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Robust Optical Detection Method for the Vibrational Mode of a Tuning Fork Crystal Oscillator

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Abstract

We present an optical detection method for the fundamental vibrational mode of a tuning fork crystal oscillator in air. A focused He/Ne laser beam is directed onto the edge of one vibrating tine of the tuning fork; its vibrating motion chops the incoming laser beam and modulates the intensity. The beam with modulated intensity is then detected and converted to an electrical signal by a high-speed photo-detector. This electrical signal is a sinusoid at the resonant frequency of the tuning fork vibration, which is 32.76 kHz. Our scheme is robust enough that the sinusoidal signal is detectable at up to 40° of rotation of the tuning fork.

Keywords: Optical detection, Vibrational mode, Tuning fork crystal oscillator, Sensors

1. INTRODUCTION

Detection of the mechanical motions of purpose-designed artificial structures is of great importance in diverse areas of science and engineering [1-5]. Among such structures, the tuning fork is a popular basis of diagnostic techniques, partly as a result of its high quality factor and narrow resonances. Currently, detection methods for the fundamental mode of commercially-available tuning fork crystal oscillators are under extensive investigation for sensor applications. Resonant-frequency changes are a primary means of detecting specific input stimuli, using frequency modulation schemes. Consequently, detection of the resonant oscillation is of utmost importance in these applications. Both optical and electrical detection methods have been successfully applied. Among the optical techniques, for example, an interferometric method utilizing phase modulation between the two light paths has been used to detect not only the fundamental but also the higher harmonic modes [6]. It has been successfully shown that an electrical method that measures frequency-response characteristics can also detect the vibrational mode [7]. Depending on the requirements of the application, either type of detection scheme can be used. Here, we present a simple and robust optical detection scheme that relies on amplitude modulation of the laser beam intensity when it impinges on one tine of the tuning fork crystal oscillator. Here, we present a simple and robust optical detection scheme that relies on amplitude modulation of the laser beam intensity when it impinges on one tine of the tuning fork crystal oscillator.

2. EXPERIMENTAL SETUP

The measurement setup for the optical detection method is shown in Fig. 1. It consists of a He-Ne laser, 10X beam expander, focusing lens, high-speed photo-detector, and tuning fork crystal oscillator mounted on a manual stage that scans in the XYZR

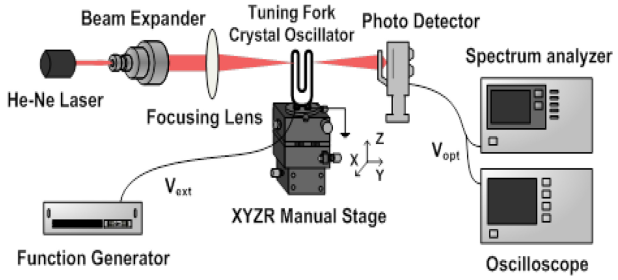

Fig. 1. Measurement setup, consisting of a He-Ne laser, beam expander, focusing lens, high-speed photo-detector, and tuning fork crystal oscillator mounted on an XYZR manual stage. A function generator is used to apply an excitation signal, and a spectrum analyzer and an oscilloscope are for recording the outputs.

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directions for alignment and movement. A function generator is used to apply excitation voltage to the oscillator, and an oscilloscope and a spectrum analyzer are used to measure the photo-detector signal. The tuning fork crystal oscillator (CH-308, 32.768 kHz; Sunny Electronics) is excited with a sinusoidal voltage waveform from the function generator. A 20 mW He-Ne laser beam (λ=623.8 nm) is expanded by the beam expander and subsequently focused on the edge of one of the vibrating tines of the tuning fork crystal oscillator. The beam diameter at the fork is 0.3 mm. The vibrating tine chops and partially blocks the incoming focused laser beam, which modulates the beam intensity. The modulated beam is then detected by the high-speed photo-detector, which has a bandwidth of 60 MHz. For low signal levels, the converted AC electrical signal is saved in the oscilloscope or spectrum analyzer.

3. RESULTS AND DISCUSSIONS

In Fig. 2(a), we show a typical measured optical response obtained using our measurement setup. Excitation was a 500 mV_{rms} sine wave from the function generator at the oscillator resonant frequency of 32.76 kHz. The output response was optimized by adjusting the position and orientation of the tuning fork crystal oscillator with the XYZR manual stage. The output voltage signal from the photo-detector clearly exhibited the same frequency as the excitation waveform.

In order to investigate the response linearity, we varied the amplitude of the sinusoidal excitation signal from 100 to 800 mV_{rms} with a step size of 50 mV_{rms}. Fig. 2(b) shows the measurement results. The amplitude of the photo-detector output increased linearly with excitation input. Error bars were deduced from the least-squares fit to the output signals and were smaller than the size of the graph symbols; they represent the noise level in our system. The results clearly show that the system response is linear up to an excitation voltage of 800 mV_{rms}.

In Fig. 3, we show the change in photo-detector response from moving the beam through a distance of 3 mm from the end of the tuning fork tine toward its base. This was done in order to verify excitation of the fundamental mode. We again applied excitation voltages of 300, 500, and 700 mV_{rms}, this time to verify the linearity as a function of position on the tine. The maximum amplitude of the optical output is slightly offset from the end for all three traces. This can be attributed to the electrode shape of the tuning fork crystal oscillator. The scanning electron microscope (SEM) picture of the metal electrode is shown in the top-right inset. It does not accurately represent the end of the tine, showing a reflectivity change as the SEM beam moves from the bare quartz onto the metal electrode near the end. After passing the maximum optical response, the amplitude of the optical response

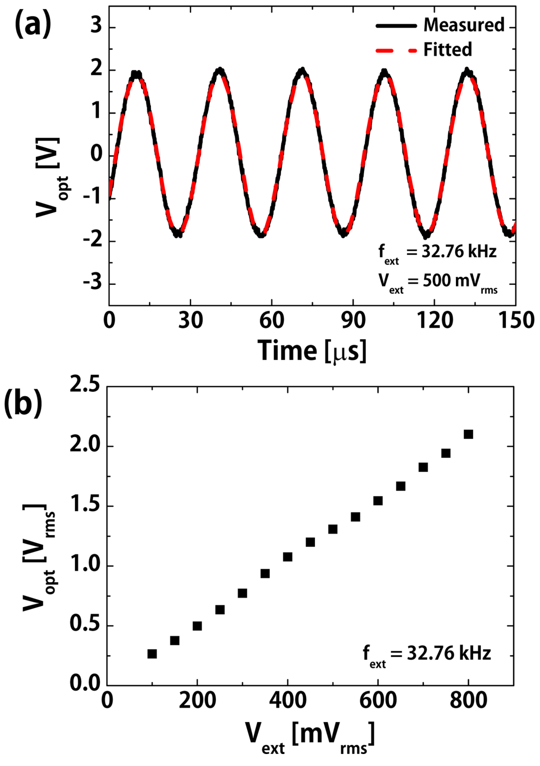

Fig. 2. (a) A typical photo-detector output signal; oscillator excitation was a 500 mV_{rms} sine wave from the function generator at 32.76 kHz. A dashed-line represents the least-squares fit. (b) Photo-detector output signal as a function of excitation, which ranged from 100 to 800 mV_{rms} in steps of 50 mV_{rms}. The output is clearly in the linear regime. Errors do not exceed the size of the graph symbols.

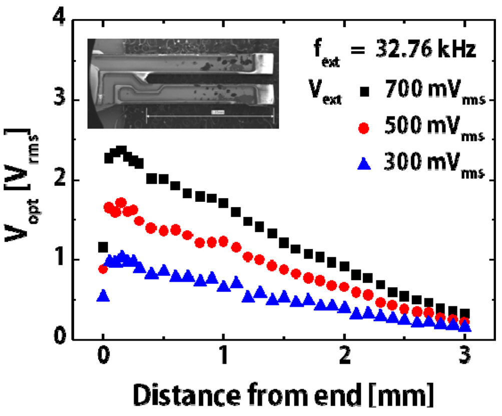

Fig. 3. Photo-detector output for the fundamental mode at 32.76 kHz as a function of distance from the end of the tine, for excitations of 300, 500, and 700 mV_{rms}. The inset shows a scanning electron microscope (SEM) image of a tuning fork crystal oscillator of the same kind.

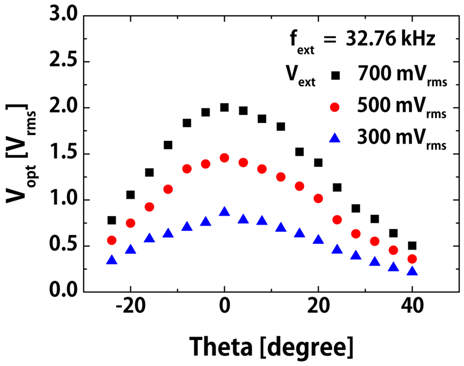

Fig. 4. Photo-detector output signal for the fundamental mode of 32.76 kHz, as a function of rotation angle and excitation voltage.

decreases continuously [6]. Small deviations from the smooth decrease are believed to be caused by electrode shape irregularities. The monotonic amplitude decrease implies the fundamental mode of vibration.

In order to show the robustness of our setup, we measured the optical response as a function of the rotational angle of the tuning fork crystal oscillator in the XY plane and the excitation voltage from the function generator. The angle ranged from -24 to 40° and the voltage from 300 to 700 mV$_{rms}$. The results are shown in Fig. 4. They are symmetric with respect to 0° and roughly follow a cosine curve, as expected. Although the response decreased monotonically as the angle increased from 0°, it was still detectable up to 40°. This characteristic results from the particular properties of amplitude modulation. Compared to phase modulation schemes, a slight misalignment in optical setup in the amplitude modulation scheme would not significantly degrade the optical response. Thus, in harsh measurement conditions where misalignments can occur, it would be advantageous to adopt an amplitude modulation scheme.

4. CONCLUSIONS

A relatively simple and robust optical detection method for the vibration modes of a tuning fork crystal oscillator has been presented. The method is based on amplitude modulation of a laser beam's intensity by the chopping action of the vibrating tine of a tuning fork crystal oscillator. Using this method, we successfully detected the fundamental mode at 32.76 kHz even when the beam was focused near the base of the tine of the crystal oscillator. Our setup was robust enough that the output signal survived despite rotation of the tuning fork crystal oscillator up to 40°. Our scheme would be suitable for applications where immunity to misalignments is desirable.

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