A resonant micro-cantilever frequency tracking system based on dynamic phase difference

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***Abstract*—Gravimetric system based on resonant micro-cantilever had drawn significant attention in trace material detection. Adsorption quantity could be measured by the change of cantilever's resonant frequency, and phase-locked loop (PLL) was commonly used to keep the cantilever resonating. However, in the application of traditional PLL, we have to adjust parameters of the phase shifter to make sure the locked frequency matching with the cantilever's resonant frequency. In this manuscript, we promoted a frequency tracking system based on software phase-locked loop. Locked phase was calculated automatically, so the system could match with cantilevers of different resonant frequency, and no adjusting is need anymore. This system could combine with instruments based on frequency tracking and detection easily, not only limited to resonant cantilevers.**

Keywords—frequency track; cantilever; phase-locked loop; trace detection; MEMS

I. Introduction

In many applications, the detection has to face formidable challenges due to the rather low concentration of target molecules and environment interference. So trace detection methodologies and instrumentations have been developed remarkably in recent years due to the necessity of solving safety problems in various fields, such as explosive component, food safety, heavy metal pollution, etc. However, most of these commercial analytical devices, such as mass spectrometry, are rather expensive, bulky, complex, inefficiency and require skilled technicians. Because of these limitations, intelligent system that features ultrafine resolution, high selectivity, miniature, and low-cost batch fabrication are urgently demanded[1~4]. Quite a lot of efforts have been made in exploring innovative detection system to fulfill the application demands.

Among all these researches, gravimetric system based on resonant micro-cantilever had drawn significant attention. The cantilever is functioned with a chemical sensing layer which could absorb the determinand, in such a way that the value of the quantity can be derived by the shift of the resonant frequency. Many achievements in cantilever geometry optimization and chemical reactant selection have been obtained, however fewer work on improving the interface circuit and analytic system have been done[5~9]. Commonly, the major component of the interface circuit is phase-locked loops, which consists of phase detector, operation amplifier, loop filter, phase shifter, voltage controlled oscillator, and etc. But there is one crucial problem that, the phase difference between the two input signals of the phase detector is usually fixed in design, while the phase offset of operation amplifier and loop filter change with the frequency of the signal. So if the sensor is replaced by an alternate one with different resonant frequency, the phase-locked loops would not work properly. The phase shifter circuit needs to be tuned by highly skilled technicians with sophisticated instrumentations to meet the requirement of closed-loop self-excitation again[10~14]. It is quite inconvenient during the research work and also limits the appliance of trace detection instrumentation in daily life.

A novel system based on dynamic phase difference had been developed recently, and we are eager to exhibit it to our peers in this manuscript. Every time the system starts up, the phase difference to be locked is dynamically calculated by advanced signal processing. Even if the sensor was replaced or the environment condition changed, the system could work precisely without adjustment.

II. System Description

A. Principles

The schematic diagram of the system was illustrated in Figure 1, and it was comprised of computer, multifunctional data acquisition device, direct digital synthesizer, resonant cantilever, operational amplifier and loop filter. Signals were acquired and analyzed by the computer with cross-power spectrum algorithm to calculate the phase difference α between the response signal and the driving signal of the cantilever.

When the cantilever is driven at its resonant frequency f_0, the phase difference α is equal to 90°. After the cantilever absorbs molecular, the mass increases and the resonant frequency changes to f_1. But if the frequency of the driving signal is still set as f_0, then α will no longer be equal to 90°. The computer increase the frequency of the driving signal and calculate the phase difference α, until it is equal to 90° again, then the cantilever is back to resonation status. Absorption quantity could be calculated by $\Delta f = f_0 - f_1$ with calibrated mass sensitivity of the cantilever.

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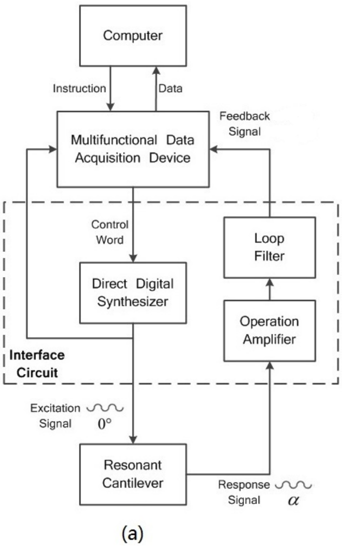

Fig. 1 Schematic Diagram of the System.

B. *Components*

The system is consist of four main components: the sensor, multifunctional data acquisition device, interface circuit and the computer. The sensor was made by our research group in 2011, used for explosive trace detection. Fig.2 (a) shows the FE-SEM image of the integrated silicon resonant micro-cantilever that is loaded with the HFIP-functionalized mesoporous silica. (b) shows the Multifunctional Data Acquisition Device USB-6366 provided by National Instruments Corp, which is able to acquire the multiple channels signal at two million samples per second synchronously (c) illustrates the interface circuit and the reaction cavity developed by our research team. The interface circuit includes sinusoidal signal generator to drive the cantilever and instrumentation amplification to enhance the response signal before been acquired. The reaction cavity provided an environment filled with relatively stable vapor to be tested. (d) displays the User Interface of the system, which exhibit the instant signal of feedback signal, the amplitude-frequency graph, the phrase-frequency graph, the real-time frequency of the micro-cantilever, and some other informations.

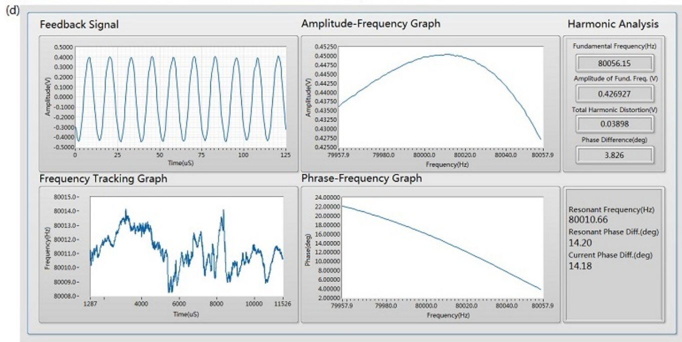

Fig. 2 Components of the system.
(a) Sensor, (b) Multifunctional data acquisition device,
(c) Interface Circuit, (d) User Interface of the system.
Experiments and Results

C. *System sensitivity testing*

We detect TNT with the system developed, and study the sensitivity of the system. Fig. 3(a) shows the binding progress of TNT and HFIP-functionalized mesoporous silica. Fig. 3(b) plots the sensing response of the HFMS-functionalized resonant cantilever to ultralow concentrations TNT vapor. When 45 ppt TNT vapor is introduced by injection into the testing chamber where the sensor is located, about 2.6 Hz frequency drop is observed that is about 13 times of the 0.2 Hz noise grade (see Fig. 3(c)). Fig. 3(d) shows one experiment we did in the reaction cavity showed in Fig. 2(c).

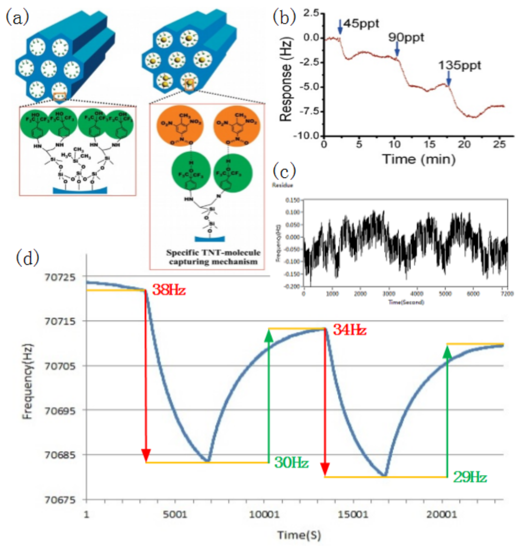

Fig. 3 System sensitivity testing (a) binding progress, (b) sensing response of the cantilever, (c) noise grade, (d) testing result in reaction cavity

CONCLUSION

This study illustrates the system we developed for frequency tracking based on software phase-locked loop, and the noise grade is about 0.2Hz in application field. Locked phase was calculated automatically, so the system could match with cantilevers of different resonant frequency. Even if the sensor was replaced or the environment condition changed, the system could work precisely without any adjustment needed. The application is not only limited to resonant cantilevers, but also many other measuring instruments which are based on frequency detection.

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