# RECENT PROGRESS IN BEAM COMMISSIONING OF J-PARC LINAC

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*Abstract*

The beam commissioning of J-PARC linac has been started since November 2006. After the scheduled shutdown in summer 2007, the beam is successfully delivered from the linac to the RCS. Since then, nine beam commissioning runs were conducted in total, in which a stable beam provision to RCS was emphasized. During these commissioning runs, the stability of the ion source, the RF system, and cavities has steadily been improved. Commissioning cycle of the J-PARC linac is summarized in this proceeding together with the operating experiences, and the demonstrations for a higher power operation and the residual radiation level of the accelerator are discussed.

# J-PARC リニアックビームコミッショニングの進展

## INTRODUCTION

The J-PARC (Japan Proton Accelerator Research Complex) is a multi-purpose accelerator facility aiming at achieving 1 MW class proton beam power[1]. The J-PARC comprises a linac, an RCS (3GeV rapid-cycling synchrotron), an MR (50 GeV main ring synchrotron) and experimental facilities. The front-end system of the linac consists of a volume-type negative hydrogen ion source with 30 mA peak current and an RFQ (Radio-Frequency Quadrupole linac) with 3 MeV output energy. The 3 MeV-$H^-$ beam from RFQ is chopped by an RF-chopper system in an MEBT1(Medium Energy Beam Transport 1). For matching to a DTL (Drift Tube Linac) with 50 MeV output energy, we have the quadrupole magnets and two bunchers in the MEBT1. From 50 MeV to 400 MeV, the linac accelerator consists of an SDTL (Separated-type DTL) with 191 MeV output energy and an ACS (Annular Coupled Structure linac). At the initial commissioning stage, we started the beam operation with 181 MeV due to that the installation of ACS is postponed until an energy upgrade in the near future. The R&Ds for the production version of the ACS module are ongoing and a satisfiable performance is obtained from the high power test. Presently, we are optimizing the procedure of the mass production of the ACS cavity for the energy upgrade to 400 MeV [2]. In this initial commissioning, the last two SDTL cavities are moved to L3BT (Linac-3GeV Beam Transport line) to utilize them as debunchers.

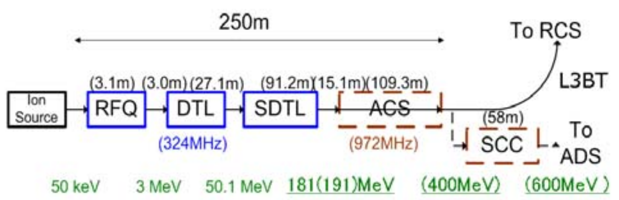


Figure 1: Block diagram of the J-PARC linac.

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With 181 MeV operation of the linac, the goal beam power is 36 kW. Table 1 summarizes the design parameters of the linac and those achieved to date.

Table 1: Summary of achieved beam parameters

| Parameter | Design | Achieved to date |
|---|---|---|
| Output energy [MeV] | 181 | 181 |
| Peak current [mA] | 30 | 30 (RFQ exit)*<br>27 (RCS inj.) |
| Average current after chopping [μA] | 200 | 6.6 (w/o chop)<br>19.5 (w/ chop)** |
| Linac beam power [kW] | 36 | 1.2 (w/o chop)<br>3.5 (w/ chop)** |
| Pulse length / Repetition / Chopper beam-on duty [ms / Hz / %] | 0.5 / 25 / 53 | 5mA :<br>0.5 / 2.5 / 100<br>0.05 / 25 / 60<br>25mA:<br>0.05 / 2.5 / 100<br>0.12 / 25 / 26** |
| RF flat-top width / Repetition [ms / Hz] | >0.5 / 25 | >0.5 / 25 |

* Pulse length : 0.25 ms
** Sustained for four minutes by the limitation of dump capacity

J-PARC linac has finished its installation in summer 2006. The beam commissioning of the linac started in Nov. 2006. Before the beam commissioning, we conducted a high power conditioning of RF cavities for one month. From Nov. 2006 to Jun. 2007, the beam commissioning was addressed for aiming at realizing the beam quality necessary for a coming RCS beam commissioning. The basic beam commissioning was completed in the series of commissioning runs [3]. After the scheduled shutdown in summer 2007, the beam was successfully delivered into the RCS in Oct. 2007. Since then, we conducted nine commissioning runs until the scheduled shutdown in summer 2008. In these commissioning runs, we focused on providing a stable beam to RCS, and also continued the beam tuning and demonstrations for a coming higher power operation. In this proceeding, we report our operation schedule and the improvement of the accelerator stability, the beam tuning results, and the residual radiation level in the accelerator tunnel.

## OPERATION CYCLE AND STABILITY ISSUES

### *Operation schedule*

A typical run cycle for the beam commissioning consists of a beam operation of two or three weeks with one-week interval. The run history since the start of the linac operation is summarized in Fig. 2. In this chart, each vertical rectangular block (labelled with the name of the month on top of it) shows the operation history of a month, and each row (labelled with its date) shows the operation status of a day. A day is divided into three eight-hour shifts, and each shift is represented with a square. A blank square denotes scheduled downtime, and a yellow square denotes the operation for RF conditioning without beam. A blue and a green squares are respectively show the beam-on time for linac beam study and those for downstream facilities. Finally, a red square denotes unscheduled downtime. It should be noted here that a beam fault shorter than four hours is not shown in this chart. The beam commissioning is interrupted in the midnight in our operation schedule, although, the RF conditioning is continued 24 hours during a run. The unscheduled downtime by faults longer than one minute is analyzed from the operation log [5]. In run 17, the unscheduled downtime is 6.4 % of the total beam time (259 hours).

### *Stability of RF source and cavity*

The stable operation of the cavities and the RF power sources is essential for a stable beam operation. Advancing the RF aging since Oct. 2006, the stability of the RF cavities has steadily been improved. The recovery period after the intermission has been shortened, and it takes about 24 hours for the beam acceleration. After checking the reproducibility of the beam in the linac, we can deliver the beam to RCS in the third day of the commissioning run.

The short unscheduled downtime is mainly due to an RF reflection from a cavity detected by an LLRF (low-level RF) fast interlock system. The trend of this fault is shown in Fig. 3. The fault rate is improved in later runs. However, the fault rate increased in run 7, presumably, because the linac was commissioned with the peak current of 25 mA for the first time. Since the start of the linac commissioning, the operation time of a klystron exceeds 5900 hours without any serious trouble.

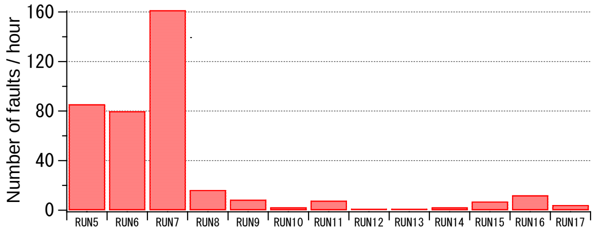


Figure 3: The rate of RF faults detected by LLRF fast interlock system

### *Maintenance cycle for ion source*

The lifetime of the filament for the ion source should be carefully estimated for scheduling the maintenance cycle. To maintain the discharge condition, the ion source is overhauled (for the cleaning of the filament and the discharge chamber) during every interval. The ion source has been operated continuously for 24 hours since run 16. In addition, this 24-hours operation was kept for three weeks without any maintenance. The beam current decreasing rate at the 30 mA operation is less than 0.015 mA/h without operator's assistance [6]. The total

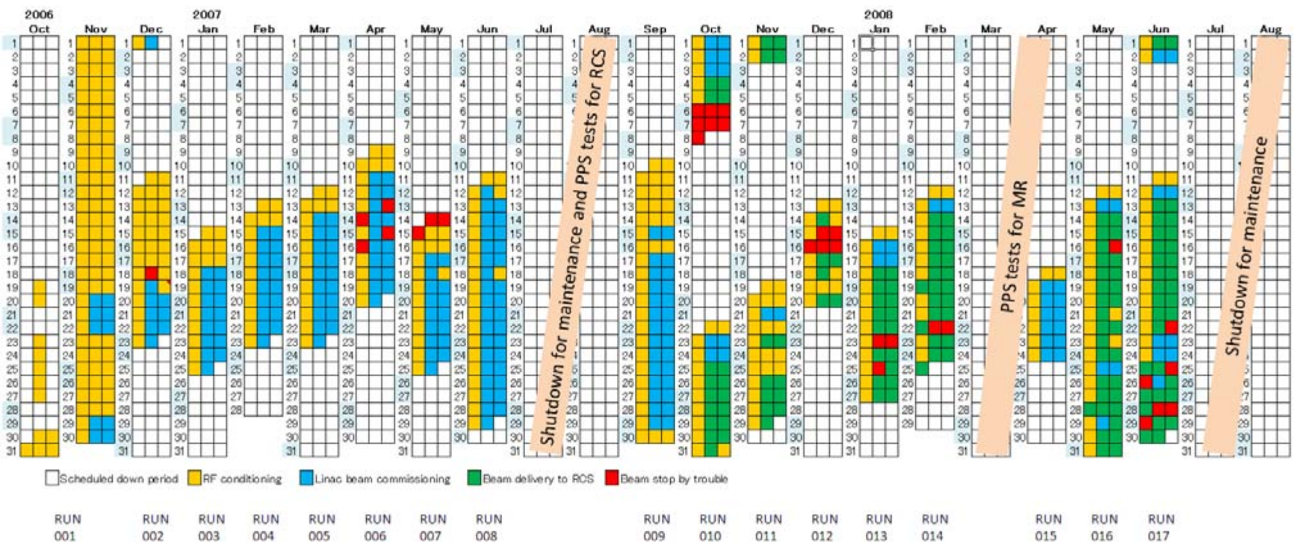


Figure 2: Linac operation history since Oct. 2006.

operation time of the ion source so far is 3360 hours, during which the filament was exchanged three times due to short-circuit and cut-off.

## LINAC BEAM TUNING

Taking time out from beam delivery to RCS, occasional beam studies have been performed for linac. Details on the beam studies are left for separated papers [7]. We just touch upon the demonstration studies for future beam power ramp-up.

The design power for 181 MeV operation of the linac is 36 kW, in which the pulse length, the peak current, the repetition, and the chopper beam-on duty factor are 0.5 ms, 30 mA, 25 Hz, and 53 %, respectively. As a step toward the beam power ramp-up, we demonstrated 3.5 kW beam power (0.12 ms, 25 mA, 25 Hz, 26 %) in run 14. This beam was accelerated to 3 GeV at RCS and extracted to a beam dump successfully. This operation was sustained only for four minutes due to the limited beam dump capacity. For a longer pulse length operation, we demonstrated 0.5 ms pulse length in run 15. In this demonstration, the unchopped beam was transported to the linac beam dump, in which the peak current and the repetition of the beam were 5.7 mA and 2.5 Hz respectively. During these high power demonstration and the long pulse demonstration, we could not observe any problems such as an instability, an increase in RF fault, a worse vacuum, an unexpected beam loss, and so on.

## RESIDUAL RADIATION LEVEL

A residual radiation level of the accelerator components was surveyed after the end of each run. Figure 4 shows the survey results after run 17, in which the value was measured with contact on vacuum chamber. With the exception of the beam window and the dump section, the highest value of 10 μSv/h was detected at the entrance of the debuncher 2. In Fig. 4, the survey results at the debunchers 1 and 2 after run 5 are also noted and those are more than one order of magnitude higher than those after run 17. The beam aperture is narrowed at the entrance of the debunchers 1 and 2, because we temporally utilize SDTL cavities as debunchers. Then, the relatively higher radiation level was detected at the entrance of those debunchers. We have experienced that the relatively higher residual radiation was observed after a run, in which the beam tuning such as phase scan and matching are conducted. The residual radiation induced by the beam losses during the beam tuning processes seems to have the majority and should be carefully controlled.

The residual radiation level is nearly negligible in the present stage. However, we are aiming at realizing the beam power more than one order of magnitude larger than the current value. Therefore, we need to carefully monitor the trend of the residual radiation level as we increase the beam power, and take a counter measure if necessary in an appropriate timing.

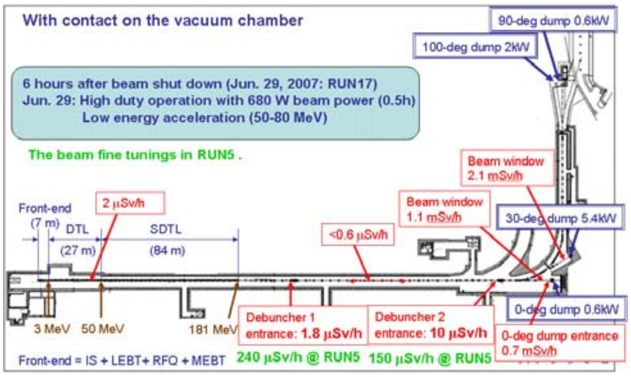


Figure 4: Residual radiation level after run 17.

## SUMMARY AND FUTURE PLAN

Since Sept. 2007, the J-PARC linac has conducted nine commissioning runs in total without any serious troubles, where the 181 MeV beam was delivered to RCS with an acceptable beam quality and stability. Meanwhile, the beam tuning was continued to enhance the beam quality and demonstrated the performance of the linac for a higher power operation. Currently, the residual radiation level is still low. A higher duty operation with more than 1 kW output power of the linac is planned from Sept. 2008, in which a significant radiation level might be detected. And then, the production run will start in Dec. 2008.

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