



非均匀多场耦合接触力学辛方法

Symplectic Framework for Contact Analysis of Inhomogeneous Media with Multi-field Coupling

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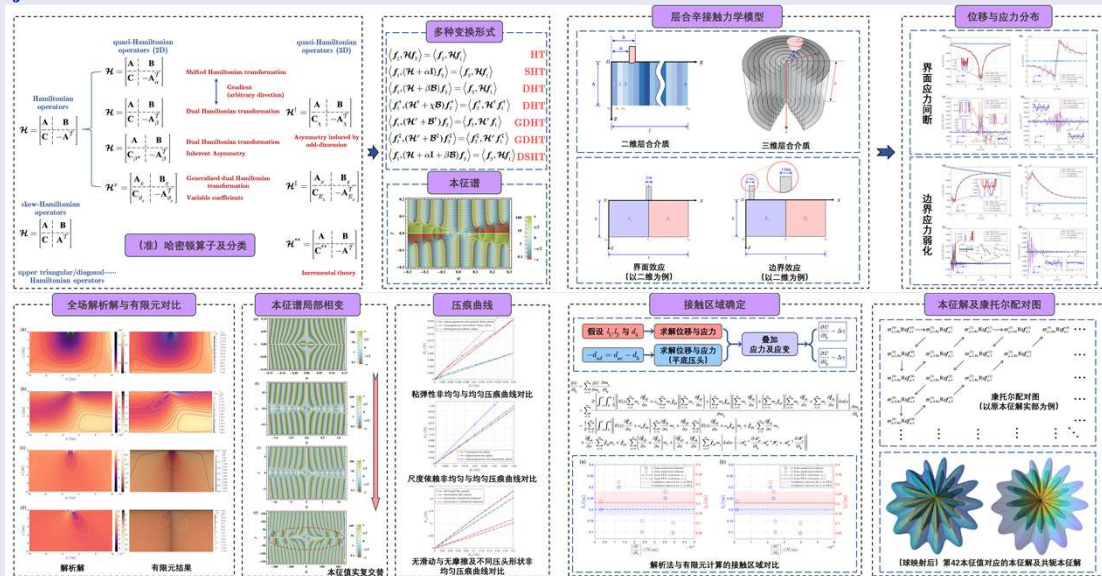
研究概况(Research Overview)

材料多重基本性能的定量化表征，是多场耦合条件下材料与结构短时力学行为描述以及长效服役寿命预测的基础。高通量实验对材料样本密集化的迫切需求，促使材料的高通量制备逐渐从传统的“分立式”阵列样品向“连续型”梯度样品转变。然而，原本适用于分立、均匀样品的经典压痕表征理论无法直接沿用至梯度样品中，亟需发展基于梯度样品的高通量表征力学理论，实现对梯度样品多重材料性能分布的定量化表征。

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The quantitative characterization of various fundamental material properties serves as a cornerstone for describing short-term mechanical behavior of materials and structures with multi-field coupling and predicting their long-term service life. The urgent demand for a highly time-efficient and space-compact method in high-throughput experiments has led to a transition in material preparation methodologies, shifting from traditional “discrete” samples to “continuous” graded samples. However, the classical indentation theories, which were originally formulated for homogeneous media, are incompatible for graded specimens. Consequently, there is a necessity to develop a high-throughput characterization theory tailored for gradient specimens, which enable a quantitative characterization of the distribution of multiple material properties within gradient samples.

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关键技术与成果 (Key Technology and Achievements)

- 构建了接触力学辛体系，提出并证明了准哈密顿算子及其对偶算子特征向量间的对偶辛正交和对偶辛共轭
Establish a symplectic framework for contact analysis, propose and prove the dual symplectic orthogonality and dual symplectic adjoint between eigenvectors of quasi-Hamiltonian operator and its dual operator.
- 构造了基于辛形式解的非均匀介质接触区域确定方法，并利用康托尔配对图使之适用于三维情形
Develop a strategy for the determination of contact areas in inhomogeneous media based on symplectic solutions and apply the strategy to three-dimensional cases via Cantor pairing diagram.
- 探究跨尺度接触力学机制，揭示了本征谱局部相变与尺度效应的联系
Investigate the mechanisms of size-dependent contact mechanics and reveal a relation between local phase transition of spectrum and size effect.
- 建立多场耦合层合辛接触力学模型，分析了界面效应与边界效应，并利用辛子空间表示给出了三维全场解析解
Construct a model of symplectic contact mechanics for laminated media with multi-field coupling, analyze the interfacial and boundary effects and derive three-dimensional analytical solutions on the whole domain through sub-symplectic representation.