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THE LINACS SIMULATION FRAMEWORK

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Abstract

LINACS is a simulation framework for designing, simulating, and analyzing optics and beam dynamics of charged particles in particle accelerators. LINACS is an open-source software that enables the user complete control over all design and simulation parameters of RFQs. This includes beam-driven design, fully 3D simulation using precise quadrupolar symmetry, and rigorous Poisson solution for external and space charge fields. The code can handle simultaneous particle beams with analytical input distributions and allows input beam scans. The software offers a relatively short running time and provides extensive analysis techniques. This work provides a historical overview of the code, presents results from RFQ models, and discusses future developments.

INTRODUCTION

Systematic design code for linear accelerators altogether is rare, and comprehensive frameworks that include space charge physics as a primary focus and utilize an *inside out* design, i.e., a design that specifies the desired beam behavior as influenced by space charge and specifies the external field that produces that behavior, are currently only represented by LINACS [1]. As a result, the emphasis is heavily placed on design aided and followed by simulation, both of which require equal care and a framework approach. The example of RFQ design is used to illustrate this point, as it is considered the most challenging linac to design due to the beam's evolution from DC injection to the formation of accelerated bunches.

R. A. Jameson and several students at the Institut für Angewandte Physik (IAP) aimed to enhance the physics fidelity of general linacs, specifically focusing on RFQ design, simulation, and optimization [2].

The motivations included:

- Full and direct control over all parameters.
- Close the agreement between actual RFQ performance and simulations.
- Improving the physics modeling.
- Open source programs.
- Develop guidelines for model optimization.

The ultimate objective was to develop a new, open-source code called LINACS for particle accelerator design and simulation. This code would integrate the most advanced physics that current computer technology can accommodate. It would also provide options for the designer to prioritize between accuracy and execution speed, with a clear understanding of the potential consequences. Additionally, the code would offer a versatile library of analysis capabilities.

LINACS FRAMEWORK

The LINACS framework is composed of three main codes: LINACSrfqDES, LINACSrfqSIM, and LINACSapf. The first two are specialized for RFQ design, and the last one was developed for the Alternating-Phase-Focused (APF) linacs [3]. In this report, we will focus on the RFQ codes: LINACSrfqDES and LINACSrfqSIM.

The LINACSrfqDES framework controls all RFQ parameters, including the space charge physics. This ensures that the beam is controlled in the design by requiring the root-mean-square (rms) beam envelope to be matched transversely and longitudinally at each cell. Therefore, the rms beam envelope is known at each cell. LINACSrfqDES is unique in using a good approximation of the external field (8-term multipole), applied in the design at the rms beam sizes, so that the design and LINACSrfqSIM are fully connected.

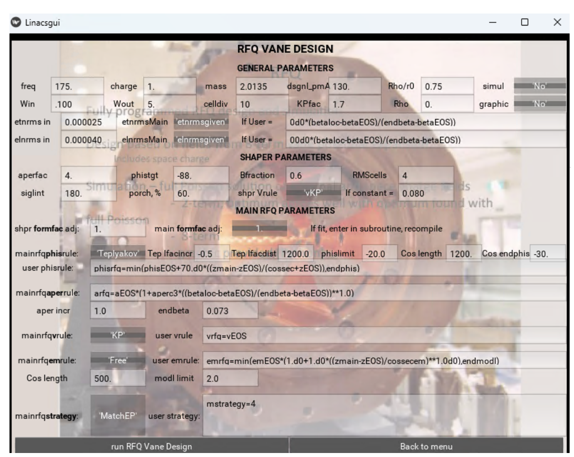

Figure 1: Graphical user interface for the RFQ design.

Figure 1 shows the graphical user interface for the RFQ design. Using this interface, the user can define the general parameters of the RFQ, shaper, and main RFQ parameters. The user has the option to choose from various predefined rules, or they can create and implement their own rules to control the parameters. The *simul* bottom on the top-right

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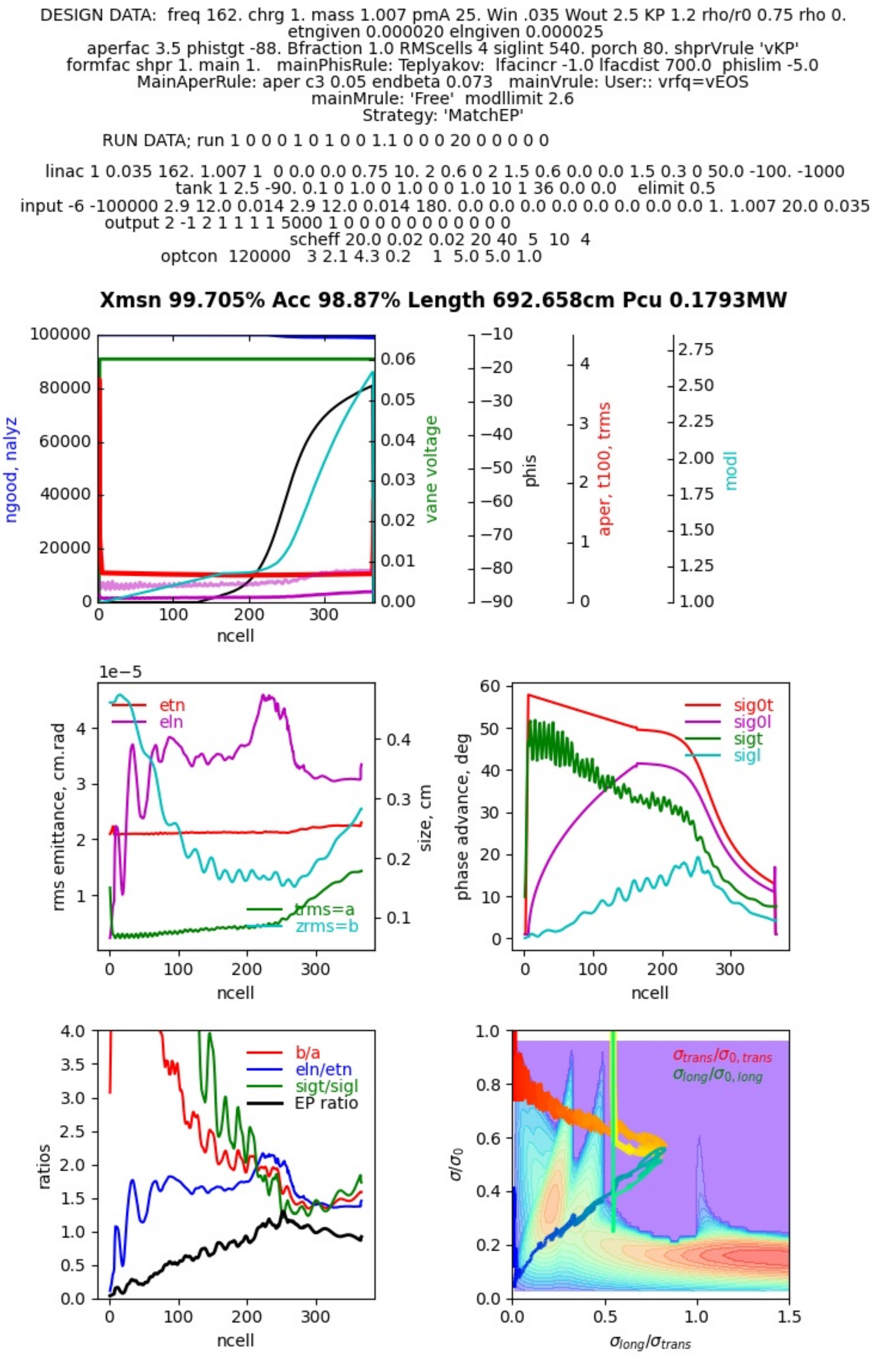

Figure 2: Output result from LINACS simulation.

allows execution of the LINACSrfqSIM program for particle simulations.

The simulation of the RFQ beam is carried out by LINACSrfqSIM. This is a time-domain code that accurately simulates space charge effects. It utilizes the exact RFQ vane surfaces and determines the external and space charge fields using the multigrid Poisson method with quadrupole symmetry. The code reads input values that are organized in dictionaries. The simulations save the RFQ parameters per cell, vane profiles, surviving particles, particles inside the acceptance, losses, final distribution, etc.

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Figure 2 shows a summary of the RFQ simulation. The top part provides a summary of the design value, followed by the data for the beam-dynamics simulations. Next, it presents the particle transmission, the particles inside the acceptance, RFQ length, and power consumption. In the plot section, the top plot presents the evolution of the particles and RFQ parameters per cell. The middle plots display the rms emittance and size on the left, and the phase advances on the right. The bottom-left plot illustrates figures of merit for the Equipartition (EP) [4] condition, while the bottom-right plot shows the Hofmann chart.

STUDIES

RFQ Designs

LINACS has been used to design, build, and analyze RFQ projects including:

- Ion RFQ projects built at the Rikagaku Kenkyusho (RIKEN) center [5, 6].
- The International Fusion Materials Irradiation Facility (IFMIF) Conceptual Design Reference (CDR) EP RFQ [7], see Fig. 3.
- High energy and high duty RFQ design at IAP [8, 9]
- An EP RFQ design to accelerate $C6^{+}$ ion beam for direct plasma injection scheme (DPIS) at the Institute of Modern Physics [10].
- 3 MeV 50 mA H^{-} RFQ built for the Japan Proton Accelerator Complex (J-PARC) [11, 12].
- EP proton RFQ for the accelerator-driven subcritical system design of the Japan Atomic Energy Agency (JAEA) [13].

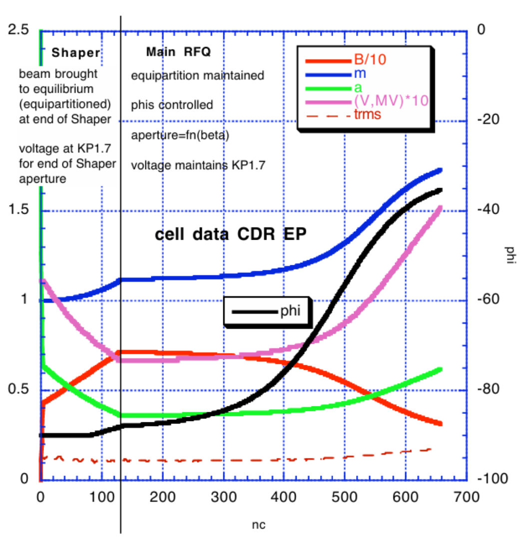

Figure 3: RFQ parameters for the IFMIF 140 mA CDR EP RFQ. Aperture (a) and trms = transverse rms beam radius are in cm. (m) is the vane modulation, V is the vane voltage, B is the transverse focusing strength. Phi is the synchronous phase (phis). Rho/r0 = 0.75 [7].

Improve Emittance Control: Truncated Vanes

During optimization of the EP JAEA-ADS RFQ design [13], it was found that vane truncation resulted in better control of the emittance growth [14]. Figure 4-top compares the longitudinal emittance growth for a truncated vane versus a non-truncated vane. Vane truncation avoids most of the damaging longitudinal field variations that occur during the bunching process; consequently, achieving a small emittance growth. It is worth mentioning that truncation does not affect the maximum modulation depth or the synchronous phase.

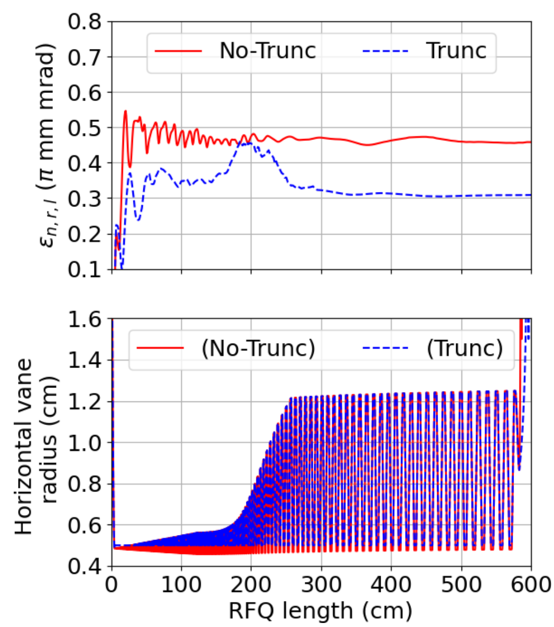

Figure 4: Comparison between Truncated vanes (Trunc) and No-truncated vane (Non-trunc) for the JAEA-ADS EP RFQ. The top plot presents the longitudinal emittance and the bottom the horizontal vane radius along the RFQ [14].

CONCLUSIONS

The ultimate goal was to create a new, open-source RFQ code that integrates the most advanced physics capabilities currently available in computers. This code would also include rigorous optimization, a flexible library of analysis tools, and a range of options that allow the user to prioritize either accuracy or execution speed, with an understanding of the trade-offs involved, e.g. Future high-intensity accelerators will require more powerful and self-consistent techniques to ensure successful operation. Therefore, it is necessary to develop simulation models that allow for experimental testing for true design optimization. LINACS can be freely downloaded from the following link [1].

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