Design of MEMS Vibratory Gyroscopes

Lo Van Hao
Supervisor: Ivanova V. S., Ph.D., Associate Professor
Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk, 634050, Russia
E-mail: lovanhao.pro@gmail.com

Introduction

MEMS (Micro-electro-mechanical Systems) refer to devices or systems integrated with electrical and mechanical components in the scale of microns. Due to them small size, low cost, low power consumption and high efficiency, MEMS technology has been widely used in many fields. MEMS technology is used to make sensors (devices that measure physical and chemical characteristics), actuators (devices that produce displacement, force, or torque), or structures. Historically, MEMS technology has enabled such products as ink jet printing, automotive airbag sensors, automotive tire pressure sensors, medical pressure sensors, digital light processors, acoustic sensors, accelerometers, and gyroscopes. Over the years, MEMS technology has found big applications in automotive industry, biomedical industry, printing and display industry, and portable electronics [6]. In this paper MEMS vibratory gyroscopes, there construction, operating principles, advantages and disadvantages will be considered.

Term "Gyroscope" is attributed to the mid-19th century French physicist Leon Foucault who named his experimental apparatus for Earth's rotation observation by joining two Greek roots: gyros - rotation and skopeein - to see. Traditionally, gyroscopes were mechanical devices that measured the angular rate of rotation. One common use of gyroscopes has been in navigation systems to provide heading estimation [1]. But the traditional gyroscopes are too large and their cost is high. MEMS gyroscopes are quickly replacing conventional gyroscopes in inertial navigation. The reason behind this increasing popularity is, the MEMS gyroscopes are much smaller, lighter, and more reliable and are produced for a fraction of the cost of the conventional gyroscopes [2].

They have been good examples for MEMS commercial products and have made their way into various applications. One of the most common uses for MEMS gyroscopes is spacecraft orientation. In this case gyroscopes are used to sense angular velocity of the spacecraft.

Historical Overview of Vibratory Gyroscope Technologies

In order to discuss MEMS gyroscopes we must first understand gyroscopes in general and what role they play in science. Technically, a gyroscope is any device that can measure angular velocity. As early as the 1700's, spinning devices were being used for sea navigation in foggy conditions. The more traditional spinning gyroscope was invented in the early 1800's, and the French scientist Jean Bernard Leon Foucault coined the term gyroscope in 1852. In the late 1800's and early 1900's gyroscopes were patented for use on ships. Around 1916, the gyroscope found use in aircraft where it is still commonly used today. Throughout the 20th century improvements were made on the spinning gyroscope. In the 1960, optical gyroscopes using lasers were first introduced and soon found commercial success in aeronautics and military applications [3]. Vibratory gyroscopes were demonstrated in the early 1980’s. In the late 1980’s, after successful demonstration of batch fabricated silicon accelerometers, some efforts were initiated to replace quartz with silicon in micro-machined vibratory gyroscopes. Charles Stark Draper Laboratory demonstrated one of the first batch fabricated silicon micro-machined rate gyroscopes in 1991's [4]. In the last ten to twenty years, MEMS gyroscopes have been introduced and advancements have been made to create mass-produced successful products with several advantages over traditional macro-scale devices.

Structure design and principle of operation

The proposed structure of 3-axis Mems vibratory gyroscope is shown on figure 1.

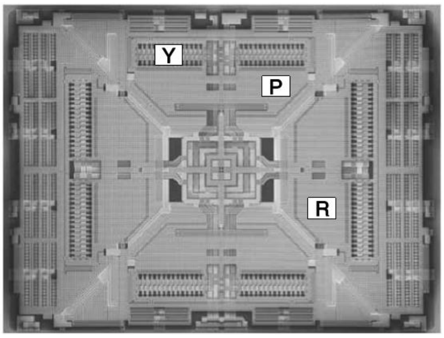

Figure 1- Structure of 3-axis Mems vibratory gyroscope L3G4200D [5]

Designations Y, P and R stand for the sensing masses for yaw pitch and roll modes. The perfect symmetry and the differential approach adopted in the structure design assure a high level of rejection to linear acceleration acting on the sensor (i.e. vibration). The driving mass consists of 4 parts M1, M2, M3 and M4. They move inward and outward simultaneously at a certain frequency in the horizontal plane. When an angular rate is applied on the Z-axis, due to the Coriolis effect M2 and M4 will move in the same horizontal plane in opposite directions as shown by the red and yellow arrows. When an angular rate is applied on the X-axis, then M1 and M3 will move up and down out of the plane due to the Coriolis effect. When an angular rate is applied to the Y-axis, then M2 and M4 will move up and down out of the plane [5].

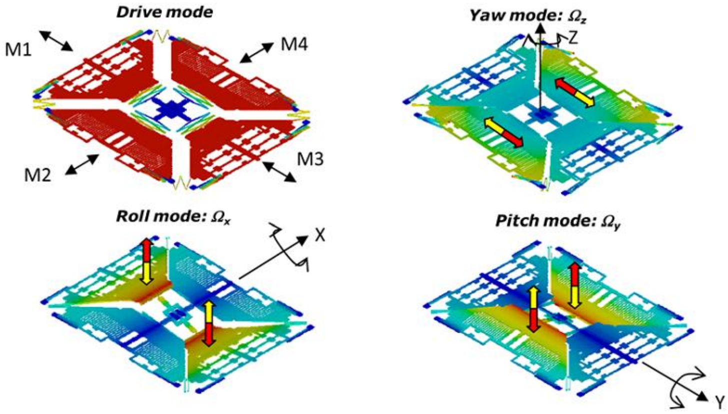

Figure 2- Principle of operation MEMS gyroscope L3G4200D [5]

Roll axis is defined as the Y-axis. Angular rotation along the Y-axis Ωy is called pitch mode which will cause the pitch angle to change. Pitch axis is defined as the X-axis. Angular rotation along the X-axis Ωx is called roll mode which will cause the roll angle to change. Yaw axis is defined as the Z-axis. Angular rotation along the Z-axis Ωz is called yaw mode which will cause the yaw angle to change.

Whenever the Coriolis effect is detected, the continuous movement of the driving mass will cause a capacitance change ΔC which is picked up by the sensing structure and then ΔC is converted to a voltage signal by the internal circuitry. The voltage signal, which is proportional to the applied angular rate, is then converted to 16-bit digital format and stored in the internal data registers. External microprocessors can retrieve gyroscope measurements by accessing these data registers through the I2C or SPI interfaces. When linear acceleration is applied along the X-, Y- or Z-axis, thanks to the differential approach adopted, the driving masses (M1 and M3 or M2 and M4) will move in the same direction which will cause ΔC to be 0. This means that the gyroscope is able to reject linear acceleration such as shock or vibration.

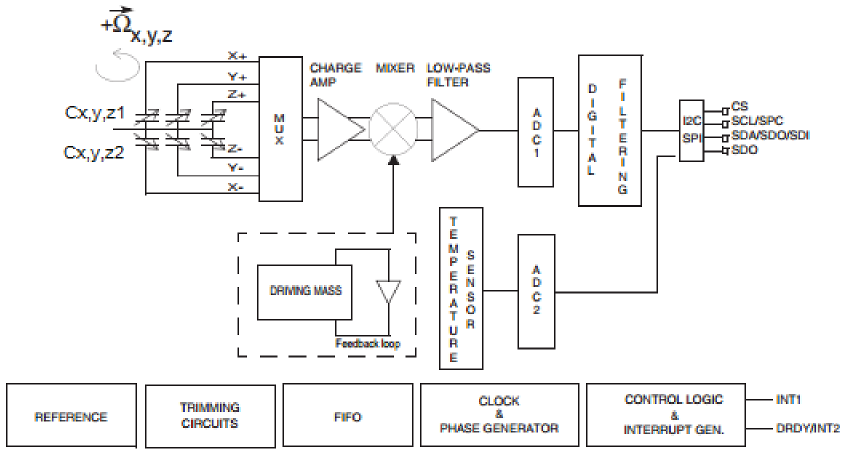

Figure 3- Block diagram MEMS gyroscope L3G4200D [5]

Angular rotation along axis will cause movement of the driving mass and capacitance change ΔCx,y,z. The capacitance change is signal. The sensing signal is filtered and appears as a digital signal after passing through analog-to-digital converter. Digital signal is passed through digital filtering and is sent at the output. In result receive an output signal that is proportional to the capacitance change or angular rotation and rate of rotation.

Advantages and Challenges of MEMS

Main advantage of MEMS gyroscopes is their small sizes**.** It is attractive to many applications because feature sizes are typically as small as 1 centimeter or less. Other advantages include the on-chip integration of electromechanical systems and the circuitry used to control them, allowing further miniaturization. Furthermore, many MEMS fabrication technologies allow parallel fabrication of thousands of systems by leveraging the parallel fabrication techniques of the integrated circuit industry. These may lead to a reduction in the manufacturing cost and improvement in reliability. Like any technology, MEMS gyroscopes present some challenges. Because MEMS gyroscopes or micromechanisms operate at a size scale far below that of typical mechanical devices, surface forces such as adhesion and friction may dominate over other forces in the system, leading to failure of the device. Small sizes of MEMS gyroscopes also make them difficult to interact mechanically with other MEMS components. In addition, packaging of MEMS components has often presented a challenge because each device must be packaged in a way that keeps the components clean and free from contamination, while also allowing mechanical motion and, in many cases, interaction with the environment.

Conclusion

Advances in MEMS technology and processes have led to low-cost, high-performance MEMS gyroscopes with lower power consumption and smaller size, enabling new exciting applications in handheld devices. MEMS gyroscopes are calibrated during the characterization and qualification process. They do not require re-calibration for most applications. However, for complex and demanding applications such as navigation and dead reckoning, re-calibrate the zero-rate level and sensitivity after the gyroscope mounted on the PCB is recommended [7].

MEMS devices have evolved from laboratory curiosities of the 1980s to commercial products of today. If this growth trend continues, MEMS will very likely be the next generation of machinery to service mankind for the next century.

References:

1. Sujit Kumar, B. Hemalatha / Design and Simulation of MEMS Based Gyroscope /India . May. - Jun. 2013. - 7 c.

2. Haifeng Dong, Xingguo Xiong / Design and Analysis of a MEMS Comb Vibratory Gyroscope, 2009. - 12 с.
3. Aaron Burg, Azeem Meruani, Bob Sandheinrich, Michael Wickmann / MEMS gyroscopes and their applications.- 20 с.
4. Mr. Nasiri / A Critical Review of MEMS Gyroscopes Technology and Commercialization Status.- 8с.
5. Everything about STMicroelectronics' 3-axis digital MEMS gyroscopes/ STMicroelectronics, 2010.-40 с.
6. Overview of MEMS - The Art of MEMS [Electronic resource] - URL: http://www.memscentral.com/overview_of_mems.htm
7. Introduction to MEMS gyroscopes, November 15, 2010 [Electronic resources] - URL: http://electroiq.com/blog/2010/11/introduction-to-mems-gyroscopes/.

Welding in Space

Lozhkova K.A.
Supervisor: Troitsky O.Yu., Doctor of Physics and Mathematical Sciences, Professor
Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk, 634050, Russia
E-mail: kris_lozhkova@mail.ru

In the late 50s of this century was born a new branch of human activity – astronautics. This was made known to the whole world the signals of the first Soviet satellite, thereby approving the leading role of our country in space exploration.

Space has delivered a wide range of tasks before and welders : it took radically revise and improve many processes, welding technology to create special light and heat-resistant alloys , develop and master the production of highly reliable automated welding equipment. And in the early 60s on the initiative of the chief designer of space-rocket systems Academician Sergei Korolev was given a brand new task - to explore the possibility of welding directly in space.

When conducting research suggests that welding in space will be used primarily for the following works: a) repair spaceships, space stations and different metal are in space flight or on the Moon and other planets; b) the assembly and installation of steel structures that are in orbital flight or on the surface of the moon and other planets.

It was necessary to develop the techniques and technology of welding works in a fundamentally new for the human environment - the space, the main differences are:

1) Weightlessness;

2) a high vacuum at a high pumping speed (diffusion) of gases and vapors ,

3) a wide range of temperatures at which it may be welded product (approximately 180 to 400 K).

Should take into account a number of additional adverse factors that have a negative impact on the quality of welded joints (extremely limited mobility operator in open space, the complexity of fixation and orientation, the presence of various types of radiation).

Getting the job done, first of all, had from the variety of existing welding methods to select the most promising with regard to the possibility of their use in such unusual circumstances At the same time guided by specific welding evaluation criteria (universality, technology, simplicity, ability to perform cutting), as well as the criteria adopted for space equipment (reliability, safety, low energy consumption, minimal weight and volume. In the early stages of research were selected following welding methods: electron beam, consumable electrode arc, plasma, contact, cold and diffusion.

In electron beam welding and cutting pressure beam and jet vapor pressure of a liquid metal tend to displace the tub from the melting zone. Therefore, it was important to determine whether the molten metal held in the weld or cut cavity at work in weightlessness. Experiments have shown that