文章编号 1004-924X(2009)06-1355-06

双质量硅微陀螺仪驱动模态测试

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摘要:考虑双线振动双质量硅微陀螺仪环境适应性强且两个质量块的差动输出能够有效消除共模干扰的影响,提出了一种新型双质量陀螺仪。依据双质量硅微陀螺的结构和工作原理,对该陀螺的驱动模态进行了理论分析,并提出了简化的动力学方程。利用 ANSYS 有限元软件对陀螺的驱动模态进行了数值仿真,并对陀螺仪样品进行了电路测试。通过几种不同的加载方式,分别得到了相应的仿真和测试的幅频曲线,结果表明,仿真和实验结果与理论分析完全一致,且双边驱动方式要优于单边驱动方式,反向驱动方式可以使陀螺仪在工作模态运动。仿真和实验结果验证了双质量硅微陀螺的驱动模态特性。

关 键 词:双质量陀螺;驱动模态;Ansys 仿真;扫频实验

中图分类号:U666.12 **文献标识码**:A

Driving-mode test of dual-mass MEMS gyroscope

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Abstract: A new dual-mass gyro is studied in this paper, for double-linear vibrational dual-mass MEMS gyroscopes are insensitive to the environment, and their differential outputs can effectively suppress the common mode interference. On the basis of the structure and the principle of operation, the driving modal of the dual-mass gyro is analyzed in theory, and the simplified dynamic equations are proposed. Then, the finite element software ANSYS is used to numerically simulate the driving modal, and a driving circuit is used to test the driving modal of a fabricated gyro sample. By using several loading methods in simulations and tests, the amplitude-frequency curves are obtained. These results are in agreement with the theory analysis, which shows that dual-side driving method is better than single-side driving one, and the opposite-direction driving method can drive a dual-mass gyro in working mode. Simulation and experiment results verify the driving-mode characteristics of this dual-mass micro-gyro.

Key words: dual-mass gyroscope; driving-mode; Ansys simulation; scanning frequency experiment

Received date: 2009-01-20; **Revised date**: 2009-05-30.

Foundation item: Supported by the Research Foundation of CPLA General Equipment Department during 11th Five-Year Plan Period (Grant No. 6922002055)

1 Introduction

With development of the micromachining and electronic technologies, MEMS (micro-electro-mechanical system) emerged as requirements of time require and developed rapidly[1]. Silicon micro-machined gyroscope is a kind of MEMS. The working of a single mass gyro can be seriously affected due to the axial acceleration which is a common mode interference and causes the invalidation of the electronic circuits. Dual-mass silicon micro-machined gyroscopes are more practicably than the single-mass ones. They are insensitive to the environment, and the differential output can effectively suppress the common mode interference.

In this paper, a new double-linear oscillation dual-mass gyro is studied. The gyro′s driving-mode is analyzed in theory and simulated by using the finite element software. Finally the fabricated gyro sample is tested to verify the driving-mode characteristic of this dual-mass micro-gyro.

2 Theoretical analysis

2.1 Structure and operating principle

A schematic diagram of the dual-mass MEMS gyroscope is depicted in Fig. 1. This structure uses symmetrical geometry, including anchor, driving electrodes, driving combs, left driving frame, right driving frame, right proof mass, sensing combs and supports, sensing electrodes, and left proof mass[2].

By supplying an alternating voltage between stationary driving electrodes and moving driving electrodes, two proof masses are forced to oscillate in anti-parallel direction along the x-axis. If there is an external angular rate Ω around the z axis, this motion will be translated to the sensing parts and picked up by means of the comb capacitor structure due to their change in capacitance.

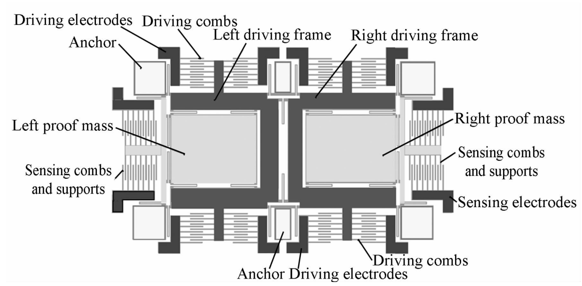
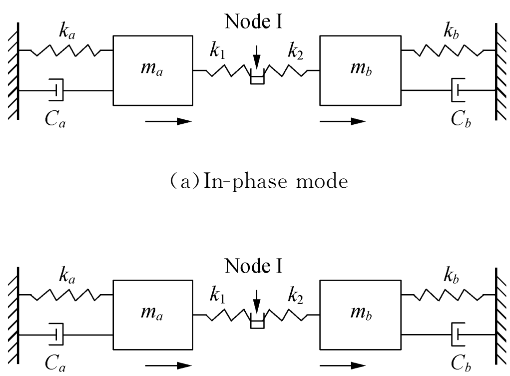


Fig. 1 Schematic structure of the gyro

2.2 Simplified dynamical modal

The dual-mass gyro can be treated as a second-order linear system with multi-degree of freedom[3-4]. The driving part can be simplified as a spring-mass-system (Fig. 2), where m is the mass, k is the spring stiffness, and c is the damping coefficient.



(a) In-phase mode

(b) Reversed-phase mode

Fig. 2 Two oscillation modes of the gyro

Dynamic equations of this second-order spring-mass-system can be expressed as

$$\ddot{x}+2\xi_x\bar{\omega}_x\dot{x}+\bar{\omega}_x^2x=\frac{F_d}{m_a+m_b}\sin(\bar{\omega}_dt) , \quad (1)$$

where $\bar{\omega}_d$ is the driving frequency, $\bar{\omega}_x$ is the natural frequency, ξ_x is the damping ratio, and $F_d\sin(\bar{\omega}_dt)$ is the sinusoidal driving force. This equation has two solutions:

$$\bar{\omega}_{x1}=\sqrt{\frac{k_a+k_b}{m_a+m_b}}, \bar{\omega}_{x2}=\sqrt{\frac{k_a+k_b+k_1+k_2}{m_a+m_b}} , \quad (2)$$

where $\bar{\omega}_{x1}$ is the in-phase mode frequency, and $\bar{\omega}_{x2}$ is the reverse-phase mode frequency. In the driving modal, the micro-gyro has two modes of oscillation: in-phase mode and reversed-phase mode. As for a dual-mass gyro, the gyro needs to work in the reversed-phase mode so that the outputs of the gyro are differential.

3 Simulation and sample test

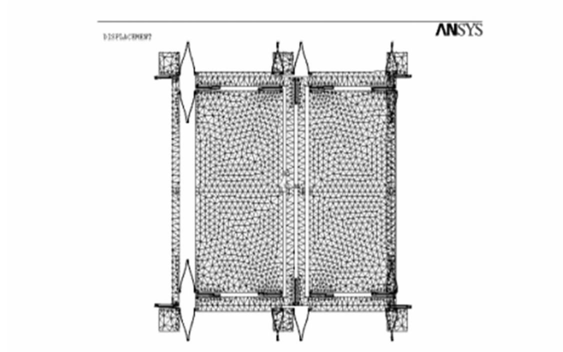
3.1 Harmonic response simulation

Ansys software is a kind of finite element software that can be used to carry out harmonic response simulation. Every periodic load can cause periodic responses for a linear system. The whole structure's responses under a specified frequency will be obtained, or a specified point's response of the structure in a frequency range will be obtained[5-6].

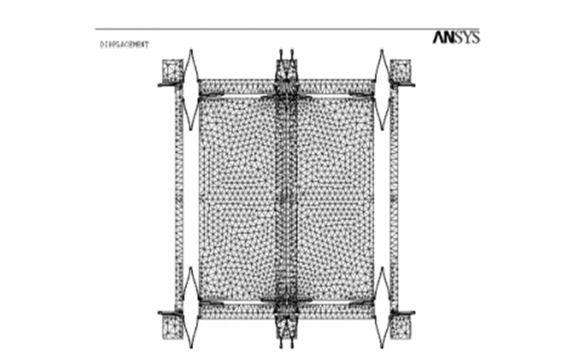
Before carrying out harmonic response simulation, the analytical module of this software should be used in advance, which can find the gyro's two driving-mode frequencies and modal shapes of the gyro (Fig. 3). A simplified structure model is used in this modal simulation. By means of the modal simulation, the in-phase mode (Fig. 3(a)) frequency is 3 040 Hz and the reverse-phase mode (Fig. 3(b)) frequency is 4 080 Hz.

Subsequently, harmonic response simulation is carried out. Point a and b are picked from the model. Three loading methods (Fig. 4) are used to simulate the gyro's three driving methods: single-mass of one-direction, dual-mass of one-direction, and dual-mass of opposite-direction. Harmonic response module of Ansys software is used to get the amplitude-frequency curves at a certain point of the gyro in the selected frequency ranges.

By using the loading methods in Fig. 4, three amplitude-frequency curves (Fig. 5) at a certain point of the gyro are obtained. Fig. 5(a) is the single-mass single-direction driving method, Fig. 5(b) is the dual-mass single-direction drive method, and Fig. 5(c) is the dual-mass reversed drive method.

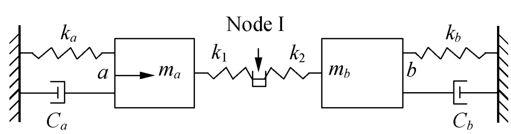


(a) In-phase mode

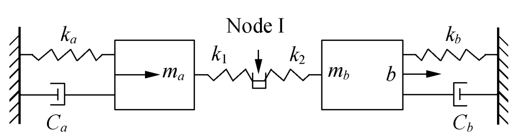


(b) Reversed-phase mode

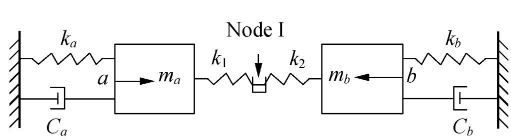
Fig. 3 Modal shapes of the gyro



(a) Single-mass of one-direction

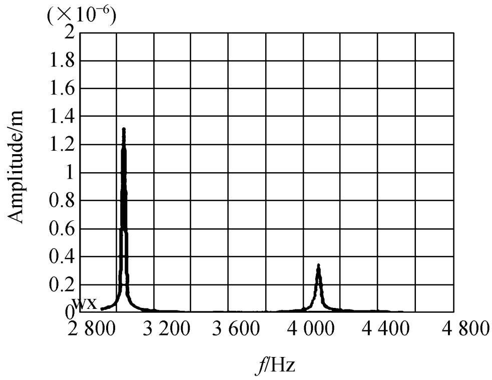


(b) Dual-mass of one-direction

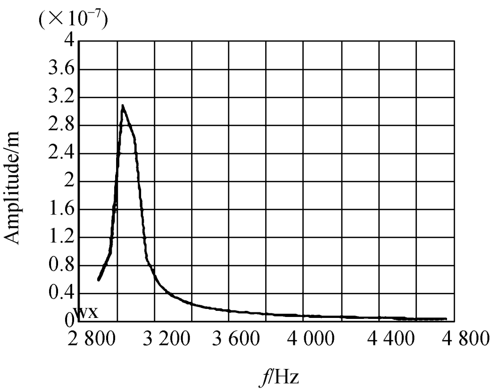


(c) Dual-mass of opposite-direction

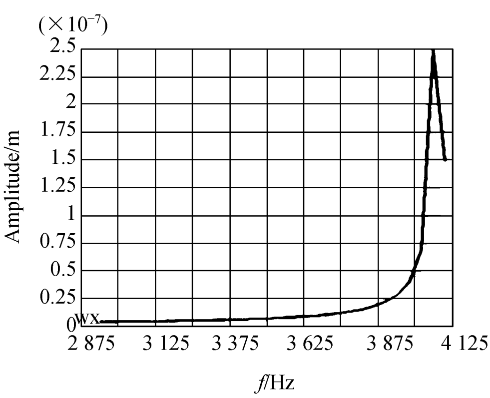
Fig. 4 Three loading methods



(a) Single-mass single-direction driving



(b) Dual-mass single-direction driving

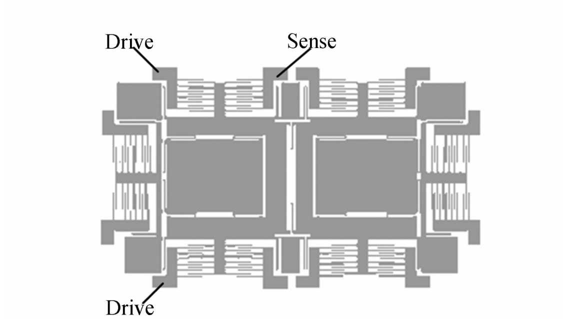


(c) Dual-mass reversed drive

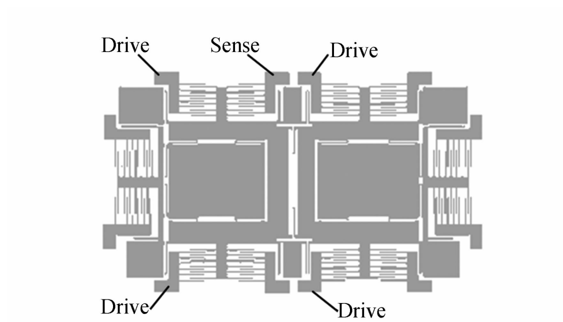
Fig. 5 Amplitude-frequency curves

3.2 Sample test

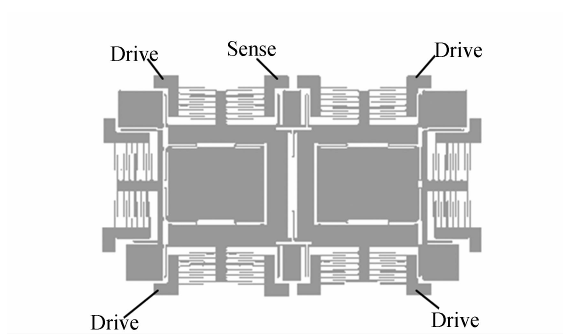
The driving circuit is used to test the driving modal of the fabricated gyro sample[7]. The microstructure is manufactured by silicon bulk micromachining. The scanning frequencies experiments are carried out by using four methods: single-mass of one-side one-direction, dual-mass of one-side one-direction, dual-mass of one-side opposite-direction, and single-mass of dual-side one-direction (Fig. 6).



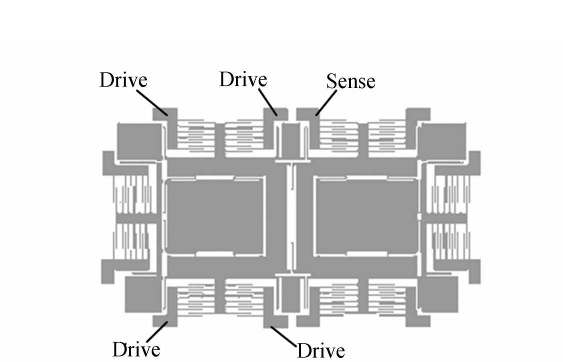
(a) Single-mass of one-side one-direction



(b) Dual-mass of one-side one-direction



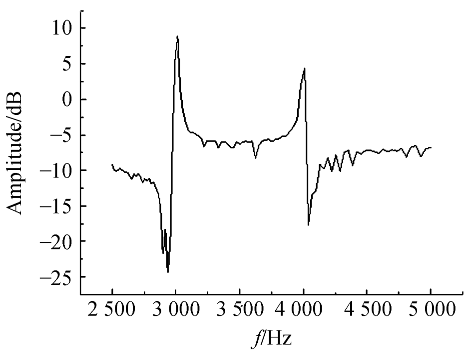
(c) Dual-mass of one-side opposite-direction



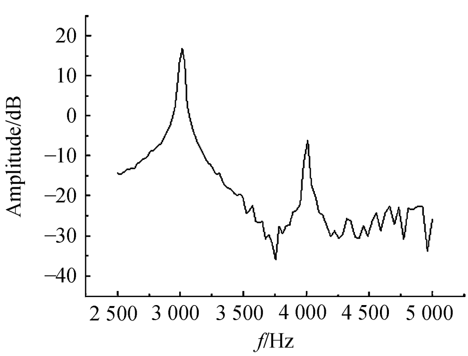
(d) Single-mass of dual-side one-direction

Fig. 6 Schematic diagrams of driving methods

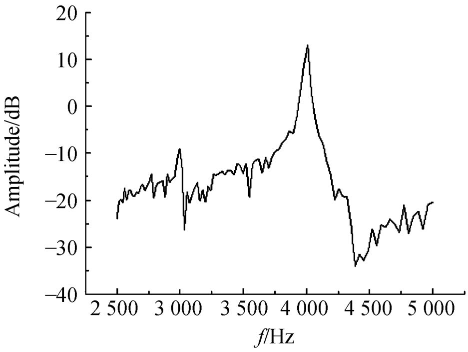
The four amplitude-frequency scanning curves of these experiments (Fig. 7) are obtained by a spectrum analyzer. Fig. 7 (a) was the single-mass of one-side one-direction, Fig. 7(b) is the curve of the dual-mass of one-side one-direction, Fig. 7(c) is that of the dual-mass of one-side opposite-direction, and Fig. 7(d) is that of the single-mass of dual-side one-direction.



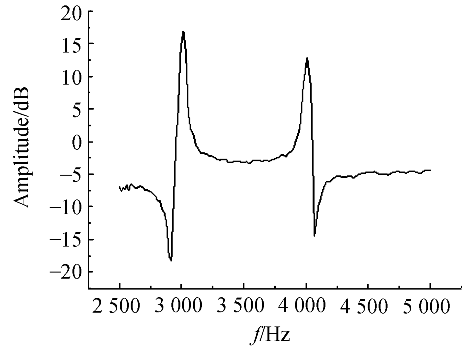
(a) Single-mass of one-side one-direction



(b) Dual-mass of one-side one-direction



(c) Dual-mass of one-side opposite-direction



(d) Single-mass of dual-side one-direction

Fig. 7 Amplitude-frequency curves of scanning experiments

4 Result analysis

The dual-mass micro-gyro has two resonant frequencies that can be seen from these curves (because the Ansys simulation results merely save the amplitudes greater than 0 dB, the two frequencies can only be seen in the single-mass of one-direction simulation result), for the frequencies of in-phase and reversed-phase modes respectively. But for the processing error of silicon micromachining, the frequencies have little differences between the simulative and experimental results. When using different loading and driving methods, the simulation results are agree with the experiments results. Here only the amplitudes vary, and the frequencies keep invariant. The experimental curve gotten by the single-mass of dual-side one-direction method is more smoothly than the one gotten by single-mass of one-side one-direction method. So the dual-side driving method is better than the one-side driving method. From the experiments′ curves gotten by dual-mass of one-side opposite-direction driving method, the amplitude of 3 955 Hz is greater than the amplitude of 3 001 Hz, which can also be seen from the simulation curves gotten by dual-mass of opposite-direction loading method. This curve shows that the sample of gyro oscillationing in reversed-phase mode is just in the working mode.

5 Conclusions

In this paper, simulations and tests are carried out. These results are in reasonable agreement with the theory. From these curves, it can be seen that the dual-side driving method is better than single-side driving method. To drive a dual-mass gyro in working mode, the dual-mass of opposite-direction driving method is useful. Simulation and experiments results verify the characteristic of this dual-mass micro-gyro in the driving-mode.

References:

[1] MASAKO T. An industrial and applied review of new MEMS devices features [J]. *Microelectronic Engineering*, 2007,84(5-8):1341-1344.

[2] YIN Y, WANG SH R, WANG C CH, *et al.*. Structural scheme design and simulation of structure-decoupled dual-mass MEMS gyroscope [J]. *Journal of Southeast University (Natural Science Edition)*, 2008,38(5):918-922. (in Chinese)

[3] ANTONELLO O R, CARBONE R, NUNZI P, *et al.*. Design of a Delta-Sigma bandpass demodulator for a Z-axis MEMS vibrational gyroscope [C]. *Proceedings of the 2005 IEEE/ASME international Conference on Advanced Intelligent Mechatronics, Monterey, California, USA*, 2005:238-242.

[4] CHIOU J A. Process window of micromachined gyroscopes subjected to vibrational frequencies [J]. *Sensors and Actuators A.: Physical*, 2006, 125(2):519-525.

[5] LI J L, FANG J CH, SHEN 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)

[6] LI J M. *Research on high signal-noise ratio of capacitive micromechanical gyroscope* [D]. Taiyuan: North University of China, 2007:127-129. (in Chinese)

[7] WU X ZH, XIAO D B, LI SH Y. Application of auto gain control in micromachined vibratory gyroscope [J]. *Chinese Journal of Sensors and Actuator*, 2006,19(3):790-792.

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