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Novel Sensory Tool Holder Design and Optimization for Multi-axis Cutting Force Sensing in Manufacturing

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***Abstract*—Compared to traditional techniques, sensory tool holders can achieve higher sensitivity and accuracy in cutting force characteristics. However, existing methods require complex structure modifications to enhance sensor sensitivity, leading to weakened processing performance and expensive customization costs. Therefore, this study describes the mechanical design and optimization of a sensory tool holder with embedded piezoelectric sensors, which has an almost identical rigidity to that of a standard tool holder. A high-fidelity sensing model was developed by the integration of piezoelectricity and multi-axis stress analysis. Sensor locations and orientations were optimized within standard tool holders to achieve high sensitivity, accuracy, and cross-axis decoupling in specific directions. Static tests indicated that under optimized parameter configurations, the designed tool holder achieved a maximum cross-coupling error of approximately 4.6%, only half of existing researches; it also demonstrated better performance in sensitivity, linearity, hysteresis, and repeatability. The proposed model was verified through simulation, with a maximum sensitivity error of only 5.34%, confirming its applicability for sensor embedding optimization in various types of standard tool holders without the need for structure modification.**

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