

TOPOLOGY OPTIMIZATION OF A HIGH-PRECISION MACHINE TOOL STRUCTURE CONSIDERING HIGH-FREQUENCY DYNAMIC RIGIDITY AND THERMOELASTIC LOADS

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Abstract

Ensuring sub-micron accuracy in continuous generating gear grinding machines requires highly rigid structures capable of withstanding complex external disturbances, particularly high-frequency dynamic excitations and thermal loads. Conventional structural optimization is often insufficient for these operational conditions. This study proposes a comprehensive topology optimization methodology explicitly addressing both high-frequency dynamic responses and thermoelastic deformations for advanced machine tool structures.

First, to maximize dynamic rigidity at targeted high frequencies vital for heavy grinding, we minimize dynamic mean compliance. However, optimizing dynamic compliance at frequencies higher than the fundamental natural frequency inherently leads to unmanufacturable intermediate density (grayscale) distributions. To overcome this critical numerical instability, we introduce a regularization method appending static mean compliance to the objective function. This approach successfully eliminates grayscale regions, ensuring an interconnected, manufacturable topology.

Second, we address structural rigidity against thermal loads caused by heated coolant. Since entirely suppressing thermal displacement near heat sources is physically impractical, this study compares minimizing average relative displacement with minimizing displacement restricted to specific single-axis directions. The single-axis approach successfully guides thermal deformation parallel to the machine axes, significantly facilitating structural compensation through numerical control. Furthermore, to ensure the machine retains its essential overall stiffness against general working loads, static mean compliance is integrated into this directional objective function.

Applied to the core components of a newly developed gear grinding machine, this methodology provides a robust theoretical foundation for realizing highly rigid, ultra-precise machine tool architectures.