COMMISSIONING PLAN FOR ENERGY UPGRADE OF J-PARC LINAC

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Abstract

The output energy of J-PARC linac is to be upgraded from present 181 MeV to 400 MeV in an extended summer shutdown in 2013. We review the planned beam commissioning schemes after the energy upgrade in this paper.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) linac presently consists of a 50-keV negative hydrogen ion source, 3-MeV RFQ (Radio Frequency Quadrupole linac), 50-MeV DTL (Drift Tube Linac), and 181-MeV SDTL [1]. The operating frequency for these accelerating cavities is 324 MHz. The linac output beam is delivered to a 3-GeV RCS (Rapid Cycling Synchrotron). The linac is operating with the peak current of 15 mA, the macro-pulse width of 0.5 ms, and the repetition rate of 25 Hz. After chopping at MEBT (Medium Energy Beam Transport) between RFQ and DTL, the average linac beam power is 18 kW sustaining 300-kW operation of RCS [2].

To achieve the design RCS beam power of 1 MW, we need to mitigate the space-charge effect in RCS by increasing the injection energy. To this end, we will upgrade the linac output energy to 400 MeV by adding ACS (Annular Coupled Structure linac) during an extended summer shutdown in 2013 [3]. ACS is a variety of a coupled-cavity linac, and its operating frequency is 972 MHz with threefold frequency jump from SDTL.

We also need to increase the linac peak current to 50 mA to realize the design beam power for RCS. We plan to have an front-end upgrade where we replace the ion source and RFQ to meet the requirement for the peak current [3]. While the front-end upgrade was also planned in summer 2013, it is presently under consideration to postpone it to summer 2014 [3]. While intensity upgrade also includes many important issues regarding beam commissioning, we here focus on the beam commissioning plan after the energy upgrade assuming postponement of the front-end upgrade.

SCHEDULE AND STAGING STRATEGY

The maximum available peak current with the present ion source is around 25 mA at the exit of the linac. We have experience in operating with this peak current for a short period of time for high beam-power trial operation. In the trial, we have confirmed that the beam loss is increased mostly in proportion to the peak current compared with the present nominal peak current of 15 mA [2]. It is consistent with our understanding that the present beam loss in linac is mainly caused by H^0 particles generated in residual gas scattering [4]. The loss rate from this mechanism is mostly determined by the vacuum pressure level on the beam line, the improvement of which is out of scope of this paper. The aim of the beam commissioning here is to suppress excess beam losses from insufficient operation parameter tuning, of which the effect is not clearly seen in the present 181-MeV operation. Another issue we should deal with is the beam loss at the RCS injection area. If we have wider transverse tail at the RCS injection, we need to adopt a larger charge-exchange foil. It results in an increase of the beam loss around the injection area due to enhanced foil scattering of circulating beams. Therefore, it is also important to mitigate the transverse tail width at the RCS injection.

A four-month summer shutdown is scheduled in 2013 from the beginning of August to the end of November to accommodate the linac energy upgrade. It will be followed by a one-month beam commissioning for linac scheduled in December. After beam commissioning of RCS for a few weeks, we plan to resume the user operation with the RCS beam power of 300 kW at the end of January 2014. Namely, we plan to resume the user operation with the same beam power from RCS as before the energy upgrade. An additional beam commissioning campaign of several days is planned in April 2014 to seek higher beam power by increasing the peak current to 25 mA.

Then, the linac beam commissioning is naturally divided into two stages. The first stage is that scheduled in December 2013, and the second in April 2014. The aim of the first stage is to provide a 400-MeV beam to RCS for its beam commissioning with the peak current of 15 mA. Also, the accompanying beam loss should be in a tolerable range for 300 kW user operation. The aim of the second stage is to establish operating parameters with higher peak current of 25 mA, with which we can suppress the beam loss to a tolerable level for user operation. With this peak current, we expect to reach 500 kW beam power from RCS.

THE FIRST STAGE: ESTABLISHMENT OF 400-MEV OPERATION

Establishment of 181-MeV Acceleration

In the first stage of the beam commissioning, we first try to establish 181-MeV acceleration. It is required to perform phase/amplitude scan tuning of all DTL and SDTL cavities to restore the 181-MeV acceleration [5, 6]. This tuning is necessary as the RF reference signal distribution system will be upgraded to accommodate ACS cavities. We don’t foresee particular difficulty in this part, as no significant change will be made for the system up to this energy.

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After establishing the 181-MeV operation, we check the performance of beam monitors in ACS section delivering the 181-MeV beam to the straight beam dump.

We add a number of beam monitors in ACS section at the upgrade [7]. Among them, we can confirm the proper functioning of beam position monitors and WS's (Wire Scanners) by examining the responses to a change in strength of a quadrupole or a steering magnet. We may repeat the procedure described in [2] for the check of BSM's (Bunch Shape Monitors). Then, we here discuss the check of FCT's (Fast Current Transformers) and BLM's (Beam Loss Monitors). Especially, FCT's deserve particular attention as we had some difficulty with them in the recommissioning after the earthquake [8].

We plan to check FCT's while delivering the 181 MeV beam to the straight beam dump. As the bunch structure of a beam is reasonably sustained for the ACS section, we can measure the beam energy with various FCT pairs in the ACS section with the TOF (Time-Of-Flight) method. The beam energy measured with FCT pairs should agree with each other in the expected accuracy for the TOF method with some reduction in the beam energy by exciting idle cavities. Conducting a consistency check among FCT pairs, we could identify malfunctioning FCT's if any, as we experienced after the earthquake [8].

As for BLM's, we plan to use the same BLM's as in the 181 MeV operation. Then, we have accumulated experience on the relation between the BLM signal level and the resulting residual radiation dose. However, this relation will not hold after the energy upgrade as the surrounding geometry for BLM's will be completely different after the upgrade. In other words, the BLM's is expected to be significantly less sensitive to the beam loss after the upgrade shielded by ACS cavities. To relate the BLM signal level after the energy upgrade with that before the upgrade, we plan to have a simple calibration experiment. In a preparatory experiment before the upgrade, we first insert the wire of the most upstream WS in the ACS section into the beam center, and record the BLM signal levels. Then, after the upgrade, we try to reproduce the experiment with 181-MeV acceleration. Comparing the signal levels in these two measurements, you can find a rough factor to calibrate for the change in geometry (See top figure of Fig. 1). To calibrate the sensitivity difference due to change in beam energy, we can conduct similar experiment after ACS exit (See bottom figure of Fig. 1). In that section, the geometry will not be changed at the upgrade. Then, you can deduce a calibration factor for energy difference by conducting a wire-inserting experiment with 400-MeV acceleration and compare the result with preparatory measurement before the upgrade. It should be noted that we adopt the same type of BLM for ACS and the beam transport line after the ACS exit.

Establishment of 400-MeV Acceleration

After confirming the proper functioning of FCT's, we move to the phase/amplitude scan tuning for ACS cavities. We plan to perform the tuning with the same method as our

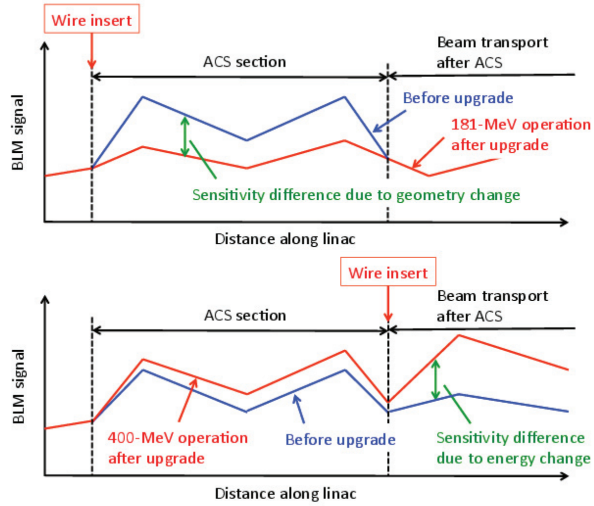

Figure 1: Schematic for the proposed BLM calibration for the effect of geometry difference (top) and energy difference (bottom).

SDTL cavities [6]. The ACS section consists of 21 ACS modules, each of which consists of two ACS cavities connected by a bridge coupler [9]. Then, the RF power for an ACS module is fed by a klystron. The phase/amplitude scan tuning will be done module by module from the most upstream one. In the tuning, the RF drive phase is scanned for 360 degree while monitoring the output beam energy from the module under tuning. The output beam energy is measured with an FCT pair by means of the TOF method. Therefore, the confirming of FCT functioning in the previous subsection is crucial for this tuning.

We measure the dependence of the output beam energy on the phase setting, or a so-called phase scan curve. By obtaining several phase scan curves with varied RF amplitude and comparing them with the one obtained with IMPACT [10] simulation, we find adequate RF amplitude and phase setting for an ACS module.

We also have two buncher modules between SDTL and ACS, and two debuncher modules after the ACS exit. We adopt the same tuning scheme for these cavities in this stage to set them to the design phase and amplitude setting.

Transverse and Longitudinal Matching

After establishing 400-MeV acceleration, we need additional tuning to suppress beam loss and improve beam quality. It includes orbit correction, chopper phase tuning, transverse and longitudinal matching, and so on. We here focus on the transverse and longitudinal matching at the SDTL-ACS transition, as other tunings will be done with the same scheme as in the present 181-MeV operation.

As we have a three-fold frequency jump at the SDTL-ACS transition, the proper matching there will be crucial to suppressing excess beam loss. We have two bunchers for the longitudinal matching between SDTL and ACS. There also are six quadrupole doublets, four of which are sup-

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posed to be used for the transverse matching. A way to conduct the matching is to treat the transverse and longitudinal matching separately and to iterate them until these matchings converge. The other way is to perform the transverse and longitudinal matching at the same time employing a six-parameter optimization. While we still need investigation on which method is more advantageous in our case, we here show the matching procedure in line with the former scheme. We expect that the former scheme could be advantageous with modest space charge effects as we can employ the same transverse matching scheme as in 181-MeV operation [11].

In the transverse matching, we use four WS's installed periodically at the entrance of ACS section. The strength of knob quadrupoles are adjusted so that the measured rms beam widths with the WS array become the same. We need three WS's for this tuning, and the remaining one is prepared for redundancy. We plan to adopt a similar scheme for the longitudinal direction using three BSM's installed periodically at the entrance of ACS section. The amplitude of two bunchers are adjusted so that the measured rms beam widths with the BSM array become the same.

THE SECOND STAGE: BEAM POWER RAMP UP

The aim of this stage is to establish 25-mA operation while accelerating to 400 MeV. We have demonstrated short-term operation with 25 mA with 181-MeV operation with the beam loss in the linac suppressed satisfactory [2]. We will try to confirm it with 400-MeV acceleration first.

If the beam loss rate in 400-MeV acceleration is more significant than expected, the matching between SDTL and ACS is most likely the cause of the excess beam loss. In that case, we should try to improve accuracy of the matching by identifying the cause of inaccuracy. Besides, it could also be a possible remedy to adopt a trial-and-error longitudinal matching. We successfully adopted a trial-and-error longitudinal matching to MEBT bunchers [12]. We suppose that it might be worth to try it for the SDTL-ACS matching in case the model-based matching there is not accurate enough due to some reasons.

If the beam loss increases in proportion to the peak current also in 400-MeV acceleration with respect to the 15 mA case, the beam loss mitigation by means of the operation parameter tuning is supposed to be sufficient. The next step would be to improve matching at every matching sections to reduce the tail width at the RCS injection. As discussed above, the tail width influences the beam loss around the injection region. It may be reasonable to start with or focus on the matching at MEBT and the SDTL-ACS transition as we expect the matching at these sections has particular difficulties.

Another possible issue is beam loss due to IBSt (Intra-Beam Stripping) [13]. This issue is specific to 400-MeV operation, where the beam density is significantly increased after the SDTL-ACS transition. While we expect modest IBSt beam loss with 25 mA, a careful optimization of lattice setting would be required to mitigate it with higher peak current [14].

SUMMARY

We will have an energy upgrade for J-PARC linac to increase its output energy from present 181 MeV to 400 MeV. The planned beam commissioning after the upgrade is reviewed in this paper. The upgrade is realized by adding ACS cavities with three-fold frequency jump from the existing SDTL. The beam commissioning after the energy upgrade is divided into two stages. One is a one-month beam commissioning campaign scheduled in December 2013, where we intend to establish 400-MeV operation without increasing the RCS beam power, The other is an additional campaign of several days scheduled in April 2014, where we seek higher RCS beam power by increasing the linac peak current from present 15 mA to around 25 mA. Thereby, we expect to reach 500 kW beam power from RCS. The design beam power of 1 MW from RCS will be achieved after the front-end upgrade, which we are considering to postpone to summer 2014.

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