648. Measurement of trajectories of piezoelectric actuators with laser Doppler vibrometer

V. Grigaliūnas[1], G. Balčiūnas[2], A.Vilkauskas[1]
[1] Kaunas University of Technology, Kaunas, Lithuania
E-mail: *valdas.grigaliunas@ktu.lt*
[2] Kaunas University of Technology, Kaunas, Lithuania
E-mail: *gintautas.balciunas@ktu.lt*

(Received 11 July 2011; accepted 5 September 2011)

Abstract. Various measurement techniques have been developed for analyzing performance of piezoelectric devices. Recently laser Doppler vibrometer (LDV) has become a widely applied instrument for vibration measurements both in scientific studies and industry. The most common type of LDV is a single-point vibrometer. In this article we propose a system consisting of the single-point LDV, beam deflector and mirrors, which enable automated 2D/3D trajectory or 2D vibration measurements, where a high number of target points can be measured with a very high spatial resolution. We used two test objects to demonstrate the performance of the system: piezo-actuator, which transforms vibrations to the rotational movement and a micrometric screw with piezo-adjustment.

Keywords: trajectory measurement, piezo-actuator, laser Doppler vibrometer.

Introduction

During the last three-decades various techniques have been developed for analyzing piezo actuators performance: visualizing dynamic characteristics, vibrations, trajectories of operating/contact points of actuators in static or quasi-static and dynamic regimes.

Measurement methods based on optical techniques have been very successful because they are non-contact, nondestructive and accurate. Optical non-contact profilometry has been very widely used for 3D sensing, mechanical engineering, machine vision, intelligent robot control, accurate stress, strain and vibration measurement [1, 2]. Optical methods based on fringe projection are often used for 3D shape measurement. These systems include projection unit to project the desired encoding fringe patterns onto the object and the object shape can be obtained by analyzing the images captured with a camera or CCD (charge-coupled device) for each projection. The system accuracy is primarily determined by the quality of components, and the speed of operation. It is possible to reach accuracy around 0.2 pixels [3], but usually measurement error of such systems is 40 µm with an uncertainty of ±35 µm [4]. For high-speed 3D shape measurement using digital fringe projection it is possible to achieve simultaneous 3D shape acquisition, reconstruction, and display at a speed of 30 frames/s at 300 K points per frame [5].

For accurate deformation and vibration measurements at higher frequencies a real-time digital holographic technique is used [6, 7]. When object is excited harmonically at a single frequency the standing vibration patterns are measured. The resulting hologram provides information about the shape mode of the vibration and its approximate amplitude at a dynamic range from approximately 20 nanometers up to 10 microns. Digital holography measurement systems usually operate from several tenths to several hundred hertz. The disadvantage for such kind of systems is that operator experience is needed for hologram interpretation.

Recently the laser Doppler vibrometer (LDV) became a widely used instrument in both scientific studies and industrial applications. Most common type of LDV is a single point vibrometer. Polytec is the leading manufacturer of LDV systems, but there are several others – MetroLaser, B&K, Piezojena.

In opposite to traditional contact vibration transducers (accelerometers) LDV have no physical contact with the test object and the laser beam impact in most cases can be neglected. In addition, the ability to incorporate advanced optical mirror systems together with the laser source provides automated scanning measurements, where a high number of measurement points can be measured with very high spatial resolution [8, 9]. Therefore such scanning system leads to significant improvements in the accuracy and precision.

The main disadvantage of scanning LDV is a long measurement time. However, it is the most advanced instrument for accurate and reliable vibration measurement. Besides, there are multi-beam laser Doppler vibrometers for simultaneous registration of vibrations at multiple target points. This type of LDV is used when measuring temporary, non-stationary responses or when faster measurement time is necessary [10].

LDV systems (in particular, scanning LDVs) are very expensive. In this article we propose a system consisting of single point LDV, beam deflector and mirrors, which enable 2D/3D trajectory or vibration measurement.

Measurement system

The measurement system was developed at Mechatronics Centre for Research, Studies and Information of Kaunas University of Technology for measurements of 2D/3D trajectories and 2D vibrations of piezoelectric actuators.

The structure of the measurement system is shown in Figure 1. The system consists of Polytec LDV (fiber interferometer OFV-512 and vibrometer controller OFV-5000), Scanlab galvanometric laser beam deflection system (inteliSCAN 14), Gwinstec oscilloscope (GDS-2104), Agilent arbitrary wave generator (33220A), amplifier, personal computer and mirrors (Fig. 3).

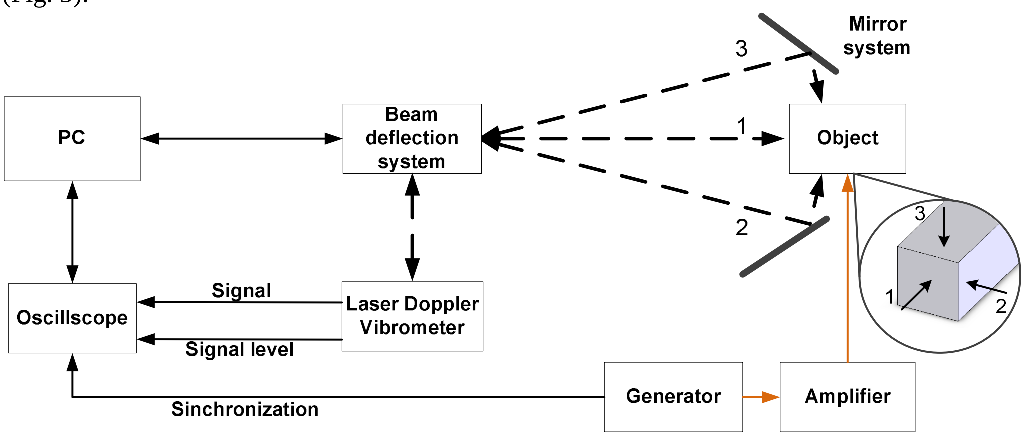

Fig. 1. The structure of the measurement system

An excitation harmonic signal from generator is amplified and goes to the object. Two signals from LDV are transmitted to the oscilloscope: one signal is from velocity channel, which is proportional to object velocity and the second one indicates signal level. One more signal, which travels from generator to the oscilloscope, is a synchronization signal. The oscilloscope is connected to PC through USB interface and signal processing is performed in

Matlab. The galvanometric laser beam deflections system is also controlled from Matlab through RS232 interface.

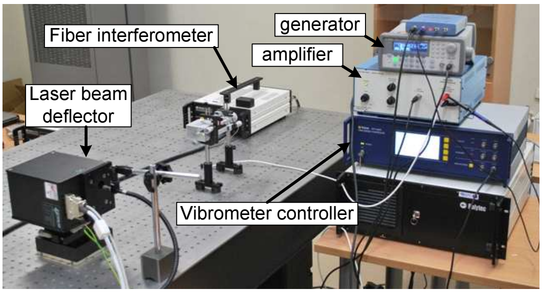

Fig. 2. General view of the experimental setup

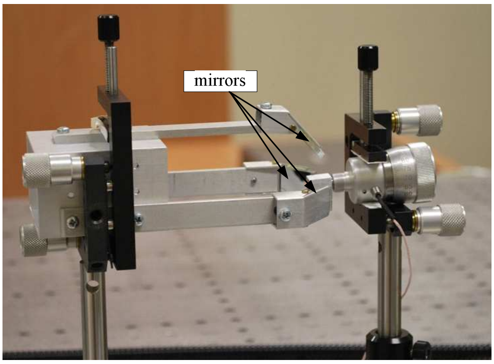

Fig. 3. Mirrors system

Measurement results

We used two objects: piezo-actuator that transforms vibrations to the rotational movement (Fig. 4) and micrometric screw with piezo-adjustment (Fig. 11).

The object of the first measurement example is shown in the Figure 4. Piezoceramics is exited with sinusoidal signal of 33,57 kHz frequency. The galvanometric laser beam deflection system periodically redirects laser beam, coming from LDV, from the point in the front of the piezoceramic (X1) to the point of the side (X2) and vice versus at 917 Hz frequency. The oscilloscope measures synchronization signal that comes from generator and two signals from LDV: one is proportional to the vibration velocity and the other one describes the quality of the signal. All three signals are saved and transmitted to a personal computer (PC) for further data processing and representation.

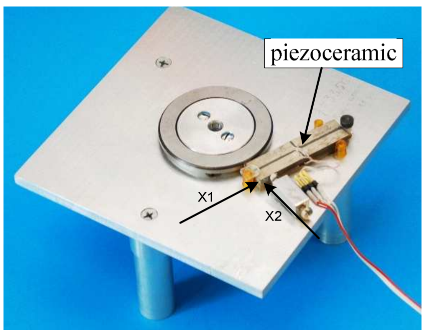

Fig. 4. Piezoceramic actuator

The point at the position X1 (in the front of the piezo-actuator) represents longitudinal vibrations of the actuator. The point at the position X2 (at the side of the piezo-actuator) represents transversal vibrations of the actuator (Fig. 4). In the latter case the laser beam is deflected in such a way that the beam reflected from a mirror falls perpendicular to the surface of the test object. The generator synchronization signal is necessary for the phase at the points X1 and X2 not to be lost. An example of the measurement is shown in Figs. 5-7.

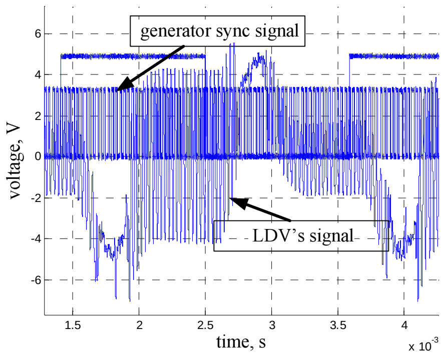

Fig. 5. An example of a measurement (oscilloscope window)

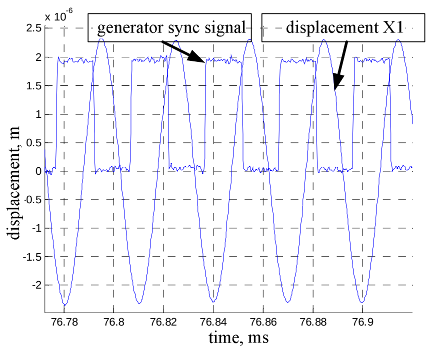

Fig. 6. LDV and generator synchronization signals at the position X1 (in the front of the piezo-actuator)

We measured vibration speed, when LDV sensitivity was 125 mm/s/V. Displacement and vibration speed are related by this equation:

$$\Delta = \frac{v}{\omega};$$

where Δ – displacement, v – vibration speed, ω – vibration frequency.

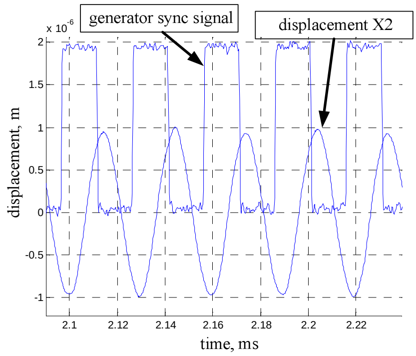

Fig. 7. LDV and generator synchronization signals at the position X2 (at the side of the piezoceramic)

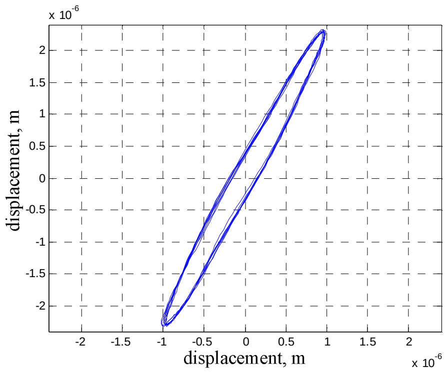

Fig. 8. Measurement result after signal processing

For the graphical data representation, the data of points X1 and X2 are plotted at XY coordinates. We obtained a shape that is similar to an ellipse (Fig. 8). The number of ellipsis is equal to the integer number of measured signal periods. Transversal vibrations are plotted on X axis and longitudinal vibrations - on Y axis.

The frequency of the excitation signal (resonant frequency) is $f = 33{,}57\ kHz$. The results of the measurement are obtained when excitation signal voltage is changed from 5 to 20 V in steps of 5 V (Fig.9).

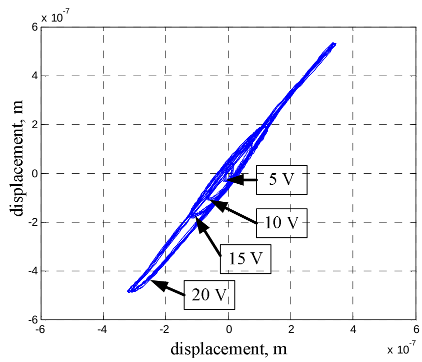

Fig. 9. Vibration trajectories of the piezo-actuator at different excitation voltages

The trajectory of actuator vibrations when it oscillates at resonant frequency and is slightly untuned to one side from the resonant frequency and to the other side is shown in Figure 10. The amplitude of the untuned signal is changed in such a way that it would be 0,7 times less than in the resonant frequency.

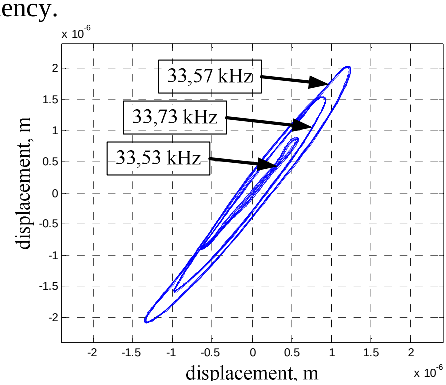

Fig. 10. Vibration trajectories of the piezo-actuator at different frequencies

Analogous measurements were performed with the second object – micrometric screw with piezo-adjustment (Fig. 11).

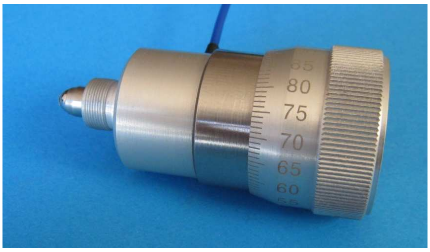

Fig. 11. Micrometric screw with piezo-adjustment

In this case instead of two-dimensional trajectory we obtain the three-dimensional one. The measurement was carried out in a quasi-static regime while operating in a piezo-adjustment mode: $f = 10\ Hz$, $U_{pp} = 80\ V$. The result is presented in Figure 12.

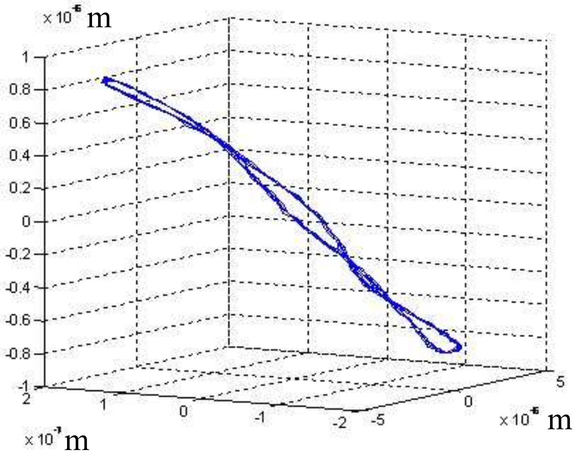

Fig. 12. Trajectory of micrometric screw with piezo-adjustment f = 10 Hz, U_{pp} = 80 V.

Conclusions

1. New relatively low-cost automated measurement system for 2D/3D trajectory and 2D vibration measurements was developed. It consists of single-point LDV, beam deflector and mirrors.
2. The presented system is particularly effective in measurement and optimization of 2D and 3D trajectories of high-resolution piezoelectric motors and actuators.

References

[1] **Srinivasan V., Liu H. C., Halioua M.** Automated phase-measuring profilometry of 3-D diffuse objects // Applied Optics, 1984. No. 23, – P. 3105-3108.

[2] **Yingsong H., Jiangtao X., Enbang L., Joe C., Zongkai Y.** Three-dimensional profilometry based on shift estimation of projected fringe patterns // Applied Optics, 2006. No. 45, – P. 678-687.

[3] **Izquierdo M. A. G., Sanchez M. T., Ibanez A., Ullate L. G.** Sub-pixel measurement of 3D surfaces by laser scanning // Sensors and Actuators, 1999. No. 76, – P. 1–8.

[4] **Xiaobo C., Jun Tong X., Tao J., Ye J.** Research and development of an accurate 3D shape measurement system based on fringe projection: Model analysis and performance evaluation // Precision Engineering, 2008. No. 32, – P. 215–221.

[5] **Zhang S.** Recent progresses on real-time 3D shape measurement using digital fringe projection techniques // Optics and Lasers in Engineering, 2010. No. 48, – P. 149–158.

[6] **Fu Y., Pedrini, Hennelly B. M., Groves R. M., Osten W.** Dual-wavelength image-plane digital holography for dynamic measurement // Optics and Lasers in Engineering, 2009. No. 47, – P. 552–557.

[7] **Borza D. N.** High-resolution time-average electronic holography for vibration measurement // Optics and Lasers in Engineering, 2004. No. 41, – P. 515–527.

[8] **Vanlanduit S., Guillaume P.** An automatic scanning algorithm for high spatial resolution laser vibrometer measurements // Mechanical Systems and Signal Processing, 2004. No.18, – P. 79–88.

[9] **Venkatakrishnan K., Tan B., Ngoi B. K. A.** Two-axis-scanning laser Doppler vibrometer for precision engineering // Optics and Lasers in Engineering, 2002. No. 38, – P. 153–171.

[10] Multi - Beam Laser Vibrometer. (Internet access: <http://www.hgl-dynamics.de/en/mainmenu-laservibrometer/mbldv/105-mb-ldv>. Viewed 2011-04-29).