Contribution ID: **48**   Type: **Oral**

Intelligent Design Optimization of Half-Wave Resonator (HWR): A Machine Learning-based Approach

Thursday, November 13, 2025 3:30 PM (20 minutes)

This study presents a methodology for the radio-frequency (RF) design optimization of a half-wave resonator (HWR) that can be used at the SCL-21 section of the RAON heavy ion accelerator. To overcome the limitations of conventional manual parameter sweep methods, such as computational inefficiency and convergence to a local optimum, we introduce a machine learning-based, data-driven optimization workflow. To build a dataset that efficiently represents the entire design space, we applied Latin Hypercube Sampling (LHS) and utilized a Support Vector Machine (SVM) classifier with probabilistic output to efficiently acquire valid CST simulation data. Based on the acquired data, we trained a Gaussian Process Regression (GPR) surrogate model with an ARD (Automatic Relevance Determination) kernel, which automatically infers the importance of each variable. The hyperparameters of this model were automatically optimized through Bayesian Optimization. Finally, we coupled the highly trained surrogate models with a Multi-objective Genetic Algorithm to derive a Pareto optimal front for the conflicting objectives of maximizing the accelerating electric field (Eacc), and minimizing the peak surface electric field ratio (Epk/Eacc) and magnetic field ratio (Bpk/Eacc). During this process, we iteratively performed adaptive sampling, which leverages the uncertainty information from the GPR models, to progressively improve the model's predictive accuracy and enhance the search for a global optimum. The proposed methodology offers a new direction for the complex field of accelerator cavity design by providing both significant design time reduction and performance enhancement, overcoming the limitations of previous experience-based design approaches.

Paper submission Plan

No

Best Presentation

No

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Track Classification: ICABU: Working group 1: Accelerator systems