RF AMPLITUDE AND PHASE TUNING OF J-PARC DTL

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Abstract

In the beam commissioning of J-PARC (Japan Proton Accelerator Research Complex) linac, the RF amplitude and phase tuning has been performed for its DTL (Drift Tube Linac). The tuning has been performed with a "phase-scan" method, monitoring the output beam energy from each DTL tank. Comparing the obtained phase dependence of the output beam energy with those from the modeling, we have tuned the RF phase and amplitude for DTL tanks mostly within the required tuning accuracy of 1 deg in phase and 1 % in amplitude, although further analysis is required to quantitatively evaluate the achieved tuning accuracy.

INTRODUCTION

The beam commissioning of J-PARC (Japan Proton Accelerator Research Complex) linac [1] has been performed since November 2006 and to be continued until the end of June 2007 [2, 3]. As a high intensity accelerator, it is crusial to mitigate the beam loss in the beam commissioning of J-PARC linac in order to avoid the excess machine activation. From this viewpoint, the RF set-point tuning is one of key commissioning items, where the optimum set-points of the phase and amplitude are determined for RF power sources. The beam loss due to longitudinal halo generation is expected to be minimized by finding the correct RF set-point. The RF set-point tuning of J-PARC DTL (Drift Tube Linac) has been performed in December 2006 following the beam commissioning of RFQ (Radio Frequency Quadrupole linac). In this paper, the detail of the DTL RF tuning is presented together with the associated preparatory procedures.

TUNING PROCEDURE

The planned tuning procedure has been described in the reference [4]. Then, we don't reiterate the detailed descriptions, but we just show its outline here. We have three DTL tanks (DTL1, DTL2, and DTL3 from the upstream side) in the DTL section, each of which is driven by a 3-MW klystron. Each DTL tank has an FCT (Fast Current Transformer) at its exit for the beam phase measurement, and the output energy from the tank is measured with the TOF (Time-Of-Flight) method utilizing two downstream FCT's. The RF set-point is tuned with a "phase-scan" method, where the klystron phase is scanned monitoring the output beam energy. The FCT layout for the DTL tuning is shown in Fig. 1. As the FCT pair for the TOF measurement has a downstream DTL tank (or three SDTL tanks for DTL3 tuning) in-between, the downstream tanks are turned off during the tuning so that we can avoid their influences on the TOF measurement. Phase-scan curves (which show the phase dependence of the output energy) are obtained for several tank amplitudes, and then compared to those from the modeling to determine the set-points of RF phase and amplitude. The optimum set-point is determined from the characteristic shapes of the phase-scan curves, such as a flat part or an intersection of two specific curves. We have used PARMILA [5] for modeling in the analysis. While we just need information on the beam centroid energy, it is essential to properly handle the phase slip effects in the modeling.

The tuning is performed with the peak current of 5 mA (30 mA in design), the pulse width of 20 μs (500 μs in design), and the repetition rate of 2.5 Hz (25 Hz in design). The tuning is performed with the RF feedback control, and the FCT signal is sampled nearly at the end of the macro-pulse where the feedback control is the most effective. We have tried a tuning with the increased pulse width of 50 μs also, but no noticeable difference is observed in the obtained phase-scan curves.

The tuning has been performed manually, and it takes about one hour for each DTL tank. The automated tuning is now under testing, extending the application software for the SDTL tuning [6].

MEBT BUNCHER TUNING

The 3-MeV beam accelerated with RFQ is injected into DTL after the longitudinal matching in MEBT (Medium Energy Beam Transport). In the longitudinal matching, the RF amplitudes of two buncher cavities in MEBT are set to the design values that are determined with Trace3D [7]. The RF amplitude is confirmed with a phase-scan tuning using the FCT's located in MEBT [8]. As the buncher cavity is a single-gap cavity, its phase-scan curve is to be a simple sinusoidal shape and its tank amplitude is easily obtained from a phase-scan curve.

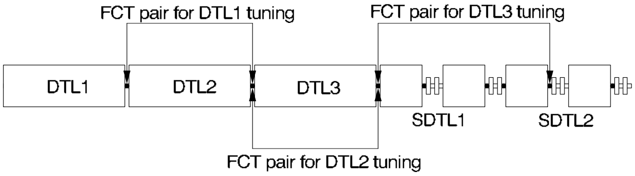

Figure 1: FCT layout for DTL tuning. A dot shows the location of an FCT.

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PRESET OF RF SET-POINTS

Before proceeding to the phase-scan tuning, it is required to establish sufficient beam transmission to an adequate beam dump or beam stop. We don't have a beam stop in the beam line after DTL so as to prevent excess residual radiation. Then, the lower energy beam (which is not accelerated with downstream tanks) is to be delivered to a beam dump located about 300 m downstream during the phase-scan tuning. As the phase-scan tuning is performed tank by tank from the upstream end, we need to deliver the lower energy beam of 19.7 MeV from DTL1 to begin with. When we injected the beam into DTL1 for the first time, we performed a coarse and swift phase scan with the tank amplitude preset through an RF measurement. As shown in Fig. 2, DTL1 has a wide phase acceptance when the tank amplitude is around or higher than the design value. In addition, the output beam energy is not so sensitive to the detailed tuning within the acceptance. Meanwhile, the beam is not accelerated properly at the outside of the phase acceptance, and the output energy from DTL1 is mostly at around 3 MeV. Then, such a low energy beam is easily lost due to transverse mismatch in the downstream DTL tanks without any practical harm. The coarse phase scan was performed to make a rough adjustment of the output beam energy with monitoring a downstream beam current monitor, and the beam transport was established in several minutes after we injected the beam into DTL1. After establishing the beam transport, we proceeded to the fine phase-scan tuning of DTL1.

While a similar procedure can be adopted for DTL2 and DTL3, it is less preferable because the higher beam energy might cause loss-related problems downstream. Therefore, a different approach is adopted to establish the beam transport for DTL2 and DTL3 tuning. As the inter-tank spacing for DTL tanks is set to be $1\beta\lambda$ with β being the beam velocity relative to the speed of light and λ the RF wavelength. Then, the RF field is supposed to have the same phase for all DTL tanks. Then, once the RF phase of DTL1 is set, the RF phase of DTL2 can be preset with the accuracy of a few deg by an RF measurement of the relative phase between DTL1 and DTL2. This procedure replaces the coarse phase scan in establishing the beam transport. An analogous procedure has been performed for DTL3 also.

TUNING RESULTS

The obtained phase-scan curves are shown in Figs. 3 to 5. The results for DTL1 and DTL2 show a tendency that the measured phase-scan curve deviates from the modeling with lower tank level, while they show a reasonable agreement in the vicinity of the design tank level. That for DTL3 shows a better agreement in wider range of the tank level. While we need further study on the discrepancy between the measurement and the modeling, we have concluded that the required accuracy (1 deg in phase and 1 % in amplitude) can be met with the current performance of the TOF measurement after the following changes of the analysis procedure.

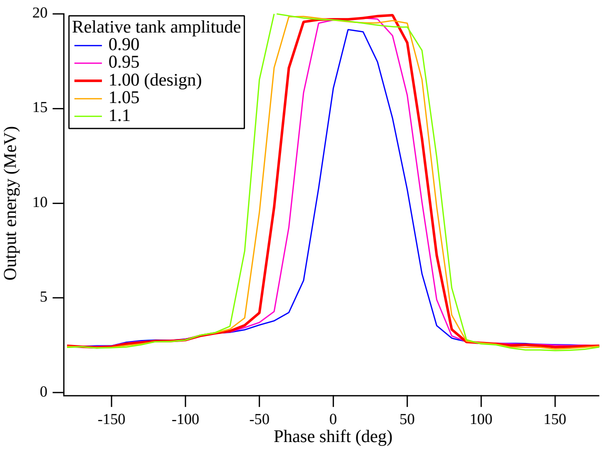

Figure 2: Phase acceptance of DTL1 (simulated).

We originally planned to use an intersection point of two phase-scan curves to determine the optimum phase [4]. However, it is found to be difficult to choose an adequate pair, because phase-scan curves tend to deviate from the modeling especially away from the design set-point. Then, we have determined the RF set-point so that we can reproduce the overall shapes of the simulated phase-scan curves instead of using the location of a specific intersection point. This tuning strategy is the so-called "phase-scan phase signature matching" [9], and the same scheme has been adopted in SNS [10, 11]. According to this change of analysis procedure, the scanning range of the phase is widened from that originally planned to enable the effective signature matching.

To put it concretely, we need to find a linear conversion factor between the amplitude set-value and the actual RF amplitude in a cavity, and an offset between the phase set-value and the actual RF phase felt by the beam. Then, these two parameters are adjusted in the data analysis to provide the best agreement between the measurement and the modeling. We also assume a small offset in the TOF measurement, which is typically less than 100 keV. Then, we are performing a three-parameter optimization in the data analysis assuming the linearity between the set-values and real-values. We also assume the correct injection energy to each DTL tank in the analysis. Only the injection energy to DTL1 is adjusted with the second buncher cavity in MEBT, because the phase-scan curve shows insufficient agreement with the modeling without the acceleration. It should be noted here that this acceleration is performed for the real beam, not just in the modeling. Then, in the tuning where Figs. 3 to 5 are obtained, the beam is accelerated by about 40 keV before injecting into DTL1. No correction has been performed for the injection energy into DTL2 and DTL3, because the output energy from DTL1 and DTL2 is not so sensitive to the RF tuning error.

As the shape of the phase-scan curve is sensitive to the

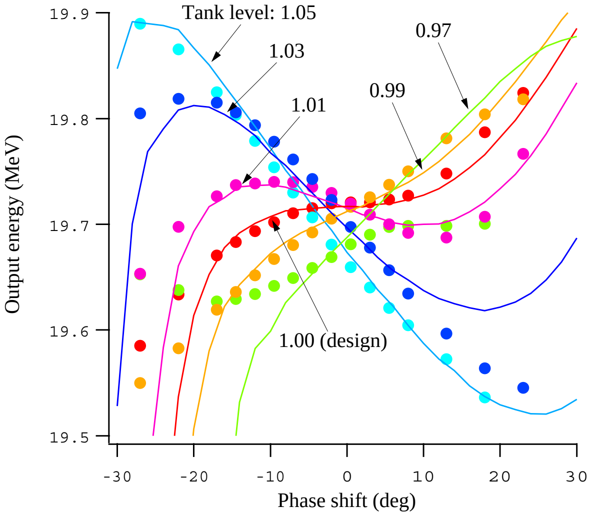

Figure 3: Phase-scan curves for DTL1. A filled circle shows a measured beam energy, and the solid line shows that from modeling. The RF amplitude for each phase-scan is also shown with relative to the design tank level.

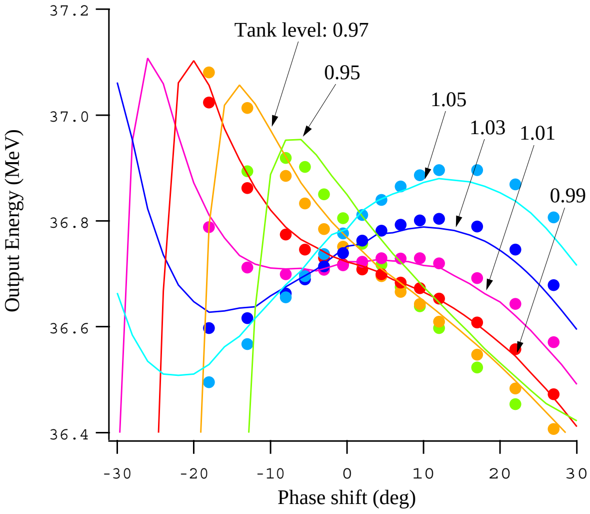

Figure 4: Phase-scan curves for DTL2.

RF amplitude, the requirement of the amplitude tuning can be satisfied more easily than that for the phase tuning. Although further effort is required to quantitatively evaluate the tuning accuracy, we have concluded that the requirement for the phase tuning is also roughly met because the phase shift of 1 deg causes a visible deterioration in the agreement between the measurement and the modeling.

SUMMARY

The beam commissioning of J-PARC linac has been started since November 2006. In the beam commissioning, the RF set-point tuning of DTL has been performed with a phase-scan method, where the output beam energy from the DTL tank is monitored with the TOF method using two downstream FCT's. The obtained phase-scan curves show a reasonable agreement with those from modeling in the vicinity of the design set-point. While further efforts are required to quantitatively evaluate the tuning accuracy, we have concluded that the required accuracy of 1 deg in phase and 1 % in amplitude has mostly been achieved in the tuning.

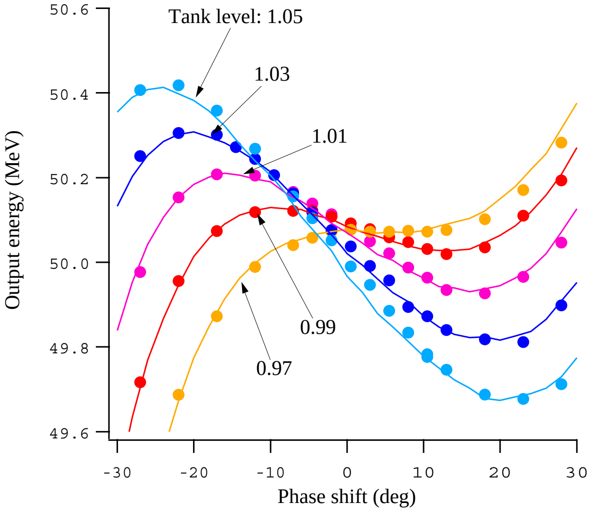

Figure 5: Phase-scan curves for DTL3.

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