RECENT PROGRESS IN BEAM COMMISSIONING OF J-PARC LINAC

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Abstract

J-PARC linac resumed beam operation after the earthquake in December 2011, and the operation before the earthquake was mostly recovered until the summer shutdown in 2012 as has already been reported. We here review the progress of the linac beam commissioning thereafter, which includes beam commissioning of newly installed longitudinal monitors, high beam power operation trial, and ramp-up of the user operation beam power.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator facility aiming at delivering a 1-MW class beam to multiple user facilities. Its accelerator consists of a 181-MeV linac, a 3-GeV RCS (Rapid Cycling Synchrotron), and a 30-GeV MR (Main Ring). The injector linac is comprised of a 50-keV negative hydrogen ion source, a 3-MeV RFQ (Radio Frequency Quadrupole linac), a 50-MeV DTL (Drift Tube Linac), and a 181-MeV SDTL (Separate-type DTL) [1]. The beam commissioning of the linac was started in November 2006, and the user operation utilizing the beam from RCS was started in December 2008. Since then, the beam commissioning of the linac has been conducted to rump up the beam power while sustaining user operation [2].

After a magnitude 9.0 earthquake in March 2011 which forced us to shutdown the accelerator for about nine months, we resumed the beam commissioning in December 2011 and user operation in January 2012. The operation before the earthquake was mostly restored until the summer shutdown in 2012, and the recommissioning effort during this period was reported in previous literatures [3, 4]. We here review the progress of beam commissioning in J-PARC linac thereafter. It will include the beam commissioning of BSM's (Bunch Shape Monitors)[5] newly installed in summer 2012, higher beam power operation trial, and the beam power rump up for user operation among others.

COMMISSIONING OF BUNCH SHAPE MONITORS

During the shutdown in summer 2012, we installed three BSM's at the upstream end of the future ACS (Annular Coupled Structure linac) section. ACS is a variety of coupled-cavity-linac, which will be installed in summer 2013 to upgrade the linac energy [6]. A BSM, or a so-called Feschenko monitor, is a longitudinal profile monitor developed at INR (Institute for Nuclear Research), Russia [5]. You will find details of a BSM and its layout in J-PARC linac in other literatures [5, 7]. These BSM's are installed to be utilized for the longitudinal matching after the energy upgrade.

The beam commissioning of the BSM's has been one of main issues in the linac beam time after the summer shutdown in 2012. Presently, there is no RF cavities between the exit of SDTL and the first BSM. Then, the phase width of the beam starts to grow rapidly after the SDTL exit due to space-charge effect. As there also is no RF cavities between BSM's, the beam phase width further grows between BSM's. Then, the beam phase width measured with a downer stream BSM should be larger than an upper stream one. Using this relation, we have made a rough check on the consistency among BSM's. Then, we turn off the last SDTL module, or SDTL15, to move the starting point of phase width growth upstream. Thereby, the beam phase width measured with each BSM should be increased. By comparing the measured phase widths with and without SDTL15 excitation, we have made a rough confirmation on the response of each BSM.

After confirming basic consistency and response of BSM's, we have had more detailed monitor verification as follows. We set the synchronous phase of SDTL15 to -90 degree to have longitudinal focusing without acceleration. Then, we scan the amplitude of SDTL15 while monitoring the beam phase width with BSM's. The measured dependence of the beam phase width on the SDTL15 amplitude is then compared with a 3D PIC (Particle-In-Cell) simulation employing IMPACT [8]. Figure 1 shows the measured dependence and simulation results. It is readily seen in this figure that the experimentally obtained phase width dependence agrees with the simulation for the first and second BSM's, or BSM1 and BSM2. However, the result for the third BSM, or BSM3, shows some discrepancy. While we need a further study on the discrepancy observed in BSM3, we suppose that basic functioning of BSM's has been successfully confirmed with a beam experiment. The next step would be to confirm the reproducibility of the measurement, and to study optimization of operating parameters for a BSM to improve its accuracy.

While we need to install a magnetic shield around a BSM to suppress the influence of fringing field from neighboring quadrupole magnets[7], the effect of the magnetic shield to the H^- beam has been confirmed to be negligibly small by measuring the beam profile downstream with and without the magnetic shield.

The above measurements have been conducted with a peak current of 15 mA, which is the present nominal for user operation.

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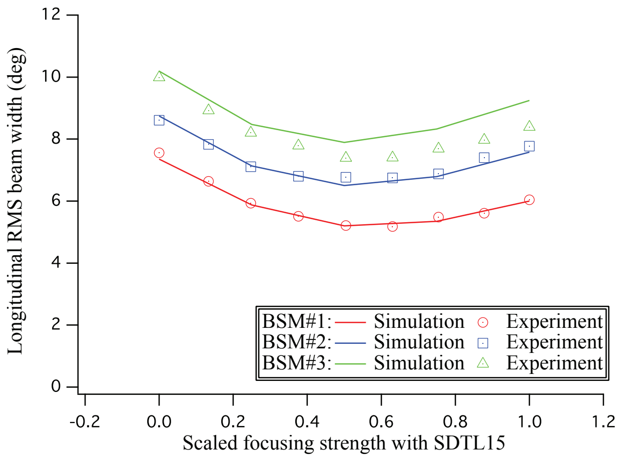

Figure 1: The measured longitudinal RMS beam width vs the RF amplitude of SDTL15 scaled by its nominal. The measured beam width with 3 BSM's and corresponding simulation result are shown.

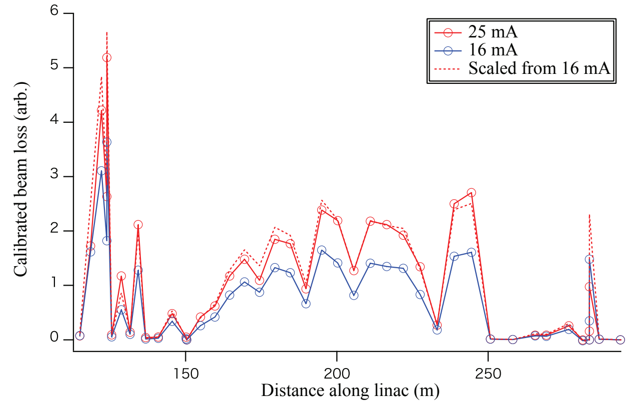

Figure 2: Measured beam loss profile along the linac with the peak current of 16 mA and 25 mA. A projected beam loss profile for 25 mA is also shown, where we assume the beam loss increases in proportion to the peak current with respect to the 16 mA result.

HIGH BEAM POWER OPERATION TRIAL AND BEAM POWER RAMP UP

The operating beam power from RCS was 220 kW as of March 2011 (when we had the earthquake), which corresponds to the linac beam power of 13.3 kW. After the earthquake, we resumed user operation with an RCS beam power of 120 kW in January 2012 and increased it to 220 kW in March 2012. While the beam loss level in the linac was significantly higher when we resumed 220 kW operation, it was gradually reduced through beam loss mitigation efforts [3, 4]. Then, the beam loss level before the earthquake was mostly recovered by June 2012. After confirming that the residual radiation has been suppressed to a comparable level to that before the earthquake, we have started to seek operation with higher beam power.

To be noted here is that we are still operating with a temporal RF setting for 5th SDTL module, or SDTL5, which has been adopted as a remedy to avoid the multipacting [3, 4]. The beam loss has been successfully mitigated with irregular RF setting for SDTL5.

In November 2012, we had a beam study to demonstrate our highest beam power from RCS for a limited period of time. The aim of this study is to confirm the beam loss level with higher beam power utilizing BLM's (Beam Loss Monitors). In this study, the linac peak current is increased from the nominal 15 mA to 25 mA. The RCS beam power has reached 540 kW, which corresponds to the linac beam power of 33 kW.

Figure 2 shows BLM signals along the linac in the high beam power trial. We also show BLM signals with 16 mA which is near to the present nominal peak current for user operation. These two data are taken with the same beam duty factor. To compare these two results, we also show a projected beam loss level for 25 mA assuming that the beam loss increases in proportion to the peak current with respect to the 16 mA result. As readily seen in Fig. 2, the projected beam loss level mostly agrees with the 25 mA result. It is consistent with our understanding that the present beam loss is mainly caused by H^0 particles generated in the residual gas scattering [2]. It indicates that we will likely be able to increase the peak current of user operation to 25 mA with reasonable increase in residual radiation.

After the higher beam power trial, we have increased the beam power for user operation from 220 kW to 300 kW, which corresponds to the linac beam power of 18 kW. The beam power is increased by raising the beam duty factor while keeping the peak current to 15 mA. As the beam duty factor has increased to the design value, further beam power increase would be done by raising the peak current. Considering the result of the high beam power trial, it may be reasonable to assume that the linac is mostly ready to operate with 30 kW for user operation, which corresponds to the RCS beam power of 500 kW.

Figure 3 shows typical residual radiation dose after user operation with the linac beam power of 18 kW, which corresponds to the RCS beam power of 300 kW. The listed residual doses are measured 5 hour after beam shutdown on contact to the chamber surface. It is seen in this figure that the residual radiation doses are kept around or less than 1 mSv/h on contact. Considering that the dose at one foot distance is typically around one order of magnitude lower, the present dose level is considered to be in a tolerable range with a sufficient margin.

BEAM LOSS MITIGATION IN DTL1

During the beam commissioning campaign after the summer shutdown in 2012, we have also conducted a beam loss mitigation study in the first DTL tank, or DTL1. The details of this study is to be discussed in a separated paper [9]. To be noted here is that this study is to deal with residual radiation increase in the middle of DTL1 (not shown

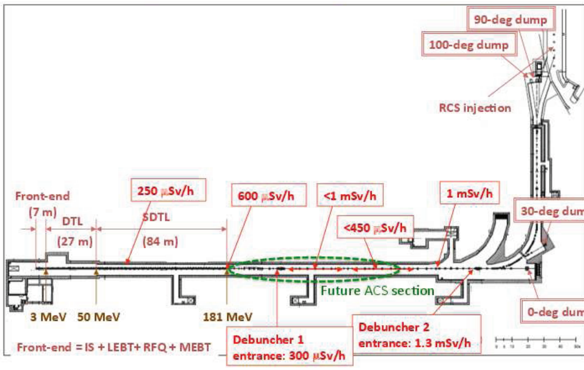

Figure 3: Residual radiation dose on contact 5 hour after shutdown of operation with 300 kW from RCS.

in Fig. 3 as its absolute value is small), which could be attributed to misalignment of DT's (Drift Tubes) caused by the earthquake. We have not performed the realignment of DT's after the earthquake to realize swift restoration of beam operation. It has been a serious concern for the linac operation after the earthquake, as there is no steerer and beam position monitor in the DTL section.

In the experiment, we have installed some BLM's utilizing plastic scintillator on the tank surface of DTL1 to detect the beam loss. Then, the beam injection orbit to DTL1 is successfully adjusted to minimize the beam loss.

COUPLING RESONANCE STUDY

We also had a study on the emittance exchange due to space-charge-driven coupling resonance in SDTL. The detail of this study is to be presented in a separated paper [10]. The resonance study has been conducted to obtain basic information for the optimization of quadrupole setting after the energy upgrade. After the energy upgrade, we have to deal with trade-off between suppressing space-charge-driven coupling resonances and mitigating intra-beam-stripping beam losses [11]. It has motivated careful optimization of lattice parameters [12].

In the resonance study, we change the quadrupole setting of SDTL part to hit the resonance of $k_z/k_x = 2$, where k_x and k_z are depressed tunes for the transverse and longitudinal directions, respectively. Then, we have tried to measure increase of the transverse emittance with an array of wire scanners and decrease of the longitudinal emittance with BSM's. We have successfully observed the emittance exchange for $k_z/k_x = 2$, which is the first experimental observation in a linac. The degree of observed emittance exchange is more significant than a particle simulation and it is accompanied with an unexpectedly developed halo. The experimental observation seems to indicate that the effect of the coupling resonance is more significant than in simulation for some reasons. It provides us with valuable information for the lattice parameter optimization.

SUMMARY AND FUTURE ISSUES

We have reviewed the progress in beam commissioning for J-PARC linac after summer shutdown in 2012. After restoring the beam operation before the earthquake, the focus of the beam commissioning has been shifted to preparation for the energy upgrade and the beam power ramp up. The former includes the beam commissioning of BSM's and the coupling resonance study, and the latter the high beam power operation trial and actual ramp up of user operation beam power from 13.3 kW to 18 kW. Along with this linac beam power increase, the RCS beam power for user operation is increased to 300 kW.

The beam loss measurement in the high beam power trial indicates that we can increase the linac beam power to 30 kW with reasonable increase of beam loss, which corresponds to the RCS beam power of 500 kW. The residual radiation survey after user operation of 300 kW from RCS shows that the radiation dose in the linac is sufficiently in a tolerable range with this beam power level.

We have successfully confirmed the basic functioning of BSM's in the beam commissioning. However, one of the BSM's shows some discrepancy from a particle simulation with varied SDTL15 amplitude. We need to pursue the reason for this discrepancy. Also, we should continue the resonance study to deepen our understanding and to find an optimum lattice setting after the energy upgrade.

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