COMMISSIONING SCENARIOS FOR THE J-PARC ACCELERATOR COMPLEX

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Abstract

The J-PARC (Japan Proton Accelerator Research Complex) facility is now under construction in the Tokai campus of Japan Atomic Energy Agency (JAEA) as a joint project between JAEA and High Energy Accelerator Research Organization (KEK). The beam commissioning of the facility is scheduled to start from December 2006. The commissioning plans and scenarios of the accelerator complex are presented.

INTRODUCTION

The J-PARC facility consists of a 400-MeV linac, a 3.0-GeV rapid cycling synchrotron (RCS) and a 50-GeV slow cycling main ring synchrotron (MR) [1, 2] and related experimental facilities for use in various fields of science and technology. The RCS will provide a 3.0-GeV, 1-MW proton beam to neutron and muon targets in the Materials and Life Science Experimental Facility (MLF). The MR will provide a 50-GeV, 0.75-MW beam to the Hadron Beam Facility (HD) and a neutrino production target in the Neutrino Facility.

The J-PARC project is being promoted in two phases. The facilities mentioned above are constructed in Phase I. However, the maximum beam energy of the MR is 40 GeV in Phase I because of the flywheel electric power system will be ready for only Phase II. In addition, only a half of the HD facility building is constructed in Phase I and the remaining half will be added in Phase II. The energy of the linac will be increased to 600 MeV in Phase II. The linac will provide the proton beam to the Accelerator Driven Nuclear Waste Transmutation System (ADS), which is planned to construct in Phase II.

Table 1: Main features of Linac.

	Features
IS	volume production type
RFQ	π mode stabilizing loop to eliminate effects of deflecting filed
DTL	3 tanks, electro-quadrupoles in the DT
SDTL	32 short tanks (each tank has five cells), no quadrupoles in the DT
ACS	good axial symmetry, not installed on day-one

The linac [3] consists of an H^- ion source (IS), a 3-MeV radio frequency quadrupole (RFQ) linac, a 50-MeV drift tube linac (DTL), a 191-MeV separated-type DTL (SDTL), a 400-MeV annular-coupled structure (ACS) linac and a 600-MeV superconducting linac (SCL). The ACS is planned in Phase I but not installed on “day-one”, the initial beam commissioning days. The SCL will be installed in Phase II. The characteristics of the linac in Phase I are summarized in Table 1.

On day-one, the maximum peak current of the linac is 30 mA. The last two tanks of the SDTL are operated as debuncher cavities to reduce the momentum spread and jitter at the RCS injection. Then the beam energy of the linac is 181 MeV.

Figure 1 shows a plan view of the RCS and the MLF. The RCS [4] has three-fold symmetry and circumference of 348 m. The three dispersion free straight sections are dedicated to “injection and beam collimators”, “extraction”, and “rf system” as shown in Fig. 1.

The H^- beam from the linac is transported through the Linac to 3-GeV RCS Beam Transport Line (L3BT), and injected to the RCS with the charge-exchange injection. A long-lived stripper foil made of hybrid boron mixed carbon is now being developed for this purpose [5]. The proton beam is injected into two rf buckets by the painting injection.

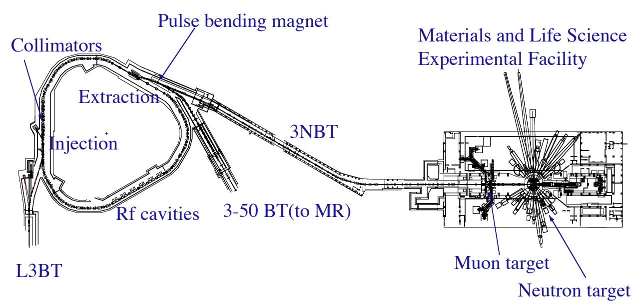

Figure 1: Plan view of RCS and MLF.

The RCS supplies 1MW pulsed beam to the MLF and also plays a role of booster for the MR. At the extraction section, there are two beam transport lines; namely, the 3-GeV RCS to Neutron Target Beam Transport Line (3NBT), and the 3-GeV RCS to 50 GeV MR Beam Transport Line (3-50BT). The beam extracted out from the RCS is divided into the two beam transport lines by a pulse bending magnet.

Figure 2 shows a plan view of the MR and the experimental facilities. The MR [2] has an imaginary transition lattice structure to avoid transition crossing during acceleration. It has a three-fold symmetry and a circumference of approximately 1.6 km. Three dispersion-free 116-m long straight sections are dedicated to “injection and beam collimators”, “fast extraction and rf system”, and “slow extraction”. The proton beam is injected into the MR by the single-turn injection.

The slow extraction beam is delivered to the HD experimental Hall for particle and nuclear physics experiments. The fast extraction beam is delivered to the neutrino production target. The produced neutrino beam is sent to Super-Kamiokande, a large water Cherenkov detector, located 300 km west for long baseline neutrino oscillation experiments.

The main parameters of the RCS and the MR are summarized in Table 2.

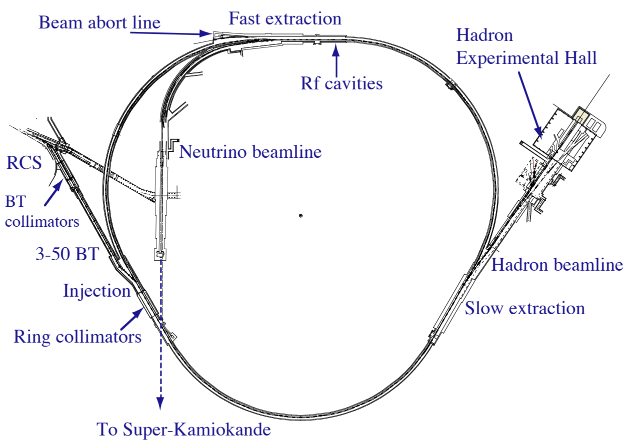

Figure 2: Plan view of MR and experimental facilities.

Table 2: Main parameters of RCS and MR.

	RCS	MR
Circumference [m]	348	1567.5
Superperiodicity	3	3
Repetition rate [Hz]	25	0.3
Injection Energy [GeV]	0.181/0.400	3.0
Ext. Energy [GeV]	3.0	30/40(Phase I)
		50 (Phase II)
Harmonic number	2	9
Number of bunches	2	8
Transition γ	9.14	j31.7
Typical tune	6.72, 6.35	22.4, 20.8
Transverse emittance at inj. [πmm-mrad]	4/6 (Inj. beam) 216 (painting)	54
Transverse emittance at ext.[πmm-mrad]	81(for users) 54 (for MR)	10(at 30 GeV) 6.1(at 50GeV)
No. of dipoles	24	96
No. of quadrupoles	60	216
No. of sextupoles	18	72 [1)]
No. of steerings	54	186
No. of rf cavities	10	6 (Phase I)
Rf frequency [MHz]	0.94/1.23-1.67	1.67 – 1.72
Nominal beam power [MW]	1.0 (at 25 Hz, 3 GeV)	0,75 (at 0.3 Hz, 50 GeV)

[1)] Sextupoles for slow extraction system are not included.

SCHEDULE

Figure 3 shows the schedule of the facility construction and beam commissioning in the next three years. The year in this figure is shown in Japanese Fiscal Year (JFY), which starts from April. "Operation" includes beam commissioning run with higher intensity. The beam commissioning will be started from the upstream accelerators while the construction of the downstream accelerators and experimental facilities is in progress. The beam schedule after the summer of 2008 is temporal one and not finally fixed yet at the present time.

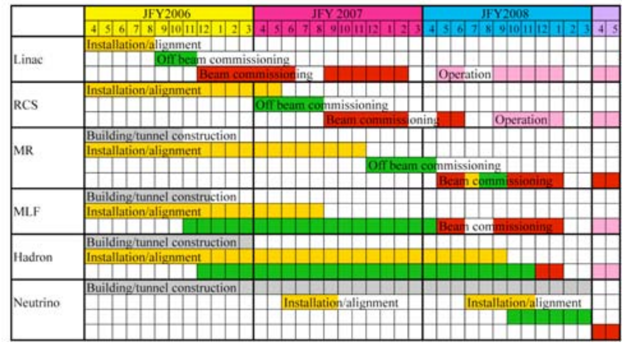

Figure 3:Schedule of the construction and commissioning of the J-PARC facilities. The beam schedule after the summer of 2008 is not finally fixed yet.

The linac construction has been almost completed. The precise alignment will be done in July and August 2006. The off-beam commissioning including high power conditioning of the accelerating cavities is scheduled from September to November. The beam commissioning of the linac will start from December. The off beam commissioning of the RCS is scheduled to start form April 2007 and the beam commissioning from September 2007. For the MR, constructions of the accelerator and tunnel are now under way. The off beam commissioning and beam commissioning are scheduled to start from December 2007 and May 2008, respectively.

COMMISSIONING PROCEDURES

In the following part of this paper, we describe the commissioning procedures of the accelerators.

At first, we start the off-beam commissioning as shown in Fig, 3. For each accelerator, test operation and tuning without beam are performed for several months just before the start of beam commissioning. In this stage, all the components should be online and ready to start the operation. For example, the utilities such as cooling water, electric power system, and air-conditioners are operated and checked. Tunings of the scheduled and synchronization timings, operations of rf system, control system, monitor system, injection/extraction systems, vacuum system, interlock system are all performed without the beam. For the RCS and MR, tracking studies of the magnet system are done in this stage.

After the off-beam commissioning, we move to the beam commissioning. In order to allow hand-on maintenance of the hardware components, the beam loss should be controlled as low as reasonably achievable (ALARA). For example, the maximum beam loss at the regular zones (not hot zones) is assumed to be less than 0.5 W/m for the MR [6] and the same order for the Linac and RCS. Then we adopt the following approaches for the beam commissioning; (1) the beam tuning is started with very low beam intensity to minimize the activation of the components, (2) beam transport to a proper beam dump should be established at first, and then fine tuning procedure is performed.

Linac commissioning

Figure 4 shows a schematic layout of the linac and L3BT. The beam commissioning of the linac [7] is divided into two stages. The first stage is from December 2006 to June 2007 and the second stage is from September 2007. The beam dumps in the linac and L3BT are shown in Fig. 4. In the first stage, only the linac area is approved as the radiation controlled area, and the RCS area, downstream of the concrete wall, is not controlled area. The available dumps in the first stage are 3-MeV beam stop at just upstream of the DTL, 0 degree beam dump of 0.6 kW and 30 degree beam dump of 0.1 kW. Therefore, the beam power is limited less than 0.6 kW. In the second stage, the RCS area is approved as the radiation controlled area. Then the capable power of the 30-degree dump becomes 5.4 kW. In addition, the 90-degree dump of 0.6 kW and 100-degree dump of 2 kW become available. Typical beam parameters for the Linac beam commissioning are shown in Table 3. The powers in this table are calculated for the 181-MeV beam without chopping.

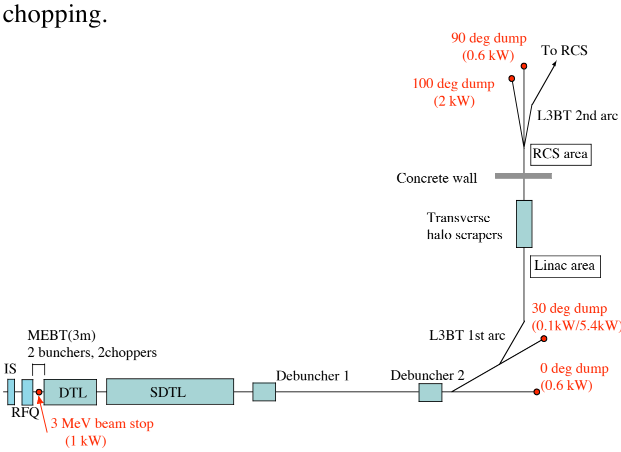

Figure 4: Layout of linac and L3BT

Table 3:Beam parameters for linac commissioning.

Mode	Peak cur.	Pulse width	Repetition	Power
Nominal	30 mA	500 μsec	25 Hz	67.9 kW
Low current	5 mA	50 μsec	5 Hz	0.23 kW
High current	30 mA	50 μsec	1 Hz	0.27 kW
Long pulse	5 mA	500 μsec	1 Hz	0.45 kW
Single shot	5 mA	50 μsec	-	-

The beam monitors available on day-one are 103 beam position monitors (BPM), 61 fast current transformers (FCT), 37 current transformers (CT), 40 wire scanners, and 117 beam loss monitors (BLM). The FCTs focus on the linac frequency of 324MHz.

The first stage of beam commissioning is start from tuning of the RFQ and the Medium Energy Beam Transport line (MEBT), which has chopper and buncher cavities. The initial tuning is performed with the low-current mode beam, and then performed with the high-current mode beam. In these tunings, the beam is dumped at the 3-MeV beam stop. Since the operation from the IS to the first tank of the DTL has been already demonstrated in 2004 [8], it is a basically reproduction. The next step is acceleration up to 181 MeV by tuning the DTL and SDTL. The beam is transported to the 0 degree dump during the tuning. After the acceleration study, chopper tuning is done to confirm the operation modes required for the RCS beam commissioning. Especially, single-shot operation with pulse on demand control is established in this stage. The overall tuning of the straight section including transverse matching and orbit correction, high current operation, and 1/3 arc tuning are then performed.

In the second stage, tunings the orbit of the L3BT first arc and orbit to the H^0 damp are performed together with the transverse matching study. In addition, the debuncher tuning is done measuring the energy gain precisely. A time of flight method using FCTs is adopted to measure the beam energy. After the debuncher tuning, beam injection to the RCS are tuned.

The detailed procedures of the tunings are given in the reference [7].

RCS commissioning

Beam commissioning of the RCS is divided into two stages. The first stage is from September 2007 to February 2008 and the second is from May 2008. The commissioning of the MR and MLF also starts from May 2008. Figure 5 (a) shows beam dumps of the RCS. In the first stage, the available dumps are 1-kW H^0 dump at the injection section and 4-kW dump in the 3NBT. The MLF beam dump is ready from the second stage.

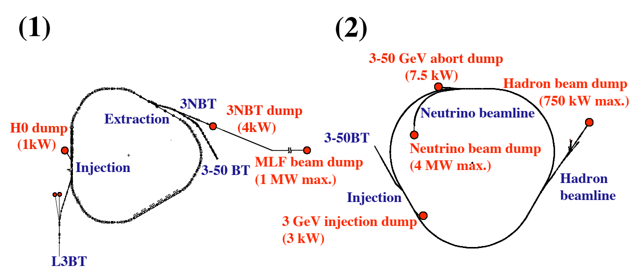

Figure 5: Layouts of beam dumps of (1) RCS and (2) MR.

Typical beam parameters of the linac for the RCS commissioning are; 5 mA peak current, 50 μsec pulse width (24 turns injection of the RCS), 54 % chopped beam. The intensity is approximately 8×10^{11} protons per pulse (ppp), 1% of the nominal value. The repetition of the linac beam is selected from the single-shot, low duty (0.1-1 Hz) and high duty (1-25 Hz) modes. The corresponding powers of the 3 GeV RCS beam are 0.4 kW and 10 kW for 1 Hz and 25 Hz repetitions, respectively.

The beam monitors [9] available on day-one are summarized in Table 4. The RCS has 54 BPM systems. On day-one, about fifteen of them are put to use as turn-by-turn BPM by setting the pre-amplifiers in the ring tunnel to measure the low intensity beam in the initial tuning. The RCS also has BPMs, which focus on the linac frequency of 324 MHz. They are used to measure the injected beam before rf capture.

Table 4: Beam monitors available on day-one for RCS

Monitors	Number
At RCS	
BPM	54
Turn-by-turn BPM (with pre amp)	~15/54
BPM (324 MHz)	4
BPM (at Injection section)	2
FCT	4
Medium CT (< 1.6 MHz)	1
Slow CT (< 20 kHz)	1
DCCT (DC-20 kHz)	1
Wall current monitor (WCM)	3
Multi Wire Profile Monitor (MWPM)	7
Ion Profile Monitor (IPM)	2(H), 1(V)
At 3NBT(to 4kW dump)	
BPM (324 MHz)	2
BPM	2
MWPM	3
CT	2
BLM at RCS and 3NBT(to 4kW dump)	84

We start the RCS commissioning from injection tuning with the single-shot or low-duty linac beam. The RCS injection system [10] has three charge-exchange foils. In the usual operation, partially stripped H^0 and unstripped H^- beams are fully stripped in the second and third foils, respectively, and then transported to the H^0 dump. In the beginning of the injection line tuning, however, the injected beam is transported to the H^0 dump by extracting out the first foil. The injection tuning is performed by the central orbit injection (not the painting injection). There are eight bump magnets in horizontal (four shift bump (SB) magnets for bump orbit and four paint bump (PB) magnets for painting injection) and two bump magnets in vertical. The position and angle of the linac beam on the location of the first charge-exchange foil are adjusted by tuning the four SBs and two vertical bumps together with injection septa. The BLMs, 324-MHz BPMs and MWPMs are used during the tuning. Twiss parameters at the first foil location are also tuned monitoring the MWPMs and other profile monitors in the L3BT.

After the beam injection tuning, we focus on establishing the closed orbit. At first, we transport the injected beam to the extraction section (1/3 turn) adjusting the dipoles, quadrupoles and corrector magnets. Then the beam is extracted to the 3NBT using DC extraction system and transported to the beam dump. The DC extraction system is designed to extract the injection beams before rf capture. The tuning is performed monitoring BLMs, 324 MHz-BPMs and MWPMs in the 3NBT line. After the tuning of 1/3 turn trajectory, we transport the beam to the remaining 2/3 turn of the ring, and then establish the closed-orbit. The revolution frequency and momentum spread just after the beam injection are measured with the WCM.

Then, we perform rf capture adjusting rf voltage and the synchronization timing between the linac chopper and the RCS rf systems. The tuning is made observing the FCT signals. All the BPMs are then commissioned and the orbit is measured. The pulse extraction system is also commissioned and tuned to transport the beam to the 4-kW dump at the injection energy. The horizontal and vertical betatron tunes are measured using an exciter and the BPMs. The closed-orbit distortion (COD) correction is also performed (response matrix correction scheme is adopted here). Then we measure the optics parameters, namely, beta function, emittance, dispersion, chromaticity and so on.

The acceleration from 181 MeV to 3 GeV is then performed using the single-shot or low-duty linac beam. The main magnets of the RCS are operated at the nominal 25 Hz pattern. The rf system and extraction system are tuned and their nominal conditions are established. Then, 25 Hz beam operation is performed with the high-duty (25 Hz) linac beam. This study should be done carefully so as not to exceed the capability of 4 kW dump in an average of one-hour.

In the second stage of the RCS commissioning, the 3NBT and 3-50BT lines are commissioned. The MLF beam dump, which is located in the end of the 3NBT, becomes available although the allowable power in this stage is limited below 20 kW. The 25 Hz beam operation of the RCS is tuned again transporting the beam to the MLF beam dump and then established.

The next step is trial to high intensity beam operation. At first, we tune the closed orbit with the PBs-on using the same procedure as the central orbit injection tuning. After establish the closed-orbit, painting injection with pattern operation of PBs is performed.

MR commissioning

Beam commissioning of the MR is divided into three stages. The first stage is from May 2008 to June 2008. From July 2008, we stop the beam operation of the MR and install the slow extraction devices. In addition, installation of superconducting magnets of the beam transport line of the Neutrino facility is started. The second stage of the beam commissioning is scheduled from Oct. 2008 to Jan. 2009 although the schedule is not completely fixed yet. Since the installation of the superconducting magnets of the neutrino beamline requires 4-5 months, time shearing of day and night for the installation and MR commissioning is planned in the first half of the second stage. The third stage is scheduled to start from April 2009.

Typical beam parameters of the linac for the MR beam commissioning are; 5 mA peak current, 50 μsec pulse width, 54 % chopped beam. The RCS provide the beam without painting. The emittance of the extracted beam is

10 πmm-mrad. In the initial tuning, the MR is operated in the single- or two-bunch mode. For the two bunch mode, typical number of the particle is 8×10^{11} ppp and the beam power at 40 GeV is 1.5 kW for 0.3 Hz repetition. The emittance of the extracted beam is estimated to be approximately 1 πmm-mrad at 40 GeV.

The beam monitors available on day-one are listed in Table 5. The MR has 186 BPM systems. All the BPMs can also be used for turn-by-turn measurement by switching the circuit.

Table 5: Beam monitors available on day-one for MR

Monitors	Number
At MR	
BPM	186
Turn-by-turn BPM	186
WCM	4
Fast CT	5
DCCT	2
MWPM	1
Flying Wire Profile Monitor	1 (H), 1 (V)
Ion Profile Monitor (IPM)	1(H), 1(V)
At 3-50 BT	
BPM	14
MWPM	3
Fast CT	5
BLM at MR and 3-50 BT	330

The layout of beam dumps of the MR is shown in Fig. 5 (b). In the first stage, the 3-kW injection dump and 3-50 GeV beam abort dump are available. At first we start the 3-50 BT commissioning. The 3-50BT is 230 m long and has 5 DC dipoles, 38 quadrupoles, 14 steerings and a collimator system. We tune trajectory of the 3-50 BT and establish the transportation to the 3-kW injection dump. The synchronization timing between the extraction beam of the RCS and injection kicker of the MR is adjusted. After establishing the transportation, fine tunings of the 3-50 BT and the MR injection section are performed.

The next step is tuning the first single turn and establish the closed-orbit. The main magnets and corrector magnets are adjusted observing the BLMs and turn-by-turn BPMs. After establishing the closed-orbit, we measure revolution frequency, momentum spread and beam currents. And then, rf capture is performed. Horizontal and vertical tunes are measured and the COD correction is also performed. The optical parameters of the ring are measured and corrected.

After the rf capture and COD correction, beam acceleration is tested. At first, we have to commission the beam abort system at the fast extraction section. The fast extraction system comprises six bipolar kickers and ten septa. Fast extraction beam is bent inward the ring, and abort beam is bent outward the ring anytime during acceleration [11]. The beam energy is increased up to 40 GeV tuning the beam abort system. The acceleration studies are also performed in the first half of the second stage.

Prior to the second stage, off-beam commissioning of the newly installed slow extraction system is done. We adopt the third-integer slow extraction scheme with six sextupoles, four bump magnets, two electrostatic septa, and seven magnetic septa [12].

In the second stage, the beam acceleration study is performed to establish the nominal operating conditions of the rf system, magnet system, beam abort system, and so on. The closed orbit tuning and measurements of the orbit parameters at the higher energies are also performed. In the latter half of the second stage, the slow extraction system and the hadron beamline are commissioned. The beam dump of the hadron beamline becomes available from the second stage. The capable power is 5 kW in the second stage and 240 kW in the third stage.

In the beginning of the third stage, the neutrino beam dump becomes ready with 240-kW availability. The fast extraction system and the neutrino beamline are commissioned in this stage. And then, we focus on the MR operation with the higher beam intensity.

After the initial beam commissioning days, studies are continued for the accelerator complex giving priority to the high-intensity. The first milestone of the intensity upgrade is achieving 100 kW beam power. We plan that the RCS will deliver 100 kW beam to the MLF by one year from the first neutron event.

SUMMARY

The construction of the J-PARC facility is now under way. The beam commissioning will take place from the upstream accelerators while the construction of the downstream accelerators and experimental facilities is in progress. The commissioning is scheduled to start from December 2006 for the linac, September 2007 for the RCS, and May 2008 for the MR.

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