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60 mA BEAM STUDY IN J-PARC LINAC

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Abstract

Upgrade of Linac peak current from 50mA to 60mA is one of the keys to the next power upgrade in J-PARC. Beam studies with 60 mA were carried out in July and December 2017, for the challenging issues such as investigation of beam property from the ion source, halo behavior throughout the LEBT, RFQ and MEBT1, emittance/Twiss measurement at MEBT1, beam emittance control, etc. Expected/unexpected problems, intermediate results and preparation for the next trials were introduced in this paper.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton accelerator facility, which consists of a Linac, a 3 GeV synchrotron (rapid cycling synchrotron, RCS), and a main ring synchrotron (MR).

The J-PARC Linac [1] 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.

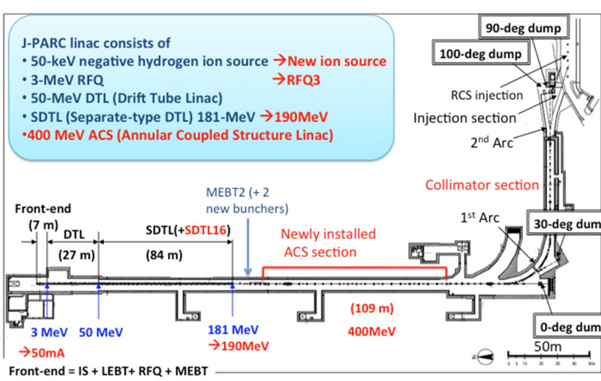

Figure 1: Layout of J-PARC Linac, before and after 2014.

From Oct. 2014, J-PARC Linac started operation at 30mA/400MeV. Maximum peak current of 50 mA became available for beam study, and 1 MW equivalent beam at RCS was demonstrated in Dec. 2014.

From Jan. 2016, J-PARC Linac started 40 mA operation, and ramp-up of the power in neutron target was scheduled toward the target limit.

Next steps will be equivalent 1.2/1.5 MW beam from RCS, which require Linac either/both of peak current upgrade from 50 to 60 mA, or/and extension of beam pulse from 500 to 600 μs.

First trial of 60 mA was conducted on Jul. 5 2017, and 68 mA of H^- beam from RF ion source and 62 mA at MEBT1 were achieved. Beam transverse property was studied with quadrupole-scan scheme.

Second trial of 60mA was on Dec. 25 - 26 2017. 60 mA beam passed (no acceleration in DTL) through DTL with roughly 100% transmission. 400 MeV 56 mA beam was obtained at the Linac exit.

Third trial is scheduled on Jul. 3 2018. And it is decided peak current of 50mA with be in operation from Oct. 2018.

PREPARATION FOR 60MA STUDY

At J-PARC ion source test-stand > 60 mA stable H^- beam were achieved and sudied [2]. A typical distribution for 66 mA is shown in Fig. 2, in which it is found that for present ~60 mA beam in J-PARC about 5% of beam could be identified as "halo". And for the 95% "core" of the beam rms emittance is about 30% higher than that of present 40mA beam in operation. This situation is so different from nomial 40 mA beam that we will confront a "new beam" for the 60 mA trial study.

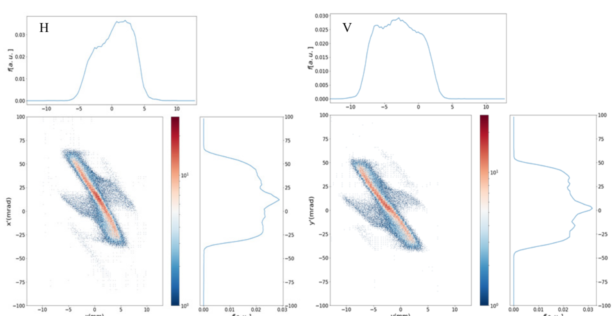

Figure 2: A typical distribution for 66 mA from ion source.

One of the most crutial problem expected is the DTL1 aperture. In the Tōhoku earthquake in 2011, DTL1 suffered deformation and the aperture were significantly reduced. For instance, if the emittance in MEBT1 of 60 mA beam is 30% higher than nominal level, the feasibilty of DTL transmission will need a critical decision.

RFQ simulation with the realistic distrubtion as shown in Fig. 2 was conducted, and the results were shown in Table 1. It is found that instead of emittance growth at the RFQ exit, the halo is scraped in the RFQ at the cost of transmission decrease for ~60 mA beam.

Another countermeasure is the increase of DTL quapoles (DTQ) strength, offering stronger focusing to control the transverse envelop in the DTL. By the way, in this case DTQ might need to be run in pulse mode to reduce the heat load.

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Table 1: RFQ Simulation Results Inputting of Measure Distribution at 66mA as Shown in Fig. 2.

			Norm. rms (mm*mrad)			Trace3d definition (mm*mrad/deg*keV)			Envelope (mm)	
	I(mA)	η	ε x	ε y	ε z	ε x	ε y	ε z	rx	ry
(For ref.)	*30.*	*0.95*	*0.26*	*0.26*	*0.32*	*20.68*	*20.92*	*583.35*	*2.16*	*1.23*
(For ref.)	*40.*	*0.94*	*0.24*	*0.24*	*0.33*	*19.07*	*19.04*	*600.90*	*2.15*	*1.21*
(For ref.)	*50.*	*0.93*	*0.22*	*0.23*	*0.34*	*17.81*	*18.02*	*624.95*	*2.12*	*1.20*
	60.	0.91	0.22	0.22	0.34	17.41	17.41	624.50	2.14	1.19
	70.	0.90	0.22	0.21	0.34	17.25	17.08	630.30	2.15	1.20

Five sets of lattices were prepared for the study, as shown in Fig. 3.

A. 40mA lattice for operation (as reference)
B. 50mA lattice for beam study (as reference)
C. 40mA lattice scaled for 65 mA, to keep the same envelop and same phase advance. About 5% increase of DTQ strength.
D. 40mA lattice scaled for 65 mA according to large emittance, with About 5% increase of DTQ strength.
E. Equipartitioning setting for 65 mA.

C and D need DTQ to run in pulse mode.

When DTQs run in pulse mode, noises will be generated in the nearby slow current transformer (SCT) used for particle counters for the personal protection system (PPS). It is necessary to correct sufficiently to keep the accelerator operating normally.

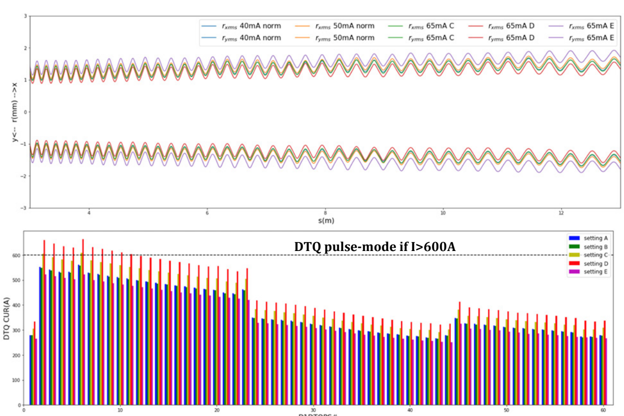

Figure 3: DTL lattice preparation, beam envelope (5*rms) and operational DTQ current.

INTERMEDIATE RESULTS

The first ~60 mA beam was obtained manually from 38 mA to 61 mA at MEBT1 entry. After fine scanning, 62 mA was achieved at MEBT1 as a J-PARC milestone in Jul. 5 2017.

Then the Q scan measurements, as sketched in Fig. 4, for both horizontal and vertical planes were conducted to obtain the emittance and Twiss parameters. For measurements like Q scan beam is stopped at the scraper to protect the downstream parts.

The Q scan results, as shown in Fig. 5 were to be used for evaluation feasibility of the DTL transmission and selection of lattice. Multi-particle simulation with IMPACT code [3] was applied to fit the Q scan results to find MEBT1 emittance initial Twiss parameters as shown in Fig. 6.

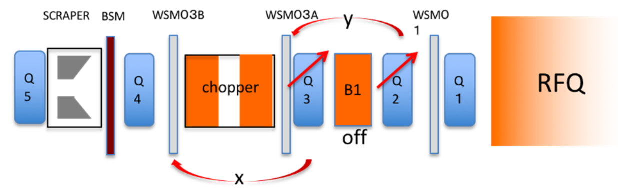

Figure 4: MEBT1 Q scan scheme for transverse measurement.

The Q scan results were consistent with simulation and close to measurements of 50 mA beam. So that both studies could continue with downstream of MEBT1.

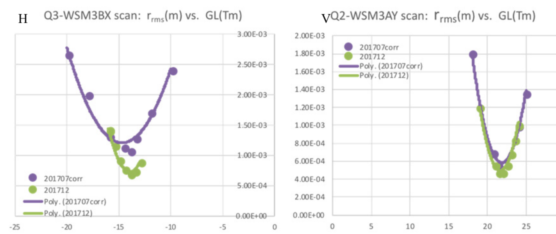

Figure 5: MEBT1 Q scan measurement results.

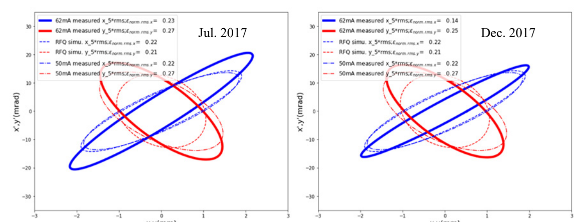

Figure 6: MEBT1 Q scan measurement analysis.

Many lessons were learnt in the first trial study. For safety reason, chopped beam with thinning was used in study, which brought difficulties to the beam monitoring. Moreover, beam chopping rate is dependent on orbit of chopper and scraper, which made much confusions. So it was concluded that unchopped beam will be used for MEBT1 orbit correction in the next study.

The candidate lattice D, with stronger transverse focusing to control envelope in DTL was chosen. And the DTQ pulse operation was successfully applied online for the first time in the study in Jul. 2018. Noises generate by DTQ pulse operation were compensated successfully, for which a few hours of beam time should be scheduled.

Based on the Twiss measurement at MEBT1 and many experiences in the first trial, 3 MeV 60 mA beam was obtained at DTL end, in second trial experiment in Dec. 2017, and 56 mA for the full-accelerated beam, as shown in Fig. 7.

The main beam loss happened in RFQ and MEBT1 scraper. Further analyses are shown in the next section.

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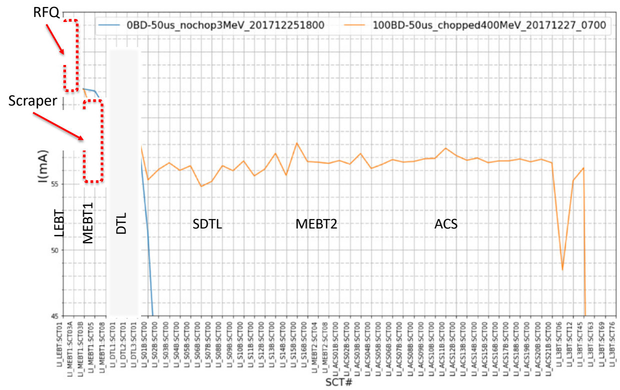

Figure 7: Transmission measured 60 mA trial in December 2018.

STRATEGY FOR NEXT TRIALS

Transmission problem is the homework left by the second trial study, which must be fully understood and solved.

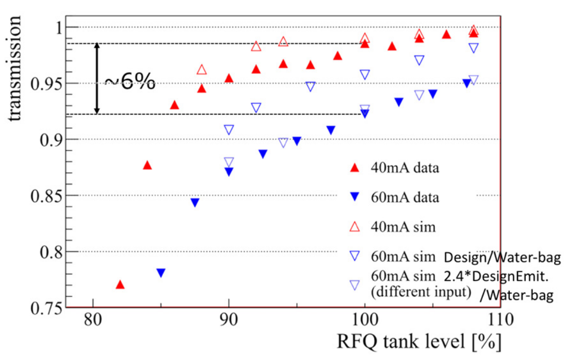

Figure 8: RFQ transmission measurement and simulation.

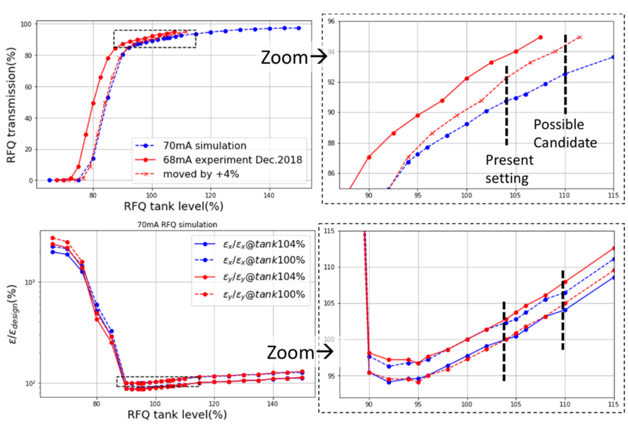

Figure 9: A more realistic RFQ simulation compared with measured transmission.

Measurements and simulation with design input emittance and Twiss with water-bag model for 40 and 60 mA were shown in Fig. 8. Measurements and simulation are quite consistent for 40 mA, but not for 60 mA. For "100%" tank level used in nominal operation, measured transmission for both current differed by 6%. It is implied that for 40 mA the real distribution from ion source is effectively the same as water-bag model assumed in design. Different behavior of 60 mA is attributed to halo, as shown in Fig. 2. Results from a more realistic simulation inputting this typical distribution is shown in Fig. 9.

Many features could be found in Fig. 9. Transmission curves have 4% gap between measurement and simulation, which could be identified as tank level calibration error. Actually the nominal "100%" tank level is 104% of design. RFQ tank level could be used as a knob for transmission according to the of the present situation of ~60 mA beam, although it is not a normal way. For example, 2% could be gained at the cost of 5% of transverse emittance growth according to 6% increase from present tank level. Of course, it is also clear that ion source should eventually reduce the halo to negligible level.

The other main source of beam loss is near the scraper, as shown in Fig. 10.

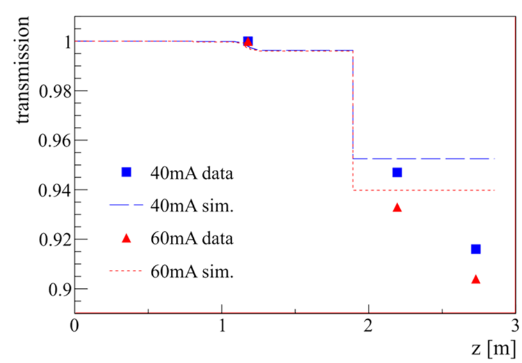

Figure 10: RFQ transmission measurement and simulation.

It is found that simulation and measurement have similar results for both currents. However, for 40 mA operation, chop-extinction has been put to a high priority and ion source output has enough margin, so that this drop is accepted.

The MEBT1 lattice is re-optimized adding condition of horizontal envelop at scraper, besides envelope at chop and bunchers. A trial optimized scheme is shown in Fig. 11.

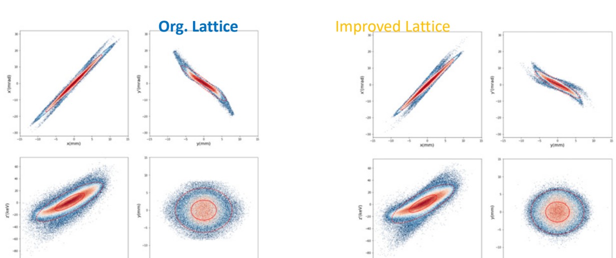

Figure 11: A trial optimization for horizontal envelop at scraper.

Base on these optimization, scraper position could be optimized, as shown in Fig. 12.

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It could be expected that the scraper position change from present 6.4 mm to 7.5 mm, the transmission will increase by about 2%. MEBT1 lattice optimization might also contribute a few percent to the transmission.

The total transmission will be improved by > 4%, i.e. from present 83% to 87%, with above practical countermeasures. It is proposed for the third trail study ion source will output 72 mA aiming at 62 mA in the Linac.

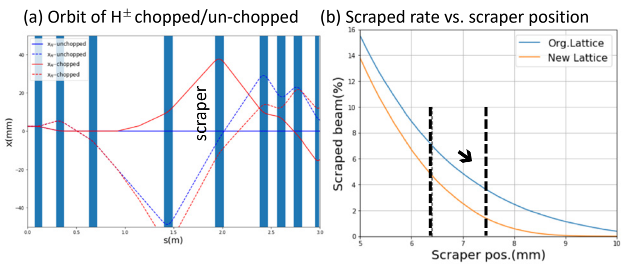

Figure 12: A trial optimization for horizontal envelop at scraper.

CONCLUSION AND OUTLOOK

J-PARC started to prepare for equivalent 1.2/1.5 MW beam from RCS. As a key of next power upgrade, 60 mA studies were conducted and two milestones were achieved. First 62 mA beam at MEBT1 and transverse measurement were obtained on Jul. 5 2017. First 56 mA beam at J-PARC Linac exit were obtained on Dec. 25~26 2017.

Third trial study of 60mA is planned on Jul. 3 2018.

Key points are transmission in RFQ and MEBT1 scraper. RFQ transmission is about 6% lower than that of nominal 40 mA because of halo from ion source. MEBT1 scraper transmission drop happened both for 40 mA and 60 mA.

Ion source should be eventually improved to minimize halo. However, for the present situation practical countermeasures, such as RFQ tank level, MEBT1 lattice re-optimization and scraper gap adjustment, are proposed to achieve ~60 mA now. All together > 4% increase of transmission is expected, and ion source will provide 72 mA aiming at ~62 mA in Linac.

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