330. Holographic Interferometry Methods for Analysis and Design of Rotary Converter

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(Received 19 January 2008; accepted 17 March 2008)

Abstract. A rotary converter used in mechanisms that require high precision displacement has proved that accuracy depends both on design and technological factors. An important feature of mechatronic systems containing links made of active sandwich beam is the performance of various functions by the same transducer thereby enabling the development of improved design methods. The analysis of various parameters and constructions of mechatronic systems has made it possible to introduce the mechanism containing a rotary converter which can turn any top around or turn a screw. A holographic interferometry method has been applied in the experimental work [1, 2].

Keywords: rotary converter, piezoelectric sandwich, measurement.

1. Measurement methods and means

The piezoelectric effect produced by natural crystals such as quartz or tourmaline was known since the end of the 19th century. During the sixties of the XX century piezoceramic materials were introduced and gradually replaced the natural ones. Piezoceramics can be a number of times more sensitive to electric and mechanical effects in comparison to natural crystals. Moreover, it is mechanically strong, chemically inert and resistant to atmospheric effects. Piezoelectric cells can be made of various sizes and parameters which enable them to be used in any manufactured structure with 90% efficiency.

In the course of investigation of piezoelectric sandwich beam developed by the authors, piezoceramics is used to perform sensing function during measurements [3, 4]. They form so-called piezosensors which are a transmission link between physical transformations and electric or data storage systems. At the input a piezosensor receives particular information on mechanical, chemical and biological processes then transforms it into an electric signal. If a piezosensor can measure the amplitude of object vibrations according to the voltage used for a piezoectric cell, then the voltage is proportional to the amplitude of the object:

$$U = \frac{d_{33} lm}{\varepsilon\varepsilon_0 S}\omega^2 x_0 \sin(\omega t) \quad (1)$$

where x_0 - amplitude of vibrations; d_{33} - piezoelectric module; $\varepsilon, \varepsilon_0$ - dielectric permittivities of a piezoelectric cell; l - height of a piezoelectric cell; S - plane of a piezoelectric cell; m - mass of a sensor inert cell; ω - frequency of vibrations.

The revised voltage expression is:

$$U = \frac{d_{33} lm}{\varepsilon\varepsilon_0 S}\left[\omega^2 x_0 \sin(\omega t) + \frac{s_{33}}{S} m\omega^4 \sin(\omega t)\right] \quad (2)$$

where s_{33} - elastic constant of a piezoelectric cell.

When the measured body vibrations are harmonic, displacement is written as follows:

$$x = x_0 \sin(\omega t) \quad (3)$$

When a piezosensor comes in contact with the vibrating surface the information signal is obtained by differentiating the piezoelectric cell signal. It is assumed that the first information signal is the second peak value from any closest spaced peaks and time intervals Δt_1 between the first and n^{th} peaks (n - even number, $n \geq 2$) and between the first $(n+1)$ and the last peak are measured (Fig. 1).

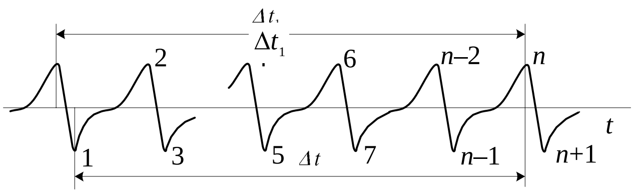


Fig. 1. Time interval Δt_1 between the first signal peak and $n = 2k, (k = 1, 2, 3...)$, time interval Δt between the first signal peak and [$n+1$]

In this case the amplitude is expressed by formula:

$$x_0 = \frac{S\Delta t^2}{2\pi^2 n^2 s_{33}\cos\left(\pi n\left(\Delta t_1/\Delta t - 1\right)2\right)} \cdot \frac{A}{(1-A)} \qquad (4)$$

where $A = ctg^2(\pi n(\Delta t_1/\Delta t - 1)/2$, s_{33} – elastic constant of a piezosensor.

This measurement method makes it possible to estimate non-linearities thus increasing the measurement accuracy 3.5 times due to spread measuring range.

In order to determine more precisely the initial stress values in sandwich beam and to choose the optimal version in the rotary converter design, a few piezoelements are inserted into the sensor. They significantly improve the operation parameters of the sandwich beam by increasing the accuracy and reliability. The structure and measurement of characteristics of this actuator, namely, its capacity variation on the measured force value is illustrated in Fig. 2. This measurement method has been applied because measuring and selecting tension force value should not damage the structure. In order to satisfy these requirements the sensor material has to be analogous to that of a rotary converter i.e. piezoceramics. Thus sensor of such structure precisely reads back the measurement results and their normal operation depends on that of a rotary converter. The sensor error is determined by measurement capacity error which is 0,25% of the maximum value and the calibrating error.

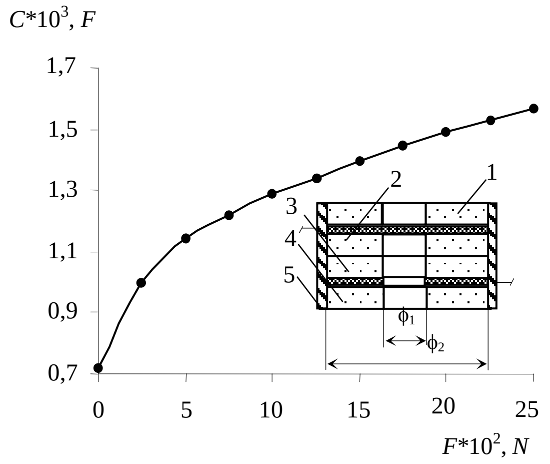


Fig. 2. Schematics of piezoelectric capacity sensor and its capacity force characteristics: 1-4 piezoelements with removed electrodes; 2-3 active elements with one electrode; 5 - binding material

In addition to the investigation results (Fig. 3) this fact admonishes that precaution should be taken when choosing the number of piezoelements for obtaining the higher displacement amplitude. The desired displacement value can be achieved with lower power consumption if optimal number of piezoelements is selected and manufacturing conditions are observed so that they do not restrict the displacement value but restrict the deflection of sandwich beam from the vertical axis.

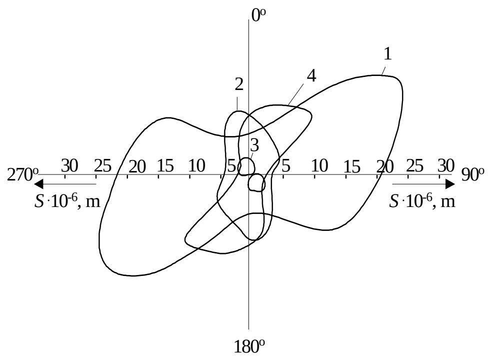


Fig. 3. Deflection of sandwich beam from vertical axis: piezostacks 1, 2, 3, 4

Ineffective electrical energy is stored as electrostatic energy in the piezoelectric material and reverts it to the power supply in the final process of operating cycle. The analyzed criteria have made it possible to choose the piezomaterial for an optimal construction achieving maximum displacement. Fig. 4 presents the mechanism containing a rotary converter which turns a monoblock by 25' at the resonance frequency of 270 Hz. This monoblock 1 is elastically connected to suspension 2, sandwich beam 3 rests on base 4. The initial sandwich beam strain depends on the chosen distance between the suspension and the base. When electric power is supplied, the sandwich beam either elongates or shortens. But since the suspension is cylinder with diagonal edges, linear displacement becomes rotational. The monoblock is given a turn at a required angle.

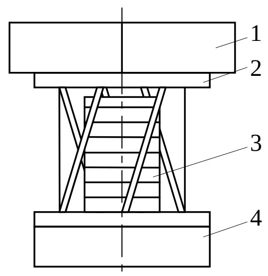


Fig. 4. Schematics of rotary converter: 1 - monoblock, 2 - suspension, 3 - sandwich beam, 4 - base

The optical circuit of the set-up includes a holographic installation with a helium-neon laser which serves as a source of coherent radiation. Structural diagram of the holography set-up is present in (fig. 5). When passing through the beam splitter 6, the beam from the laser 1 splits into two mutually coherent beams. The object beam, reflected from the mirror 10, is split by the lens 11 and illuminates the surface of the working part of the sandwich beam 2 and, after reflecting back, strikes the photographic plate 4. The reference beam, reflected by the mirror 7, via micro object-lens and spatial filtration diaphragm 8, and expanded by the lens 9, illuminates the photographic plate 4, where the interference structure is recorded. The object and reference beams create interference in the plane of the photographic plate, and during exposure temporally constant three-dimensional interference structure is generated and recorded by a hologram. In order to reconstruct the image, the hologram is illuminated by the reference beam. The reconstructed interferometric image is photographed with a camera or recorded with a video camera 5. Seeking to reduce the duration of exposure of the photographic plate 4 and improve reconstructed contrast of the interferometric image, the top of the working part of the sandwich beam 2 was painted with mat white color while analyzing with the time-averaging method. During the experiment the surface of the working part of the sandwich beam 2 is illuminated with an object beam whose incidence angle with respect to the direction of a working part shift is about 45°. Based on the character of obtained localization of interferometric bands, the optimum operation modes of the surface of working parts of sandwich beam 2 can be determined.

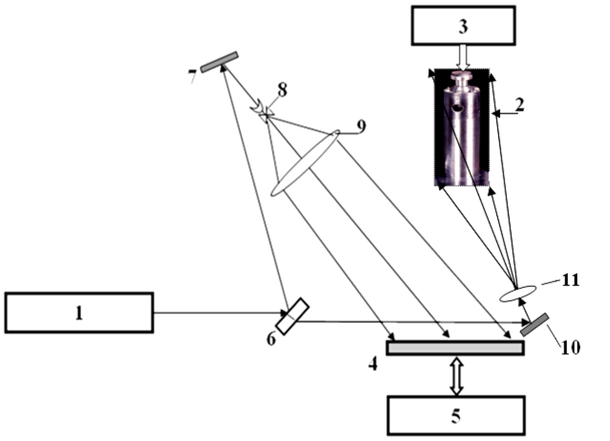
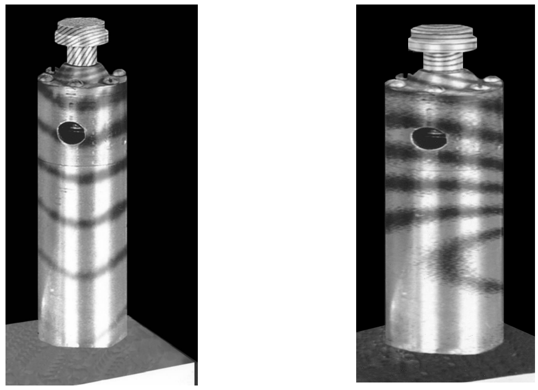


Fig. 5. Structural diagram of the holography set-up: 1 - laser, 2 - sandwich beam; 3 - unit for control of sandwich beam operation; 4 - photographic plate; 5 - photo camera or video camera; 6 - beam splitter; 7, 10 - mirrors; 8 – micro-splitter; 8 - micro object-lens and spatial filtration diaphragm; 9, 11 - lens

Fig. 5 presents the structural diagram of a stand for experimental study of deformation processes in the sandwich beam (or in its separate elements) with the aid of holographic interferometry using the me averaging in time and double-exposure [5]. The stand contains sandwich beam (or it

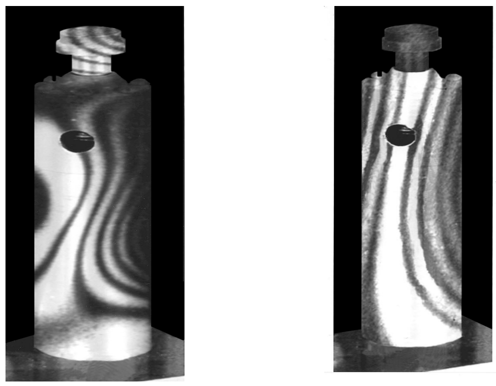
Fig. 6 (a, b) illustrates interferograms obtained with double-exposure method. When testing, the variation character of the displacement of the working part has been determined. The contact of a working element with the system stand is also determined as well as the deformation of the stand due to the control signal parameters and mechanical system matching. The strain character of a piezoceramic sandwich beam can be found out analyzing the stand deformations. It is obvious that the working element displacement in the normal direction is illustrated by the measurement results in the figures.

Fig. 7 (a, b) demonstrates interferograms obtained with a time-averaging method. They show the torsional strains created by the system. The interferogram (a) illustrates the optimal working conditions. The system is excited by periodical rectangular pulses. The dark working part indicates that during the hologram exposition it has been undergoing uniform torsional motion therefore the beam reflected from object surface could not form an interference pattern. Torsional strains are directly illustrated by localization character of the interference bands on the set-up. Figure (b) presents an interferogram when the system is operating under non-resonance frequency. The interference bands on the system working part indicate that the system is turning (i.e. turns) and it is not turning round. The character of the interference bands proves that the magnitude of longitudinal deformations of sandwich beam cannot affect the formation of torsional strains.



(a) (b)

Fig. 6. (a, b). Holographic interferograms of the links of sandwich beam



(a) (b)

Fig. 7. (a, b). Holographic interferograms of the links of sandwich beam

2. Conclusions

In the process of development of rotary converter the measurements have been made by applying sensors composed of piezoceramics - the material used for sandwitch beams. It has facilitated the development of rotary converters. Application of holographic interferometry method for their design and analysis proved to be of great importance. The developed rotary converters are proposed for production of titanium frames used for fastening ultrasound converters on human heads and also for loosening rigid tightenings and eliminating corrosion impurity (machine building).

References

[1] **Patasiene L., Fedaravicius A., Vasiliauskas R.** Holographic Methods for Analysis of Vibrodrives Transport Means 2005, Proceedings of 9th International Conference. Kaunas University of Technology, Lithuania, October 20–21, 2005. Kaunas University of Technology, IFTOMM National Committee of Lithuania, SAE Lithuanian Branch, Klaipeda University, Vilnius.

[2] **Patasiene L., Vasiliauskas R., Fedaravicius A.** Application of holographic Interferometry Methods for Analysis of Piezzodrives with Ring Actuators. Ultragarsas Nr. 3(56). Kaunas: Technologija, 2005. ISSN 1392–2114. p. 17–21.

[3] **Patasiene L., Fedaravicius A.** Analysis of piezomaterial used in mechanical systems at different temperature range. Mechanika 2006: Proceedings of the 11th international Conference, April 6–7, 2006, Kaunas Univeristy of Technology, Lithuania / Kaunas University of Technology, Lithuanian Academy of Science, IFTOMM National Committee of Lithuania, Baltic Association of Mechanical Engineering. ISSN 1822–2951. 2006. p. 263–265.

[4] **Bauriene G, Fedaravicius A., Patasiene L., Ragulskis K.** Investigation of ring–shaped Vibrator used in Electromechanical Systems. Vibroengineering 2006, Proceedings of the 6th International Conference, October 12-14, 2006, Kaunas, Lithuania. Lithuianian Academy of Sciences, IFTOMM National Committee, Kaunas University of Technology. ISSN 1822–1262. 2006. p. 100-102.

[5] **Patasiene L., Vasiliauskas R., Fedaravicius A.** Holgraphic interferometry method for determination of layer piezostack parameters. Ultragarsas Nr. 1(6)2. Kaunas: Technologija, 2007. ISSN 1392–2114. p. 23–25.