Noncontact Vibrometer Based on the Fibre Optical Michelson Interferometer

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Abstract. *Research results of designing a vibrometer based on the state-of-the-art circuitry are presented. An interferometric scheme sensitive to the distance to an object based on the Michelson interferometer is used. A quadrature interferometric signal is received by laser pumping current modulation and further signal filtering. Object surface displacement signals as a result of experimental measurements and processing of the data obtained signals of an object's surface displacement are recovered for the vibration mode with the preset frequency and amplitude. The surface vibration frequency corresponds to the generator signal frequency (30 Hz), with the amplitude of the investigated point being equal to 4 ± 0.05 µm. A random displacement amplitude equals 0.3 µm when signal is absent. It is revealed that the vibrometer setup can detect quadrature interferometric signals and recover surface displacements of vibration objects. Further research on the proposed setup as well as on improving its accuracy characteristics and bringing it to a prototype are planned.*

Keywords: Michelson Interferometer, Vibration, Quadrature Signal, Fibre Optics

1. Introduction

Measurement and inspection of vibrations are used in various fields such as microelectronics, mechanical engineering, railroad industry, aircraft construction, etc. [1]

The measuring devices must ensure noncontact method, high resolution (10…100 nm), long distance to the object (up to 10 m) and high frequency surface vibrations (1…10 kHz).

Potentially the optical methods meet all these requirements. Design of these devices is on the modern technologies edge. However, the leading experts don't publish the schemes, algorithms and methods details of their developments. Moreover, the foreign devices are enough expensive. But modern fiber optical components are of low cost and rather reliable. It allows us assembling the vibrometer optical scheme, for example, based on the structurally simple Michelson interferometer scheme by the unified blocks.

The aim of this work is to design amplitude vibrometer and its characteristic research.

2. Measuring Method and Vibrometer Scheme

This method is based on the Michelson interferometer scheme [2] which is sensitive to the distance between device and object. Resulting intensity on an interferometer photodetector is described by the equation:

$$I(L) = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(2kL), \qquad (1)$$

where

I	the signal intensity on a photodetector
I_1	the intensity signal of the first interferometer arm
I_2	the intensity signal of the second interferometer arm
k	the wave number
L	distance from vibrometer to the object.

Because the distance from the object surface to vibrometer can both increase and decrease the quadrature addition of interferometric signal is required [3], i.e. signals pair

$$x(L) \sim \cos(2kL), \tag{2}$$

$$y(L) \sim \sin(2kL), \tag{3}$$

where

x	interferometric signal
y	quadrature addition.

This problem can be solved using lasers with tunable wavelength (e.g. DFB Lasers [4]), frequency modulation and signal filtering [5].

The scheme presented in Fig. 1 is based on the fibre-optical Michelson interferometer.

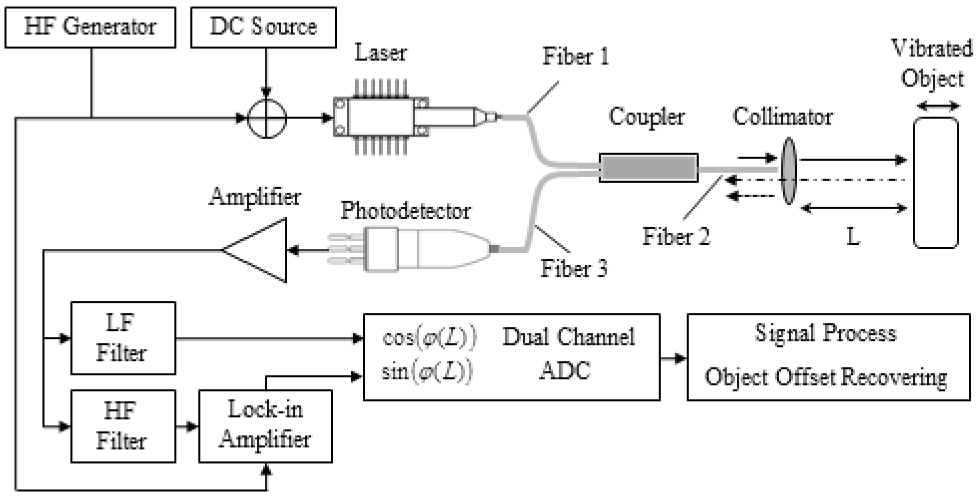

Fig. 1. The fibre-optical vibrometer general scheme.

Vibrometer operation is the following. Laser radiation propagates through Fiber 1, Coupler and Fiber 2 to butt of Fiber 2. After that the radiation is separated on 2 directions: part of it is collimated, followed to the object (solid line), reflected from this object (dash-dotted line) and entered to Fiber 2. Another part of radiation is reflected from butt (dotted line). Then these parts interfere on photodetector.

But as mentioned above quadrature signal should be received. Therefore the laser is supplied by summation of operation current from DC Source and a bit modulation current from HF generator. Due to modulation the laser generates the optical radiation with variable wavelength.

Thus the interferometric signal on a photodetector consists of a low-frequency part proportional to cosine of phase difference (2) and a high-frequency part proportional to sine of phase difference (3) after synchronous detection. Then LF and HF filters separate the original signal into two components [6]. After that the resulting signal are digitized for its further processing and analyzing to surface displacement recovering.

3. Experimental Research

Setup presented in Fig. 2 was assembled for carrying out the vibration measurement experiments. The setup consists of the fibre-optical interferometric scheme with fiber SMF-28e [7] and fibre-optical coupler Thorlabs 10202A-50-FC) [8], DFB Laser FITEL FRL15DCWD-A81 (wavelength 1550 nm) [9], collimator F810FC-1550 [10], photodetector with amplifier scheme, electronic scheme (including PC sound card with sampling frequency 44 kHz) and low-noise power supply (battery 12 V).

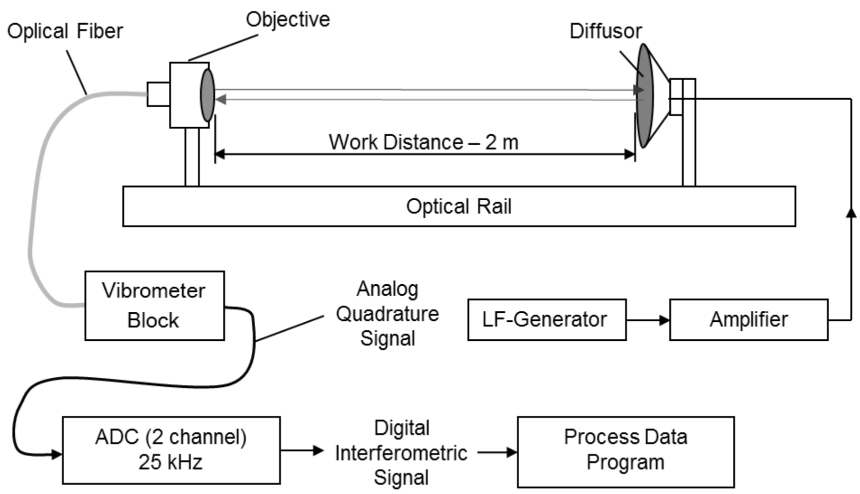

Fig. 2. Experimental setup of the vibrometer.

Two operating modes were used for carrying out experiments.

Object vibration mode with preset frequency and amplitude. The sine signal is supplied to the speaker coil with frequency equals to 30 Hz.

No signal mode of LF Generator. There isn't current to the speaker coil.

4. Results

Quadrature signal and the fragment of surface displacement recovered signal in the first mode are presented in Fig. 3 a, b.

As follows from the process physics the interferential picture is variable due to the distance changing. Surface vibration frequency corresponds to the generator signal frequency and amplitude in useful point equals to 4 ± 0.05 μm (confidence level equals to 0.95).

Quadrature signal and the fragment of surface displacement recovered signal in no signal mode are presented in Fig. 3 c, d. However, interferometric signal and its quadrature addition are variable. There is surface vibration due to diffusor own fluctuations and mechanical setup vibrations. Random displacements estimation is equal to 0.3 ± 0.05 μm.

Obviously that there is natural vibration in both modes but it is visible poorly due to high useful signal level in first mode.

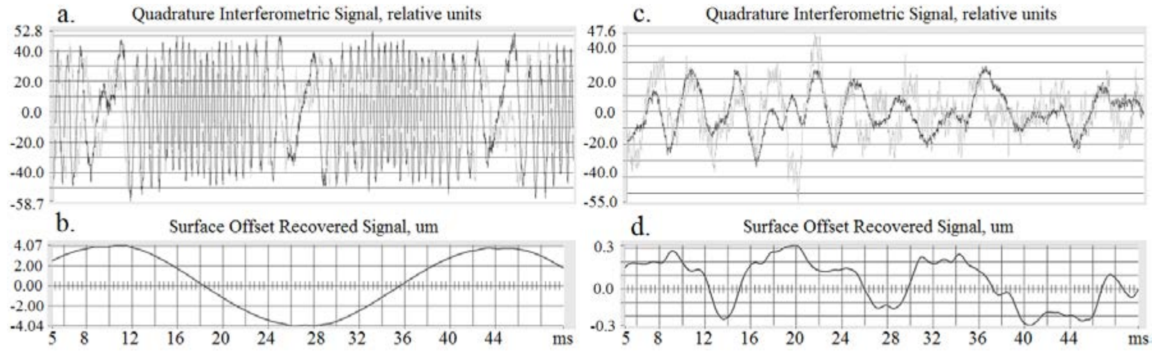

Fig. 3. Recovering signal of surface displacement (left graphs – vibrating with 30 Hz; right graphs – no generator signal mode).

5. Conclusions

The aim of this work was the vibrometer design based on modern fibre-optical components. Michelson interferometer scheme was chosen as the vibration measuring method. The vibrometer setup was assembled and experimental measurements of vibration amplitude were carried out for diffuse scattering surface. As a result the vibrometer based on the fibre-optical components can detect the quadrature signal with error of 0.05 µm and the frequency band equal to 20 kHz. It proves the ability of vibrometer realization using the fibre-optical components.

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