with one core showing severe damage. Since there were only three new cores, we replaced the three damaged cores of cavity #7 and re-install it in the ring at the end of March. 18 new cores are being manufactured for installation in cavity #7 during the summer. We carefully observe the status of the cavity and investigate for the cause of the degradation of MA cores.

Life time of charge exchange foil is one of most important issue for high-power and stable operation in the RCS. The carbon-foil whose thickness of about 280

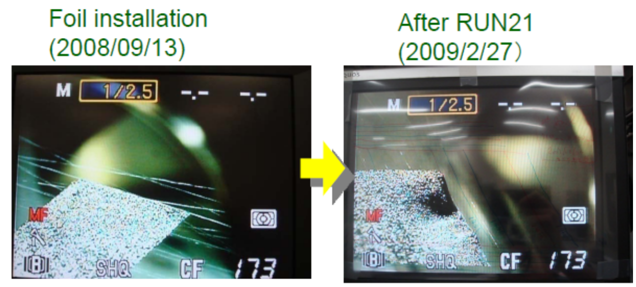

Figure 4: Pictures of carbon foil installed in the RCS before and after beam irradiation.

μg/cm^2 and made by CADAD (Controlled Ac Dc Arc Discharge) method was installed in the RCS on September 13th, 2008 [13]. Figure 4 shows pictures of the carbon-foil before and after beam irradiation. It seems that the foil hardly was deformed after beam irradiation, but charge exchange efficiency almost did not changed. We continue to observe this foil and to develop carbon-foil with long life time.

CONCLUSIONS

The RCS operations in support of the MLF were initiated in December and were providing beam to support commissioning of the MR. In parallel we are challenging to realize higher beam power operations with better stability.

- User program operation could be started from 23th December 2008, and stable beam whose power of 20 kW could be deliver to neutron and MLF users.
- Consecutive 100 kW for 1 hour and 215 kW for 70 second operation at 25 Hz were well demonstrated.
- Full painting injection in both transverce and longitudinal planes was well demonstrated with 310 kW equivalent intensity beam in single-shot operation

There are some issues for high-power and stable operation as follows, degradation of MA cores for rf cavity and life time of charge exchange foil. We continue to challenge for high power and stable operation in the RCS.

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