RF TUNING SCHEMES FOR J-PARC DTL AND SDTL

Masanori Ikegami, KEK, Tsukuba, Ibaraki 305-0031, Japan
Yasuhiro Kondo, Akira Ueno, JAERI, Tokai, Ibaraki 319-1195, Japan

Abstract

In the beam commissioning of J-PARC linac, RF phase and amplitude of RF cavities will be tuned based on the beam-phase or beam-energy measurement. In this paper, planned beam-based tuning schemes for the DTL and SDTL are presented together with the beam diagnostic layout for the tuning.

INTRODUCTION

In high-current proton linacs, precise tuning of RF amplitude and phase is indispensable to reduce uncontrolled beam loss and beam-quality deterioration. Especially, accurate RF tuning is essential for J-PARC linac [1, 2], because requirement for the momentum spread is severe ($\pm 0.1\%$ at the ring injection including jitter) to realize effective injection to the succeeding RCS (Rapid Cycling Synchrotron). To meet the requirement, tuning goals for the RF phase and amplitude are, respectively, set to ± 1 degree and $\pm 1\%$. In the beam commissioning of the linac, RF phase and amplitude are tuned based on the beam-phase or beam-energy measurement.

In this paper, planned tuning schemes for the DTL and SDTL (Separate-type DTL) are presented together with the beam diagnostic layout for the tuning. We have three DTL tanks and 32 SDTL tanks, which constitute middle energy portion of J-PARC linac. Each DTL tank is driven by a 3-MW klystron, and two neighboring SDTL tanks are driven by a 3-MW klystron. Only the klystron phase and amplitude is tuned based on the beam measurement. The relative phase and amplitude between the SDTL pair are tuned with low- and high-level RF measurements, and its procedure is out of scope of this paper.

TUNING SCHEMES

In the tuning of RF phase and amplitude of an RF cavity, a phase-scan method has widely been adopted [3]. There are a variety of phase-scan methods with different monitor setup and different approach. In the tuning of J-PARC DTL and SDTL, we are considering the following three schemes;

- Scheme I: Tank phase and amplitude are scanned with measuring the beam phase just after the tank under tuning. The output beam phase is measured with an FCT (Fast Current Transformer). Only the relative variation of output beam phase is used to find adequate RF phase and amplitude.
- Scheme II: Tank phase and amplitude are scanned with measuring the beam energy after the tank under tuning. The output beam energy is measured with two FCT's based on the TOF (Time Of Flight) method. While the beam energy is measured, only the relative variation of the beam energy is used to find adequate RF phase and amplitude.
- Scheme III: The setting is essentially the same with Scheme II, but the knowledge of the absolute output energy is used to find adequate RF phase and amplitude.

The setups for these tuning schemes are schematically shown in Fig. 1. It should be noted that the two FCT's in Scheme II and III have more than one DTL or SDTL tank in-between in our linac layout, and these tanks are detuned to avoid interference to the TOF measurement. In Scheme I and II, the required scanning ranges are modest, namely, the phase and amplitude are scanned about ± 10 deg and $\pm 5\%$, respectively. Contrary, we need a wider phase-scan (360 deg is desirable) for Scheme III. It is obvious that Scheme I is the most preferable considering its simplicity and the absence of the possible influence of idle detuned cavities, and that Scheme III is the least preferable where absolute beam energy measurements are involved. However, the applicability of these schemes is deeply dependent on the cavity characteristics. Then, we have determined the tuning schemes for each tank evaluating the applicability with PARMILA[4] simulations.

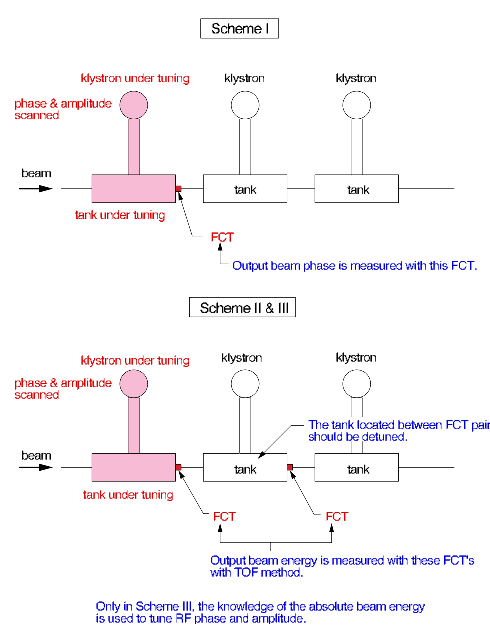

Figure 1: A schematic for RF tuning schemes.

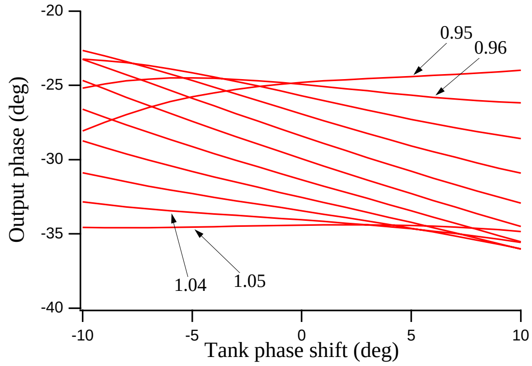

Figure 2: Simulated phase-scan curves for DTL1 (Scheme I). 11 phase-scan curves are shown for 11 different tank levels. For example, the phase-scan curve with 95 % of the design tank level is labeled as “0.95”.

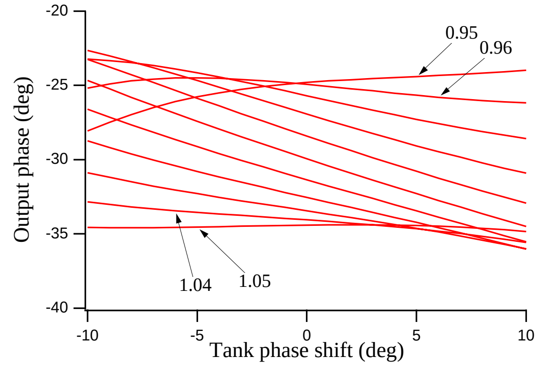

Figure 3: Simulated phase-scan curves for DTL1 (Scheme II).

DTL TUNING

DTL1 Tuning

We plan to adopt Scheme I for RF tuning of DTL1 (the 1st DTL tank). Figure 2 shows the phase-scan curves for DTL1 obtained with a PARMILA simulation. In Fig. 2, Scheme I is assumed, and 11 phase-scan curves are shown for 11 different tank-levels. The curve labeled with 0.95 shows the phase-scan curve with 95 % of the design tank level. In Fig. 2, it is readily seen that the phase-scan curve becomes flat (insensitive to the tank phase) in the right-hand side of the figure with the tank-level of 0.955, and in the left-hand side with the tank level of 1.045. Using these characteristic curves, the tank level will be calibrated. After the tank level is calibrated, the tank phase will be found using the crossing point of two phase-scan curves with different tank levels. In the RF phase calibration, two tank levels, with which phase-scan curves cross with a large crossing angle, should be selected to realize accurate phase calibration. To enable this tuning, the resolution of the phase measurement should be better than 1 deg.

DTL1 can also be tuned with Scheme II. Figure 3 shows the phase-scan curves for DTL1 with Scheme II. It is seen in this figure that the curve becomes flat with the design tank-level. We plan to adopt Scheme II as a back-up method, which needs the energy resolution of around 10 keV.

DTL2 and DTL3 Tuning

We plan to adopt Scheme II for RF tuning of DTL2 (the 2nd DTL tank) and DTL3 (the 3rd DTL tank). Figure 4 and 5, respectively, show the phase-scan curves for DTL2 and DTL3 obtained with PARMILA simulations. In these figures, Scheme II is assumed, and 11 phase-scan curves are shown for 11 different tank-levels. It is readily seen that the phase-scan curve becomes flat for DTL2 with the tank-level of 1.005. It becomes flat for DTL3 with the tank level of 0.97. Using these characteristic curves, the tank level will be calibrated. After the tank level is calibrated, the tank phase will be found using the crossing point of two phase-scan curves with different tank levels. To enable these tuning, the energy resolution of around 10-20 keV is required.

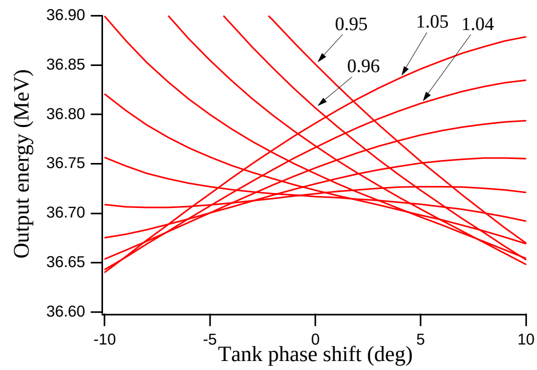

Figure 4: Simulated phase-scan curves for DTL2 (Scheme II).

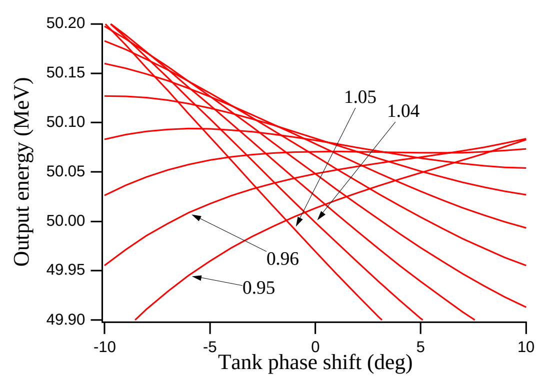

Figure 5: Simulated phase-scan curves for DTL3 (Scheme II).

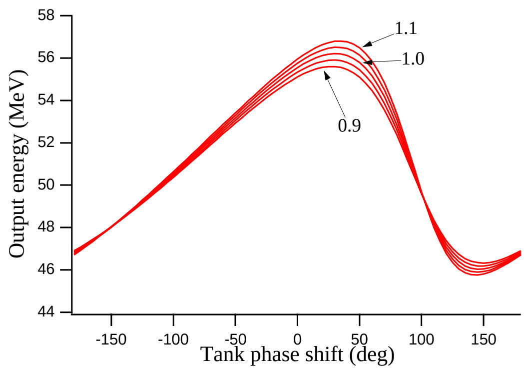

Figure 6: Simulated phase-scan curves for SDTL1-2 (Scheme III).

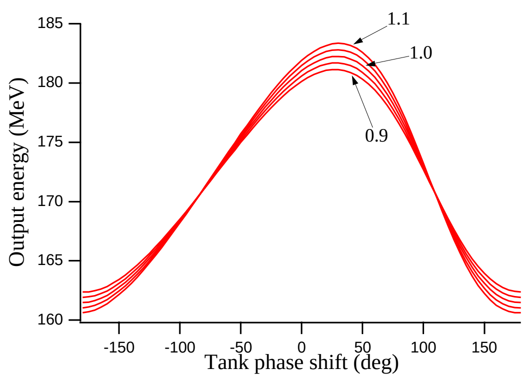

Figure 7: Simulated phase-scan curves for SDTL29-30 (Scheme III).

SDTL TUNING

As seen in the previous section, a flat part and a crossing point of phase-scan curves are required to be in the vicinity of the operation point to utilize Scheme I or II. However, the phase-scan curves for SDTL tanks are more-like a sinusoid, and they do not have a flat part and a crossing point with large crossing angle. Then, we have decided to adopt Scheme III for RF tuning of SDTL tanks. Figure 6 and 7, respectively, show the phase-scan curves for SDTL1-2 (the 1st SDTL module) and SDTL29-30 (the last SDTL module in 181-MeV operation [1]) obtained with a PARMILA simulation. In Scheme III, the phase is scanned in wider range (360 deg), and the RF amplitude will be obtained by measuring the maximum and minimum energy gain. After the RF amplitude is adjusted, the RF phase is set to give the design energy gain. To enable these tuning, the accuracy of the beam energy measurement should be better than $\pm 0.1\%$.

FCT LAYOUT

To enable RF tuning described in the previous two sections, we plan to install 45 FCT's in DTL and SDTL sections. The layout of FCT's is schematically shown in Fig. 8. In SDTL section, the TOF measurement will be performed with three idle SDTL tanks in-between to achieve required accuracy. To attain the accuracy of the TOF measurements, we plan to measure the distance between FCT's with a laser tracker with the accuracy of 0.2 mm. FCT pairs with shorter drift length are also prepared for rough TOF measurement. Utilization of these FCT pairs is discussed in a separate paper [5].

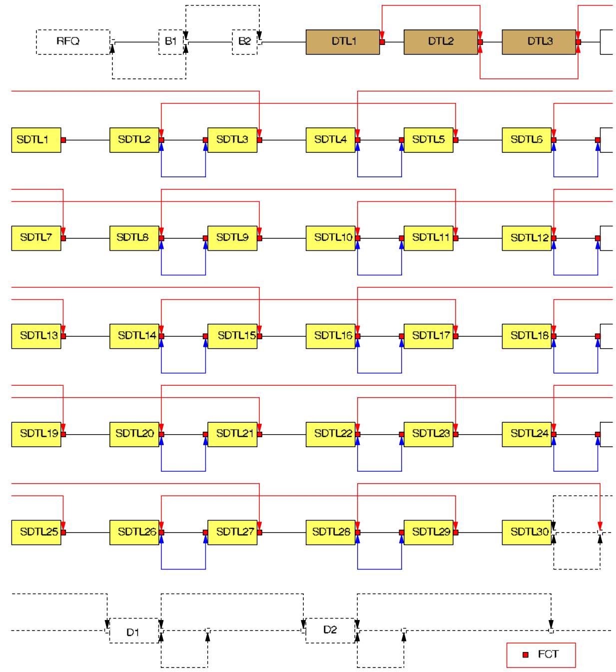

Figure 8: FCT layout in DTL and SDTL sections. Small red rectangles show FCT locations. Red arrows indicate FCT pairs for precise TOF measurement, and blue ones for rough TOF measurement.

SUMMARY

The beam-based RF tuning schemes for J-PARC DTL and SDTL are determined with PARMILA simulation. Basically, we adopt phase-scan schemes, but we use three different approaches to fit tank characteristics. FCT layout is determined to realize the tuning.

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