PROGRESSES OF J-PARC LINAC COMMISSIONING

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Abstract

In the past year J-PARC linac accomplished many upgrades. From 2016, the J-PARC linac started 40mA operation. Separated amplifiers were ready for the chopper cavities, and the ringing effects due to previous connection in series were cured. Newly designed bunch shape monitors for MEBT1 (BSM) (3 MeV) and MEBT2-ACS(~200MeV) were tested on-line, which will work for the longitudinal measurement and 3D matching to DTL and ACS. Lattices in the 200~400MeV part (ACS section) with actually redesigned both in transverse and longitudinal planes were studied and tested. Results of successfully mitigated beam loss from the intra-beam stripping effect were obtained.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC)[1] is a high-intensity proton accelerator facility, which consists of a linac, a 3GeV synchrotron (rapid cycling synchrotron, RCS), and a main ring synchrotron (MR). The J-PARC just accomplished it upgrades with Linac energy from 181 MeV to 400 MeV in Jan. 2014 and Linac peak current to 50mA in Oct. 2014. The upgrades brought about the condition for RCS output power of 1MW.

The J-PARC Linac[2] consists of a 3 MeV RFQ, 50 MeV DTL (Drift Tube Linac), 181/190 MeV SDTL (Separate-type DTL) and 400 MeV ACS (Annular-ring Coupled Structure), as shown in Fig. 1.

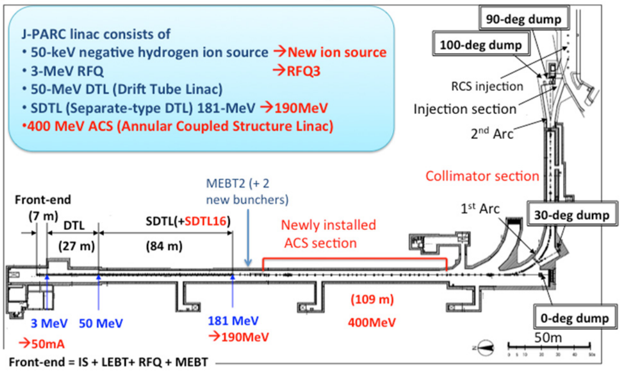

Figure 1: Layout of J-PARC Linac.

From 2016, the J-PARC linac started 40mA operation. Consequently the stepped J-PARC power-up at the neutron target was scheduled, but the schedule was stopped by a target failure at 500kW. Now the accelerator is operated at conservative power (about 150kW) for stable neutron production. J-PARC power-ramping-up will start again after target improvement.

In the summer shutdown of 2016, there were two main hardware upgrades. Separated amplifiers were ready for the chopper cavities, and the ringing effects due to previous connection in series were cured. Newly designed bunch shape monitors [3][4] for MEBT1 (3 MeV) and MEBT2-ACS(~200MeV) were tested on-line.

Efforts on the simulation studies were made to explore new lattices with actually redesigned both in transverse and longitudinal planes. Series experimental studies identified the IBSt as the dominant beam loss and successfully demonstrated beam loss mitigation.

IMPROVEMENTS IN LINAC OPERATION

From 2016, the J-PARC linac started 40mA operation. The machine protection system (MPS) fires caused by beam loss monitor (BLM) increased dramatically after 40mA operation, as shown in Fig. 2, having become the second largest reason of beam trip (just after RFQ). The phenomena were not easy to understand because it happened transiently and usually accompanying with RF MPS.

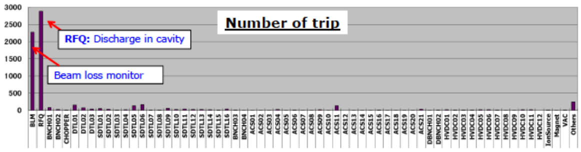

Figure 2: Linac trips in 2016.

Two completely different mechanisms were identified by carefully analyzing the waveforms of RF, BLM and MPS signals and their cause-and-effect relationships. One of them is the BLM MPS caused by a real RF failure, which is mainly related with the RF and cavity performance.

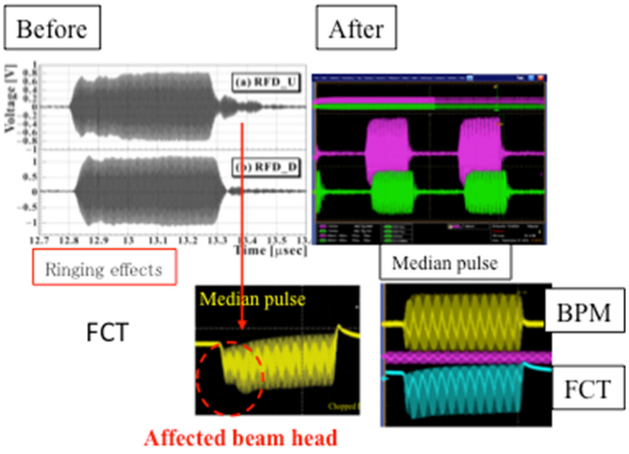

Figure 3: Chopper upgrade by amplifier-parallelization.

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The other is a little bit complicated but avoidable. When BLM reaches MPS level and fires, the beam is stopped in the low energy beam line (LEBT) in a few µs. And the RF pulse is several hundred µs. Thus RF drops in remained part of the pulse as the beam was suddenly stopped at upstream. The beam trip due to MPS fires by BLM increased dramatically as the operation peak current was increased from 30 mA to 40 mA. But no abnormal residue radiation was found.

A careful study and countermeasure were carried out to mitigate the latter case [5][6], which is caused by random BLM events and actually harmless to machine. The BLM thresholds are kept, but the thresholds of signal width are widened, so that those slim high peaks are skipped. These misfire were reduced in recent half-year operation.

After beam intensity upgrade in Oct. 2014, the ringing effects between the two cavities, powered by the same RF amplifier, in the new chopper system, as shown in the left part of Fig. 3, became a source of horizontal emittance growth. This is mitigated by powering the two cavities with independent amplifiers, as shown in the right part of Fig. 3.

Newly designed bunch shape monitors, as shown in Fig. 4 and 5, for MEBT1 (3 MeV) and MEBT2-ACS(~200MeV) were tested on-line, which will work for the longitudinal measurement and 3D matching to DTL and ACS.

The many difficulties have been encountered for the low energy BSM at MEBT1, such as several times of broken of the wire by the beam or the high voltage, noise, nearby magnetic field and etc. A first measurement results showed the beam bunch shape change vs. the MEBT1 buncher-1 amplitude, which is consistent with the simulation, as shown in Fig. 6.

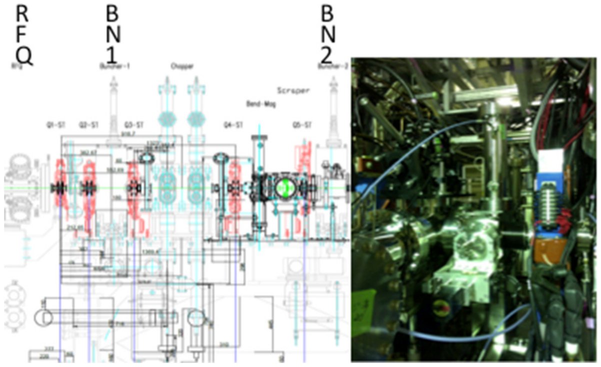

Figure 4: Layout of BSM in MEBT1.

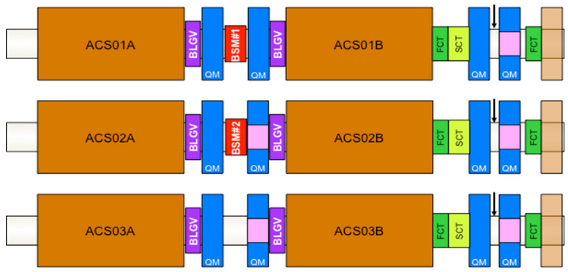

Figure 5: Layout of of BSMs in ACS.

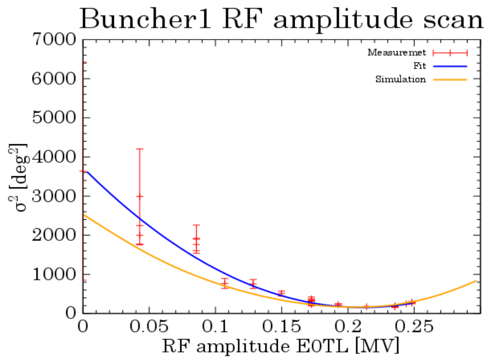

Figure 6: First measurement of BSM in MEBT1.

IBST MITIGATION

After J-PARC linac energy upgrade, beam loss caused by the intra-beam stripping effect (IBSt) in the 200~400MeV ACS section was predicted as the dominant source of residue radiation.

An early testing experiment in 2015 illustrated the dependency of the beam loss on the lattice setting, as shown in Fig.7. Two weaker quadrupole settings in the ACS section, marked with T=0.7 and T=0.5, resulted in considerable reduction of beam loss, where T stands for the "temperature ratio" between transverse and longitudinal planes. This beam loss-lattice dependency not only identified the dominancy of IBSt in ACS section (as well as in the whole linac), but also explored the possibility of mitigation. The stability of the lattices, compared with the baseline design used in the normal operation, need to be studied both theoretically and experimentally. For instance, the red line, for T=0.5 and the more away from design, has lower beam loss at the first half of the section, but ends with a peak due to instability. These are consistent with the simulation study, as shown in Fig. 8 and Fig. 9.

It is not enough to look at Fig. 8 only, which predicted the beam loss rate according to lattice settings. A finally optimization should be a overall compromise with Fig. 9, i.e. the "Hofmann Chart", which describes the intensity of coupling resonances and the consequent stability. A transverse "redesign", exactly same as in the testing experiment in 2015 with results shown in Fig. 7, moves the ACS tune down left, i.e. to the weaker transverse focusing and towards the resonant region. The IBSt were mitigated for T=0.5 (partly) and 0.7, but instability occurs for the T=0.5 case, too.

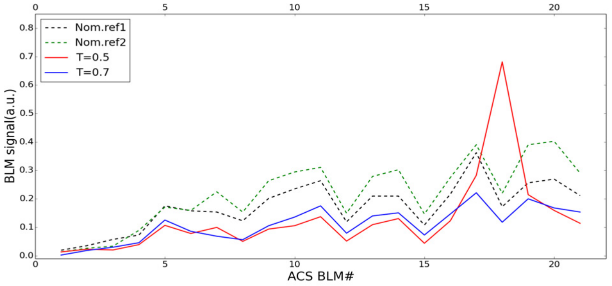

Figure 7: Testing results for beam-loss correlation with lattice setting.

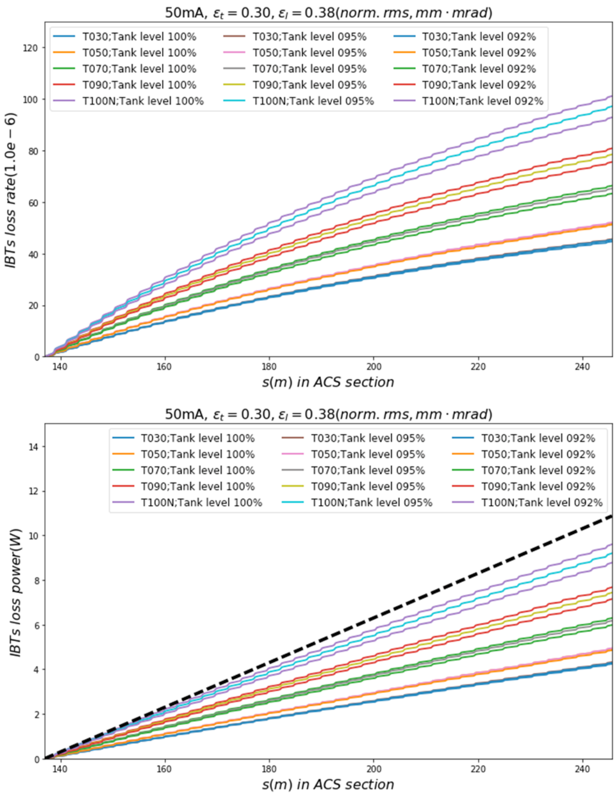

Figure 8: Theoretic prediction of beam loss by IBSt, for transverse and longitudinal lattice setting combinations.

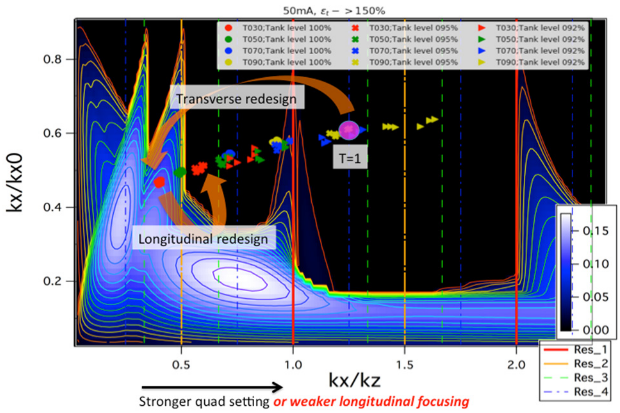

Figure 9: Stability chart for J-PARC ACS.

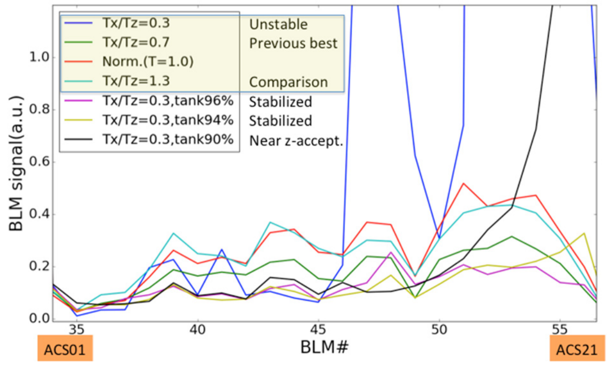

Figure 10: Beam loss measured in the experiments in 2016.

Series of new experiments were carried out in years 2016 and 2017, with a longitudinal redesign by systematically reduce longitudinal focusing and pull back the tune from the resonant region, as shown the Fig. 9. Both further mitigation of beam loss by IBSt and beam stability were obtained.

The experiment results are shown in Fig. 10. In the first step, the cases of T=0.3, 0.5, 0.7 as well as nominal case and a comparison case of T=1.3 were reproduced. The cases of T=0.3, 0.5 are identified with beam loss reduction at the first half of the section, but also encountering instability at the end. The T=0.7 case was the optimized one according in previous experiment.

For each case longitudinal “redesign” was done in the next steps, reducing the tank level and shifting the synchronous phase, thus reducing the longitudinal focusing and pull the tune back to the stable region. It was observed that near the setting of 95% of ACS tank level the “T=0.3” (according to design tank level) case was stabilized. Thus a new candidate of ACS lattice was found. According to simulation, shown in Fig.11, 60% of IBSt beam loss will be gone. When the ACS tank level was reduced down to 90%, the ACS longitudinal acceptance became too small, and part of the longitudinal halo will be lost in the ACS section. The experiment results showed good consistency with the simulation, as shown in the comparison of Fig. 10 and 11.

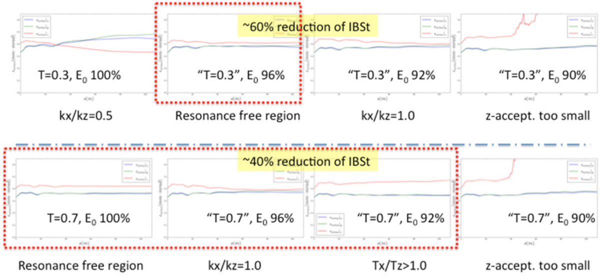

Figure 11: ACS lattice candidates predicted by simulation. The plots are the simulated emittance (blue: x, green: y, red: z) along whole ACS section, for cases with different transverse and longitudinal focusing.

Based on simulation and experiment studies on the candidate lattices shown in Fig. 11, further optimization and verification will be carried out to find the new working point with less beam loss as well as stability and good beam quality.

CONCLUSION AND DISCUSSIONS

J-PARC linac increased the peak current to 40mA in 2016, and new BLM MPS setting was carried out to mitigate the consequently increased misfire. Separated RF supplies for chopper cavities were successfully tested and the ringing effects of the new chopper cavities were cured.

New BSMs were in stalled at MEBT1 and ACS and the beam test were in progress.

Lattice studies of beam loss by IBSt were done. More candidate settings were found with additional longitudinal redesign.

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