TRANSITION FROM COMMISSIONING TO OPERATION IN J-PARC LINAC

M. Ikegami, KEK, Tsukuba, Ibaraki 305-0801, Japan

Abstract

The beam commissioning of J-PARC linac was started in November 2006, and the beam supply to the following 3-GeV synchrotron was started in October 2007. Since then, J-PARC linac has been in a transitional stage from beam commissioning to operation for nearly one year. In this period, the linac operation has been performed with its focus on the operational stability and characterization of the beam parameters. The operational experience obtained in this period has been presented in this paper with emphasis on the operational stability achieved to date.

INTRODUCTION

The beam commissioning of J-PARC linac [1, 2] was started in November 2006, and its initial stage was completed in October 2007. During the beam commissioning, the design beam energy of 181 MeV was achieved in January 2007, and the output beam power of 1.2 kW (3.3 % of the design value) was demonstrated in June 2007. Subsequently, the output beam from the linac was delivered to the succeeding RCS (3-GeV Rapid Cycling Synchrotron) in October 2007. As the details on the initial beam commissioning have already been reported in other literatures [3, 4, 5, 6], we here concentrate on the operational experiences obtained after finishing the initial beam commissioning.

The beam power of 1.2 kW (which corresponds to 20 kW from RCS) is the commissioning goal set for 2008, and it is assumed for the initial neutron production run scheduled in December 2008. Then, we marked the completion of the initial beam commissioning for the linac with achieving 1.2 kW beam power and the beam delivery to RCS without notable beam losses. After completing the initial commissioning for the linac, the beam commissioning of RCS and then MR (50-GeV Main Ring) has been started subsequently [7, 8]. Since then, the priority of the beam study has been given to those associated with the RCS and MR commissioning. Consequently, the emphasis has been put on the stable beam supply in the linac operation with the minimum beam study for the linac tuning.

Meanwhile, the average beam duty factor has been significantly reduced in this period, because the single-shot or low-duty-factor operation have been totally employed in the RCS and MR beam commissioning. It significantly contributes to avoiding excess machine activation in RCS and MR, but at the same time it prevents us from accumulating experience on the machine activation in the linac with the nominal beam operation. In other words, it has been difficult to conclude whether the reduction in the machine activation is attributable to the improved beam tuning or the reduction in the average duty factor of the operation.

In short, we have been in a transitional stage from commissioning to operation for nearly one year, where a stable operation is required and the average beam power is kept extremely low at the same time. During this period, we have been focusing on improving beam diagnostics and associated control systems to characterize the linac beam parameters and monitor their stabilities.

As the emphasis has been put on the operational stability in this period, we specifically discuss in this paper about the stability issues in J-PARC linac. Needless to say, good stability of the linac is a key to the success in the beam commissioning of the downstream facilities.

The stability issues have two aspects. One is the stability of the beam parameters, and the other is those related to its fault rate or beam availability. Both aspects are discussed after briefly reviewing the typical run cycle for J-PARC linac and its operation history. Optimized planning for the run cycle is also important for the efficient beam commissioning. We also touch upon the machine activation experienced so far, but our understanding has not been advanced so much due to the limited average beam power as discussed above.

TYPICAL RUN CYCLE AND OPERATION HISTORY

In the early stage of the beam commissioning, a typical run cycle consisted of two-week beam time with a two-week interval. The relatively long and frequent interval was scheduled to accommodate adjustments of both hardware and software. We kept this cycle through the linac commissioning and the early stage of RCS commissioning. As the commissioning of RCS has been advanced, a typical run cycle has been shifted to three-week beam time with a one-week interval. This is the design run cycle planned to achieve the design operational hour of 5500 hour/year. The one-week interval is secured to accommodate ion source maintenance, and the RF sources and magnet power supplies are turned off during the interval.

The relatively frequent short shutdown is realized with good reproducibility of the beam parameters at the start-up. Actually, it typically takes only two days to start-up after a one- to two-week interval. Namely, it takes one day for the RF conditioning and one day for the linac beam tuning.

The RF sources, magnet power supplies, and ion source

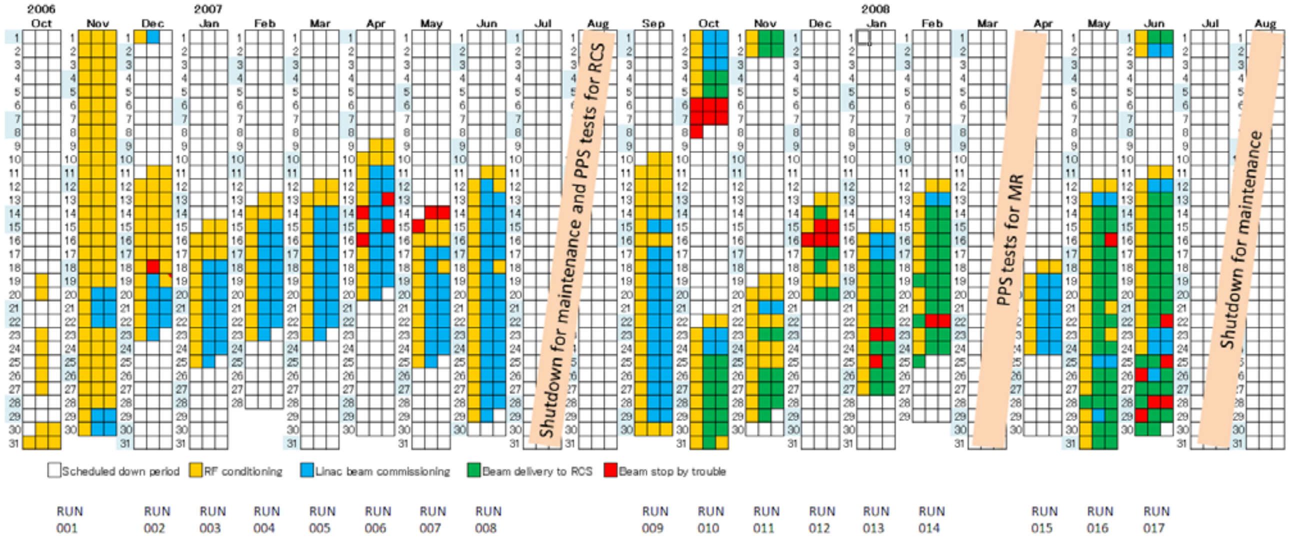

Figure 1: Operation history of J-PARC linac. Blank square: scheduled down-time, yellow: RF high-power operation without beam, blue: beam operation for linac study, green: beam operation for downstream facilities, and red: unscheduled down-time.

are operating 24 hours a day during the beam commissioning. However, the beam study is basically conducted 12 hours a day to concentrate our manpower and realize efficient beam commissioning. Around-the-clock beam supply to the neutron target is planned from this December, and the personnel training or experience sharing is an urgent task for the commissioning team to cope with it.

Figure 1 shows the operation history of J-PARC linac. In this figure, each vertical rectangular block (labeled with the name of the month on top of it) represents the operation history of a month with each row showing the operation status of a day. Each day is divided into three eight-hour shifts, and the operational status of each shift is represented with the color of a square. A blank square denotes scheduled down-time, and a yellow square the high-power operation of RF without beam. A blue and a green squares respectively show the beam-on time for the linac beam study and that for downstream facilities. Finally, a red square denotes unscheduled down-time. It should be noted here that the down-time shorter than several hours is neglected in this chart. The down-time analysis is further discussed in a later section. The down-time shown in this figure includes those caused by downstream facilities. It is clearly seen in this figure that short and frequent shutdowns are scheduled for our linac, and the operational hour is started to increase in the last two cycles.

STABILITY OF BEAM PARAMETERS

For the sake of convenience, the beam parameter stability issue is here divided into two categories, namely, short-term stability and long-term stability. The short-term stability is here defined to be concerning with pulse-to-pulse variation to hourly variation. Meanwhile, the long-term stability is that with daily to yearly variation. The long-term stability is also supposed to include the reproducibility of the beam parameter after a short-term and long-term shutdowns.

It should be noted here that the long-term stability can be improved by introducing a slow feed-back control after credibility of the monitoring system has been established. On the contrary, it is difficult to improve the pulse-to-pulse variation. Then, we assume that it is of more importance to confirm the short-term stability in the present stage of the commissioning.

As the beam commissioning of the downstream facilities are still undergoing, the linac beam parameters are often changed to meet the study requirement. Consequently, it is difficult to monitor the long-term beam stability in a systematic way at present. Then, we here focus on the short-term stability of the linac output beam.

A typical histogram of the measured beam centroid energy is shown in Fig. 2, where the energy jitter is monitored for nine hours with TOF (Time Of Flight) measurement utilizing FCT's (Fast Current Transformers). The rms jitters are respectively 39 keV, 15 keV, and 16 keV at the exit of SDTL, the first debuncher, and the second debuncher. The 100 % jitter is sufficiently smaller than the design goal of 333 keV or 0.1 % in momentum.

A typical histogram of the measured beam position is also shown in Fig. 3, where the position jitter is monitored for 30 min with two BPM's (Beam Position Monitors). These two BPM's are located at the end of the beam transport line connecting the linac and RCS, to which we refer as L3BT (Linac-to-3-GeV RCS Beam Transport). The two BPM's are 4.1 m apart with one quadrupole magnet in-between. The rms jitter is found to be around 60 μm for both BPM's, which is sufficiently small.

It should be noted here that both results for the jitter measurement include those caused by the noise in the monitor

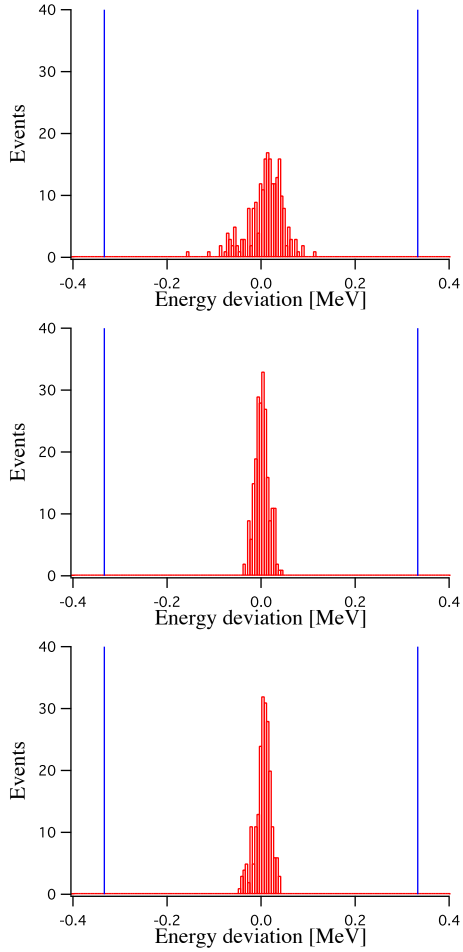

Figure 2: Energy jitter at the SDTL exit (top), the fist debuncher exit (middle), and the second debuncher exit (bottom). The blue vertical lines show the specification of ± 0.1 % in momentum.

system. Then, the actual beam jitters are expected to be smaller than the above values.

BEAM FAULT STATISTICS

The beam fault statistics are another important issue concerning the operational stability. We should note that the fault statistics presented in this section are regarding only to the linac operation. We here categorize the beam fault into three categories, namely, short, medium, and long faults. Short faults are those recovered within one minute, and medium faults within one hour. Long faults are those where it takes more than one hour to resume the beam operation. Table 1 shows the beam fault statistics in recent two runs. In these two runs, the fault rate was 0.6 /hour to 1.0 /hour for the short fault, 0.08 /hour to 0.1 /hour for the medium fault, and around 0.004 /hour for the long fault. Most of the short faults were caused by the simple RF reflection, where the RF field is automatically recovered by the LLRF (Low-Level RF) control system.

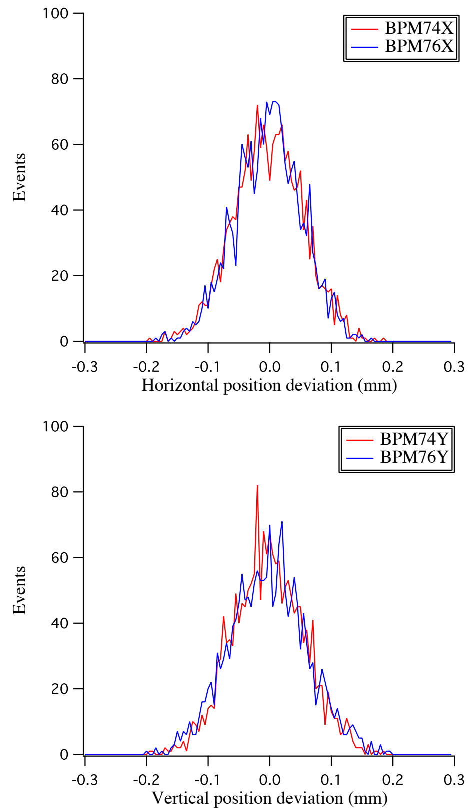

Figure 3: Beam position jitter for the last two BPM's in L3BT. Top: horizontal, bottom: vertical.

The scheduled beam time was 249 hours and 259 hours for these two runs. We here define the scheduled beam time to start with extracting a Faraday cup in the morning and to end with inserting it at night, because the actual beam-on time varies day by day depending on the study item or the progress of it in the present stage. The total down-time was 4.3 % (10.7 hour) and 6.4 % (16.6 hour) of the scheduled beam time. More than half of the down-time was attributed to rare long faults. We had one long fault in each of these two runs, and the down-times attributed to these two faults are 5.5 hour and 12.6 hour, respectively. These long faults were caused by unusually severe RF discharge at RFQ (5.5 hour) and filament breakdown at the ion

Table 1: Beam fault statistics for recent two runs

	RUN16 May 2008	**RUN17** June 2008	**Unit**
Num. of days	21	19	
Beam-on time	249	259	h
Short fault $<$1 min	170	261	
Medium fault $<$1 h	26	19	
Long fault $\geq$1 h	1	1	
Total down-time	10.7	16.6	h
Fractional down-time	4.3	6.4	%

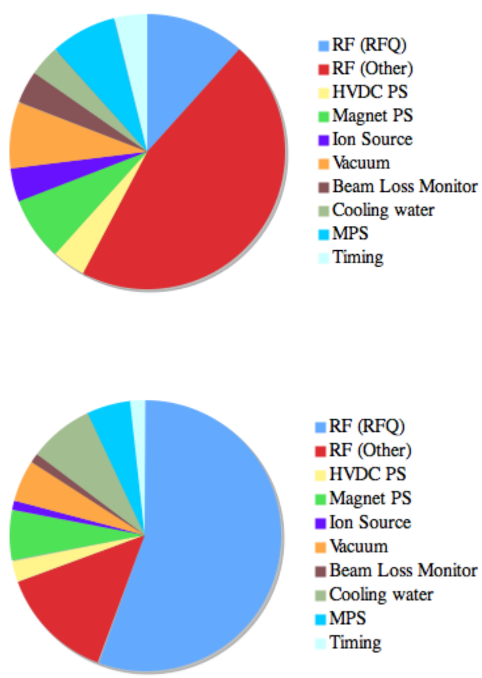

Figure 4: The cause of beam faults in RUN16 (May 2008). Top: the ratio in the number of events, bottom: in the associated down-time.

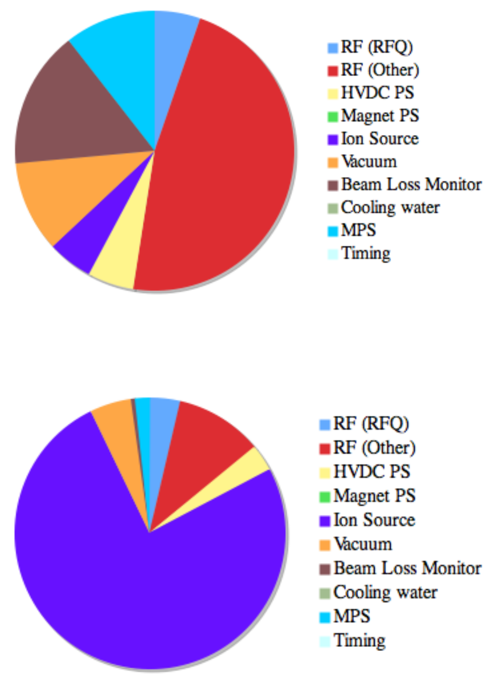

Figure 5: The cause of beam faults in RUN17 (June 2008). Top: the ratio in the number of events, bottom: in the associated down-time.

source (12.6 hour). Excluding these two rare events, the total down-time caused become around 2 % of the scheduled beam time.

The beam faults in the recent two runs are categorized by their causes in Figs. 4 and 5. In these figures, the ratio for the cause of beam faults are analyzed both in the number of events and the associated down-time duration. It should be noted that only the beam faults longer than 1 min are analyzed in these figures. Most short faults are recovered in seconds, and its contribution to the total down-time is supposed to be negligible. In these figures, HVDC PS denotes the High Voltage DC Power Supply for a klystron. Then, MPS denotes Machine Protection System. The beam operation is finally interrupted by MPS for any kind of beam fault. The beam faults categorized in "MPS" here are those caused by noise or a trouble in MPS itself. As seen in these figures, the tendency is similar in these two runs aside from the above-mentioned rare long events. Namely, the interlock caused by RF reflections are dominating in number. However, it does not occupy so significant portion in the associated down-time, because the procedure to recover has been established. Other beam faults are caused by various reasons in various equipments, and there seems to be no clear tendency.

We had similar statistics for the runs in January and February 2008, but we had longer down-time in the runs in October to December 2007. The linac started to provide beams for the RCS commissioning in these runs. During these runs, we had significantly higher long-fault rate of around 0.03 /hour. As a result, the total down-time in the runs in October to December 2007 reached 10.1 %. In this period, we had a few long down-time due to problems in the water-cooling system. However, after accumulating the operational experience, the beam faults caused by the water-cooling system become less frequent and the accompanying down-time for a fault become shorter.

While the beam time exceeds 750 hours after we start to provide the beam for downstream facilities, we need much more experience to properly deal with rare events to improve beam availability. Particularly, more operational experience is required to optimize the schedule of exchange for key expendable supplies, such as klystron and the filament for the ion source.

MACHINE ACTIVATION

The machine activation is often the limiting factor for the achievable beam power for a high-intensity accelerator. In spite of the low average beam power, we have already observed some machine activation due to uncontrolled beam losses.

We have narrow sections at two debunchers installed in L3BT, because the last two SDTL (Separate-type Drift Tube Linac) tanks are temporarily utilized for debunchers. Machine activation is mostly localized to the vicinity of the debunchers. We experienced the highest activation when we performed the fine phase-scan tuning for SDTL cavities for the first time with the beam power of 0.12 kW. In that run, the residual radiation level reached 250 μSv/h at the second debuncher with contact to the vacuum chamber 6-hour after beam shutdown. Conducting precise tuning of machine parameters, the radiation level was gradually reduced. Then, the typical radiation level at the debunchers became 10 to 40 μSv/h at the end of the initial commissioning despite the increased beam power of typically around 0.6 kW. We also see slight activation in the beam transport lines between debunchers and at the arc section after the second debuncher, but it was kept below 10 μSv/h.

We have observed that certain beam studies, such as phase-scan tuning or profile measurement with wire scanners, give rise to an increase in the beam loss. However, we can not conclude how much portion of the machine activation can be attributed to the beam studies. After the commencement of the RCS commissioning, we have conducted little beam tuning in the linac. Then, the radiation level has been reduced with the factor of several to ten. However, most of the reduction in the machine activation might be attributable to the reduction in the average duty factor as discussed above. We plan to carefully monitor the trend of machine activation in the stable beam operation planned for neutron production. It will enable us to more accurately predict the activation level with the nominal operation with higher beam power.

SUMMARY

The beam commissioning of J-PARC linac has been started since November 2006, and the initial phase of it has been completed in October 2007. In October 2007, we started to provide a beam to downstream facilities for their beam commissioning. Since then, we have been in a transitional stage from commissioning to operation. In this period, the emphasis is put on the stability of the beam operation. The short-term stability and the beam availability have already reached the sufficient level. However, we need further study on the long-term stability and the machine activation with the nominal operation.

The RCS commissioning is now approaching to the completion of its initial stage, and stable beam supply to the neutron target is planned in this autumn to demonstrate its capacity [7]. After December 2008, the MR commissioning will be performed with pulse-to-pulse beam sharing with the neutron target. Accordingly, we expect that the emphasis in the linac tuning is gradually shifted to the beam power ramp-up hereafter in tandem with the further RCS tuning. We also expect to gain more experiences on the long-term stability and machine activation issues in the coming stable operation.

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