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Simulation and automatization of measurements process in laser interferometry

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Mathematical simulation of mechanical vibration amplitude measuring processes by laser interferometry has been considered. A software has been developed to obtain the time dependence of the interferometer output signal at various parameters of vibration and of the measuring unit and to automatize amplitude determination.

Рассмотрено математическое моделирование процесса измерений амплитуд механических колебаний с помощью лазерной интерферометрии. Разработана программа, которая позволяет получить зависимости значения выходного сигнала интерферометра от времени при различных значениях параметров колебаний и измерительной установки, а также автоматизировать процесс определения амплитуды.

Laser interferometry is used to measure parameters of mechanical vibrations of diffuse-reflecting objects. It provides the real-time remote amplitude determination for normal and tangential vibrations in a wide frequency range (1 to 10^5 Hz) at a high accuracy [1]. Fig. 1 displays the optical train of a laser interferometer for measuring amplitudes of normal mechanical vibrations of objects with rough surface.

The laser measuring unit is a modified Michaelson's interferometer. Lens 1 and light divider 4 focus the emission of helium-neon laser HNL on the surface of an object 2 under study and the reference surface 3. As a result of adding two coherent waves reflected from two rough surfaces, namely, that under study and the immobile reference one, an interference speckle pattern is produced in the recording space of photomultiplier tube PMT. In the course of time, as the intensity of the interference changes, it is recorded by PMT, the output signal thereof is sent to a digital recording oscillograph C9-8.

To study the vibration amplitude distribution along the sample surface, the object under study is moved in two mutually orthogonal directions perpendicularly to the optical axis of the interferometer. Piezoelectric acoustic ceramic transducers of hydroacoustic antennas are used as objects under study. The qualitative pattern of amplitude distribution over the transducer surface was obtained preliminarily by time-averaging holographic interferometry (Fig. 2).

The use of laser electron interferometry facilitates measurements to a considerable extent, since it does not require the hologram or interferention pattern recording on

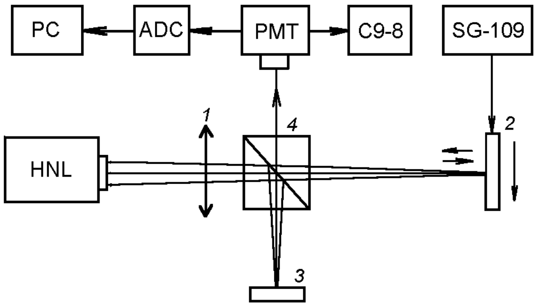
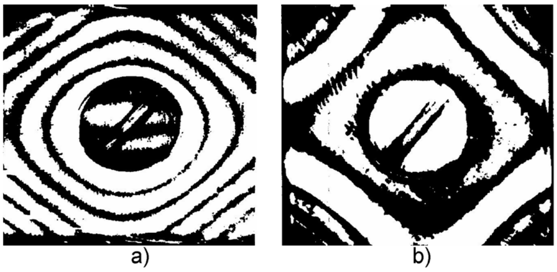


Fig. 1. Laser interferometer optical train to measure amplitudes of normal vibrations: *1*, lens; *2*, the object under study; *3*, reference surface; *4*, light divider.



a) b)

Fig. 2. Holographic interference patterns of vibration amplitude distribution over the surface of a hydroacoustic transducer: a) f_1 = 31.74 kHz; b) f_2 = 49.05 kHz.

a photographic plate or another photosensitive carrier. Nor should the record be further decoded or interpreted. It makes possible the computer-aided determination of vibration parameters. Mechanical vibrations of a piezoelectric acoustic ceramic transducer are excited using of a generator of sound signals SG-109. A point on the surface of the sample under study produces normal, mechanical harmonious oscillations:

$$S = a \cdot \sin(2\pi f t + \alpha), \qquad (1)$$

where a is amplitude; f, frequency and α, the initial phase of mechanical vibrations. As a result, the optical difference Δ between the waves which go from the reference surface and the object in the recording space. The electric signal value at the photoreceiver output depends upon time as (Fig. 3):

$$U(t) = U_m \cdot \cos\left[\frac{4\pi}{\lambda} \cdot a \cdot \sin(2\pi f t + \alpha) + \varphi\right], \qquad (2)$$

where $\lambda = 0.6328$ μm is the helium-neon laser (HNL) wavelength; $\varphi = 2\pi\Delta_0/\lambda$, the initial phase difference between the interfering optical waves.

In order to obtain a symmetric signal from the PMT output, one needs to adjust the optical pattern to gray interference band, where the initial phase difference of interfering waves equals $\varphi_1 = \pi/2$ (Fig. 3 and 4). This is provided by shifting the reference surface 3. When the initial phase φ is changed, the $U(t)$ signal form changes considerably (Fig. 5).

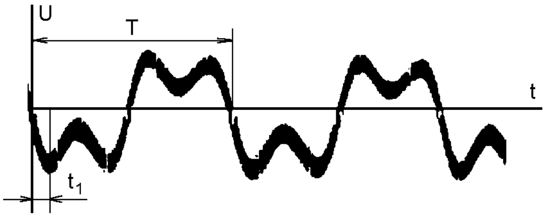


Fig. 3. Oscilogram of the output signal of laser interferometer (picture taken from the screen of C 9-8): a_n = 0.14 μm; φ = 90°.

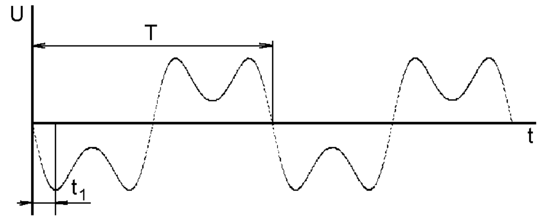


Fig. 4. The output signal $U(t)$ of the laser interferometer: a_n = 0.14 μm; φ = 90°.

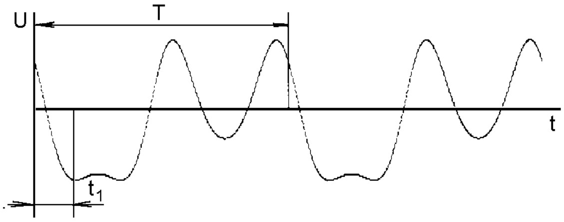


Fig. 5. Signal form $U(t)$ at the interferometer output, where a_n = 0.14 μm; φ = 45°.

The signal waveform $U(t)$ from laser interferometer output was simulated mathematically using a personal computer, thus allowing to study the signal dependence upon the parameters of the measuring unit (λ, φ) and parameters of mechanical vibrations (a, f, α) and then to develop an algorithm for solution of the inverse problem of the vibration amplitude determination when the waveform is known from the photodetector. A software was developed to obtain the signal image on the PC display and print out the $U(t)$ plot (Fig. 4 and 5). To that end, the vibration period T is subdivided into discrete time intervals with a constant step $\Delta t = T/N_{max}$ ($N_{max} = 1200$) and the value $U(t)$ is calculated for the preset parameters a and φ. The detailed analysis of this signal form and its dependence on the amplitude of normal mechanical vibrations and the initial phase of interfering waves allowed to propose a simplified algorithm to solve the inverse problem of finding a mechanical vibration amplitude a using an analog-to-digital converter ADC and a PC. First, the initial phase φ is calculated from the known signal value of U_0, $t = 0$

$$\varphi_2 = \arccos U_0/U_m. \qquad (3)$$

Next, for the case $0 < \varphi < \pi$, where the signal is reduced, the t_1 value at which the signal value is minimum is determined by iterative comparisons. Then the condition is met:

$$\varphi_2 + \frac{4\pi}{\lambda} \cdot a \cdot \sin 2\pi \frac{t_1}{T} = \pi. \quad (4)$$

Hence, the amplitude of oscillations is:

$$a_2 = \frac{(\pi - \varphi_2)\lambda}{4\pi \cdot \sin \frac{2\pi t_1}{T}}. \quad (5)$$

The relative error is also determined for the proposed calculation algorithm of the vibration amplitude:

$$q = \frac{|a_2 - a|}{a} \cdot 100\% . \quad (6)$$

The values of φ_2, amplitude a_2 and relative error q are also shown on the computer display (Fig. 4, 5). The computer-aided mathematical simulation results have shown that the developed algorithm and the software for the determination of vibration parameters using laser interferometry may be applied in the amplitude range $\lambda/8 < a < 2\lambda$ (0.08 μm $< a <$ 1.3 μm) at the relative error not exceeding 4 %.

Thus, the laser interferometry enables accurate remote real-time measuring of mechanic vibration parameters for objects with rough surface in a wide range of amplitudes and frequencies. Mathematical simulation of the interferometer signal form makes it possible to develop a software for computer-aided measuring and processing of experimental results.

References

1. N.V.Morozov, V.V.Solodov, Patent USSR No.1696890.

Моделювання і автоматизація процесу вимірювання у лазерній интерферометрії

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Розглянуто математичне моделювання процесів вимірювання амплітуд механічних коливань у лазерній интерферометрії. Розроблено програму, що дозволяє отримати залежність величини сигналу з виходу інтерферометра від часу для різних параметрів коливань і вимірювальної установки, а також автоматизувати процес визначення амплітуди.