COMPARING RF-CAVITY PHASE-SCAN SIMULATIONS IN THE ESS LINAC SIMULATOR WITH MEASUREMENTS TAKEN IN THE SPALLATION NEUTRON SOURCE COUPLED-CAVITY LINAC

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Abstract

The ESS Linac Simulator (ELS) is the model that will be used at the European Spallation Source ERIC in Lund, Sweden, to simulate the transport of the beam envelope for the operations. During the machine restart in August 2015 at the Spallation Neutron Source (SNS) in Oak Ridge, USA, we were able to perform the first benchmarking studies of the ELS. In this paper, we present the results of the phase-scans performed in four RF cavities of the coupled-cavity linac at SNS compared with the same scans simulated in the ELS. The phase of the cavity was modified while the phase of the beam was recorded in two BPMs downstream from the cavity. This measurement was repeated for four independent cavities and the results are compared here with the model, which favourably reproduces the BPM response to the cavity scans.

INTRODUCTION

The ESS Linac Simulator [1–3] has been tested in the control system of the Spallation Neutron Source (SNS) in Oak Ridge, Tennessee, USA during August 2015. We had the opportunity to test both transversal and longitudinal dynamics in two different sets of measurements. The results of the transversal dynamics comparison are summarised in [4], while in this paper we will illustrate the evaluation of the ELS code's treatment of longitudinal dynamics.

The ELS was directly connected to the control system of the accelerator acquiring the data from the EPICS system through the OpenXAL framework [5]. The experiment consisted of scanning the phase of a radio-frequency cavity in the Coupled-Cavity Linac [6] (CCL in Fig. 1) and measuring the time of flight between two BPMs downstream.

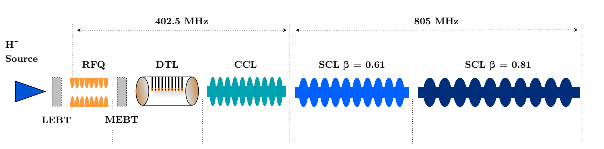

Figure 1: Spallation Neutron Source Linac.

This measurement should provide an estimate of the energy gained by the particle in the cavity, and such an estimate depends on the accuracy of the cavity model. The time of flight is estimated as the phase difference between the two BPMs, using [7]

$$\Delta\phi \sim -\frac{2\pi\Delta s}{\lambda}\frac{\beta-\beta_0}{\beta_0^2} \qquad (1)$$

where Δs is spatial separation; λ is the wavelength of the radio-frequency cavity; and β and β_0 are the relativistic parameters of the actual energy and the reference energy respectively.

ELS implements a field-map model to evaluate the beam dynamics in the cavities. The field-map E_z is provided as the longitudinal electric field in the z direction. The energy gain used to calculate the β parameter in Eq. 1 is evaluated integrating numerically the Eq. 2 [3]

$$\Delta W = q\int_{-\infty}^{\infty} E_z(s)\cos(\phi(s))ds. \qquad (2)$$

MEASUREMENTS

Four cavities tanks, composed by eight cells each, were scanned in the CCL section: CCL1, CCL2, CCL3, CCL4. For each cavity, the phase of the beam in the first BPM downstream of the cavity was measured and set as reference in ELS. The phase in the second BPM downstream is then measured and compared with the result of the ELS simulation. For each cavity the phase was scanned in the range from $-180°$ to $180°$ with $10°$ of step.

The measured phase of the BPM is the time between the start of the acquisition of the BPM and the time when the signal of the passage of the beam is detected. Because the beginning of the time acquisition is arbitrary and defined by the master time of the control system [8], this number cannot be predicted with ELS. For this reason the ELS phase is matched with the measurements of the first BPM and the model is validated using the measured phase of the second BPM. In this process we assume that the reference time between the two BPMs does not change and, once calibrated in the first BPM, it can be used in the second BPM. Table 1 shows the BPMs used for the measurements.

Table 1: BPMs Used for the Scan

Cavity	Reference	Check
CCL1	BPM101	BPM112
CCL2	BPM202	BPM212
CCL3	BPM302	BPM312
CCL4	BPM402	BPM409

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The results of the four phase scans are reported in Fig. 2. The value on the vertical axes is arbitrary and depends on the calibration factors of the individual BPMs.

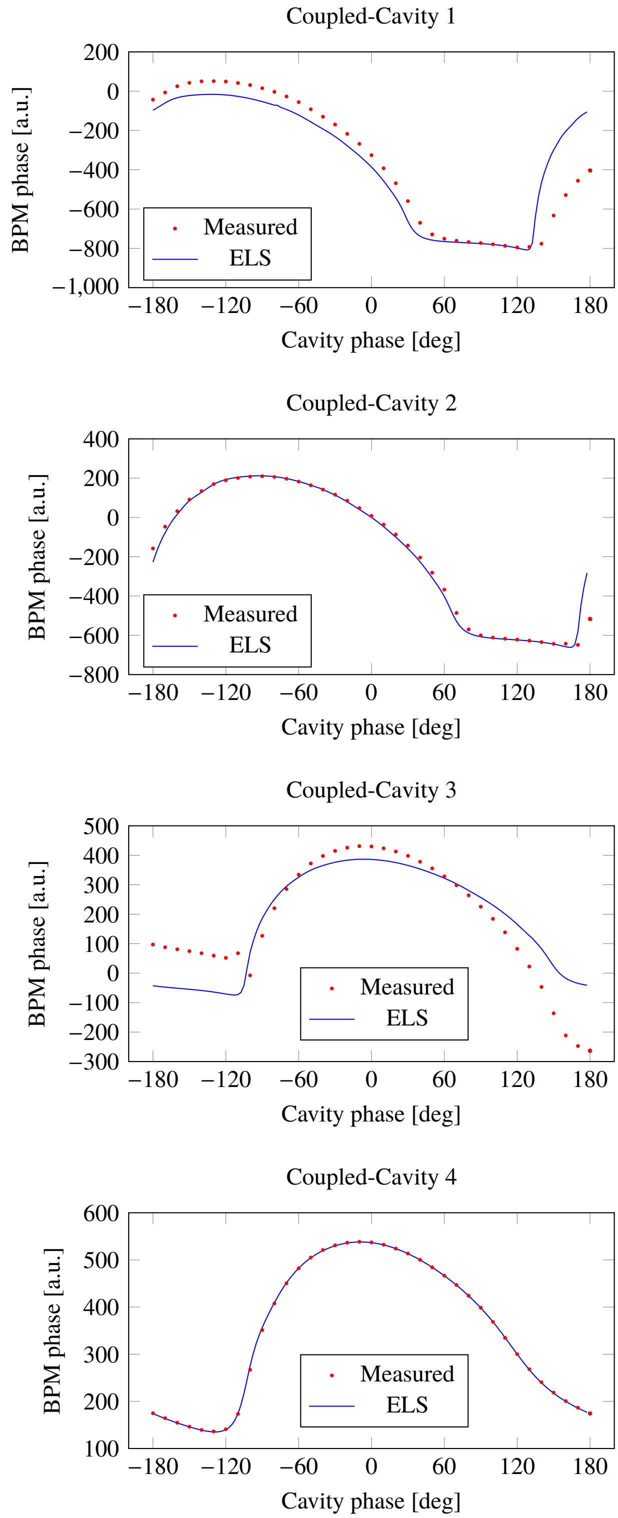

Figure 2: Comparison of CCL1-4 BPMs phases versus ELS-prediction.

Together with the BPM phase we are able to predict the BPM amplitude. This is a measurement of time length of

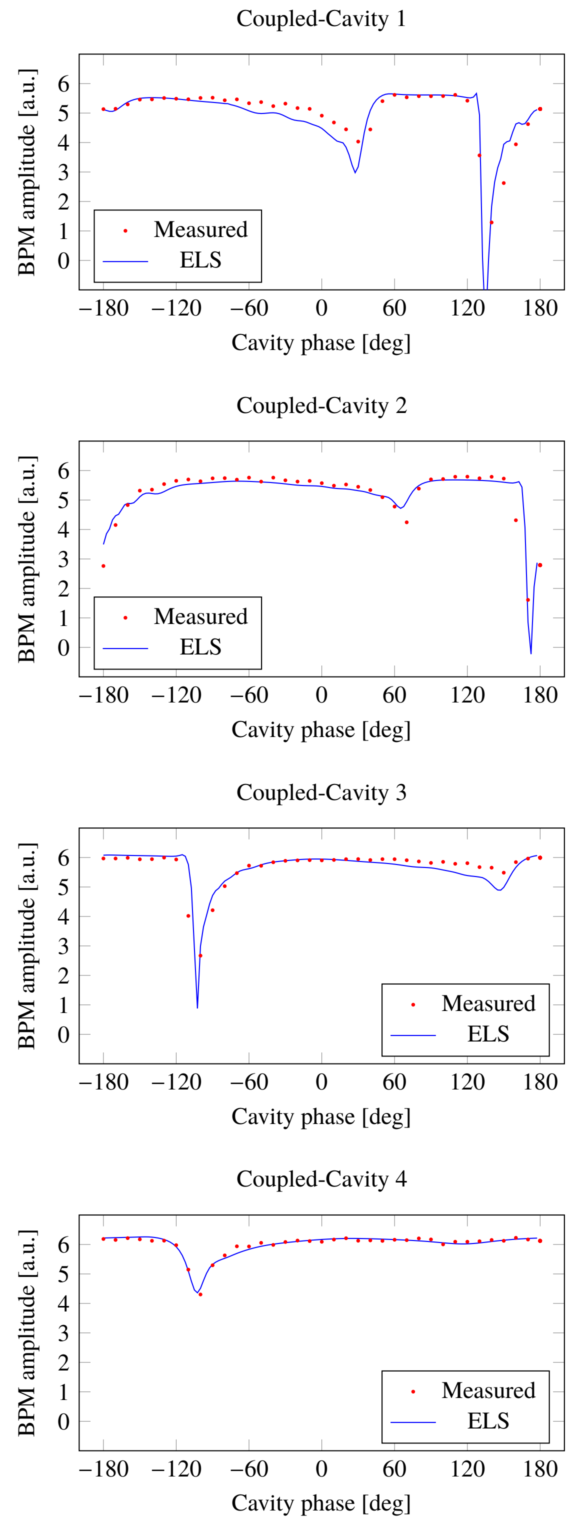

Figure 3: Comparison of CCL1-4 BPMs amplitudes versus ELS-prediction.

the signal registered by the BPM. The quantity that best represents the BPM amplitude in the ELS model is the bunch length. The length has to be multiplied for a linear scaling factor evaluated in the first BPM and then compared with the measurement of the second BPM as done for the phase measurements. The result of the amplitude measurements is in Fig. 3.

According to the Eq. 2 we expect a sinusoidal relation between the cavity phase and the BPM phase, that it is not the case from our Fig. 2. The reason is that the Coupled-Cavities are composed by 96 cells divided in blocks of 8. The BPM used as reference is placed after the first 8 cells and the second BPM used for the phase measurement is placed after the following 8 cells. The phases of all the cells is changed together, so the dynamics (and energy gain) between the two BPMs is effectively influenced by 8 RF cells, and the behaviour shown in Fig. 2 is the composition of 8 sinusoidal functions.

The layout of the CCL described above is probably also the source of the discrepancy in the cavity number 3. The relative phases between the two blocks of 8 cells should be fixed and identical in the model and in the real accelerator. Probably there is a tiny discrepancy between what is used in the model and how the cavities were tuned in the accelerator. Tuning the relative phase difference between the cells 1-8 with the cells 9-16 of the CCL3 in the model, it is possible to restore a perfect matching between ELS and the measurements.

CONLCUSIONS

We benchmarked the field-map RF-cavity model the ESS Linac Simulator in the H^- linac at the Spallation Neutron Source in a 2 hour machine development time slot in August. The model is capable to reproduce well the phase difference between a pair of two BPMs located downstream of a cavity during a phase scan. The model is also capable to predict the length of the bunch measured in the BPM as a function of the phase of the cavity.

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