BEAM LOSS MITIGATION AND COMISSIONING PROGRESS AT J-PARC LINAC

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Abstract

J-PARC linac is now successfully operated at 50mA/400MeV for 500kW at neutron target, and promisingly on the way to 1MW. Beam loss at linac became one of the crucial issues. Simulation and experiment studies have been carried out to mitigated the intra-beam stripping (IBSt) effect in H- beam at 200~400MeV section, which was found to be the dominant source of beam loss at same type of accelerator. An IBSt-mitigation lattice with beam "temperature" ratio between transverse and longitudinal planes, T=0.7, away from the equipartition condition (T=1) followed by the J-PARC linac baseline design was carefully tested and selected to put into operation. Measured residue radiation dose verified the prediction of 40% reduction. Other recent progress of beam study in the commissioning will be also reported.

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[2,3] 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.

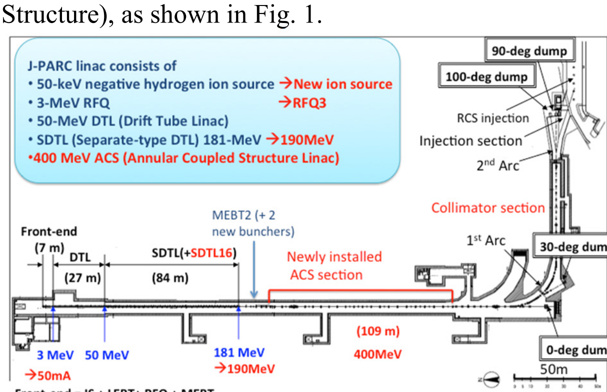

Figure 1: Layout of J-PARC Linac.

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, as shown in Fig. 2. Then the accelerator is operated at conservative power (about 150kW) for stable neutron production until July 2017. After target improvement, J-PARC power-ramping-up started again via 300 kW (Oct. 2017~) and 400 kW (Nov. 2017~April. 2018), to presently 500kW.

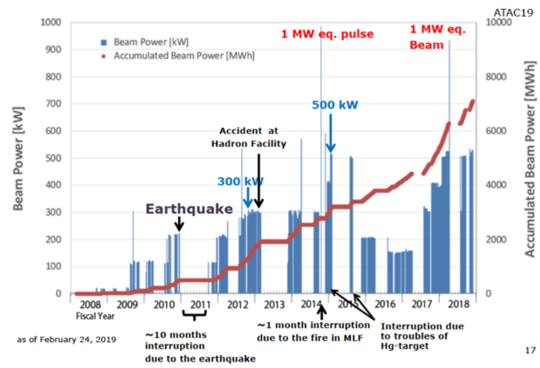

Figure 2: Beam power history of MLF.

In the summer shutdown of 2018, the aperture rearrangement was completed for the whole ACS section, which helped to remove hot radiation spots caused by the bottleneck parts at current monitors.

Based on the consistent experimental and simulation studies intra-beam stripping (IBSt) effect of H- beam was identified as the dominant beam loss at J-PARC linac[2], at ACS section (about 200~400 MeV). A first fully matched IBSt mitigation lattice with "temperature ratio" of Tx/Tz=0.7 with relaxed quadrupole setting was prepared in Oct. 2018 and applied from April 2019, away from the baseline equi-partitioning (EP) (Tx/Tz=1.0) condition. The residue radiation measurement successfully verified experimental and simulation study result.

LINAC OPERATION FOR 500KW AT MLF

From April 2018 to present (July 2019), the J-PARC started operation for 500kW at MLF.

J-PARC linac was operated with peak current of 40 mA for April to June 2018, and 50 mA since Oct. 2018. The operation with ACS at Tx/Tz=0.7 started from April 2019. Residue radiation on surface measured along ACS section with 5-hours cooling down after MLF 400~500kW operation in Mar.~Jun. 2018 was shown in Fig. 3. The hottest spots were as high as 3.5 mSv/h on surface, which may be doubled for designed 1 MW operation. It is obviously high for maintenance and must be mitigated.

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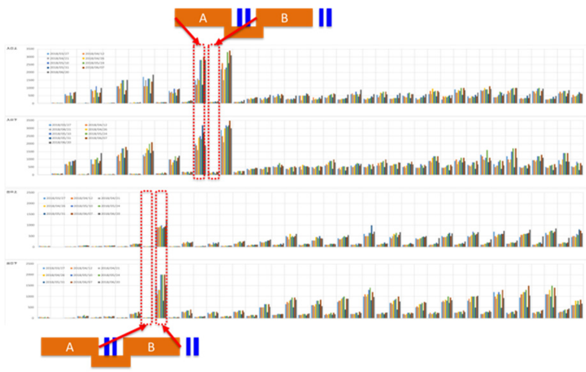

Figure 3: Residue radiation on surface for MLF 400~500kW in Mar.~Jun. 2018.

ACS APERTURE REARRANGEMENT

It is notable that the residue radiation doses near (some of) ACS A-cavity and B-cavity are unsymmetrical.

IBSt in H- beam in ACS section was the dominant source of residue radiation. Stripping (mostly resulting in neutral H0) does not mean loss at once, but loss after meters. In J-PARC linac H0 loss peaks in about 20 m downstream. As a result, the loss distribution will be approximately uniform if the aperture is uniform and will be deformed by aperture irregularities.

For instance, for the original design, ACS section has almost uniform aperture of Φ 40 mm except for the Φ 37 mm current monitors (SCTs for beam current, FCTs for beam phase) at downstream of each B-cavity. Due to this "slight" difference local beam loss rate of H0 differs by two order of magnitude, as shown in Fig. 4. This is one of the main reasons for the unsymmetrical residue radiation of cavity A and B. At the beginning of ACS operation in 2014, this A-B un-symmetricity exists in all the 21 ACS tanks with completely the same pattern. The secondary reason for the non-symmetricity is that the ferrite CT part has higher residue than other circumstance such as duct made of titanium.

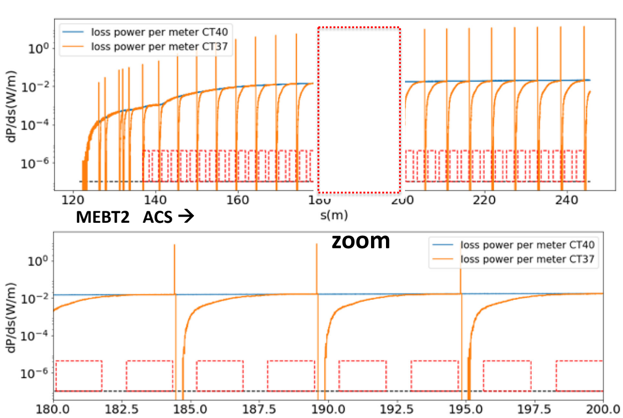

Figure 4: Simulated H0 loss-pattern in MEBT2-ACS.

Since 2015, bottleneck CTs were removed or replaced to Φ 40 mm aperture one by one, starting from the second half of ACS section. In summer shutdown 2018, all the remained narrow apertures were replaced (mainly in the first half). And the residue radiation was largely improved, as simulation prediction, as shown in Fig. 5, compared with Fig. 3.

The hottest spots were successfully removed by aperture rearrangement, but the total amount of the beam loss does not change in principle. This task is to be handed over to the next section.

Figure 5: ACS Residue Radiation on surface at 500kW, Nov.~Dec., 2018, after aperture rearrangement at ACS.

IBST MITIGATION BY LATTICE

The dominant source of beam is found to be IBSt in H- beam in ACS section, which is only affected by lattice setting. There are considerable flexibilities in J-PARC linac to set the operation point in the tune diagram (Hofmann chart), by setting strength of the quadrupole magnets and/or RF cavity amplitude-phase, as shown in Fig. 6. The theoretic and experiment study results of IBSt and stability dependency on lattice were summarized in [3]. It was concluded that compared with the baseline design with Tx/Tz=1.0, lattice with ACS set at Tx/Tz=0.7 could be a next candidate with 40% mitigation of IBSt loss rate and good stability (non-EP, but free from major resonances).

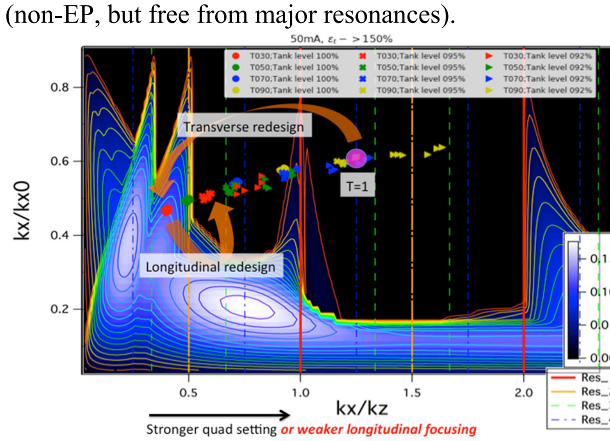

Figure 6: Stability chart for J-PARC ACS section operation tune setting.

In Oct. 2018 fully matched linac parameter with $Tx/Tz|_{ACS}$=0.7 was prepared and studied with RCS injection trail test. After verification again in study period in

March 2019, the $Tx/Tz|_{ACS}$=0.7 setting was applied in operation since April 2019. From Nov. 2018 to July 2019, the linac was operated with identical condition with peak current of 50 mA for 500kW MLF operation. The comparison of the residue radiation under two set of parameters is shown in Fig. 7. The measurement in the centre of the doublet quadrupoles is added in the figures, which is not influenced by the aperture rearrangement but now become the highest hot spots (max. ~2.4 mSv/h for T=1.0).

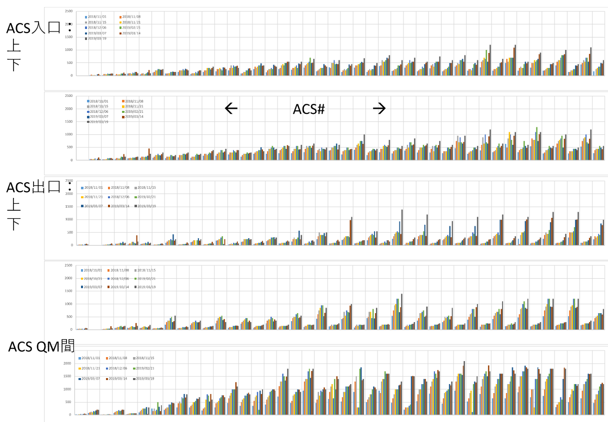

Figure 7a: ACS Residue Radiation on surface at 500kW, linac peak current 50mA in Nov. 2018 to March 2019 at ACS, with baseline design with Tx/Tz=1.0.

Figure 7b: ACS Residue Radiation on surface at 500kW, linac peak current 50mA in April and May 2019 at ACS, with IBSt-mitigation setting with with $Tx/Tz|_{ACS}$=0.7, with mitigated residue dose.

It is clearly shown that residue radiation dose was successfully mitigated after application of the new lattice, and consistent to the predicted 40% reduction.

According to the measured spots at the doublet centre, the max. dose reduced from about 2.4 to 1.6 mSv/h and averaged dose from 1.2 to 0.75 mSv/h.

The mitigation is in general successful and consistent, but there seem to be some zigzags after application of the new lattice. Next step will be investigation on long-term reproducibility of the non-EP lattices.

SUMMARY OF J-PARC LINAC POWER UPGRADE

The design operation power of J-PARC is 1 MW from RCS. Equivalent 1 MW was demonstrated in 2014, after the linac beam energy and current upgrades to 400MeV*50mA. Based on simulation and experiment studies and practical considerations, the next aim will be 1.2/1.5 MW, with either or both of current and pulse width (design: 500μs) upgrades to 60 mA and/or 600μs. The progresses of study activities are as follows,

- 181/190MeV → 400MeV: Jan., 2014 Operation/Study 15/30mA → 30/50mA: Oct. 2014
- ➔ 400MeV, 50mA: ready for 1MW from RCS (Demo:Dec.2014)

----------------- Design accomplished -----------------

- 40mA in Operation: Jan. 2016

Next step: 50→60mA or/and 500→600us: aim at 1.2/1.5MW@RCS

- 1st Trial of 60mA: Jul.5 2017: 68mA(IS) 62mA(MEBT1)
- 2nd Trial of 60mA: Dec.25,26 2017 60mA(DTL no accel.), 57mA(Li)
- 3rd Trial of 60mA: Jul.3, 2018 62mA(Li)
- 50mA in Operation: Oct. 2018
- 50mA, 600us injection to RCS: Oct. 19, 2018 (~1.2MW@RCS)
- 60mA (4th Trial), 500us injection to RCS: Dec. 26, 2018 (~equivalent 1.2MW@RCS)
- 60mA (5th Trial), 600us injection to RCS : Jul. 8, 2019 (~equivalent 1.5MW@RCS)

CONCLUSION AND DISCUSSIONS

J-PARC has successfully operated with 500kW at MLF, and residue radiation dose in linac, especially at 200~400MeV section, has manifested to be a potential problem for future power upgrade.

Aperture rearrangement at ACS section helped to remove the abnormal hot spots, and the final part of rearrangement work was completed in summer shutdown 2018.

A first IBSt loss mitigation lattice was prepared in Oct. 2018, and was applied in April 2019, based on simulation and experiment studies in recent years. The mitigation was successful and consistent with previous study results.

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