

ROBUST DESIGN OF VIBRATORY RAMMERS WITH MAXIMIZED ENVIRONMENTAL OPERATING RANGE

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Abstract

The performance of vibratory rammers used for soil compaction is strongly governed by the nonlinear interaction between machine dynamics and soil behavior. Combined with uncertainty in material properties and geometry, this interaction makes the realization of optimized machine designs highly challenging. Conventional robust design approaches require explicit uncertainty models, which are often unavailable for such systems. Solution space–based systems design addresses this challenge by determining admissible ranges for key design variables, such as rubber mount stiffness or component mass. These admissible ranges effectively substitute the missing uncertainty model: any combination of components whose design variable values lie within these ranges is guaranteed to satisfy the required system behavior, for example, with respect to compaction performance or hand–arm vibration levels. In this work, in addition, the soil itself is treated as a design variable, and the admissible range of soil conditions is maximized to increase the rammer’s operational versatility across varying environmental conditions. A high-fidelity three-dimensional multi-body simulation (MBS) model of the machine is validated using accelerometer measurements and coupled with a nonlinear soil constitutive model derived from measurements obtained during machine operation. A design of experiments is conducted across machine design variables, operational parameters, and environmental conditions. The resulting high-fidelity simulation data are used to train a surrogate model that approximates the system dynamics and enables efficient exploration of the high-dimensional design space. Based on this surrogate model, solution spaces are constructed to identify favorable regions of the design space and to derive

admissible parameter intervals. The surrogate representation further enables rapid prediction of system behavior under varying component properties, soil conditions and operating states, as well as sensitivity analyses that quantify the influence of machine and soil parameters on compaction performance and operator vibration. These capabilities provide a foundation for digital twin applications, in which measurement data are integrated with physics-based models to account for soil variability, update system predictions, and support adaptive operation of vibratory soil compaction machinery. {

References

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