339. Experimental investigation of ultrasound vibrations of a flexible waveguide

A. Bubulis[1] , V. Jurėnas[1] , V. T. Minchenya[2], M. Valaika[1]
[1] Kaunas University of Technology,
Kęstučio str. 27, 44312 Kaunas, Lithuania,
Phone: (370) 300-900,
E-mail: *algimantas.bubulis@ktu.lt, vytautas.jurenas@ktu.lt,marius.valaika@stud.ktu.lt*
[2] Belarus National Technical University,
Nezavisimosti 63, 220013 Minsk, Belarus

(Received 3 February 2008; accepted 20 March 2008)

Abstract. In this paper we report the results of experimental research of a new flexible and variable-rigidity waveguide, which operation is based on ultrasound vibrations. The tested waveguide is a combination of conical-stepped-cylindrical waveguides, which enables significant improvement of dynamic characteristics with respect to various existing static loads. The resonant frequency for excitation of the waveguide is in the range of 24-26 kHz. The measurements presented in this paper were performed on a STANDA vibration-isolation honeycomb-type table by means of the POLYTEC laser Doppler vibrometer system MSV-400 consisting of a laser interferometer OFV-512, vibrometer controller OFV-5000 and analog-to-digital converter ADC-2424 (PICO,GB) as well as by using HYTEC holographic interferometry system PRISM.

Keywords: ultrasound, vibrations, waveguide, cavitations

Introduction

Ultrasound energy may be harnessed for removing tissues and fragmenting stones, eliminating clots from blood vessels and other undesirable derivatives, which can appear in a human body. Usually the energy generated by a waveguide is transmitted to the environment in the form of high-frequency intensive acoustic waves that are capable of destroying tissues by means of the direct mechanical effect or cavitation phenomenon. During cavitation, as the liquid is affected by the high-power ultrasound frequency, microscopic vapor-filled bubbles or cavities are generated, which undergo fast expansion and collapse. This process is accompanied by intensive local hydraulic impacts that cause destruction of tissues. Ultrasound devices are used in the medicine where the phenomenon of cavitation is adjusted so as to destroy tissues, for example, for treating cancer, cleaning foul vessels, sucking and other procedures.

The main disadvantage of the existing medical ultrasound waveguides, as confirmed by majority of doctors, is their slow action in comparison to surgical interventions.

Therefore, a conical-stepped-cylindrical-type waveguide of a novel design was developed and its operating characteristics were determined experimentally.

Vibration measurements

Over the last 15-20 years a new technology of vibration measurement has been developed, which is suitable for investigation of modern highly-loaded and high-speed machinery.

In practice it is very difficult to avoid vibrations. They usually appear because of the dynamic effects of manufacturing tolerances, clearances, rolling and rubbing contact between machine parts and out-of-balance forces in rotating and reciprocating components. Often, small insignificant vibrations can excite resonant frequencies in other structural parts and be amplified into major vibration and noise sources.

Sometimes though, mechanical vibrations can perform a useful function. For example, the vibrating waveguide is used in modern treatments of vascular occlusive diseases. The working principle of a waveguide is based on the delivery of ultrasonic energy along the length of a small diameter wire, similar in size to an interventional guide wire. The ultrasonic energy creates cavitational streaming that is designed to rapidly dissolve thrombus and quickly restore blood flow without adversely damaging surrounding structures [4].

A fundamental requirement in all vibration work, whether it is in the design of machines which utilize its energy or in the creation and maintenance of smoothly running mechanical products, is the ability to obtain an accurate description of the vibration by measurement and analysis.

In the vibration measurement scheme, provided in [3], the motion (or dynamic force) of the vibrating body is registered by the non-contact measuring instruments, such as holographic interferometers or vibrometers based on Doppler shift of backscattered laser light. The output from the signal conversion instrument can be displayed on a display for visual inspection, registered by a recording unit or stored in a computer for later use. The data can be analyzed to determine the desired vibration characteristics of the structure.

Experimental set-ups for investigation of waveguide vibrations

The experimental investigation of vibrations of the waveguide was carried out in the Mechatronics Center of Studies and Research at Kaunas University of Technology. Vibration testing of the waveguide by means of laser Doppler vibrometer is demonstrated in Fig. 1.

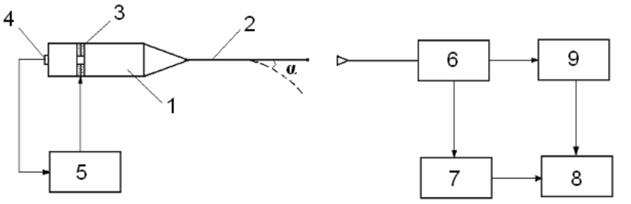


Fig. 1. Diagram of experimental set-up for vibration measurements with laser Doppler vibrometer: 1 - concentrator of vibrations; 2 - waveguide; 3 - piezorings; 4 - sensor of vibrations; 5 - control block of the system of vibration excitation; 6 - POLYTEC laser interferometer OFV-512; 7 - analog-to-digital converter ADC-2424 (PICO,GB); 8 - computer; 9 - POLYTEC vibrometer controller OFV-5000

Piezoshaker is fixed in the holders. The concentrator is attached to the piezoshaker head in order to amplify and concentrate the vibrations transmitted to the waveguide. The waveguide is attached to the concentrator. Piezoshaker and vibrometer are assembled on the isolation table in order to avoid influence of ambient vibrations that can aggravate measurement results of the experiment.

The vibrations of the waveguide are analyzed in the most characteristic point, which is located at the conical end, where the entire mass of the waveguide is concentrated. Therefore the vibrations at this point are the most intensive.

The investigation of the waveguide using holographic interferometry was performed by means of the set-up presented in Figure 2. The vibrations of the waveguide head are transferred to the aluminum plate and the plate is investigated by the method of holographic interferometry.

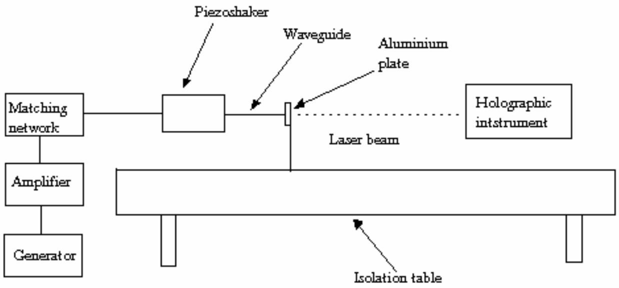
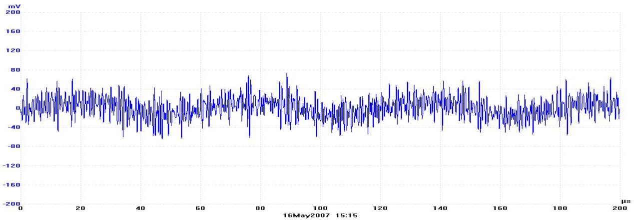


Fig. 2. The scheme for the measurement of vibrations of waveguide by holographic interferometry

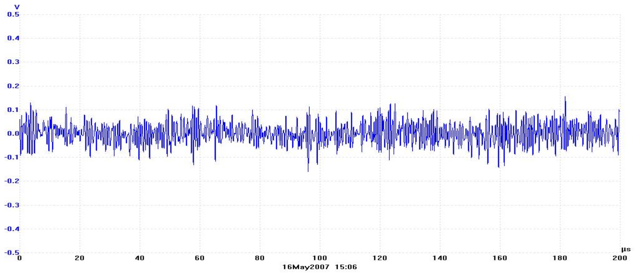
Results of the experimental research

The example of obtained results of measurement of the waveguide vibrations by means of the vibrometer are presented in Fig. 3.



(a)

(b)



(c)

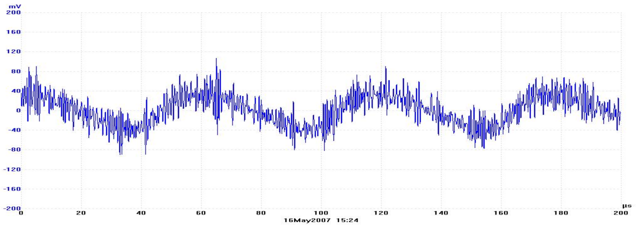


Fig. 3. Results of measurement of the waveguide vibrations of the same frequency (17 kHz), but different amplitudes: a – 100 mV; b – 400 mV; c – 600 mV

Based on obtained measurement results it is possible to determine the amplitude of vibrations by using the following equation:

$$V = A\omega = A \cdot 2\pi \cdot f \qquad (1)$$

where V is the velocity of vibrations, A is the amplitude of vibrations, f is the frequency of vibrations. Transforming equation (1), the following expression is obtained:

$$A = \frac{V}{2\pi \cdot f} = \frac{U_V \cdot K}{2\pi \cdot f} \qquad (2)$$

where U_V is the voltage peak, K is the coefficient, defined by the vibrometer instrument.

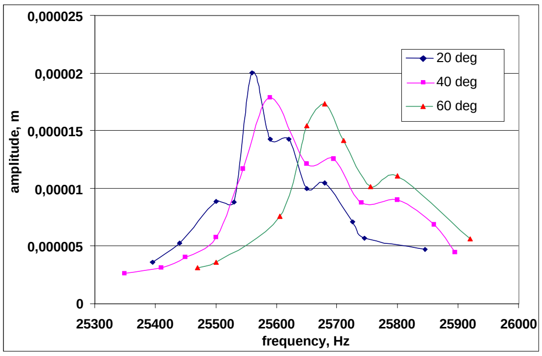


Fig. 4. Dependence of the amplitude and frequency at different bend angles of the waveguide; U1=const.

Fig. 4 illustrates dependences of the amplitude and frequency with respect to different bend angles of the waveguide (see also Table 1). Here longitudinal vibrations of the waveguide are measured at α = 20°, 40°, 60° - bending angle of the waveguide (Fig. 5.). Excitation voltage U1 is constant.

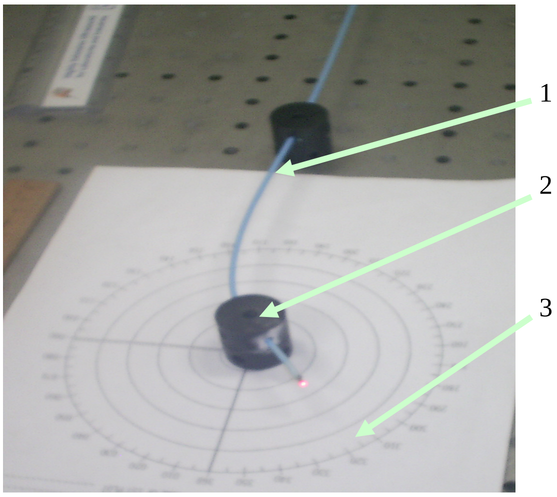


Fig. 5. View of fastened catheter with a waveguide: 1 - catheter with the waveguide; 2 - magnetic holder; 3 - chart for determination of the angle

Presented curves indicate that increase of angle α result in reduction of the amplitude of longitudinal vibrations and increase of the resonant frequency of the system.

Table 1. Dependence of the amplitude and frequency on different bending angles of the waveguide (U1= const)

U1 = const			
Angle α , deg	20	40	60
Amplitude, μm	20	18	17
Frequency, Hz	25560	25590	25680

When the waveguide is bent at angle of 20°, the amplitude of longitudinal vibrations is 20 μm at the resonant frequency of 25560 Hz. When increasing the bending angle α, tightness of the waveguide increases as well. This consequently increases the resonant frequency and reduces the amplitude of vibrations.

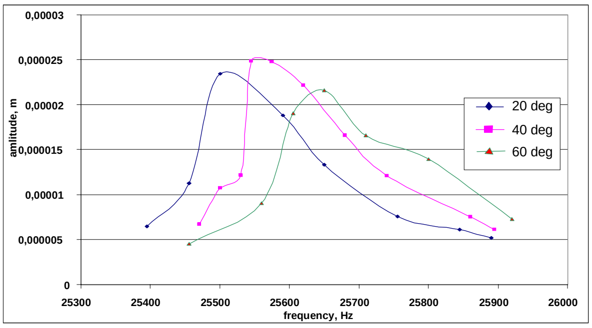


Fig. 6. Dependence of the amplitude and frequency at different bending angles of the waveguide; U2=const.

When larger power (U1 < U2) is supplied to the vibration generator, the curves presented in Fig. 6 are obtained (see also (Table 2). In this case the largest amplitude is obtained at the bending angle of 40° - 25,4 μm, while the frequency is 25545 Hz. Thus supply of larger power yields larger amplitudes of longitudinal vibrations.

Table 2. Dependence of the amplitude and frequency on different bending angles of the waveguide (U2= const)

U2 = const			
Angle α, deg	20	40	60
Amplitude, μm	23,4	25,4	21,6
Frequency, Hz	25500	25545	25650

Dependence of the resonant frequency change on the bending angle is illustrated in Fig. 7. Here the first curve corresponds to the excitation voltage U1, which is supplied to the vibration generator. The second curve is for U2, where U1 < U2.

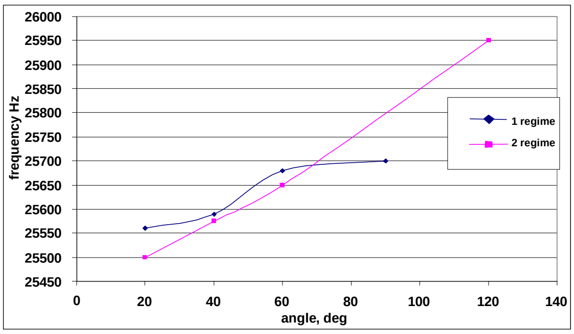
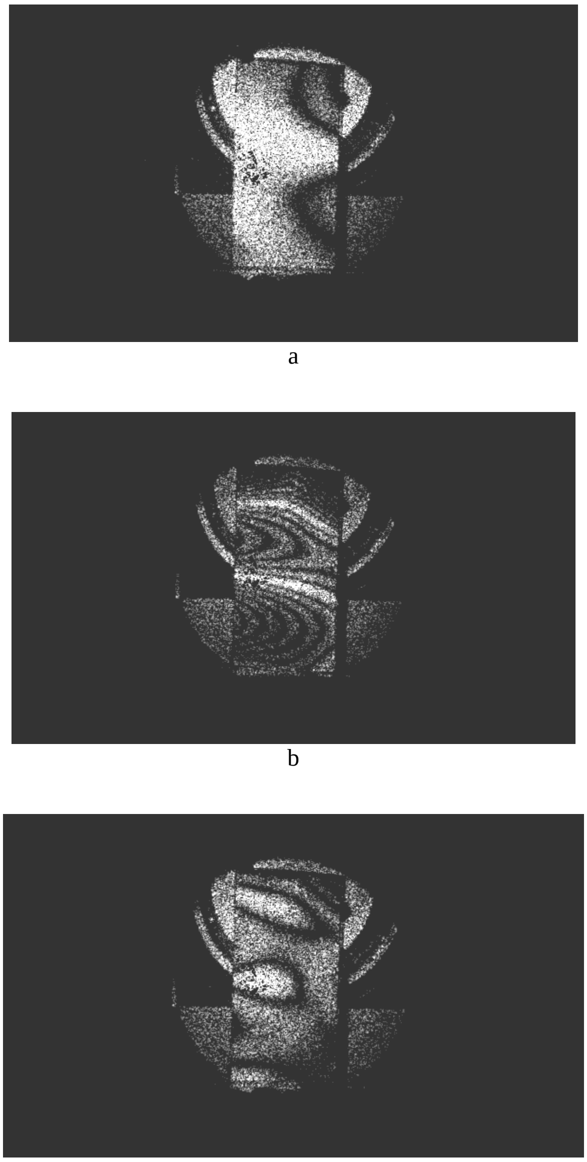


Fig. 7. Dependence of the resonant frequency change on the bend angle

When the holographic interferometry set-up is used, the vibrations of the waveguide are investigated by means of the aluminum plate that is attached to the end of the waveguide in order to get a surface vibrations of the plate, which results in sharp holographic interferograms (Fig. 2). The end of the plate is fixed in the holder and brought into contact with the end of the waveguide. The vibrations of the waveguide head are transferred to the aluminum plate. Its oscillations are registered by means of the HYTEC holographic interferometry system PRISM. This method does not allow investigation of the waveguide without fixation of its end.

The examples of the results obtained with the holographic interferometry system are presented in Figs. 8 - 9.

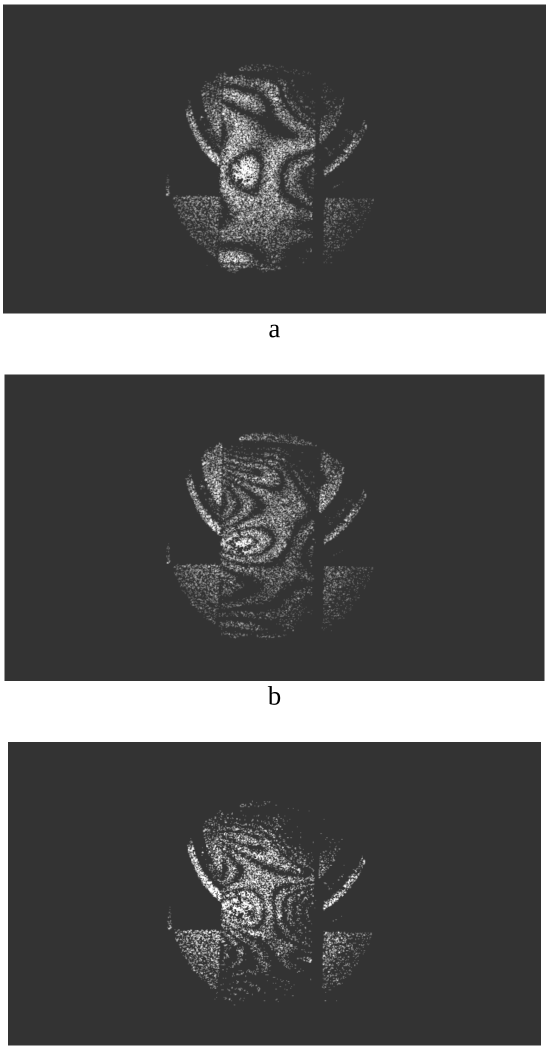


a

b

c

Fig. 8. Obtained holographic interferograms of the same amplitude (100 mV) but different frequencies: a – 12 kHz; b – 17 kHz; c – 19 kHz



a

b

c

Fig. 9. Obtained holographic interferograms of the same frequency (17 kHz), but different amplitudes: a – 150 mV; b – 300 mV; c – 600 mV

After the analysis of the obtained results it may be concluded that the vibrations of the waveguide depend both on the frequency and amplitude of the signal. According to the obtained holographic interferograms, it is possible to calculate the amplitudes of vibrations by applying procedures provided in [1]. Furthermore this may be accomplished by means of the software that is capable of processing the obtained measurement results.

5. Conclusions

In this paper the results of application of non-contact measurement techniques such as holographic interferometry and laser Doppler vibrometry were presented. Experimental set-ups based on these optical methods were employed for the measurement of vibrations of a novel waveguide, which was designed for application in modern surgery for treatments of vascular occlusive diseases. The experimental measurement layout of the tested object, described in this paper, can be used not only for the wire shape waveguids, but also as supplementary experimental method for the investigation of the surface dynamic processes.

Measured amplitude-frequency characteristics of the bended waveguide indicate that the obtained maximal vibratory amplitude decreased by 10-15% in the case of angle of 60°. Results of the performed experimental research work indicate that the frequency of resonant vibrations increases by increasing the waveguide bending angle. The largest increase was observed at an angle of 60° and is equal to 450 Hz.

References

[1] Cloud, G. L. Optical methods of engineering analysis. Cambridge: Cambridge University Press, 1998

[2] Palevičius, A., Ragulskis M., R. Palevičius. Wave mechanical systems: (theory, holographic interferometry). Kaunas: Caritas, 1998

[3] Rinkevičius, A. The investigation of piezotransducers vibrations by the method of holographic interferometry. Kaunas: KTU, 2006.

[4] http://www.omnisonics.