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微纳技术与精密机械

3自由度精密定位平台的运动特性和优化设计

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摘要： 为了实现3-RRR柔顺并联精密定位平台的精确运动,研究了它的封闭形式精确运动模型和尺寸优化设计。采用卡氏第二定理建立精密定位平台的封闭式柔度模型。根据柔顺并联机构的结构特点,将其划分为3个对称分布的运动支链,并结合铰链的柔度模型和机构力传递关系分别推导出各个支链的刚度模型,整个系统的刚度为所有支链在同一坐标系下的刚度的叠加。建立的刚度模型是以柔性铰链的柔度为变量的封闭形式模型。根据柔度矩阵可得到反映输入位移和输出位移之间关系的雅可比矩阵。理论模型与有限元分析的比较结果显示,两者所得的运动模型误差为1.0%～9.5%,证明了所推导运动模型的正确性和精确性。根据雅可比矩阵的封闭公式,分析其对结构参数的灵敏度,并由此选出对平台运动特性影响较大的优化设计变量。提出以最大化平台工作空间为目标,以铰链强度、最大输入力、几何尺寸和输入耦合为约束的优化模型。结果表明,优化后的结构参数能获得更大的输出位移,说明该方案能满足优化设计要求。

关键词： 柔顺并联机构 柔性铰链 精密定位平台 运动特性 优化设计

Kinematical properties and optimal design of 3-DOF precision positioning stage

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Abstract: To achieve the precise motion of a 3-RRR compliant parallel precision positioning stage, a closed-form exact motion model was established and the optimized design of structure parameters was investigated. The Castigliano's second theorem was applied to establishment of the closed-form compliance model for the precision positioning stage. According to the structural characteristics of compliant parallel mechanisms, the system was divided into three symmetrical motion sub-chains. Combining the compliance equations of flexure hinge with the force transmission relations of mechanisms, the stiffness model of each sub-chain was obtained, and the stiffness of the entire system was calculated by summing the stiffness of three sub-chains in the same coordinate system. The proposed stiffness model took the hinge flexibility as the independent variables in the closed form. According to the flexibility matrix, the Jacobian matrix to reflect the relationship between input displacement and output one could be derived. By comparing the kineamatic model between theoretical analysis and FEA, the results show that the errors are within 1.0%～9.5%, which illurastrates that the proposed kinematic model is correct and precise. According to the closed-form Jacobian matrix, its sensitivity to structureal parameters was analyzed,then the design variables with greater impact on the kinematic properties were chosen. By taking the maxmium workspace as a target and the hinge strength, maxmium input forces, geometric dimensions and input coupling as the constrains,an optimal model was proposed. The results show that the optimized structural parameters can obtain more output displacements, and the proposed model can meet the design requirement.

Keywords: compliant parallel mechanism flexible hinge precision positioning stage kinematical property optimal design

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