First Tests of Model-Based Linac Phasing in ISAC-II

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SCB - 'Flat'
8 cavities
β_0=0.057, f=106.08 MHz

SCB - 'Round'
12 cavities
β_0=0.071, f=106.08 MHz

SCC – 'Donut'
20 cavities
β_0=0.110, f=141.44 MHz

SEBT Transport section
- 12 quadrupoles
- 3 flight time monitors

Abstract

The 40-cavity superconducting ISAC-II heavy ion linac has been studied and modelled in the envelope code transoptr. This has allowed for real-time integration through the on-axis fields, fitting focal strengths of solenoids to achieve desired beam waists, and calculation of necessary cavity phases to achieve a desired output energy for given input beam parameters. Initial tests have been completed, successfully phasing up to 37 cavities using the transoptr model and achieving a final output energy within 1% of the expected while maintaining nominal (>90%) transmission. Setting up for an ISAC-II experiment previously took 8+ hours. Outlined here are improvements that led to much shorter tuning and recovery times.

Motivation

- 40 cavities x 2 variables (phase, amplitude)
- 8 solenoids x 1 variable (current)
- 8 cryomodules x 2 variables (x, y steerers)

Large configuration space with interdependent tuning parameters.

Setting up for a new experiment can take a long time (>8 hours)

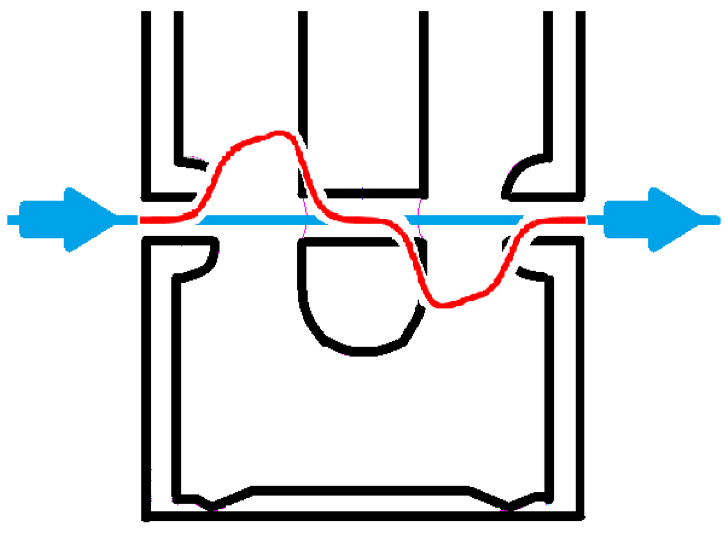

Figure 1 – Schematic of an ISAC-II cavity. Electric field along beam axis at one instant in time shown in red, beam path in blue.

Improvements

Some highlights of the developments completed to enable model-based phasing of the linac include:

1. Non-linear behaviour of the cavity phase shifters have been measured and used in the model calibration.
2. The High Level Application (HLA) framework at TRIUMF is utilized to pull live values from the controls system into the model, and then after optimization to set directly back to the control system.
3. Transoptr, an open-source beam envelope code written in Fortran, is used to model beam transport including RF defocusing for the live cavity amplitudes and optimize the transverse focusing solenoids accordingly (Fig. 3).
4. Cavity phase offsets and amplitude scaling from control system have been calculated using a calibration tune.

Calibrated from past tunes

$$\mathcal{E}_z(s,t) = A_{EPICS} \cdot C \cdot \mathcal{E}_{norm}(s) \cdot cos(\omega t + \theta_{EPICS} - \theta_{offset})$$

tuneable knobs

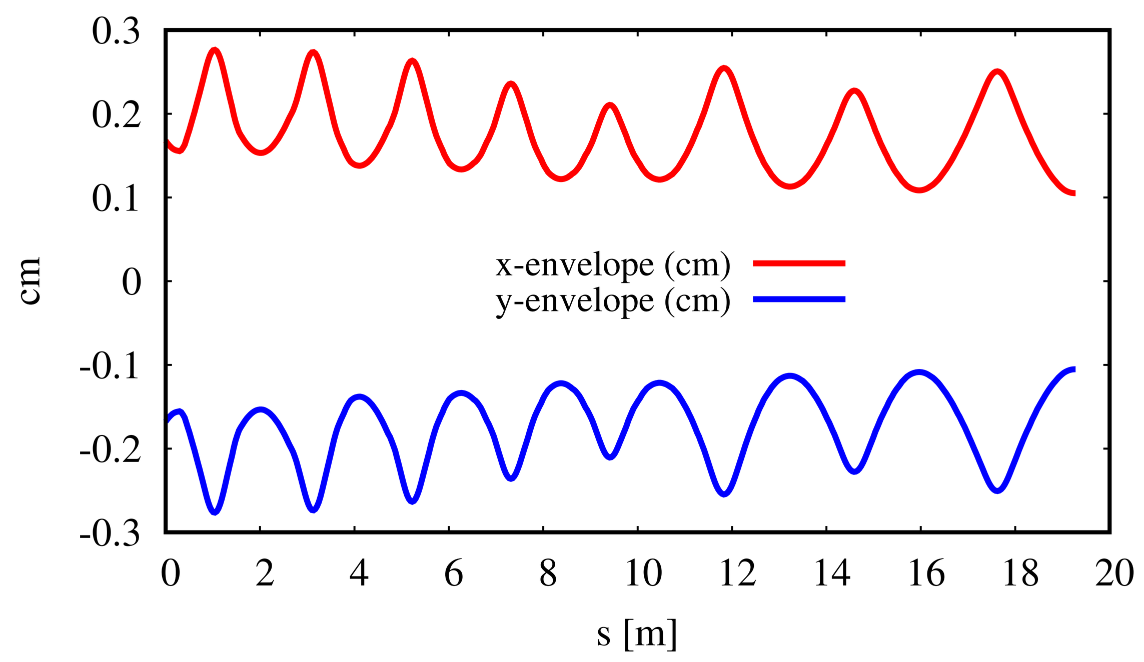

Figure 3 – Optimized 2rms transverse beam envelope calculated in transoptr for the 35 cavity test

Model Based Tuning with Transoptr

Transoptr is a first-order beam envelope code developed at TRIUMF [1]. It calculates the beam's sigma matrix, representing the beam envelope in 6-dimensional phase space (x, P_x, y, P_y, z, P_z). Notable benefits include the available expertise at TRIUMF, fast execution times (on the order of 1 second), and the ability to integrate through an-axis field maps of accelerating cavities [2].

The new approach uses transoptr to find the optimal cavity phases as well as focal strength of the solenoids for a given configuration of the linac.

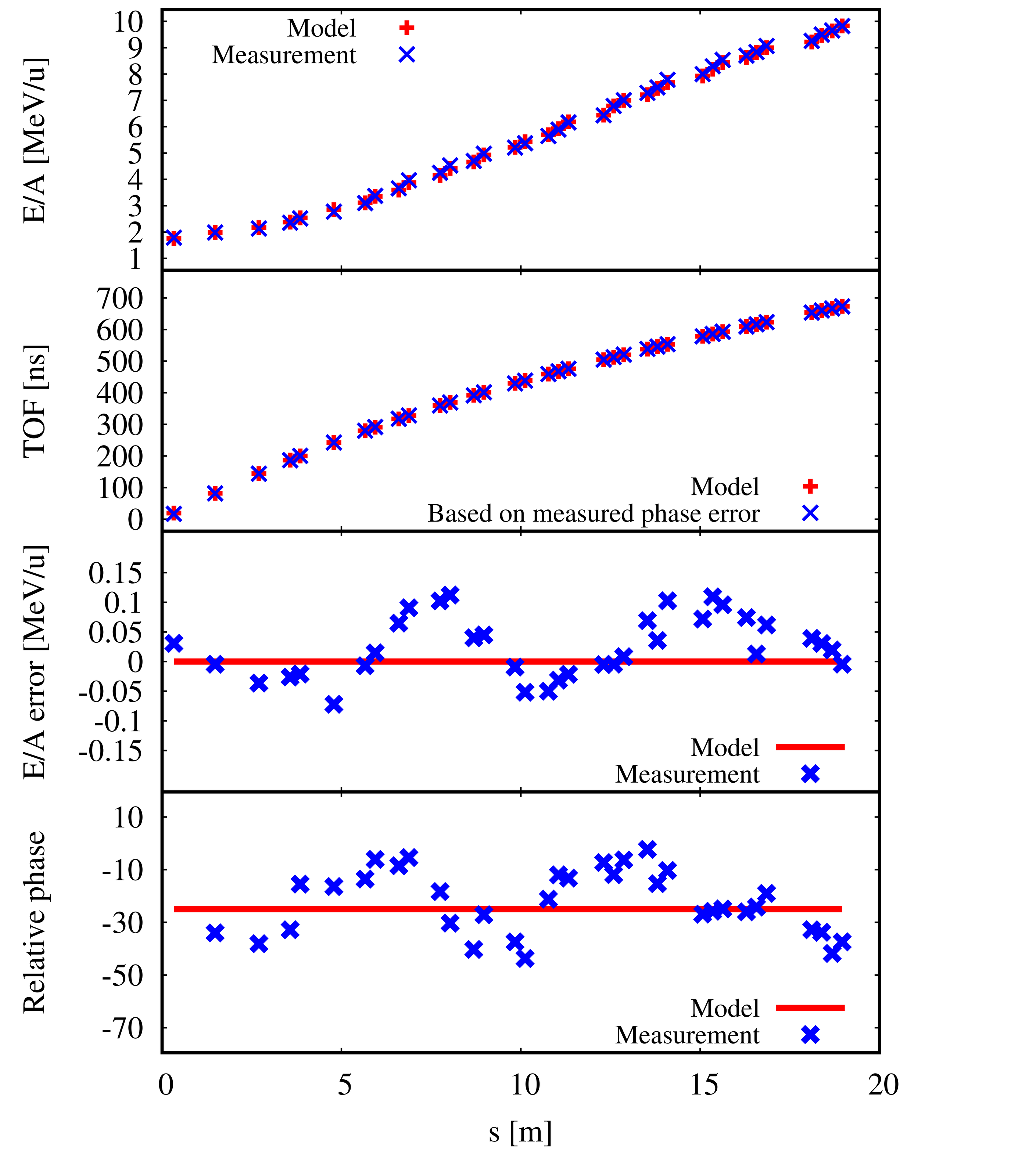

Figure 2 – Measured energy and phase after each cavity of the test (blue) compared to values calculated in the model (red). X-axis is distance along the beamline.

Results

Two tests were successfully completed, one with 35 and one with 37 operational cavities. As each additional cavity was turned on, the phase vs output energy beheviour of the cavity was measured to assess the error associated with setting cavity phase from the model.

- Energy per nucleon error was less than 0.15 MeV/u
- Cavity phase error was less than 20 degrees
- Linac transmission averaged over 90%
- Both established tunes were successfully used for delivery to an experiment in early August 2021.

These tests have demonstrated the capability to now setup the linac for a new experiment in under an hour where it historically has required 1 shift (8 hours).

References

[1] Baartman, R., "TRANSOPTR: Changes since 1984," TRIUMF, Tech. Rep. TRI-BN-16-06, 2016.

[2] Baartman, Richard. "Fast Envelope Tracking for Space Charge Dominated Injectors." 28th Linear Accelerator Conf.(LINAC'16), East Lansing, MI, USA, 25-30 September 2016. JACOW, Geneva, Switzerland, 2017.

Discovery, accelerated