Development of non-contact laser vibrometer

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Abstract. Modified schemes of noncontact laser sensors for vibrometry are considered. The results of investigation of two laboratory models of laser speckle vibrometers are presented. Advantages and disadvantages of the vibrometer sensors are discussed.

1. Introduction

Development of methods and devices for nondestructive control of physico-mechanical properties of different objects is one of the important tasks of modern technique and machinery. There are a number of methods and devices for remote control of mechanical characteristics; however, the challenges and new tasks require the development of methods and devices of vibrational monitoring of different objects.

The laser-based optical methods of non-contact remote monitoring are in fact an extremely powerful tool for the study of the behavior of components during operation. One of the contactless optic methods is laser speckle-interferometry based on rather simple and cost-effective optical sensors. At the same time the method accuracy is comparable with the precision of more complex holographic systems.

The aim of our work was to develop methods and create laboratory models of laser speckle-vibrometry sensors for non-contact remote vibrometry of large- and small-scale objects. Vibration characteristics are important for evaluation of physical and mechanical parameters of different objects, such as bridges, dams, jet engines, electric motors, biological cells and tissues, etc.

2. Experimental study

Registration of input light signal by optical fiber with core diameter which is smaller than size of single speckle is mostly used in studies of speckle field. A magnitude of signal transmitted through the fiber is small and photomultiplier is necessary. However, this scheme can be simplified by using of a diaphragm and wide-aperture photodetector.

Speckle pattern is formed in plane of aperture with average radius of speckle \( \rho \)

\[ \rho = \frac{\lambda z}{d}, \]  

where \( \lambda \) is wavelength of the laser; \( z \) is the distance between surface of the object and photodetector plane; \( d \) is the diameter of illuminated area of object’s surface.
Speckle pattern is formed in plane of photodetector by changing $d$ and $z$ with average speckle size $\rho$, which fulfil the condition:

$$h < \rho < D$$

(2)

where $h$ is the shift of speckle in plane of photodetector; $D$ is the size of aperture in plane of photodetector.

In this study special attention was paid to non-contact registration of man’s pulse shape of the radiocarpal artery. To solve this problem two laboratory models of speckle-vibrometers were developed: the first one was based on the point contactless sensing of skin and the second one was based on ringed light field sensing. The scheme of the speckle-vibrometer model with point sensing is presented in fig. 1.

We had revealed a number of limitations of the speckle-vibrometer model with point sensing:

- criticality to location of the sensing laser beam;
- detecting of signal from various light sources on photodetector and so the presence of pulse interferences;
- loss of signal in case of laser beam shifting from the artery.

To reduce the influence of sensor positioning on the signal it was proposed to use several infrared LEDs circumferentially. To create the circular illumination the optical system with axicon was developed (fig. 2). Vibrations with intended frequency were simulated by membrane which was excited by sound wave from generator of acoustic oscillations GZ-112.

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The experimental setup is presented in fig. 3.

![Experimental setup](image)

**Figure 3.** Experimental setup.

Diameter of ring illumination remained constant for longitudinal displacement of optical system within at least ten centimeters (Fig. 4).

![Ring diameter versus distance](image)

**Figure 4.** Ring diameter versus distance from the surface of the object.

Measured dynamic range of laboratory model of the sensor was 30 dB. Linear mode was observed up to output voltage of generator 0.3 V. After this threshold nonlinear mode of target stimulation was observed (Fig. 5).
3. Conclusion

The results of our study are the following:

1. Technique of non-contact opto-electronic registration of pulse wave form was developed;
2. Scheme of non-contact sensor based on registration speckle field was proposed and created;
3. Axicon-based scheme of optical sensor with ring illumination was developed and investigated;
4. Advantages of scheme based on axicon were confirmed:
   - high sensitivity;
   - relative insensibility to positioning on arm;
   - independence of diameter of the formed ring on distance to study object;
   - contactless measurement of recording pulse signal.

The obtained results provide the basis for further investigation and development of laser vibrometer.

References

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