ULTRASONIC TRANSDUCER PEAK-TO-PEAK OPTICAL MEASUREMENT

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Abstract. Possible optical setups for measurement of the peak-to-peak value of an ultrasonic transducer are described in this work. The Michelson interferometer with the calibrated nanopositioner in reference path and laser Doppler vibrometer were used for the basic measurement of vibration displacement. Langevin type of ultrasonic transducer is used for the purposes of Electro-Ultrasonic Nonlinear Spectroscopy (EUNS). Parameters of produced mechanical vibration have to been well known for EUNS. Moreover, a monitoring of mechanical vibration frequency shift with a mass load and sample-transducer coupling is important for EUNS measurement.

Keywords

Homodyne interferometer, Langevin transducer, light interference, optical vibrometer.

1.   Introduction

The primary motivation for this work was a need for testing of the ultrasonic transducers. We have used Langevin type transducers for high power transmitting capability necessary for the Electro-Ultrasonic Nonlinear Spectroscopy (*EUNS*). EUNS is non-destructive testing method for crack and inhomogeneity detection in conductive materials [1]. The peak-to-peak value of the transducer mechanical oscillation is in order of tens of the nanometers (for the resonant frequency). Frequency depends considerably on the temperature, load and excitation voltage.

The knowledge of mechanical exciter properties is one of the key points for proper EUNS results interpretation. Although resonant frequency can be measured in terms of electrical measurement, for the real peak-to-peak measurement the vibrometry techniques have to been used.

Interferometric techniques are used in various fields of science, mostly in optical metrology. It can be used for measurement of the sample surface profiles with nanometer resolution, laser gyroscopic measurements and also for vibrometry. Optical vibrometers are preferred compared to the transducer vibrometer types because they are noncontact and so they do not change the mass load of vibrating sample and the resonant frequency.

2.   Experimental Description

First EUNS transducer will be shown, and then an optical vibrometer will be described.

2.1.   Ultrasonic Transducer

Experimental Langevin transducer has a cylindrical metal body with upper radius of 20 mm. Transducer consists of two PZT ceramics rings, copper contacts and metal body (Fig. 1). Advantages of this transducer type are free operation maintenance and easy usage. Its drawback is the fact that the peak-to-peak value of the mechanical vibrations strongly depends on the temperature, generator excitation voltage and frequency.
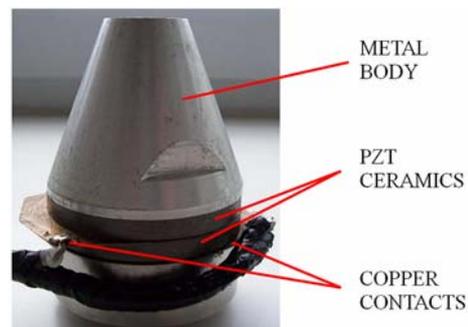
Fig. 1:   Experimental Langevin ultrasonic transducer.

The resonant frequency value of the transducer depends on the dimensions and acoustic characteristics of the metal sections and the ceramics. Therefore, special effort was needed for the design of the transducer for

ENUS purposes. For the transducer end sections, metals of different density are generally used in order to increase vibration amplitude at the radiating face and to improve matching to the load [2].

An electrical equivalent circuit for Langevin type transducers allows the evaluation of transducer electromechanical parameters. Simulation model can be used for improving transmitting efficiency and transducer performance simulations [3].

2.2. Optical Vibrometer

Optical vibrometer is in principle an interferometer that measures rapid phase or frequency differences between two waves. One laser beam is considered as reference while the second is used for sample measurement. Resulting interference can be measured using fast photodetectors. Depending on detection system setup two types of interferometers can be distinguished: homodyne and heterodyne ones.

1) Homodyne Interferometer

Interference of two coherent waves of the same wavelength results in detected intensity changes due to phase shift of the waves. The basic scheme of Michelson interferometer is presented in Fig. 2. Displacement of the sample mirror located on the body of the vibrating system (here ultrasonic transducer with generator) causes subwavelength periodical changes in one setup arm and consequently intensity changes in detector output emerged. The top polished side of transducer was used as the sample mirror so there was no change in the mass load.
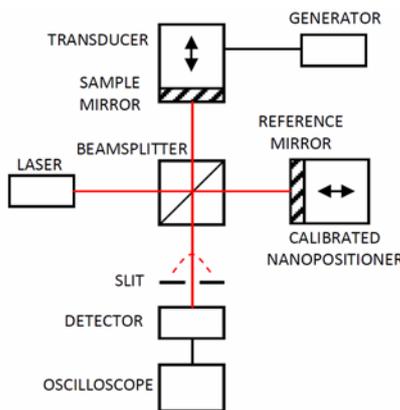
Fig. 2: Michelson interferometer-vibrometer setup.

For the displacement $> \lambda/2$ of laser light and resolution $< \lambda/2$, a fringe counting method is applied. For smaller displacements, another method can be used. Since the detector output does not change linearly with sample mirror displacement, peak-to-peak value of the light path change cannot be directly determined using the basic scheme with fixed reference mirror. Although the detector output can be linearized, factors such as laser stability, medium fluctuation and surface reflection

properties considerably limit the resolution. We have modified the basic scheme and added the linear nanopositioner that could displace the reference mirror (traceable resolution 0,1 nm, linearity 0,03 %). For the static displacement, this configuration allows linearizing a detector output, and for the vibrometry, it helps to determine the peak-to-peak oscillation value with sufficient accuracy. There are several approaches how to obtain proportional output signal in homodyne scheme, such as digital signal processing of quadrature detectors signal or phase modulation homodyne interferometer.

For the basic scheme and vibrating sample, output of the detector can be observed as a periodical signal on the oscilloscope screen (related to sample vibration). If the peak-to-peak value is lower than the $\lambda/4$, the detector signal can be displayed without double frequency effect. By moving the reference mirror so that the minimum of the detector signal reaches the beginning level of the maximum, the peak-to-peak value can be determined.

The setup of orthogonal laser polarized homodyne type interferometer is shown in Fig. 3. The advantage of the orthogonal laser polarized interferometer is that it can eliminate some disturbances, such as the light intensity fluctuations.
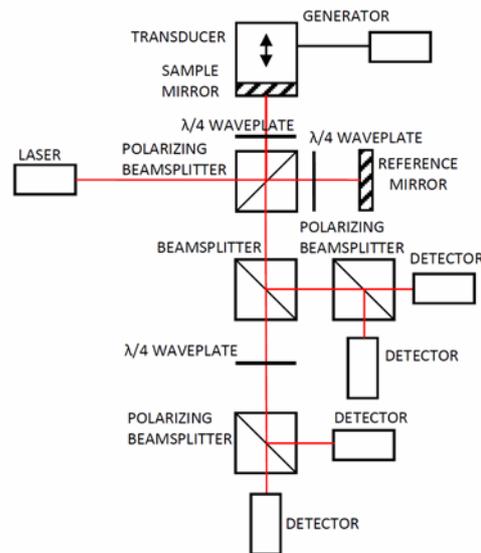
Fig. 3: Orthogonal polarization laser interferometer setup.

If classical errors (stability of the laser source, alignment error, vibration, temperature variation and air turbulence) are suppressed enough, the noise and the nonlinearity due to optical cross talk represent practical limitations of the interferometer. In this case a subnanometer resolution can be reached using a laser source at a wavelength of 633 nm and the polarization state measurement technique [4].

2) Heterodyne Interferometer

This interferometer needs two slightly different laser frequencies. They are usually generated by Zeeman laser, or acousto-optic modulator. Two different waves with

different frequencies orthogonally polarized lead to the creation of beat signals $(f_1 - f_2)$ and $(f_1 - f_2 + \Delta f)$. Principle of heterodyne interferometer is shown in Fig. 4. The phase difference between the measured beat signal and reference beat signal indicates the displacement of the moving reflector. This interferometer often uses corner reflectors, which advantage is that all impinging light beams are always reflected back in parallel to incidence light beams even if it is not placed in accurate perpendicular plane.
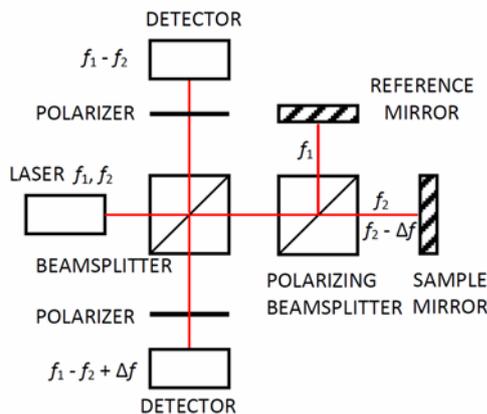
Fig. 4: Heterodyne laser interferometer.

Laser Doppler vibrometer setup based on Mach-Zehnder interferometer is shown in Fig. 5. The light is modulated using optical modulator (here Bragg cell) at a particular frequency (typically 40 MHz). The movement of transducer results in Doppler shift and thus in frequency change. Frequency modulated signal can be measured at the detector output.

In Doppler´s method, a displacement is indirectly calculated through an integral of the target velocity [5]. For the static or slowly varying displacement measurement of the sample, a Doppler shift is almost zero. Therefore, for lower frequency measurement heterodyne detection is being used.

Accuracy of the measurement is determined by stability of laser frequency, modulation fluctuation, arrangement of experiment and detection system properties.
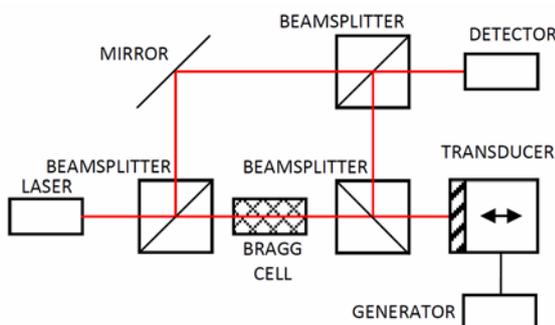
Fig. 5: Laser Doppler vibrometer setup.

Electrical output of the detector can be processed

in terms of quadrature demodulation. This can be done by electronic and subsequent digital signal processing. The generation of the quadrature signal pair is based on the mixing of detector signal with reference modulator signal and phase shifted reference modulator signal [6]. Alternative approach is based on the mixing of a circularly polarized reference with a linearly polarized signal to produce an output that contains the real and the imaginary parts of the interference field in the two output polarizations [7].

The resolvable displacement of the measurement system was verified with fine movement by reference mirror. This was mounted on nanopositioner with closed loop resolution 0,1 nm and full range repeatability better than 2 nm. Interferometer setup was arranged on the pneumatic antivibration platform and covered with cover box to minimize medium fluctuations and acoustic signals. Battery biased fast silicon diodes with mounted interference filters for He-Ne laser wavelengths were used as detectors. The dark current of diodes is lower than 5 pA and peak responsivity 0,5 A/W at the wavelength of 750 nm.

3. Results

Serial capacity of unloaded transducer in the frequency range from 20 Hz to 1 MHz has been measured (Fig. 6) for experimental transducer resonant frequency determination. For the used transducer, the resonant frequency is assessed as f_{res} = 32 kHz.

In the excitation frequency range (20 – 140) kHz, peak-to-peak values of transducer with mechanical load of EUNS on investigated sample has been optically measured. Generator and power amplifier were used to driving transducer with constant voltage value.
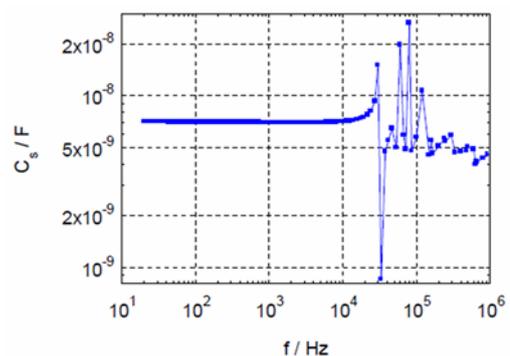
Fig. 6: Serial capacity C_S of the ultrasonic transducer.

Transducer was fixed to the antivibration platform with Langevin central screw and mounting bracket. For the measurement, Laser Doppler vibrometer setup was used. Investigated samples consist of cermet film and ceramic substrate (dimensions $2 \times 5 \times 100$ mm^3). The sample was fixed to the transducer with beeswax. Although an epoxy could give better results, beeswax was used by reason of the previous experimental EUNS measurements, which

were performed with beeswax as a coupler. Some parasitic mechanical resonant frequencies in a higher range were also observed. They were results of the sample sample-transducer fixation, but not the transducer itself (Fig. 7).
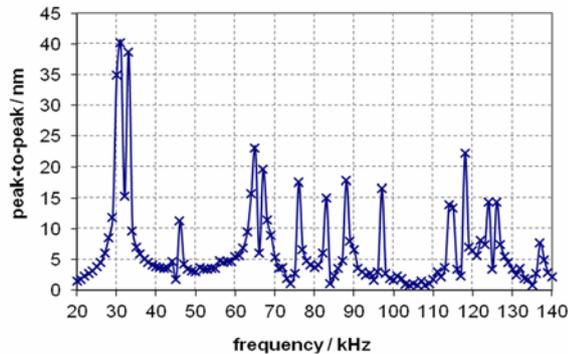
Fig. 7: Peak-to-peak measurement of Langevin ultrasonic transducer using Laser Doppler vibrometer, excitation voltage $U_{ef} = 5$ V, laser wavelength $\lambda = 633$ nm.

We also have investigated the excitation peak-to-peak value of ultrasonic transducer (laser beam directed on the polished top of the transducer metal body) while, in the previous measurement, a beam was directed on vibrating sample. Transducer was setup precisely to a reflected beam in parallel to the incident beam (perpendicular reflection) in a static state. Nevertheless tilting of the mirror plane cannot be excluded in dynamic mode as a source of false signal.

Michelson homodyne type vibrometer was used (Fig. 8). Two parasitic vibrating frequencies have been observed at 31,0 kHz and 31,5 kHz. Dominating vibrations occur at excitation resonant frequency of $f_{res} = 32,2$ kHz.
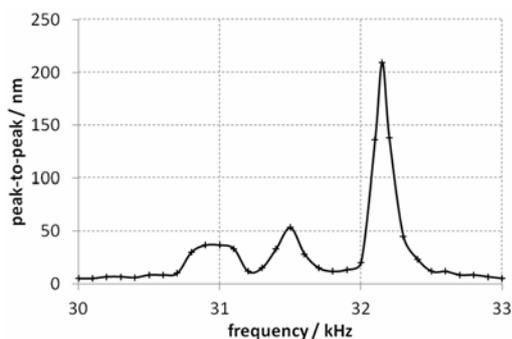
Fig. 8: Peak-to-peak measurement of Langevin ultrasonic transducer using Michelson type vibrometer, excitation voltage $U_{ef} = 10$ V, laser wavelength $\lambda = 633$ nm.

4.   Conclusion

Interferometric optical methods for measurement of peak-to-peak value of Langevin ultrasonic transducer were discussed. Two types have been used for the experimental measurement: Michelson homodyne type vibrometer and Laser Doppler vibrometer.

It was experimentally verified that sample influence on the resonant frequency of the transducer is negligible. Experimental results show that, except mechanical vibration at the resonant frequency, there are several parasitic vibration frequencies resulting from the sample-transducer fixation. Thus, monitoring and accurate measurement of a mechanical vibration is important for the particular EUNS results interpretation.

Acknowledgements

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