本期目录 | 下期目录 | 过刊浏览 | 高级检索 　　　　　　　[打印本页] [关闭]

微纳技术与精密机械

脉冲密度反馈对力平衡微机械陀螺的影响

杨亮，苏岩[*]，裴安萍，夏国明

南京理工大学 机械工程学院，江苏 南京 210094

摘要： 通过研究脉冲密度反馈力对微机械陀螺性能的影响,设计了基于机电结合ΣΔ调制器原理的微机械陀螺检测闭环电路。首先，根据微机械陀螺敏感模态的等效形式，分析得出脉冲密度反馈力对敏感模态的影响机理可以分为负刚度效应和增益效应两部分，且负刚度效应与输入角速度无关。然后，根据闭环检测理论建立了角速度和反馈脉冲密度之间的关系、量程与反馈脉冲高电平之间的关系。最后，利用量程设计指标和实际微机械陀螺参数，理论计算了所需的反馈脉冲高电平，并在Simulink中进行了仿真。仿真结果表明，所选参数满足了设计指标，且在正交误差等效输入角速度为0（°）/s、30（°）/s和50（°）/s 3种情况下，仿真得到平均脉冲密度和角速度之间的非线性分别为3.6×10-6、3.07%和5.12%。对正交误差等效输入角速度分别为30.4（°）/s和47.3（°）/s的I号陀螺和II号陀螺进行实验，结果表明，脉冲密度反馈力对负刚度的影响不随脉冲密度的变化而变化；得到的平均脉冲密度和角速度之间的非线性分别为2.9%和4.8%，实验与仿真结果符合得到较好。

关键词： 微机械陀螺 sigma delta调制器 脉冲密度 检测闭环电路

Effect of pulse density feedback on force balance micro-machined gyroscope

YANG Liang, SU Yan[*], QIU An-ping, XIA Guo-ming

School of Mechanical Engineering, Nanjing University of
Science and Technology, Nanjing 210094, China

Abstract: The effect of Pulse Density Force Feedback (PDFF) on the performance of a micro-machined gyroscope was investigated and a closed-loop circuit for the micro-machined gyroscope was designed based on a mechanical and electrical ΣΔ modulator. Firstly, from the equivalent forms of a sense mode for the micro-machined gyroscope, the effect principle of PDFF on the performance of sense mode was analyzed and it was divided into two parts: negative stiffness and gain effects. The analysis shows that the negative stiffness is independent on the input of angular rate. Then, the relationship between pulse density and input angular rate, and that between input range and high level feedback pulse were built based on the theory of closed-loop detection. Finally, the circuit parameters were calculated by using the range design index and the actual parameters of gyroscope, then these parameters were simulated in Simulink. Simulation result shows that the parameters satisfy the design objective, and the nonlinearities between average pulse density and angular rate are 3.6×10-6, 3.07% and 5.12%, respectively, when the quadrature error equivalent input angular rates are 0（°）/s, 30（°）/s and 50（°）/s. Two gyro sample I and II with the quadrature error equivalent input angular rates of 30.4（°）/s and 47.3（°）/s were tested, and the experiment results show that the effect of PDFF on the negative stiffness doesn't change with the pulse density; and the nonlinearities between the average pulse density and angular velocity are 2.9% and 4.8%, respectively. The experimental and simulation results get a better match.

Keywords: Micromachined gyroscope sigma delta modulator pulse density sense closed-loop circuit

通讯作者: 夏国明

作者简介: 杨亮（1985－），男，河南三门峡人，博士研究生，2008年在南京理工大学获得学士学位，主要从事MEMS惯性传感技术研究。

作者Email: xiaguoming@njust.edu.cn

参考文献：

[1]夏国明,杨波,王寿荣.硅微机械陀螺自激驱动数字化技术[J].光学 精密工程,2011，19(3):635-640. XIA G M, YANG B, WANG SH R. Digital self-oscillation driving technology for silicon micro machined gyroscopes [J]. Opt. Precision Eng., 2011,19(3):635-640. (in Chinese) [2]卢海曦,王寿荣,周百令.微机械陀螺仪反馈控制器鲁棒性分析及闭环接口检测电路设计[J].东南大学学报,2011，41(3):526-532. LU H X, WANG SH R, ZHOU B L. Robustness analysis of a type of feedback controller and design of closed-loop sensing circuit of micro-machined gyroscope [J]. Journal of Southeast University, 2011, 41(3):526-532. (in Chinese) [3]CUI J, GUO Z, ZHAO Q, et al.. Force rebalance controller synthesis for a micromachined vibratory gyroscope based on sensitivity margin specifications [J]. Journal of Microelectromechanical Systems, 2011,20(6):1382-1394. [4] SUNG S, SUNG W-T, LEE J G,et al.. Vibratory gyroscope controller design via modified automatic gain control configuration [C]. International Conference on Control, Automation and Systems, 2007 ICCAS'07, 2007:1361-1367. [5] NORTHEMANN T, MAURER M, ROMBACH S, et al.. A digital interface for gyroscopes controlling the primary and secondary mode using bandpass sigma－delta modulation [J]. Sensors and Actuators A: Physical, 2010, 162(2):388-393. [6] CHINWUBA D E, BEMHARD E B. A mode-matching ΣΔ closed-loop vibratory gyroscope readout interface with a 0.004o/s/√Hz nosie floor over a 50 Hz Band [J]. IEEE Journal of Solid-State Circuit, 2008, 43(2): 3039-3048. [7]RAMAN J, CRETU E, ROMBOUTS P, et al.. A closed-loop digitally controlled MEMS gryoscope with unconstrained sigma-delta

force-feedback [J]. IEEE Sensors Journal, 2009, 9(3):297-305. [8]NORTHEMANN T, MAURER M, ROMBACH S, et al.. A digital interface for gyroscopes controlling the primary and secondary mode using bandpass sigma-delta modulation [J]. Sensors and Actuators A: Physical, 2010,162(2):388-393. [9]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）：894-898． SHI Q, QIU A P, SU Y, et al..Mechanical coupling error of silicon microgyroscope [J]. Opt. Precision Eng.，2008，16(5)：894-898. (in Chinese) [10]李疆，董景新，刘云峰，等. 预载电压对力平衡微硅加速度计性能的影响[J]. 传感技术学报，2004，23（8）：35-40． LI J, DONG J X, LIU Y F, et al..Effects of preload voltage on performance of force-rebalance micro silicon accelerometer [J]. Journal of Transducer Technology，2008, 23(8)：35-40. (in Chinese) [11]万明亮，张卫平，黄晓刚，等. 基于Sigma-Delta技术的差分电容检测电路设计[J]. 电测与仪表，2007，44（11）：59-61. WANG M L, ZHANG W P, HUANG X G, et al.. Differential capacitance detection circuit design based on the sigma-delta technology [J]. Electrical Measurement & Instrumentation, 2007,44(11):59-61. (in Chinese) [12]RICHARD S. Delta Sigma Toolbox[OL]. File Exchange, 2011. HHUUhttp://www.mathworks.cn/matlabcentral/fileexchange/19-delta-sigma-toolbox.