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Numerical investigation of external losses in superconducting radio-frequency cavities

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For the design and the operation of particle accelerators, detailed knowledge about the electromagnetic behaviour of
the accelerating structures plays a crucial role. The electromagnetic fields are generally computed numerically by solving the
Helmholtz equation in a certain frequency interval of interest. A goal for the design is the damping of so-called Higher-Order
Modes (HOMs) which might lead to a deflection of the beam or a reduction of the beam quality. The damping of these HOMs
is enabled by certain coupler structures that couple the energy out of the resonator. These losses are denoted as external losses.
The computation of external losses generally leads to a nonlinear, complex-valued eigenvalue problem (NLEVP), in which
the boundary conditions at the waveguide ports depend on the eigenvalues. While this problem is solved straight forward for
small structures, the solution of this NLEVP for real-life applications with several millions of unknowns is generally solved
introducing some simplifications (e.g. linearisation). The effective solution of the full problem is currently an open question in
accelerator physics. The above mentioned simplifications can lead to large errors in the arising field-patterns and in the external
quality factors (up to several orders of magnitude). In this paper we present a method that can solve the full NLEVP for several
millions of unknowns on standard workstation computers and by this, compute the arising field pattern and external quality
factors precisely. To accomplish that, we will first perform a model-order reduction (MOR) for the closed and lossless structure.
For this reduced-order model, in a perturbation approach, a termination condition is defined such that no energy is reflected
back into the structure. The arising NLEVP can be solved by simple techniques like Newton-Iteration since the combination
with a suiting MOR keeps the systems size relatively small. An application example for the FLASH third harmonic module
is shown, where the solution of the NLVEP is compared to a commercial software as well as linearisation approach and
pole-fitting.

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