AN ALTERNATIVE SCHEME FOR J-PARC SDTL TUNING

Masanori Ikegami , KEK, Tsukuba, Ibaraki 305-0801, Japan
Yasuhiro Kondo, Akira Ueno, JAERI, Tokai, Ibaraki 319-1195, Japan

Abstract

In the beam commissioning of J-PARC linac, we plan to perform phase-scan with precise TOF (Time Of Flight) beam-energy measurement to tune RF phase and amplitude of SDTL tanks. As a back-up method, we are considering to prepare a simpler RF tuning scheme with rough TOF measurement for SDTL which does not involve TOF measurements with idle SDTL tanks in-between. In this paper, the principle of this scheme is presented, and its advantages and disadvantages are discussed based on a systematic particle simulation.

INTRODUCTION

In the beam commissioning of J-PARC linac [1, 2], RF phase and amplitude are tuned based on the beam phase or beam energy measurement. As presented in a separate paper [3], we plan to perform phase-scan with precise TOF (Time Of Flight) beam-energy measurements in RF tuning of SDTL (Separate-type DTL) tanks. However, that scheme is presupposing an accurate TOF measurement of absolute beam energy having idle detuned cavities between beam phase monitors, which may involve technical difficulty. Then, we are considering to prepare an RF tuning scheme with rough TOF measurement as a back-up method for SDTL tuning. In this paper, the principle of this scheme is presented, and its advantages and disadvantages are discussed based on a systematic particle simulation.

ALTERNATIVE TUNING SCHEME

We have 30 SDTL tanks in SDTL section in 181-MeV operation [1], and the neighboring two SDTL tanks are driven by a 3-MW klystron. The beam energy measurement in SDTL section is performed based on the TOF (Time Of Flight) method utilizing two FCT's (Fast Current Transformers). Figure 1 schematically shows the FCT layout in SDTL section. Precise beam energy measurement is performed with a FCT pair which has three idle detuned SDTL tanks in-between. Although the accuracy of precise measurement is expected to reach 0.05 %, the measurement cannot be performed while nominal beam operation. For the beam energy measurement while nominal beam operation, additional FCT pairs with shorter drift length are prepared, to which we refer as "rough TOF pairs".

With these FCT pairs, we are able to perform rough TOF measurement of the beam energy without interfering with beam operation. The drift length in a rough TOF pair is around $2\beta\lambda$ with β and λ being the beam velocity scaled by the speed of light and the RF wave length, respectively. The accuracy of the beam energy measurement is limited to be around 0.5 % because of its short drift length. While the measurement accuracy is limited, it is advantageous that the measurement can be performed while nominal beam operation without possible influence of idle detuned cavities. We are considering two roles for the rough TOF pairs. One is the continuous watching of RF tuning to detect long-term drift or sway of RF properties. The other is the utilization for initial RF tuning of SDTL modules. The sensitivity of the former utilization is closely related to the achieved tuning accuracy of the latter. In this paper, we seek the possibility of using these pairs for initial RF tuning of SDTL tanks. It will also provide us information on the sensitivity for the watching of the long-term RF stability.

The accuracy of beam energy measurement is insufficient for precisely determining the RF phase and amplitude of an individual RF module. Our strategy for the RF tuning is to avoid undesirable build-up of the effect of errors, tolerating large phase and amplitude errors for individual RF modules. The rough TOF pairs are located after every SDTL module, and, hence, the output energy of every SDTL module can be monitored. In this tuning scheme, we first perform rough preset of the RF phase and amplitude of SDTL modules with, for example, low- and high-power RF

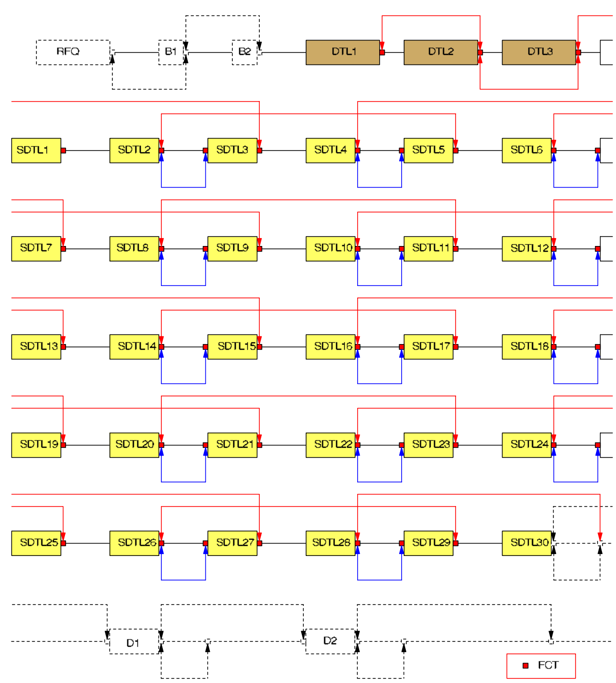

Figure 1: Schematic layout of FCT's in SDTL section (181-MeV operation). A red arrow indicates a FCT pair for presice TOF measurement, and a blue arrow rough TOF measurement.

measurements, and then we fine-tune the RF phase and amplitude to make the beam-energy deviation from its design value lower than the detectable limit at all the 15 measurement points. The RF phase and amplitude of individual SDTL module are assumed to be preset with the accuracy of around 5 deg and 5 %, respectively. In this paper, we examine the feasibility of this approach with a systematic PARMILA[4] simulation.

SIMULATION CONDITIONS

In this paper, simulations are performed with PARMILA from the exit of RFQ to the injection point to RCS for the 181-MeV case [1]. In the simulations, we assume the peak current of 30 mA, which is the design value for 181-MeV operation. The initial distribution at the exit of RFQ is obtained with PARMTEQM[5]. The number of simulation particles is 95,322 and the number of meshes is set to 20x20x40 (XxYxZ) for 3D cases and 20x40 (RxZ) for 2D cases. The quadrupole magnets in DTL and SDTL sections are set to satisfy the equipartition condition. No error has been assumed except for the RF phase and amplitude of DTL and SDTL. We assume the RF phase and amplitude of DTL tanks are set with the accuracy of 1 deg and 1%. We also assume the RF phase and amplitude of SDTL modules are preset with the accuracy of 5 deg and 5 %. The RF phase and amplitude errors are assumed to be uniform-randomly distributed in the above-mentioned range.

SIMULATION RESULTS

At first, we tried 400 cases with different random seeds with 2D space-charge option. Figure 2 shows the longitudinal rms emittance at the SDTL exit obtained in the simulation. The horizontal axis is the maximum of the output energy deviations observed at the 15 measurement points, to which we refer as “the maximum enery deviation”. It is seen in Fig. 2 that there is clear dependence of the longitudinal emittance on the maximum energy deviation, which suggests that the excess longitudinal emittance growth can be avoided by eliminating large energy deviation.

Here, we assume that we can avoid the case if the enegy deviation at the measurement points exceeds 0.5 %. The energy deviation after each SDTL module is checked for each case, and we find 42 cases in the above 400 cases which pass the test. For the selected 42 cases, we perform 3D PARMILA simulations to see the beam quality at the RCS injection in more detail. Figure 3 shows 99.9 % energy spread at the RCS injection. The requirement for the momentum spread at RCS injection is $\pm 0.1\%$ including jitter, which corresponds to ± 0.333 MeV in energy spread. The energy spread is increased by around 50 % compared to the cases with the reference tuning scheme in which each klystron is tuned with the accuracy of 1 deg and 1 % [3, 6]. However, we have confirmed that the contribution of RF setpoint errors on the final energy spread is rather small compared to that of RF dynamic errors [6]. Then, there

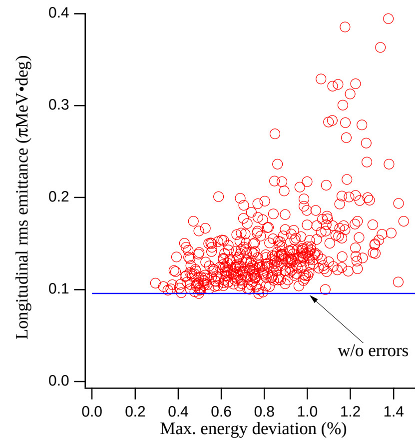

Figure 2: Longitudinal rms emittance at SDTL exit vs maximum energy deviation at 15 measurement points (2D case).

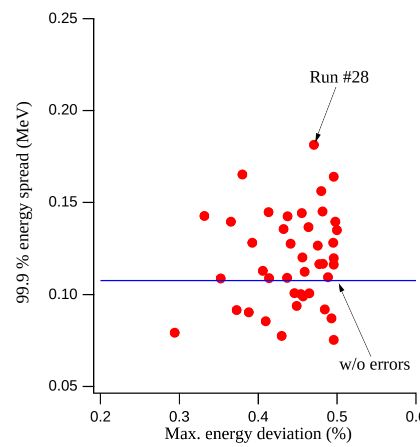

Figure 3: 99.9 % energy spread (half width) at RCS injection vs maximum energy deviation (3D case).

is a reasonable possibility to meet the requirement for the energy spread with the rough TOF-based tuning.

Figure 4 shows the 99.5 % transverse emittance at the RCS injection, in which considerable emittance growth is observed. We also have a requirement for the transvese emittance at the RCS injection (4πmm·mrad in normalized), and we have a halo collimator section in the beam transport line to meet the requirement. An excess emittance growth results in an increase of the collimator load, i.e., the fraction of a beam which must be removed at the halo collimator. Figure 5 shows the collimator load in these cases. While the collimator load nearly reaches 5 % in some cases, it is still tolerable in the 181-MeV operation. However, to be compatible with 400-MeV operation, the collimator load should be reduced to less than $\sim$ 1.5 % level, which means we need to improve the accuracy of rough TOF measurements to 0.3-0.35 %.

Figures 6 and 7 show the phase-space distributions obtained for the cases with the largest energy spread and

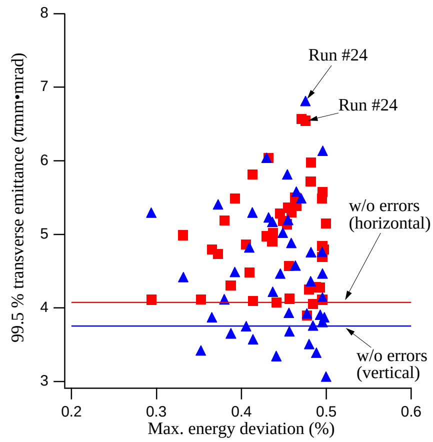

Figure 4: 99.5 % transverse emittance at RCS injection vs maximum energy deviation (3D case). Red squares show the horizontal emittance, and blue triangles the vertical.

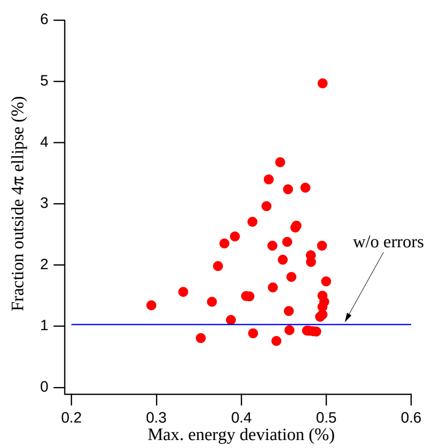

Figure 5: Halo collimator load vs maximum energy deviation (3D case).

largest vertical emittance, respectively. Figure 6 shows complicated filamentation due to combined effects of RF errors and the debunching effects, and clear halo development is seen in Fig. 7.

DISCUSSIONS

An alternative scheme for the SDTL RF tuning is proposed in this paper. Our basic strategy is to avoid undesirable build-up of the effect of errors, by eliminating the combinations of errors whose energy deviation can be detected with an array of rough TOF pairs. The proposed scheme is based on a statistical approach. Therefore, it is difficult to completely eliminate the possiblity that the undesirable effects of RF errors, which are undetectable with the rough TOF pairs, cause intolerable beam-quality deterioration. However, the simulation results suggest that these possiblities can be reduced by improving the accuracy of TOF measurements, and there is a reasonable possibility

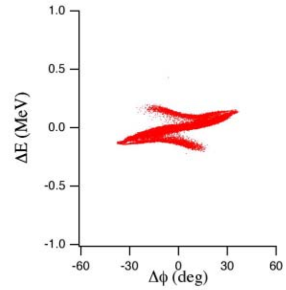

Figure 6: The longitudinal phase-space distribution at RCS injection for the case with the largest energy spread (Run #28).

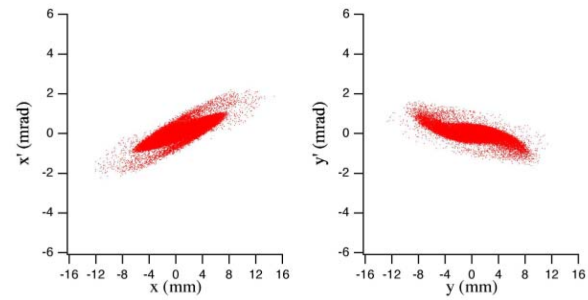

Figure 7: The transverse phase-space distribution at RCS injection for the case with the largest vertical emittance (Run #24).

that our requirement for 181-MeV operation can be met with the accuracy of 0.5 %. Based on these findings, we have concluded that it is worth while preparing the rough TOF pairs, while we need to continue the effort to improve the accuracy of rough TOF measurement. We plan to use the rough TOF pairs as both a long-term monitor of RF tuning and a back-up scheme for the initial RF tuning. We expect that it also enables swift RF retuning of SDTL modules with minimum interference with beam operation.

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