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5-UPS/PRPU冗余驱动并联机床完整刚度模型及其刚度特性

周鑫, 许允斗, 姚建涛, 郑魁敬, 赵永生

1. 燕山大学 河北省并联机器人与机电系统实验室, 河北 秦皇岛 066004;
2. 燕山大学 先进锻压成型技术与科学教育部重点实验室, 河北 秦皇岛 066004

Complete stiffness model and stiffness performance of 5-U P S/ P RPU redundantly actuated parallel machine tool

ZHOU Xin, XU Yun-dou, YAO Jian-tao, ZHENG Kui-jing, Zhao Yong-sheng

1. Parallel Robot and Mechatronic System Laboratory of Hebei Province, Yanshan University, Qinhuangdao 066004, China;
2. Key Laboratory of Advanced Forging & Stamping Technology and Science of the Ministry of Education, Yanshan University, Qinhuangdao 066004, China

摘要 基于全雅可比矩阵和虚功原理建立了5-UPS/PRPU冗余驱动并联机床的完整刚度模型。首先基于螺旋理论推导出约束分支中的约束雅可比矩阵;然后锁定分支中的主动副并利用互易积原理求得驱动雅可比矩阵,最后提出了冗余驱动雅可比矩阵。利用约束力、驱动力和冗余驱动力与外力的映射关系,结合虚功原理,得到系统整体刚度矩阵。考虑虎克铰、轴承等传动部件的轴向变形对分支轴向刚度的影响,构造了各个分支的轴向刚度模型。借助激光跟踪仪对所建立的刚度模型进行了实验测试。结果表明:该刚度模型的误差为2%~5%,验证了理论分析的可靠性。在此基础上,以机床的线刚度和角刚度的最小值为刚度性能指标,分析了其在工作空间内的分布情况。分析显示:机床线刚度的最小值主要分布在Y轴两侧,角刚度的最小值则主要分布在$-0.05 \le z \le 0.05$ m和$-0.11 \le y \le -0.05$ m,因此,在进行并联机床工具规划时应该尽量避免该区域。文中内容可为并联机床刀具运动轨迹的优化提供参考依据。

关键词 : 并联机床, 冗余驱动, 完整刚度模型, 最小刚度分布

Abstract : A complete stiffness model of the 5-UPS/PRPU redundantly actuated parallel machine tool was constructed based on the overall Jacobian matrix and the principle of virtual working. Firstly, the Jacobian matrix of a constraint limb was derived by using screw theory; then, the Jacobian matrix of actuations was derived by using the theory of reciprocal screw and by locking actuated joint in each limb; finally, a redundant Jacobian matrix was designed. By using the mapping relationship between constraint forces, actuated forces, redundantly actuated forces and external forces, the complete stiffness model of the overall system was obtained combining with the principle of virtual work. Furthermore, by taking the effect of the axial deformation of a universal joint, a spherical joint and some other transmission parts on the linear stiffness of each limb into consideration, the axial line stiffness model of each single limb was constructed. The stiffness model was further validated by a laser tracker. The experiment results show that the error of stiffness model is 2%-5%, which means that the theoretical analysis is acceptable. On this basis, the stiffness performance of the machine tool was evaluated by utilizing the minimum linear/angle stiffness values, the minimum stiffness distribution in the workspace was investigated, and the minimum stiffness area was generalized. It shows that the minimum linear stiffness distributes on both sides of Y-axis, the minimum angle stiffness distributes on the $-0.05 \le z \le 0.05$ m and $-0.11 \le y \le -0.05$ m, which suggests that the programmer should avoid this area when the trajectory of the Parallel Machine Tool(PMT) is planned. The research provides a theoretical reference for the track programming of the 5-UPS/PRPU redundantly actuated PMT.

Key words : parallel machine tool actuation redundancy complete stiffness model minimum stiffness distribution

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作者简介: 周鑫(1988-),男,河北石家庄人,博士研究生,2010年于燕山大学获得学士学位,主要从事机器人技术及应用等方面的研究。E-mail:zhouxin@ysu.edu.cn;许允斗(1985-),男,浙江温州人,讲师,研究生导师,2007年、2012年于燕山大学分别获得学士、博士学位。主要从事锻造操作机技术、并联机器人技术及应用等方面的研究。E-mail:ydxu@ysu.edu.cn;赵永生(1962-),男,吉林龙井人,教授,博士生导师,1987年于东北重型机械学院获硕士学位,1999年于燕山大学获博士学位,主要从事机器人技术,传感器技术,先进制造技术等方面的研究。E-mail:yszhao@ysu.edu.cn

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