PRESENT STATUS OF J-PARC

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Abstract

Japan Proton Accelerator Research Complex (J-PARC) is the scientific facility with the high-intensity proton accelerator aiming to realize 1 MW class of the beam power. J-PARC is the joint project between High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Agency (JAEA). The accelerator of J-PARC consists of a 181-MeV linac, a 3-GeV Rapid-Cycle Synchrotron (RCS) and a 50-GeV Main Ring synchrotron (MR). The beam energy of the linac will be extended to 400 MeV from 181 MeV in the near future. As all components of the linac were aligned on the beam line, the beam commissioning has been started in November 2006. Furthermore the excitation test of the aligned magnets in the RCS has also been started. The RCS beam commissioning is scheduled to start in September 2007. Finally the beam commissioning for the 50-GeV synchrotron will be started in May 2008.

INTRODUCTION

Japan Proton Accelerator Research Complex (J-PARC) is the high-intensity proton accelerator facility which was formed by joining together the Neutron Science Project (NSP) of Japan Atomic Energy Agency (JAEA) and the Japan Hadron Facility (JHF) Project of High Energy Accelerator Research Organization (KEK). J-PARC is aiming to realize 1 MW class of the beam power, which was the target value of NSP and JHF. J-PARC has three main purposes; (1) the study of the material science using the strong neutron beam; (2) the nuclear/particle physics using several secondary particle beams which include the neutrino; (3) the experiment of the Accelerator-Driven transmutation System (ADS) for the nuclear waste.

The construction of J-PARC has been started at Tokai campus of JAEA, where is about 130 km north-east of Tokyo. At the present stage, J-PARC consists of the following accelerators:

- a 181-MeV normal-conducting linac (H^- beam: Peak;30mA, Width;500μs, Repetition;25Hz),
- a 3-GeV rapid cycle synchrotron ring (RCS), which provides proton beams at 333μA (1MW), and
- a 50-GeV main synchrotron ring (MR), which provides proton beams of 15μA (0.75MW).

The schematic layout of the facility is shown in figure 1. The design energy of the normal-conducting linac is 400-MeV. However it is limited by the budget problem [1]. The energy recovery of the linac from 181 to 400 MeV is the essential subject to be carried out before the second phase

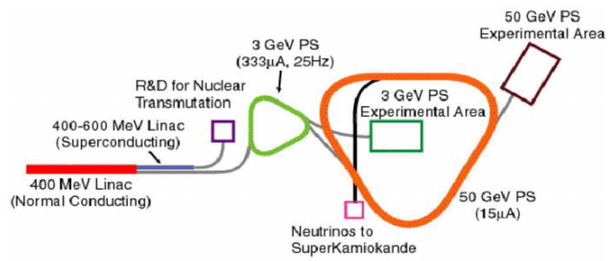

Figure 1: Configuration of J-PARC.

of the project which includes a super-conducting (SC) linac and the ADS. In the second phase the repetition rate of the linac beam is doubled from 25 to 50 Hz. Then one half of the 400-MeV beam from the linac is injected into the RCS, while the other half is further accelerated up to 600 MeV by the SC linac. The 600-MeV beam is transported to the experimental area for the ADS.

The 3-GeV beam from the RCS is mainly used to produce pulsed spallation neutrons and μ-ons for the study of the material and the life sciences.

A part of the beam from the RCS is injected into the 50-GeV synchrotron. The 50-GeV beam is slowly extracted in order to produce the secondary particles for the nuclear/particle physics experiment. It is also fast extracted for the production of the neutrinos, which are sent to the SUPER-KAMIOKANDE detector located 300 km from J-PARC.

The installation of linac has been completed. Thus the linac beam commissioning has been started in November 2006. For the RCS the installation of the components is in progress. In particular, the main magnets have been aligned in the ring. Thus the excitation test of the magnet has been started in December 2006. The linac commissioning and the RCS magnet test are being carried out alternatively. The start time of the beam commissioning of the RCS is scheduled in September 2007. Finally the beam commissioning of the MR will be started in May 2008. The schedule of the J-PARC is shown in figure 2.

LINAC

The linac uses normal-conducting cavities up to 400 MeV, while it uses superconducting cavities (SCC) from 400 to 600 MeV, as shown in figure 3 [1]. The linac is composed of an H^- ion source, an RFQ, a Drift-Tube Linac (DTL), a Separated DTL (SDTL), an Annular Coupled Structure (ACS) linac, an SCC linac and several beam transport lines. All components, except for the ACS and the SCC have been installed in the tunnel. Total number

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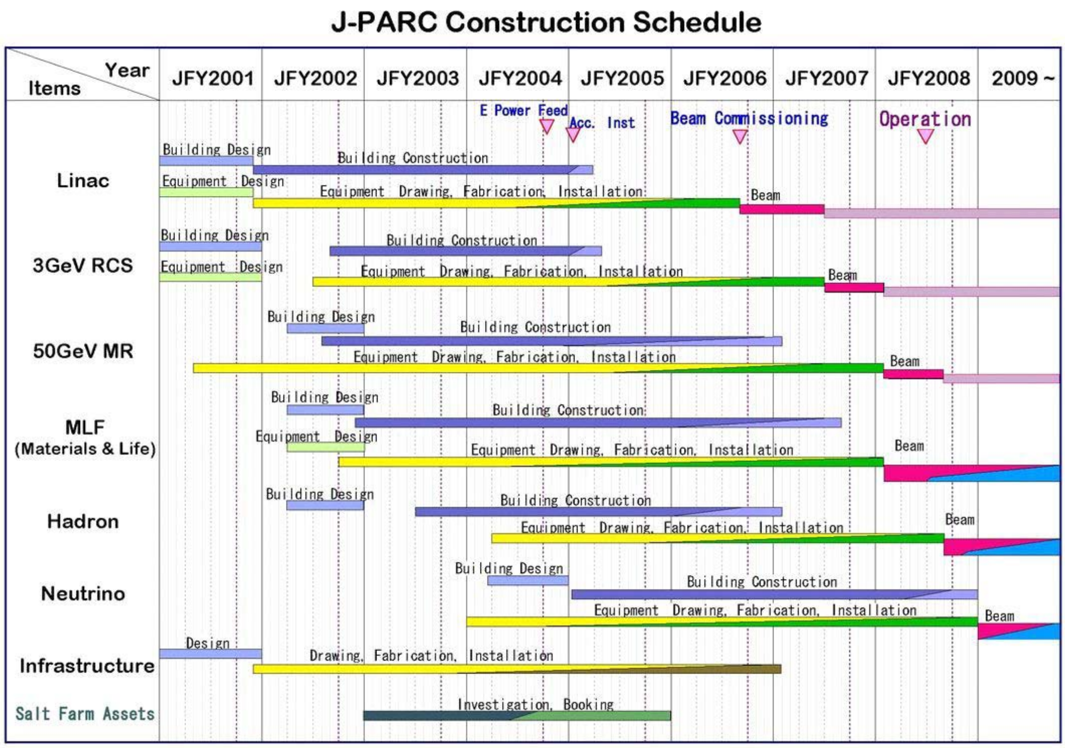

Figure 2: J-PARC Construction Schedule. JFY: Japanese Fiscal Year (It starts April.)

of the DTL and SDTL tank are three and 32, respectively. The SDTL can accelerate the beam up to 191 MeV with 32 tanks. However the last two tanks of them are used as the debunchers in the beam line between the SDTL and the RCS tentatively. As a result, the beam energy is limited to 181 MeV now.

Requirements for the linac up to 400 MeV are summarized as follows;

Current	Average	675 μA
	Peak	50 mA
Pulse	Pulse width	500 μsec
	Chopping ratio	56 %
	RF duty (600 μsec)	3%
Beam	Momentum width	Δp/p = $\pm$0.1% (100%)
	Emittance	3$\sim$5 π mm-mrad (99%)

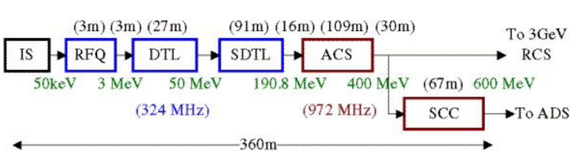

Figure 3: Layout of the proton linac.

H^- ion source

An H^- ion source without cesium has been developed in KEK for JHF project in order to produce a peak current of 30 mA with a pulse length of 500 μsec and a repetition rate of 50 Hz. The extraction voltage of the source is 50 kV.

The H^- ion source has achieved nearly a beam current of 30 mA in maximum with 50 μsec in pulse length and 25 Hz in repetition rate with the filament made of LaB_6. However the study of the source showed that it was very hard to keep the maximum current stable and the filament life was too short for the practical use. Therefore the modification of the H^- ion source is still on going [2].

RFQ

The RFQ has been designed to accelerate 30 mA beam up to 3 MeV with a transmission of more than 90%. The resonance frequency of the RFQ is 324 MHz. The vane is 3 m in length. The contamination of the dipole mode which deflects the beam is minimized by the pi-mode stabilizing loop. The designed performance has been confirmed by the beam study in KEK and the results has been approximately re-confirmed by the beam test in J-PARC in November 2006 [2]. Fine study of the RFQ will be carried out.

MEBT

The 3MeV beam from the RFQ is transferred to the DTL through the MEBT for the matching and diagnostics of the beam. The MEBT consists of the following components:

- 8 quadrupole magnets (Q-mag) with the steering coils,
- two buncher cavities,
- a chopper cavity with two gaps,
- a bending magnet for beam analysis, and
- the beam position monitors in the Q-mags and current transformers.

Figure 4 shows the preliminary data for the chopped beam. The curves show the beam current. Top three lines are the beam current before the chopper. The bottom line shows the chopped beam current. The chopped beam shows the comb pattern. At the moment the rise time of the chopper is slower than that measured at KEK before. Thus we are going to tune the chopper system more.

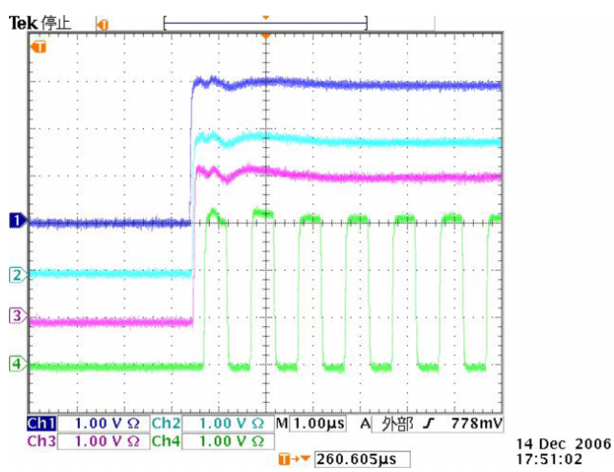

Figure 4: Chopped beam.
Top 3 lines: Output from CTs before the chopper.
Bottom line: Output from CT after the chopper.
(CT: Current Transformer)

DTL

The Alvarez type DTL, which accelerates the H^- beam from 3 MeV to 50 MeV, consists of three independent tanks of which the length is about 9 m. Each tank is composed of three short unit tanks, which are 3 m in length. The resonance frequency of the DTL is 324 MHz. The accelerating field in the tank is stabilized by using the post-couplers.

Since each drift tube (DT) in the DTL accommodates the electromagnetic quadrupole, the DTs have been assembled in the tank very precisely. Maximum deviation of the DT bore center position from the beam axis is approximately less than $\pm 50 \mu$m for both x- and y-directions [2]. Overall alignment error of the DT from the beam axis for the DTL section is approximately less than 0.1 mm in x-y plane [3]. The aligned DTL is shown in figure 5.

Figure 5: DTL1,2,3 in the tunnel

As the high-power conditioning of the DTL was completed upto the 1.2 times the desired power level with the repetition rate of 25 Hz and the rf pulse length of 600 μs, the beam commissioning of the DTL has been started in December 2006. The beam accelerated by the DTL-1 (the peak current is 5 mA, the beam pulse width is 20 μs, the repetition rate is 5 Hz, the beam energy 19.7 MeV) passed through the following whole cavities and the beam duct to the beam dump without an observable loss. The initial test was done without the correction of the beam direction by the steering magnet for the DTL and SDTL. It proves that the alignment accuracy of the linac components is sufficiently high. The tuning for DTL-2 and 3 has been roughly carried out. The preliminary result of the phase scan of the DTL-1 is shown in figure 6. The measured data are consistent with the results of the simulation.

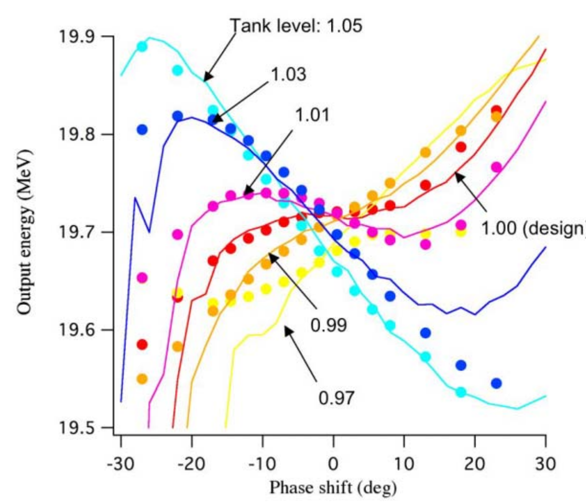

Figure 6: DTL1 phase scan result (Preliminary)
Solid lines are the results of the simulation.
Circles are measured data.

SDTL

The separated DTL (SDTL) has no focusing quadrupole in the drift tube. The doublet quadrupole magnet is set between the adjacent tanks. The resonance frequency is also 324 MHz. It consists of the 32 tanks and it can accelerates the H^- ion beam from 50 to 191 MeV. However the beam energy is limited to 181 MeV because the last two tanks have been installed as the debuncher in the beam line as mentioned above.

The progress of the rf conditioning of the SDTL is relatively slow because the accelerating field of the SDTL is much higher than that of the DTL and one klystron feeds the power to two SDTL tanks. The conditioning status is shown in figure 7. Although the conditioning is not completed, it is possible to accelerate the beam if the pulse length of the beam is short. Therefore the first beam acceleration test to 181 MeV was started with the short pulse beam (5 mA of the peak current, 20 μs of the pulse width and 2.5 Hz of the repetition rate) on January 17, 2007. After the adjustment of the beam monitor system, it has been confirmed that the beam achieved the energy of 181 MeV on January 24, 2007. The test is still continued.

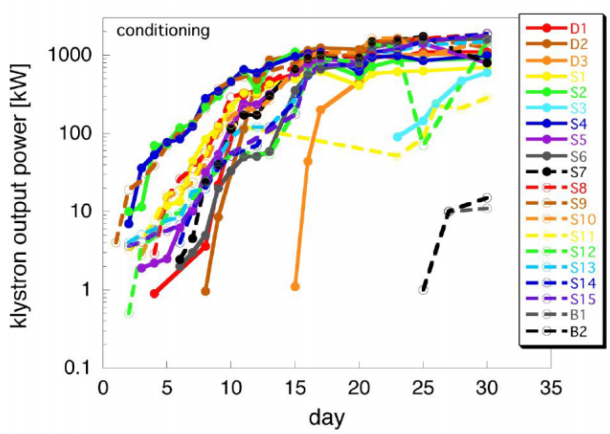

Figure 7: Conditioning history of DTL & SDTL.
D1,2,3: Klystron power for the DTL 1,2 & 3.
Sn (n:integer): power for SDTL(2n-1) & SDTL(2n)
B1,2: Output power for the debuncher 1 & 2.

ACS

J-PARC adopted the Annular Coupled Structure (ACS) as the normal conducting coupled-cavity linac for 191-400 MeV part. The operating frequency is 972 MHz. The 23 modules will be constructed. The ACS has good axial symmetry which is the desirable property for the linac structure. As the result of the many development for the construction, the first practical ACS type debuncher has been assembled and tested by the high-power RF. Figure 8 shows the results of the rf conditioning history of the ACS debuncher [4]. Maximum applied power was 1.2 times the required power. The conditioning has been completed without any trouble.

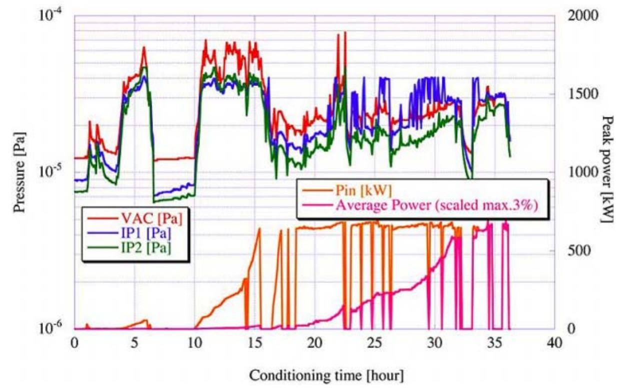

Figure 8: Conditioning history of ACS debuncher.
Upper lines: vacuum level shown in the left ordinate .
Lower lines: Power level. (Orange lines shows the peak power which is denoted in the right ordinate. Pink line show the average power, which is equal to 3% of the value shown in the right ordinate.)

RF system

The 324-MHz high-power pulsed klystron with a modulating anode has been developed for the RFQ, the DTL and the SDTL. Maximum power of 3 MW with the rf pulse width of 600 μsec and 50-Hz repetition rate is required. The results of the high-power test of the klystron achieved the requirements. It is shown in figure 9. The fine tuning of the low-level feed-back system for the klystron is being done with the beam in order to keep the electric field accuracy less than $\pm 1\%$ in amplitude and ± 1 degree in phase.

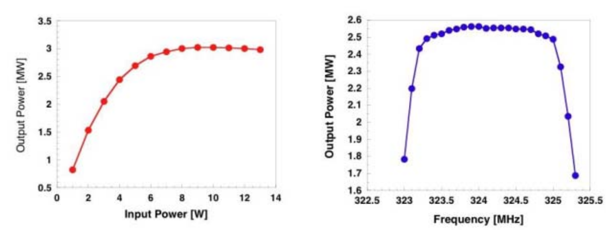

Figure 9: Properties of the 324-MHz klystron.
(Left) Output power vs. input power. (HV=105kV.)
(Right) Frequency dependence of the klystron output.

The development of the 972-MHz modulating-anode klystron for the ACS cavity has been also completed. It was used for the rf-conditioning of the ACS debuncher. The required power for driving the standard ACS cavity is 2.5 MW.

RCS

The status of the rapid cycle synchrotron (RCS) is as follows;

- The dipole, quadrupole and sextupole magnets have been installed with the ceramic beam duct;

- The magnet excitation test has been started;
- A part of the components of the beam injection region has been installed;
- Installation of the RF cavities has been started in January 2007.

The issues for the RCS are concentrated in the injection region. For instance the check of mechanical consistency of each component for the RCS injection region shown in figure 10 is not completed because it is so complicated. Now the consistency is being checked. Furthermore the development of the long-lived beam-stripping foil is the special issue for RCS. Recently the hybrid boron doped carbon foil is found as a candidate of the stripping foil. The test of the foil is being done by irradiation of 650 kV H^- beam accelerated by the Cockcroft-Walton generator in the KEK [5].

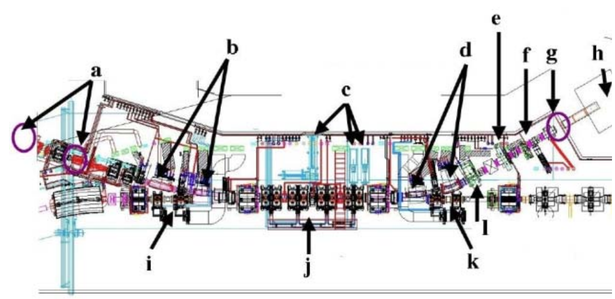

Figure 10: RCS beam injection region.
(a) vertical painting magnet, (b) injection septum magnet, (c) drivers for the stripping foil, (d) septum magnet for H0 dump, (e) vertical steering magnet, (f) horizontal steering magnet, (g) current monitor, (h) dump for H0 beam (H0 dump), (i) painting bump magnet, (j) bump magnet for beam shift, (k) painting bump magnet, (l) Q-magnet for H0 dump

MR

Main tunnel of the MR has been completed [6, 7]. The construction of the experimental area and the beam lines are still continued. In the tunnel, more than half of the (dipole, quadrupole and sextupole) magnets have been installed as shown in figure 11 [8, 9].

For the injection/extraction septum and kicker magnet systems, performance tests are now being carried out intensively. The magnet systems will be installed after that their reliability will be confirmed enough for the practical use.

Some magnetic alloy cores of the RF cavity were seriously damaged under high rf power loading as reported in Ref [10]. The problem is being solved carefully, and long term continuous operation of the cavities is now in progress.

Figure 11: Installed MR magnet.
Blue: Dipole magnet, Yellow: Quadrupole magnet.

CONCLUSION

The beam commissioning of the J-PARC linac has been started in November 2006. The beam accelerated by the DTL has passed through in the following whole equipments (DTLs, SDTLs and magnets) and arrived on the beam dump without the correction by the steering magnet. Although the tuning of the SDTL system is still continued, it has been confirmed that the beam accelerated by the SDTL achieved the energy of 181 MeV. Furthermore the excitation test of the aligned magnet in the RCS tunnel has also been started. For the MR the magnet installation has been started. The beam commissioning for the RCS and the MR is scheduled for September 2007 and May 2008, respectively.

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