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Research of Resonant Frequency and Quality Factor Test Methods for High Vacuum Sealed Microgyroscope Based on LabVIEW

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Abstract

In this paper, we demonstrate an efficient and precise method for measuring the resonant frequency and quality factor of high vacuum sealed microgyroscope based on the free vibration theory with NI platform. A comparison is carried out between the proposed method and the conventional sweep-frequency test method. Experiments indicate that the results obtained by these two methods are nearly the same for the low-Q (<2000) sealed gyroscopes. However, as for the high-Q (>50000) sealed gyroscopes, the consecutive-test-error and test-period of quality factor with sweep-frequency test method and the free vibration test method are about 2000, 10 minutes and 500, 5 seconds, respectively. Furthermore, sweep-frequency method extremely depends on experience while vibration method hardly does. The automatic test method based on vibration theory can much enhance the accuracy and efficiency of the performance test for high vacuum sealed gyroscope.

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Keywords: high vacuum sealed; microgyroscope; quality factor; resonant frequency; LabVIEW.

1. Introduction

Microgyroscopes have tremendous advantages such as miniature size, low weight, and batch production etc. However, the precision and stability of these devices can be easily affected by the materials, fabrication error, working condition and so on. In order to enhance the performance of the gyro system, the role of packaging becomes increasingly important [1-4]. Vacuum packaging is one of the most

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important steps for protecting the fragile mechanical components from the environment and advancing signal-to-noise ratio [5-7].

However, it is difficult to test the resonant frequency and quality factor of high vacuum sealed gyros accurately because of the limited abilities of some equipments and test methods. Since these measurements are so important for picking out excellent gyros, it is imperative to develop an efficient and precise test system. This paper achieves two test systems based on sweep-frequency method and free vibration method respectively with NI hardware and software platform, and makes a detailed comparison of them.

2. Measurement theories

2.1 sweep-frequency test theory

Sweep-frequency test is a frequency-domain test method. When the driving input is IN(s) and the response output of the gyroscope system is OUT(s)， then the amplitude-frequency response and phase-frequency response can be calculated by the following formula:

$$H(s) = OUT(s) / IN(s) \tag{1}$$

2.2 free vibration test theory

Free vibration test is a time domain test method. Fig.1 (a) shows the simplified model of gyros. The driving mass is driven vibrating in X axis direction, and an induced Coriolis force will make the sensing mass vibrating in Y axis direction if there is an external angular rate input from Z axis direction.

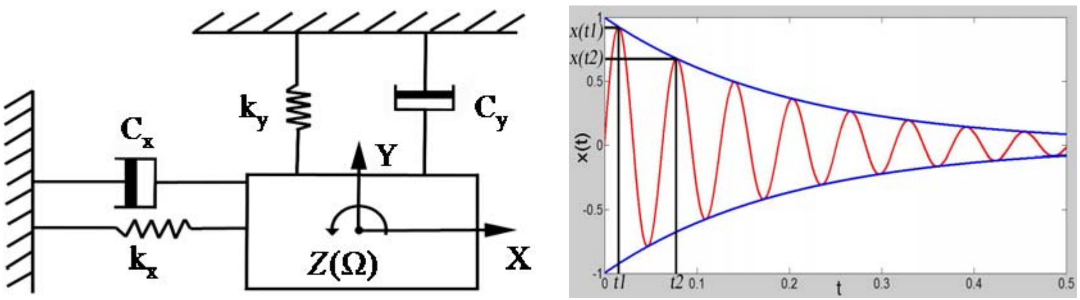


Fig.1 (a) A simplified model of gyros; (b) Time domain response *of underdamped free vibration*

Assume the driving force is $F_d = F_0 \sin(\omega_d t)$, then*,* the dynamic equation of the driving mode is given by:

$$m_x \ddot{x}(t) + c_x \dot{x}(t) + k_x x(t) = F_0 \sin(\omega_d t) \tag{2}$$

Where, m_x、k_x、c_x are mass, stiffness and damping coefficient of the drive mode, respectively. The solution of equation *(2)* can be written as:

$$x(t) = A_x e^{-\omega_x t/(2Q_x)} \sin(\sqrt{1 - \frac{1}{4Q_x^2}}\omega_x t + \alpha) + B_x \sin(\omega_d t - \varphi_x) \tag{3}$$

When the gyroscope works in the steady state, the solution is:

$$x(t) = B_x \sin(\omega_d t - \varphi_x) \tag{4}$$

After removing the excitation source, the gyroscope will make an underdamped free vibration:

$$x(t) = A_x e^{-\omega_x t/(2Q_x)} \sin(\sqrt{1-\frac{1}{4Q_x^2}}\omega_x t + \alpha) \tag{5}$$

Fig1.(b) shows the underdamped free vibration curve. All peaks and valleys coordinates can be obtained by peak-detection technology. Now that the period can be calculated with the time interval between these peaks, the resonant frequency can be also calculated:

$$\omega_0 = \sqrt{1-\frac{1}{4Q_x^2}}\omega_x = \frac{1}{2\pi T} = \frac{1}{2\pi\left|t_2 - t_1\right|} \tag{6}$$

Since the quality factor (Q) is very big, so we can regard ω_0 as ω_x. After exponential function fit with these peaks (or valleys), we can obtain the decay factor: $\sigma = \frac{\omega_x}{2Q_x}$， then quality factor is： $Q_x = \frac{\omega_x}{2\sigma}$.

3. **Experimental test and analysis**

3.1 test platform

Test platform mainly includes probe table, NI PXI data acquisition card and LabVIEW software. The self-developed LabVIEW test software can not only automatically calculate the resonant frequency and quality factor, but also make the frequency-response analysis, harmonic analysis and FFT noise analysis and so on.

During the experiment, the proposed test method is applied to two separated gyroscope: #1 gyroscope (quality factor is less than 1000) and #2 gyroscope (quality factor is greater than 50000).

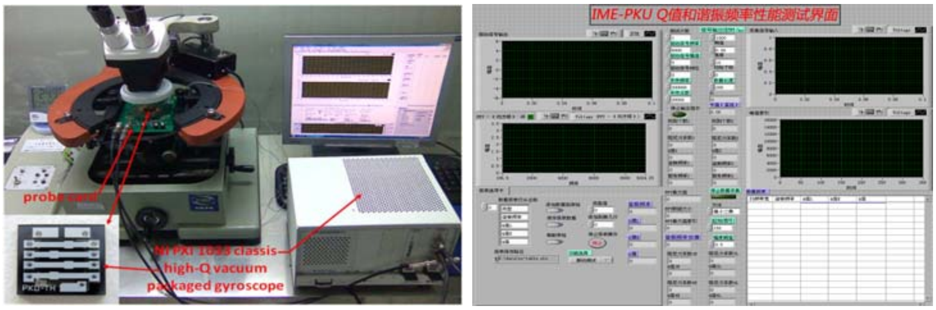


Fig.3 (a) Gyroscope test platform ; (b) Self-developed LabVIEW vibration test software interface

3.2 low-Q #1 gyroscope test and analysis

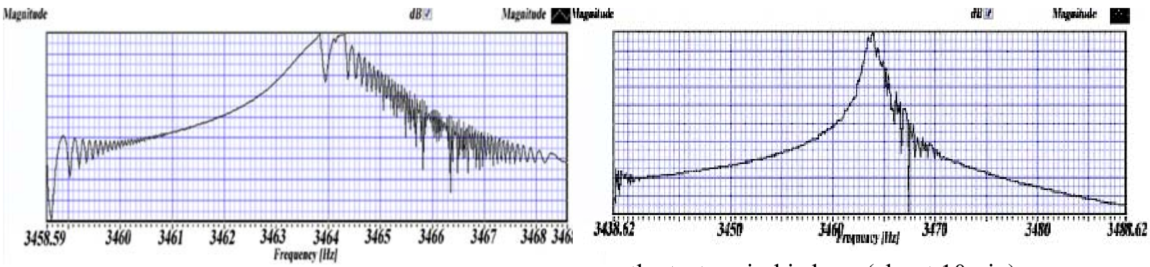
As for low-Q #1 gyroscope, the resonant frequency, Q-value and test period are 3303Hz, 900, 1min tested by sweep-frequency method, while they are respectively 3303Hz, 901 and 5s tested by free vibration method. Therefore, it demonstrates that as for low-Q gyroscope, the results tested by these two methods are nearly the same, but the test time of the latter is smaller than that of the former.

3.3 high-Q #2 gyroscope test and analysis

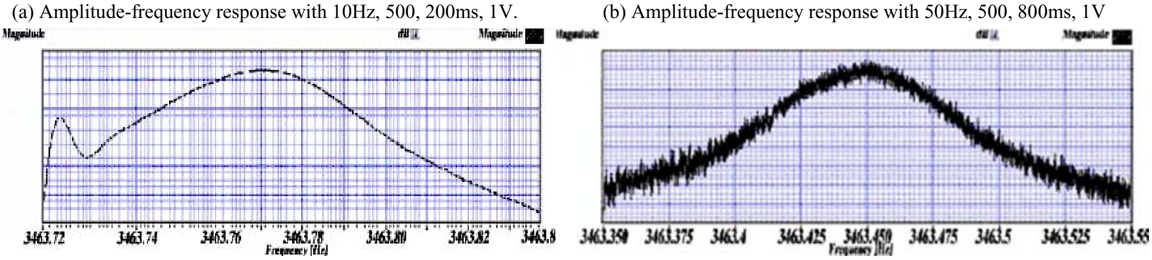
3.3.1 sweep-frequency method

As for low-Q gyroscopes, it's hard to get a good response curve when the Q-value (i.e. #2 gyroscope's) arrives to several tens of thousands. In fig.4 (a), we can see that there are oscillations on the right of the resonant frequency, because the block time (200ms) of every sweep-frequency point is too short and the driving voltage is big enough for a violent vibration, the latter frequency driving source is started before the former damping motion is stopped. In fig.4 (b) we can improve the oscillation when the block time is set 800ms, however, it is at the cost of sweeping time and it is still hard to calculate the resonant frequency and Q-value. Simultaneously, the phenomenon can be improved by reducing the driving voltage. Experimental results figure out that sweeping bandwidth, sweeping points, block time and AC driving voltage are the main parameters affecting the results.

In fig.4 (a), the sweeping bandwidth, sweeping points, block time and AC driving voltage are respectively set 10Hz, 500, 200ms and 1V. It is obvious that the oscillation is suppressed in fig.4 (c) if these parameters respectively are 0.12Hz, 1000, 800ms and 1mV. The resonant frequency and Q-value can be calculated with the curve, namely 3463.77Hz and 71162. Repeating two more tests, the resonant frequency are still 3463.77Hz while the Q-value are 69792 and 70143, and the consecutive-test-error is within 2000. From fig.4 (d), we can see that the noise will be big enough to make a big effect on the measurement if the AC driving voltage is very small, such as 10uV. The Q-value reaches 93030. Therefore, as for high vacuum sealed gyroscope, sweep-frequency method much relies on experience and the test period is long (about 10min).



(a) Amplitude-frequency response with 10Hz, 500, 200ms, 1V. (b) Amplitude-frequency response with 50Hz, 500, 800ms, 1V



(c) Amplitude-frequency response with 0.12Hz, 1000, 800ms, 1mV. (d) Amplitude-frequency response with 0.12Hz, 1000, 800ms, 10uV.

Fig.4 high vacuum encapsulation #2 gyroscope sweep-frequency test

3.3.2 free vibration method

According to the vibration theory introduced in 2.2 section, we can make a free vibration test for high-Q #2 gyroscope. From the underdamped free vibration curve in fig.5, the resonant frequency and Q-value are calculated automatically to be 3463.66Hz and 66272. Repeating two more test, the Q-value are respectively 66645 and 66717. The consecutive-test-error is within 500, which is smaller than that of sweep-frequency test. Free vibration test hardly depend on experience because it is no need to adjust the sweeping bandwidth, sweeping points, block time and AC driving voltage. It can reduce the test time down to about 5s because it just needs a little section of response datum for calculation.

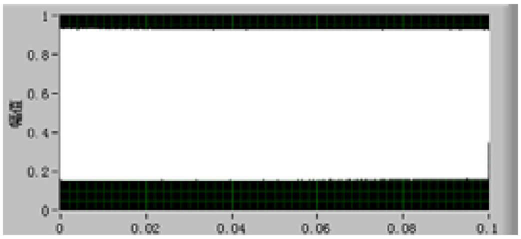


Fig.5 High vacuum sealed #2gyrocope vibration test

3.4 comparisons between the two test methods

As for high-Q gyroscope performance test, the advantage of sweep-frequency method is that it can get the frequency response and help to make the mode analysis. However, free vibration method is superior to sweep-frequency method when it comes to the test period, consecutive-test-error and experience-dependence.

4. Conclusion

In this paper, we introduce sweep-frequency theory and free vibration theory for the test of resonant frequency and quality factor, and then realize these two test systems based on NI platform. Experimental results demonstrate that the results tested by these two methods are nearly the same as for low-Q (<2000) gyroscopes. However, as for high-Q (>50000) gyroscopes, the consecutive-test-error and test-period of quality value are about 2000 and 10min using sweep-frequency test method while they are respectively 500 and 5s using vibration test method. Furthermore, sweep-frequency method extremely depends on experience while vibration method hardly does. In conclusion, the automatic test method based on free vibration theory can much enhance the accuracy and efficiency of the performance test for high vacuum sealed gyroscope.

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