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Multi-physics simulation of quadrupole resonators in the time domain under uncertainties

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Exploring the fundamental properties of materials, including niobium or Nb3Sn, in high-precision surface resistance measurements is relevant to superconducting radio-frequency (RF) technology. For the precise determination of the RF properties of such materials, the calorimetric measurement is carried out with a quadrupole resonator (QPR). Mathematically, a QPR model is governed by a set of electromagnetic-stress-heat (EM-S-T) equations in the time domain under geometric and material uncertainties. It allows for profound insight into the QPR physics phenomena, such as dynamic Lorentz force detuning and microphonics, potentially resulting in measurement bias observed for the third operating mode of the given HZB-QPR (1.3 GHz). On top of the coupled EM-S-T problem, due to manufacturing imperfections, the stochasticity of input parameters substantially affects the performance of QPRs. Thus, uncertainty quantification (UQ) becomes necessary to provide reliable and predictable simulations of QPRs. The generalized polynomial chaos (gPC) expansion technique with the stochastic collocation method is proposed to find the UQ propagation by the QPR model. This methodology offers a more realistic mathematical model of the QPR, providing statistical moments, local and variance-based sensitivity, and cumulative/probabilistic density functions. Based on that information, a physically-based approach can be proposed to re-design the QPR and improve the measurement accuracy.

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Footnotes

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