# 845. Application of incremental polymeric scales for high precision piezoelectric angular positioning system

**R. Bansevičius[1], I. Grybas[2], G. Janušas[3], A. Lazauskas[4], K. Malinauskas[5]**
[1, 2]Kaunas University of Technology, Department of Mechatronics, Kęstučio 27, 44312 Kaunas, Lithuania
[3]Kaunas University of Technology, International Studies Centre
Mickevičiaus 37, 44244 Kaunas, Lithuania
[4]Kaunas University of Technology, Institute of Materials Science, Savanorių 271, 50131 Kaunas, Lithuania
[5]Kaunas University of Technology, Institute for Hi-Tech Development
Studentų 65, 51369 Kaunas, Lithuania
**E-mail:** [1]*ramutis.bansevicius@ktu.lt*, [2]*ignas.grybas@stud.ktu.lt*, [3]*giedrius.janusas@ktu.lt*, [4]*algirdas.lazauskas@stud.ktu.lt*, [5]*karolis.malinauskas@stud.ktu.lt*

*(Received 15 May 2012; accepted 4 September 2012)*

**Abstract.** A high precision piezoelectric rotational stage with low-cost incremental polymeric scales is proposed and investigated in this work. For avoiding datum plane surface errors caused by application of additional bearings to support the rotational part, the latter one contacts with a stationary piezoelectric disc, which oscillates in travelling wave mode, at three specific points via contacting ring. The resolution of rotation is determined only by geometrical errors of external surface of the piezoelectric disc and can be easily achieved to be in the range of 1 μm. Low-cost polymeric scales are applied to measure angular displacement by means of moiré fringes. Peculiarities of scales fabrication are defined taking into consideration the final accuracy of the device.

**Keywords:** moiré pattern, piezoelectric motors, angular positioning, UV-casting, PET.

## Introduction

Moiré is a well-known phenomenon. It is an optical experimental technique for the full-field and non-contact measurement of in-plane and out-of-plane deformations [1]. Moiré phenomenon can be applied in various fields of interest from medical research to civil engineering [2, 3]. Moiré pattern is an interference pattern created when two gratings are overlaid at a certain angle, or when they have slightly different mesh sizes. Generally linear, crossed, circular and radial gratings are used. It depends on the application area and results, which are expected to be obtained. Mentioned types of gratings are utilized to measure deformations or displacements, i.e. linear, radial, etc. [4, 5]. Frequency of grating allows moiré methods to be classified into grid methods, moiré methods and moiré interferometry. For instance, when frequency is greater than 100 lines / mm, the method is referred to as moiré interferometry [2]. However, all moiré methods provide the same information.

Piezoelectric motors are used in design of positioning systems for various applications ranging from advanced manufacturing to IC industry, material science, biotechnology, etc. [6-12]. This research covers development of novel technique devoted to generation of angular positioning system driven by a synthesis of high precision piezomotor and moiré pattern with the latter being obtained when a combination of low-cost polymeric scales fabricated using UV-casting technique is employed.

## Piezomotor for angular positioning system

A high precision piezoelectric motor (Fig. 1) is characterized by high resolution, high accuracy and small dimensions in the direction of rotation axis. It consists of piezoelectric disc 1 with axial poling and electrodes on its end surfaces, contacting disc 2, which is fixed to the external diameter of the piezoelectric disc and stage 3. External surface (cylinder shape) of the contacting disc is processed by means of high accuracy grinding and polishing equipment resulting in elimination of surface defects and irregularities at sub-micrometer level.

Disc 2 contacts with stage 3 via air gap 4 in three areas, two of which (5 and 6) are rigidly fixed to the disc 2, and one (7) is elastically attached in terms of spring 8.

In order to measure the angle of rotation two circular incremental polymeric scales 9 and 10 are used: the first one is fixed to the internal surface of the stage, the second one – to its housing. The gap $\delta$ between them is of the order of 0.01-0.05 mm. A signal representing the angle of rotation is formed by the matrix of special miniature LEDs 11 and sensing photodiode (s) 12.

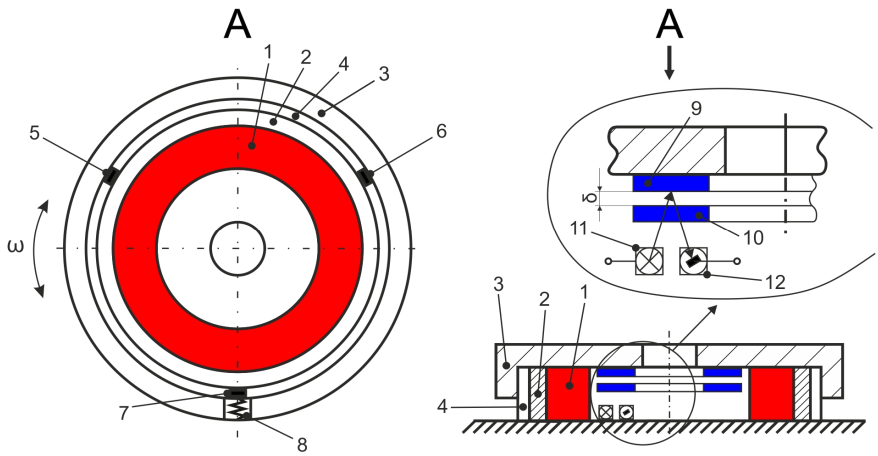



**Fig. 1.** Basic structure of conceptual piezoelectric angular positioning system: 1 – piezoelectric disc, 2 – contacting disc, 3 – stage, 4 – air gap, 5, 6, 7 – contacting material, 8 – spring, 9, 10 – incremental polymeric scales, 11 – light emitting diode(s), 12 – sensing photodiode(s), $\delta$ – gap between scales

Two lower vibration modes of radial oscillations of piezoelectric disc may be exploited: egg-like resonant form (Fig. 3a) and symmetrical ellipse form (Fig. 3b). In the first case a small rotation (circular trajectory denoted by dotted line) of neutral axis of the piezoelectric disc is generated at angular speed $\omega'$ (order of micrometer), while in the second case the displacement of the neutral axis of the disc is equal to 0 due to full symmetry of ellipse. This difference appears because topology of sectioned electrodes is distinct in Case 1 and Case 2 (Fig. 2b, 2c). However, a three-phase signal source is applied to each given configuration, what leads to the presence of travelling wave type oscillations generated by piezoelectric ring.

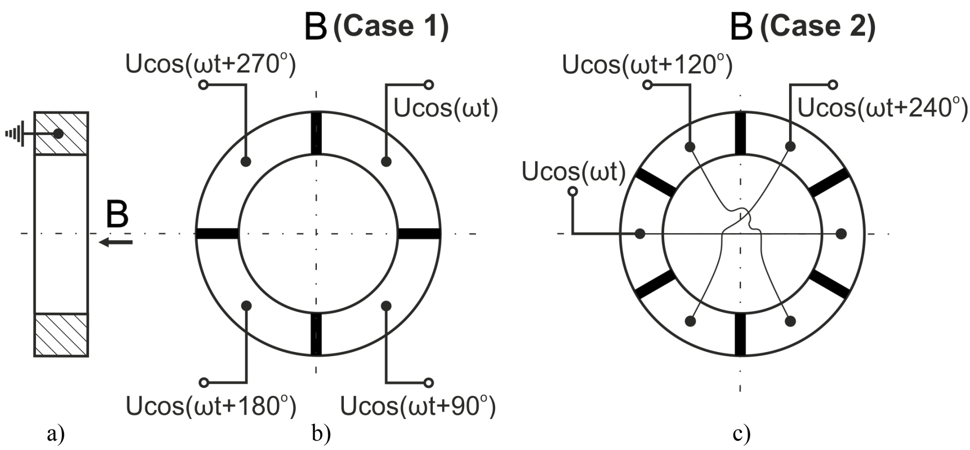



**Fig. 2.** a) Cross-sectional side view of piezoelectric disc, b) and c) two topologies of sectioned electrodes

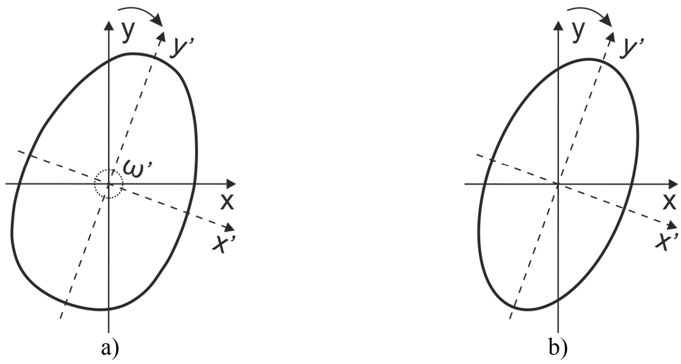



**Fig. 3.** Induced egg-like (a) and ellipse (b) radial resonant oscillations of piezoelectric disc

## Fabrication of incremental polymeric (grating) scales

UV-casting of the angular raster pattern was performed using polyethylene terephthalate (PET) substrates (thickness 110 μm) coated with acrylic photopolymer (3 μm) as a substrate for desired incremental scale. Imprint mould was pressed into the substrate applying pressure of 0.4 MPa. Optical microscope (Optika) with c-mount 2560 × 1920 resolution (5.0 Mpixel) camera (Optikam Pro 5LT) was used to measure the period of raster. As it is observed from Fig. 4a, the quality of obtained pattern is good, i.e. edges of rasters are thin, sharp and uniform. There is a relatively small amount of surface defects. A proper combination of two such scales led to the formation of moiré fringes (Fig. 4b). Correctly identified and registered accurate distance between two dark zones could be used to provide a precise (micrometer order) rotation of piezoelectric stage. This could act as the basis for retrieval of very high implemented resolution when designing new similar angular positioning systems.

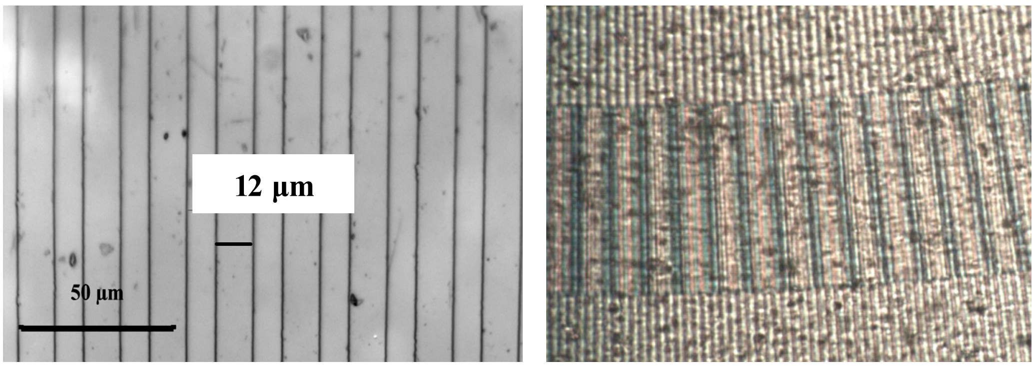



**Fig. 4.** Optical microscopy pictures: a) fragment of polymeric scale (grating) formed by UV-casting (magnification 750×), b) fragment of moiré pattern appearing when two UV-casted scales (gratings) are coincident and one of them is rotationally shifted with respect to another (magnification 75×)

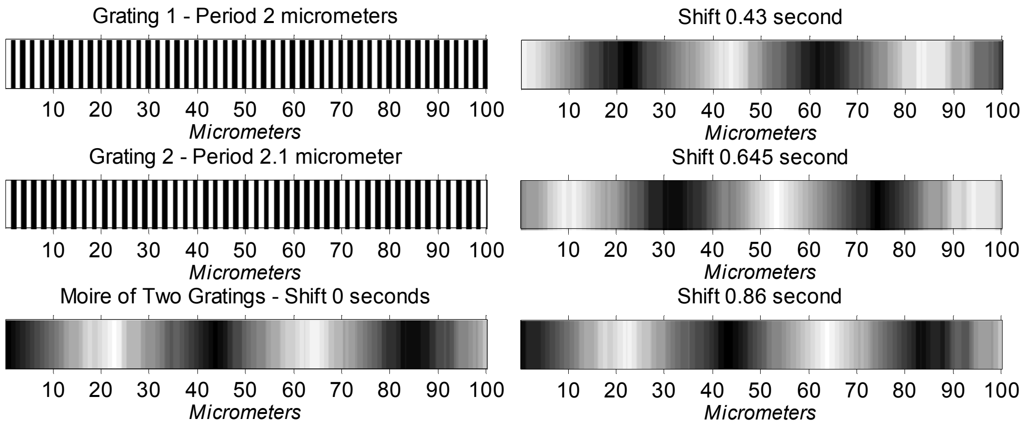
## Modeling of moiré pattern

Assuming that rotational measurements could be done, for ex., at 8 mm distance from the centre of small positioning system, two radial gratings (Fig. 5a) were modeled in MATLAB. One of them (2 μm period, 25133 lines per all circle) would be fixed to the rotating part and another one (2.1 μm period, 23936 lines per all circle) would act as a reference (Fig. 1).

A fragment of simulated moiré pattern is presented in Fig. 5a. In this case the distance between dark zones is 40 μm. Depending on the sensitivity and accuracy of sensors used in the analyzed positioning system, this distance could be changed applying different period gratings.

When grating 1 is rotated (say, clockwise) appearing moiré fringes 'move' in the same direction (Fig. 5b). Observing the pattern at 0.43 second shift it is clear that the white zone is located instead of the dark one compared to no-shift image, while after 0.86 s of rotation dark fringe returns to the initial (0 s) position. It means that using sensor, which is sensitive to bright and dark zones enough, accuracy of 0.43 s could be reached.

It is very significant that measurement accuracy is not influenced by the place, where appropriate optical signal reaches the scales (see Fig. 1), i.e. distances of 6 mm, 7 mm or 8 mm from the centre of the system lead to the same results. Such property is determined by the radial grating itself. Only distances between dark fringes vary. For instance, this distance is 38 μm at 7.5 mm from the centre, while 45 μm distance is observed at 9 mm, respectively.




a) b)

**Fig. 5.** a) Images of two gratings (period 2 μm and 2.1 μm) and their geometrical moiré pattern; b) geometrical moiré patterns of corresponding gratings when grating 1 is rotated by 0.43 s, 0.645 s and 0.86 s with respect to grating 2

## Conclusions

A combination of moiré pattern and high precision piezoelectric motor was discussed as a basis for generation of novel angular positioning system.

Operation principle of the motor, as the driving element, was explained in details putting emphasis on both mechanical and electrical aspects. Egg-like and/or symmetrical ellipse radial resonant oscillation types can be induced in piezoelectric disc causing the stage to be rotated.

UV-casting can be treated as a potential technique allowing production of high resolution low-cost incremental polymeric scales (gratings) for moiré fringes to be retrieved.

Modeling of moiré pattern revealed that using specifically formed microstructures (for ex., periods of 2 μm and 2.1 μm) it is feasible to achieve 0.43 s accuracy when shifting the rotating scale with respect to the stationary one. In addition, it was determined that accuracy of angular displacement measurement is not influenced by the place where appropriate optical signal reaches the scales in terms of positioning system construction.

## Acknowledgement

This work has been supported by Agency for Science, Innovation and Technology, Project No. 31V-14.

## References


[1] **Saunorienė L., Ragulskis M., Palevičius A., Ostaševičius V., Janušas G.** Hybrid numerical-experimental moire technique for analysis of microstructures. Proceedings of SPIE: Seventh International Conference on Vibration Measurements by Laser Techniques: Advances and Applications, Vol. 6345, 2006, p. 1 – 8.

[2] **Rossler T., Hrabovsky M., Pochmon M.** Moire methods for measurement of displacement and topography. Czechoslovak Journal of Physics, Vol. 56, Number 2, 2006, p. 101 – 124.

[3] **Ragulskis M., Maskeliūnas R., Ragulskis L., Turla V.** Investigation of dynamic displacements of lithographic press rubber roller by time average geometric moiré. Optics and Lasers in Engineering, Vol. 43, Issue 9, 2005, p. 951 – 962.

[4] **Liu M. C., Chen W. L., Wang C. C.** Nanoscale displacement measurement by a digital nano-moiré method with wavelet transformation. Nanotechnology, Vol. 17, Number 17, 2006, p. 4359 – 4366.

[5] **Hanea K., Uchidab Y., Hattoria S.** Moiré displacement measurement technique for a linear encoder. Optics & Laser Technology, Vol. 17, Issue 2, 1985, p. 89 – 95.

[6] **Tumasonienė I., Kulvietis G., Mažeika D., Bansevičius R.** The eigenvalue problem and its relevance to the optimal configuration of electrodes for ultrasound actuators. Journal of Sound and Vibration, Vol. 308, Issues 3 – 5, 2007, p. 683 – 691.

[7] **Bansevičius R., Blechertas V.** Multi-degree-of-freedom ultrasonic motors for mass-consumer devices. Journal of Electroceramics, Vol. 20, Numbers 3 – 4, 2008, p. 221 – 224.

[8] **Liu T. Y., Wang W. C.** A self-moving precision positioning stage utilizing impact force of spring-mounted piezoelectric actuator. Sensors and Actuators A: Physical, Vol. 102, Issues 1 – 2, 2002, p. 83 – 92.

[9] **Kim S. H., Cho M. Y.** Design and modeling of a novel 3-DOF precision micro-stage. Mechatronics, Vol. 19, Issue 5, 2009, p. 598 – 608.

[10] **Zheng J., Salton A., Fu M.** Design and control of a rotary dual-stage actuator positioning system. Mechatronics, Vol. 21, Issue 6, 2011, p. 1003 – 1012.

[11] **Gao W., Sato S., Arai Y.** A linear-rotary stage for precision positioning. Precision Engineering, Vol. 34, Issue 2, 2010, p. 301 – 306.

[12] **Kuo M. W., et al.** Precision nano-alignment system using machine vision with motion controlled by piezoelectric motor. Mechatronics, Vol. 18, Issue 1, 2008, p. 21 – 34.