光学精密工程 OPTICS AND PRECISION ENGINEERING
核心期刊
主管：中国科学院
主办：中国科学院长春光学精密机械与物理研究所
中国仪器仪表学会
主编：曹健林

光学精密工程 2013, 21(1) 87-93 ISSN: 1004-924X CN: 22-1198/TH

微纳技术与精密机械

硅微陀螺仪正交耦合系数的计算及验证

姜劭栋,裘安萍,施芹,苏岩

南京理工大学 机械工程学院

摘要： 硅微陀螺仪多采用微机械加工工艺制作，其加工的相对精度较低，从而易产生正交耦合误差，影响陀螺仪的输出。为了优化设计硅微陀螺仪结构，提高其性能，本文建立了陀螺仪正交耦合系数的理论分析模型。首先，利用能量方法推导陀螺仪驱动梁的面内刚度；然后，建立陀螺仪的刚度矩阵；最后，推导了正交耦合系数的理论计算公式。针对本课题组研制的双质量振动式硅微陀螺仪，理论计算出其直接耦合系数为4.74×10^{-5}，二次耦合系数为8.44×10^{-7}。得到的陀螺仪的正交耦合系数为4.75×10^{-5}，与仿真值相差8.7%。分析得到陀螺仪正交耦合系数的最大值为2.18×10^{-4}，与仿真值相差7.9%。最后，实验验证了计算结果的正确性。得到的结果表明，建立的正交耦合系数理论分析模型可为硅微陀螺仪的结构优化设计提供理论依据和实际指导。

关键词： 硅微陀螺仪 正交耦合系数 直接耦合 二次耦合

Calculation and verification of quadrature coupling coefficients of silicon microgyroscope

JIANG Shao-dong,QIU An-ping,SHI Qin,SU Yan

School of Mechanical Engineering, Nanjing University of Science and Technology

Abstract: Silicon microgroscope is processed usually by microfabrication technology. It could lead to a quadrature coupling error and influence the output of the silicon microgyroscope for the lower relative accuracy from the fabrication processing. To optimize the structure of the silicon microgyroscope and enhance its performance, a theoretical model of quadrature coupling coefficients for the microgyroscope was established. Firstly, energy theorem was used to infer the in-plane stiffness of driving beam to set up the stiffness matrix of the microgyroscope. Then, the theoretical analysis model of quadrature coupling coefficients was established. According to a dual-mass vibrating silicon microgyroscope developed by our research group, the theoretical calculation shows that the direct coupling coefficient and the second-order coupling coefficient are 4.74×10^{-5} and 8.44×10^{-7}, respectively, and the quadrature coupling coefficient of the developed microgyroscope is 4.75×10^{-5}, 8.7% different from the simulation value. Meanwhile, the analysis indicates that the maximum value of quadrature coupling coefficient is 2.18×10^{-4} , 7.9% different from the simulation value. Finally, the calculating result is confirmed by an experiment test. It concludes that the theoretical model of quadrature coupling coefficients can provide the theory foundation and application direction for improving the properties of silicon microgyroscopes.

Keywords: Silicon microgyroscope Quadrature coupling coefficient Direct coupling Second-order coupling

收稿日期 2012-08-24 修回日期 2012-10-22 网络版发布日期 2013-01-24

基金项目:

国家高技术研究发展计划（863） 汽车电子稳定程序（ESP）微传感器及系统

通讯作者: 苏岩

作者简介: 姜劭栋(1986-)，男，山东淄博人，博士研究生，2009年于南京理工大学获得学士学位，主要从事MEMS惯性传感技术方面的研究。

作者Email: suyan@mail.njust.edu.cn

参考文献:

[1]施芹,苏岩,裘安萍,等. MEMS陀螺仪器件级真空封装技术[J]. 光学 精密工程, 2009, 17(8): 1987-1992. SHI Q, SU Y, QIU A P, et al.. Device level vacuum packaging technologies of MEMS gyroscopes [J]. Opt. Precision Eng., 2009, 17(8): 1987-1992. (in Chinese) [2]李建利,房建成,盛蔚,等. 双质量块调谐输出式硅MEMS陀螺仪的理论计算及仿真[J]. 光学 精密工程, 2008, 16(3): 484-491. LI J L, FANG J CH, SHENG W, et al.. Calculation and simulation of silicon MEMS gyroscope with dual-mass resonant output [J]. Opt. Precision Eng., 2008, 16(3): 484-491. (in Chinese) [3]WEINBERG M S, KOUREPENIS A. Error sources in in-plane silicon tuning-fork MEMS gyroscopes [J]. Journal of Microelectromechanical Systems,15(3), 2006:479-491. [4]杨波,周百令. 硅微陀螺仪的正交误差分析[J]. 中国机械工程, 2007, 18(10): 1182-1185. YANG B, ZHOU B L. Analysis of quadrature error of silicon micromachined gyroscope [J]. Chinese Journal of Mechanical Engineering, 2007, 18(10): 1182-1185. (in Chinese) [5]许宜申, 王寿荣, 吉训生, 等. 微机械振动陀螺仪正交误差分析 [J]. 仪器仪表学报, 2006, 27(6): 105-107. XU Y SH, WANG SH R, JI X SH, et al.. Analysis on quadrature error of micromachined vibratory gyroscope[J]. Chinese Journal of Scientific Instrument, 2006, 27(6): 105-107. (in Chinese) [6]PHANI A S, SESHIA A A, PALANIAPAN M, et al.. Modal coupling in micromechanical vibratory rate gyroscopes [J]. IEEE Sensors Journal, 2006, 6(5): 1144-1152. [7]施芹, 裘安萍, 苏岩, 等. 硅微陀螺仪的机械耦合误差分析[J]. 光学 精密工程, 2008, 16(5): 893-898. SHI Q, QIU A P, SU Y, et al.. Mechanical coupling error of silicon microgyroscope [J]. Opt. Precision Eng., 2008, 16(5): 893-898. (in Chinese) [8]裘安萍, 施芹, 苏岩, 等. 双质量振动式硅微陀螺仪:中国, ZL200710133223.5[P]. 2008-03-05. QIU A P, SHI Q, SU Y, et al.. Dual-mass vibrating silicon microgyroscope: China， ZL200710133223.5 [P]. 2008-03-05. (in Chinese) [9]刘鸿文. 材料力学Ⅱ(第4版)[M]. 北京: 高等教育出版社, 2004: 28-59. LIU H W. Mechanics of MaterialsⅡ(Fourth Edition) [M]. Beijing: Higher Education Press, 2004: 28-59. (in Chinese) [10]IYER S V. Modeling and simulation of non-idealities in a z-axis CMOS-MEMS gyroscope [D]. Pittsburgh：Carnegie Mellon University, 2003. [12]李锦明. 高信噪比电容式微机械陀螺的研究[D]. 太原:中北大学, 2005. LI J M.

Research on High Signal-noise Ratio of Capacitive Micromechanical Gyroscope [D]. Taiyuan: North University of China, 2005. (in Chinese)

本刊中的类似文章

1. 施芹,苏岩,裘安萍,朱欣华.硅微陀螺仪器件级真空封装技术研究[J]. 光学精密工程, 2009,17(8): 1987-1992

2. 施芹,裘安萍,苏岩.硅微陀螺仪的机械耦合误差分析[J]. 光学精密工程, 2008,16(5): 893-898