TUNING OF RF AMPLITUDE AND PHASE OF J-PARC DTL AND SDTL

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Abstract

An accurate tuning has been performed for the RF amplitude and phase of J-PARC (Japan Proton Accelerator Research Complex) LINAC during the beam commissioning. The tuning has been performed using a phase-scan method for all RF cavities, including buncher, debuncher, DTL (Drift Tube LINAC), and SDTL (Separated-type DTL). An adequate set-point is determined with satisfied accuracy, which is within 1º for phase and 1% for amplitude, by matching measured absolute beam energy with those from a modeling. This paper presents detail procedures of RF tuning.

INTRODUCTION

J-PARC is a high intensity proton accelerator, and consists of a LINAC, a RCS ring, and a MR ring. The beam is accelerated from 3-MeV to 181-MeV using 3 DTL cavities and 15 SDTL stations in the J-PARC LINAC. Each DTL cavity is driven by a klystron power source. For SDTL, one klystron drives one station, which includes 2 RF cavities.

Before injecting the 3-MeV beam to the DTL, a longitudinal matching is performed with 2 bunchers in MEBT (Medium Energy Beam Transport) section, which is a beam transport line between RFQ and DTL. To satisfy the requirement of RCS ring injection, 2 debunchers are using after the exit of SDTL section.

The beam commissioning of J-PARC LINAC has been started from November 2006. A coarse tuning had been performed for the RF power sources manually [1, 2]. To quantitatively evaluate the achieved accuracy of RF tuning, and reduce the tuning time and man-power, an automated application was developed using a XAL [3, 4] framework.

During the beam study of April 2007, the SDTL were tuned using this application [5] successfully. After that, it was expanded for all other cavities. In June 2007, the last beam study before the summer shut-down, an accurate tuning was performed for all RF cavities, and a quantitative result was evaluated using the application.

A phase-scan method is adopted to tune the RF phase and amplitude. To find a proper set-point, the phase is varied over ±30º for DTL, and 360º for other cavities, and the amplitude is adjusted over ±4% around normalized amplitude. The output beam energy is measured using a TOF (Time-Of-Flight) method at exit of cavity under tuning. The time of flight of beam is measured with the aid of FCT (Fast Current Transformer) pair.

The tuning accuracy is required within 1º for phase and 1% for amplitude. To achieve the tuning goal, a signature matching method is proposed and implemented, which compares measured beam energy with those from a modeling. The set-point is determined from the best matching between the measurement and the modeling.

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TUNING PROCEDURE

A principle scheme for the RF tuning has been described in the reference [6]. Here an outline procedure is described. During tuning a cavity, the beam phase is measured using the FCT, which is located at the exit of the cavity. The RF set-point is tuned with the phase-scan method, where the klystron phase is scanned by monitoring the output beam energy. The output energy from the cavity is measured utilizing downstream FCT pair(s) with the TOF method.

A detail procedure has been presented in the reference [5] for data acquisition, absolute beam energy measurement, and analysis and quantitative evaluation for the SDTL using the automated application. For the other cavities including buncher, debuncher, and DTL, the procedure is almost same except the analysis part. According the characteristic of different cavity, that part is extended and improved.

Amplitude Set-point

The set-point of RF amplitude is determined by comparing the measured energy curve and those from modeling simulation.

The modeling data is generated at the normalized amplitude using the PARMILA [7] software in advance, and saved in a XML file. The fitting is performed in the application using Equation 1.a ~ 1.c for the modeling data of buncher/debuncher, DTL, or SDTL respectively.

$$f_0(x) = a_0 + a_1 \cdot \cos(x+\theta) \tag{1.a}$$

$$f_0(x) = a_0 + \sum_{i=1}^{12} a_i \cdot x^i \tag{1.b}$$

$$f_0(x) = a_0 + \sum_{i=1}^{5} a_i \cdot \cos(i\cdot(x+\theta)) + \sum_{i=1}^{5} b_i \cdot \sin(i\cdot(x+\theta)) \tag{1.c}$$

The klystron phase is adjusted over ±30º for DTL, and 360º for other cavities for each setting of tank amplitude. The output beam energy is measured at the exit of cavity. The obtained curve is called a phase-scan curve.

The phase-scan curves are obtained for several cavity amplitudes. All phase-scan curves are shifted using Equation 2 to find a best matching with between the shapes of scan curve the modeling curve.

$$f(x) = f_0(x+\varphi_0) + c_0 \tag{2}$$

Here, $f_0(x)$ is the fitting function in Equation 1. A matching error χ^2 is calculated using Equation 3.

$$\chi^2 = \sum_{i=1}^{m} (f_i - W_i)^2 \Big/ m \qquad (3)$$

Here f_i is calculated using Equation 2 at each scanned phase, W_i is measured beam energy at that phase setting. The χ^2 is normalized by the scanned phase number (m).

Fig. 1 demonstrates a result to search the amplitude set-point for SDTL01. Phase-scan curves are obtained for 5 amplitude settings. All are matched with the curve from the PARMILA modeling at normalized amplitude. The matching error is fitted as a 2-order polynomial function of klystron amplitude. The optimum amplitude set-point is determined from the minimum position.

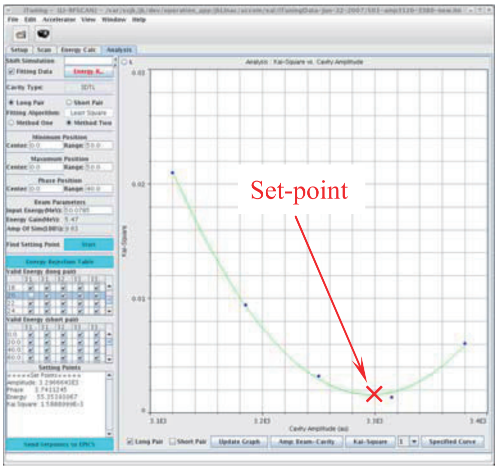

Figure 1: Signature Matching Error of SDTL01.

Phase Set-point

In principle, the phase can be determined at the same time during searching the amplitude set-point. To satisfy the tuning accuracy, a re-scan is performed after getting the amplitude setting value.

The procedure is same with that to search the amplitude set-point. The difference is that only one phase-scan curve is necessary. The set-point of phase is got from the phase shift value, φ_0 in Equation 2. The re-scan results are shown from Fig. 2 to Fig. 4, for buncher1, DTL3, and SDTL15 respectively.

RESULT AND DISCUSSION

Tuning Result

With above procedure, an excellent matching between measurement and modeling are obtained for all SDTL, buncher/debuncher, DTL2 and DTL3. The RF set-point is tuned with an accuracy of 1% for amplitude and 1° for phase.

One exception is for phase tuning of DTL1. The agreement is not perfect between the measurement and the modeling. The tuning goal for phase is not satisfied with the automated application. A future simulation is performed for all scanned amplitudes. Fig. 5 shows 7 curves are generated from modeling corresponding to 7 scanned amplitudes. It illustrates that the region is very narrow to get a good agreement between measurement and modeling.

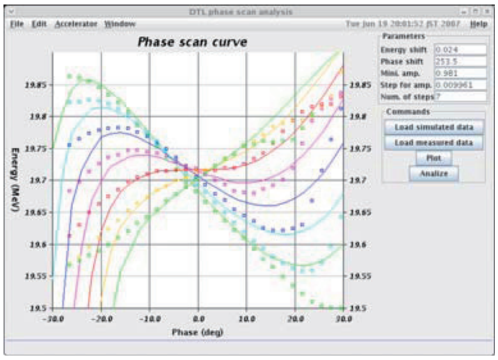

Figure 5: Comparing the measured curve with those from PARMILA modeling for DTL1. The marker is measurement, and the line is data from modeling shifted manually.

One reason caused the mismatch between measurement and modeling may be that the input energy of DTL1 is low, about 3-MeV. With the low input energy, there may be some beam loss inside the DTL1 cavity and not all particles are accelerated. It is necessary to study the detail accelerating procedure of DTL1 with other modeling software. Another possibility is that it may caused by the algorithm. A future study is necessary for DTL1 to improve the evaluation algorithm.

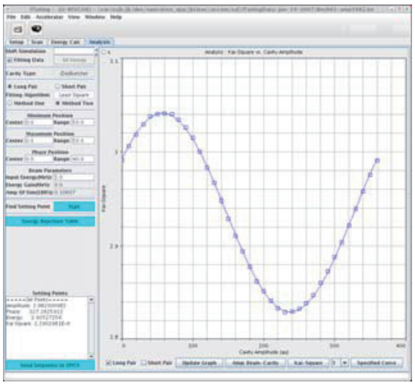

Figure 2: Re-Scan of Buncher1.

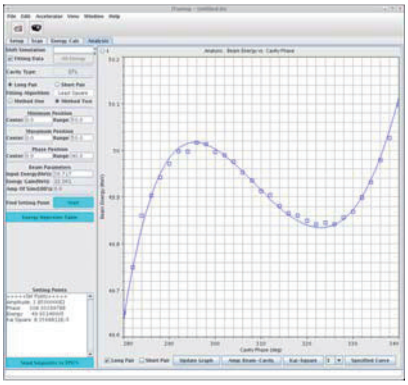

Figure 3: Re-Scan of DTL3.

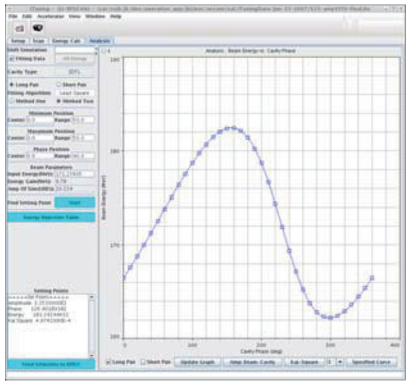

Figure 4: Re-Scan of SDTL15.

(The marker is measured beam energy, and the line is data from modeling shifted using Equation 2.)

To tune the phase of DTL1 with satisfied accuracy, an assisted application is utilized as Fig. 5 illustrated. The phase-scan curves are obtained utilizing the automated application, and loaded into the assisted application via an intermediate file. By comparing the shapes of phase-scan curves and those from modeling manually, the phase is tuned within the accuracy of 1º.

Beam Profile

After getting the set-point of RF amplitude and phase, an expected acceleration is obtained at each cavity. The beam energy profile is demonstrated as Fig. 6. The line is design beam energy at each exit of cavity. The circular marker is a measured result during the beam study of April, and the triangle marker is a measured result during the study of June. The final output energy is achieved at 181-MeV.

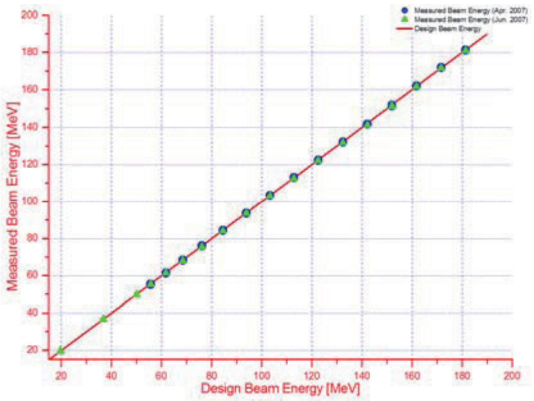

Figure 6: Energy Profile in J-PARC LINAC.

It shows that the agreement between design and measurement is excellent. It also shows the result is reproduced during June, and there is a good reproducibility.

Fig. 7 is the energy deviation of measured beam energy from design during 2 terms of beam study. A maximum deviation is observed at exit of DTL2, which is about 0.54%.

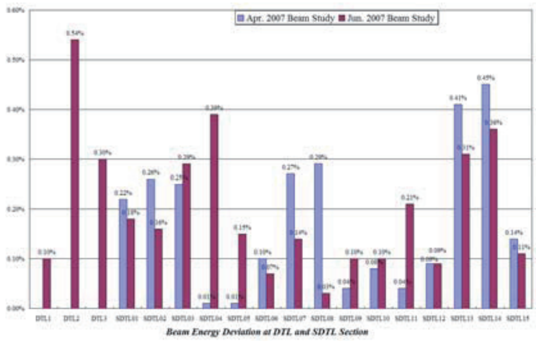

Figure 7: Energy Deviation in DTL and SDTL Section.

SUMMARY

An accurate tuning for RF amplitude and phase has been performed for all RF cavities using the phase-scan method. All set-points have been determined using the signature matching method. The tuning goal has been achieved within the accuracy of 1º for phase and 1% for amplitude. A future research is necessary to improve the evaluation for DTL1.

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