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Research of rotary piezotable driven by two harmonic signals

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1. Introduction

Rotary piezoelectric stages and motors exploiting ultrasonic vibrations are found in many mechatronical applications including positioning, metrology, manufacturing process control, pick-and-place assembly, consumer electronics, medicine, aerospace systems, etc [1-5]. This tendency is governed by such prevalent benefits over conventional electromagnetic actuators as high precision and accuracy, compactness, high torque output at low speed, simple structure, nearly zero noise level, insensitivity to magnetic field and high efficiency [1, 6-8]. Despite piezopositioning stages mostly make use of standing and/or travelling waves there is a very limited amount of information about rotational oscillations and their positive impacts.

2. System construction and operation principle

Schematic construction of the system to be analysed is given in Fig. 1, while relevant operation principle is explained in the subsequent text.

This table structure contains rotor *1* contacting with ring shaped piezoelement *3* via five frictional elements *2* (three units) and *5* (two units), what ensures precise positioning of the rotor with respect to its axis of rotation. When rotational motion takes place these five supporting points become vibroactive, and this significantly reduces resisting moment of friction forces. Ring-shaped piezoelectric transducer is composed of two groups of control electrodes, with one group inducing rotation of the rotor, while the other initiates motion of opposite direction under operational regime voltage supply.

In order to excite specific rotational type oscillations within the rotor two harmonic signals (U_1 and U_2) of different frequency and amplitude are supplied to both groups of control electrodes. Signal expressions are presented in Eqs. (1) and (2) [9]:

$$U_1(t) = U_{01}\cos(\omega_1 t - \varphi_1), \quad (1)$$

$$U_2(t) = U_{02}\cos(\omega_2 t - \varphi_2), \quad (2)$$

where U_{01}, U_{02} are voltage amplitudes, ω_1, ω_2 are angular frequencies, t is time and φ_1, φ_2 are phases of harmonic signals. Here $\omega_2 > \omega_1$ and $\omega_2 - \omega_1 << \omega_1$.

In the presence of such conditions the moving member (i.e. rotor) performs a periodic motion, which is defined by the following law [9]:

$$A = A_{max}\cos\left(\frac{\omega_2 - \omega_1}{2} t\right), \quad (3)$$

where A_{max} is the maximal amplitude and t is time of rotational type vibrations.

In this case harmonic oscillations are excited in frequency range from 0 Hz at $\omega_2 = \omega_1$, $A = A_{max}$.

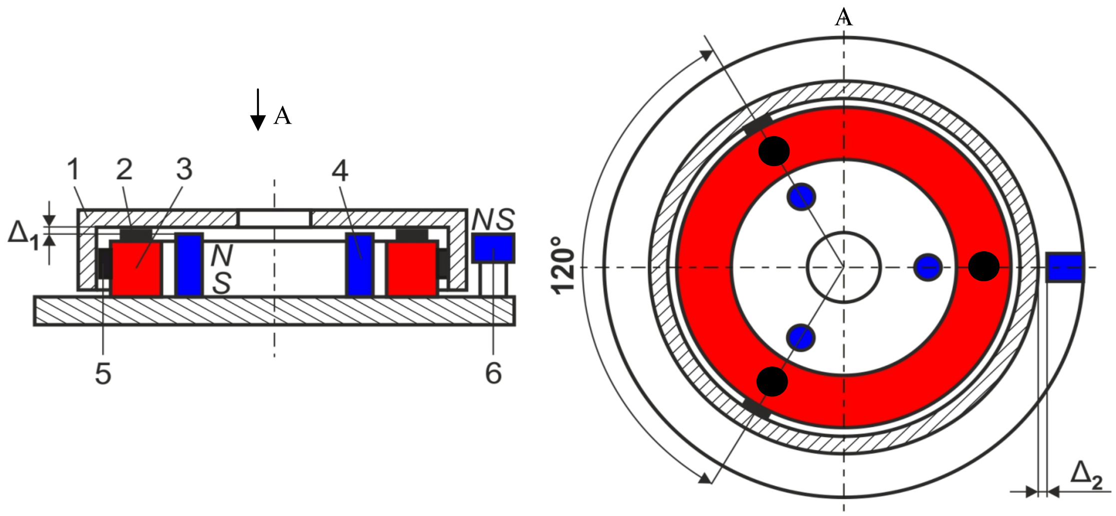

Fig. 1 Schematic construction of rotary piezotable driven by two harmonic signals: *1* – rotor, *2, 5* – frictional elements, *3* – ring-shaped piezoelectric transducer, *4* – axial attraction magnets, *6* – lateral attraction magnet, Δ_1 and Δ_2 – air gaps of axial and lateral attraction magnets

3. Experimental setup and investigation

A prototype of the piezotable researched has the piezoelectric ring-shaped transducer, in which the alternating strain is excited by an AC electrical field, preferably operating at the mechanical resonance frequency. In order to determine the resonance frequency of the designed piezoelectric ring-shaped transducer, an impedance analyzer Wayne Kerr 6500B (Fig. 2) is used to measure the impedance characteristics of the prototype, and the measurement plot of electric impedance within the measured frequencies is shown in Fig. 4.

So as to measure the dynamic characteristics of the piezotable, an experimental setup, which includes two function generators and high voltage amplifiers, the laser Doppler interferometer, vibrometer, oscilloscope and PC, was used. A simplified structural scheme can be seen in Fig. 3, a and its actual components are shown in Fig. 3, b.

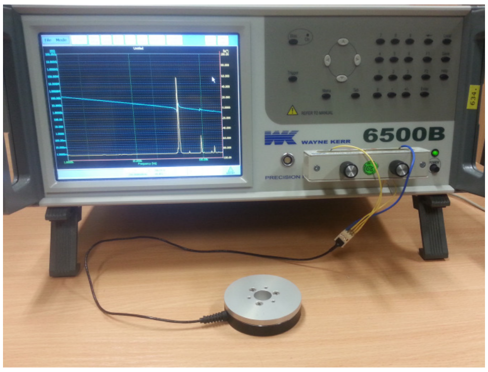

Fig. 2 Measurement of rotary piezotable impedance by impedance analyser Wayne Kerr 6500B

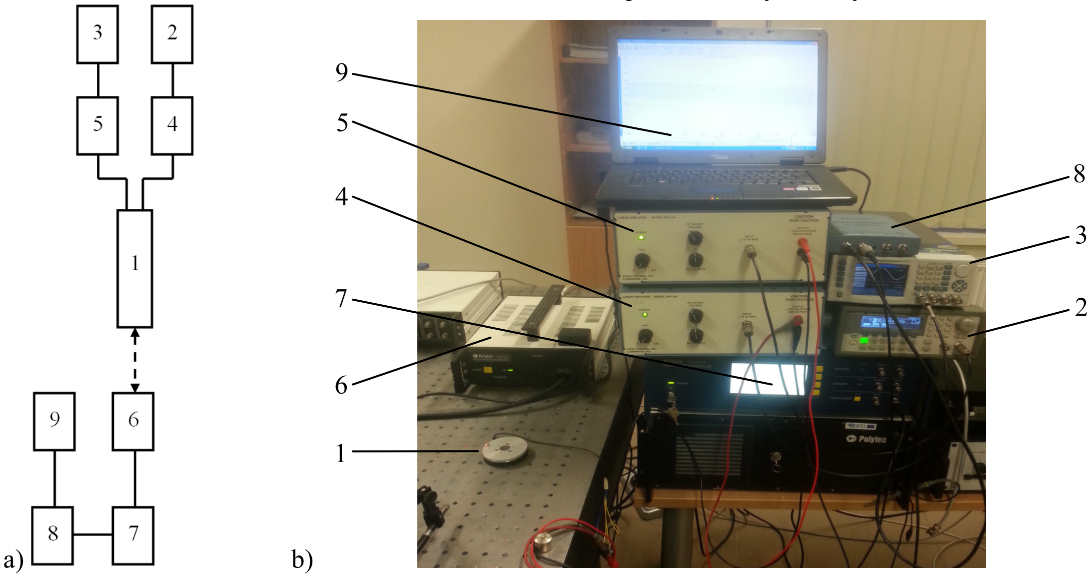

Fig. 3 Experimental setup for investigation of rotary piezotable dynamic charateristics: a) simplified structural scheme (U_1 and U_2 – harmonic excitation signals), b) actual components (*1* – piezotable, *2, 3* – harmonic signal generators, *4, 5* – amplifiers EPA-104, *6* – laser Doppler interferometer OFV 512 (Polytec), *7* – vibrometer OFV 5000 (Polytec), *8* – oscilloscope PicosScope 3424, *9* – PC)

4. Results of experimental analysis

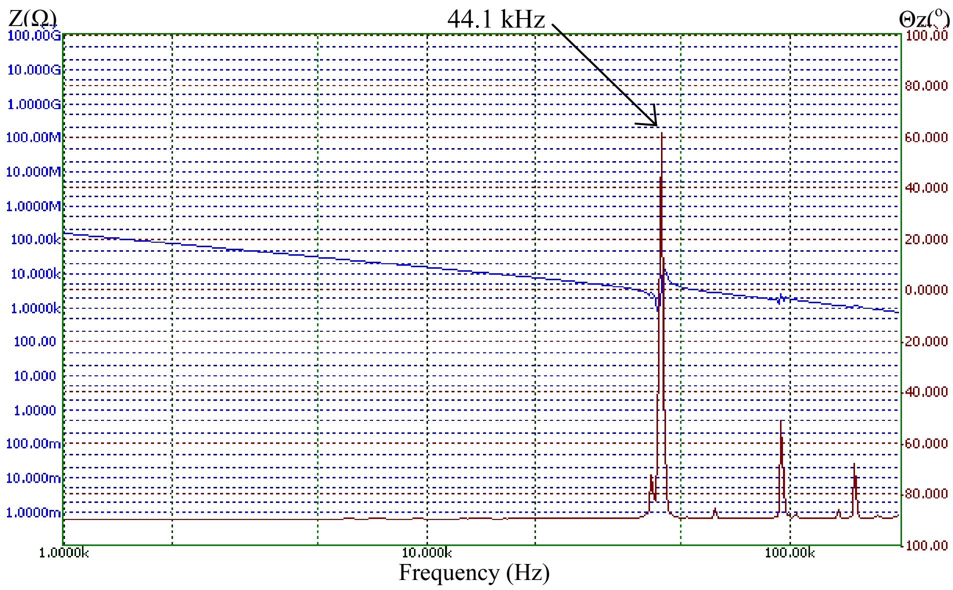

Fig. 4 The impedance (Z) and phase (θ) of ring-shaped piezoelectric transducer vs. excitation frequency (operational (resonant) frequency – 44.1 kHz)

A prototype of the piezotable was built and tested. In order to determine the operational AC frequency of the researched piezotable the measurement plot of electric impedance and phase of the ring-shaped piezoelectric transducer within the measured frequencies is shown in Fig. 4.

By observing the measured impedance vs. frequency characteristic, shown in Fig. 4, there are three resonant frequencies (around 44 kHz, 92 kHz and 132 kHz) at which the impedance reaches maximum. The operation frequency of the piezotable is 44.1 kHz, and it was determined experimentally.

However, it should be noted that rotary piezotable can also operate in a slightly wider frequency range, which is determined by width of the characteristic impedance curve in the peak zone.

Two oscillation regimes of investigated piezotable rotor were obtained with one of them exhibiting maximal vibration amplitudes (0.2 rad) and another one featured by minimal vibration amplitudes (~10 μrad). Respective plots are given in Figs. 5 and 6. In each case rotating motion of the rotor is absent, i.e. rotor just vibrates rotationally forth and back. Two harmonic signals (U_1 and U_2) of different frequencies and equal amplitudes are supplied to both

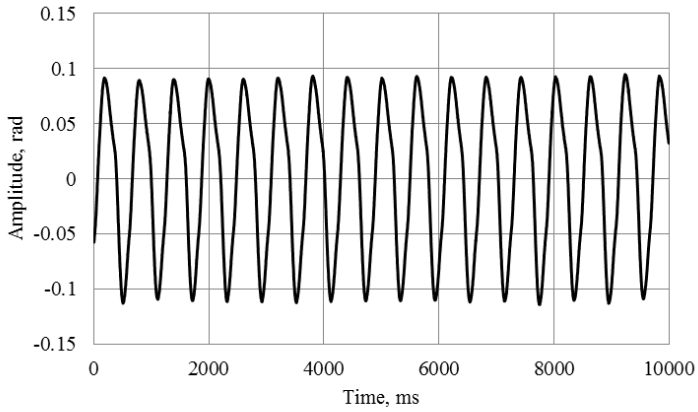

Fig. 5 Waveform of maximal oscillations of the rotor at the frequency of 2 Hz (f_1 = 44100 Hz, f_2 = 44102 Hz) and amplitude of harmonic signals voltage is $U_1 = U_2 = 60$ V

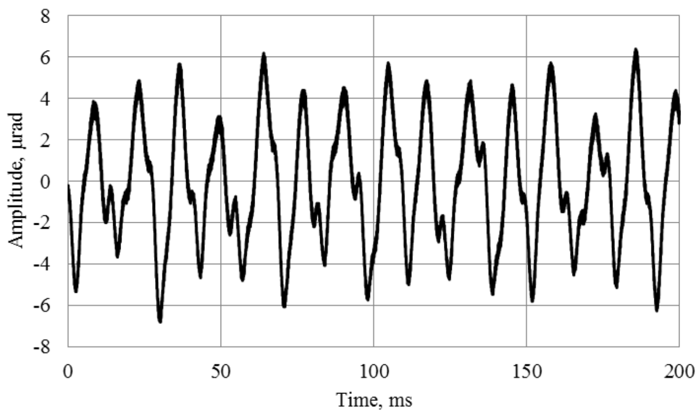

Fig. 6 Waveform of minimal oscillations of the rotor at the frequency of 74 Hz (f_1 = 44100 Hz, f_2 = 44174 Hz) and amplitude of harmonic signals voltage is $U_1 = U_2 = 10$ V

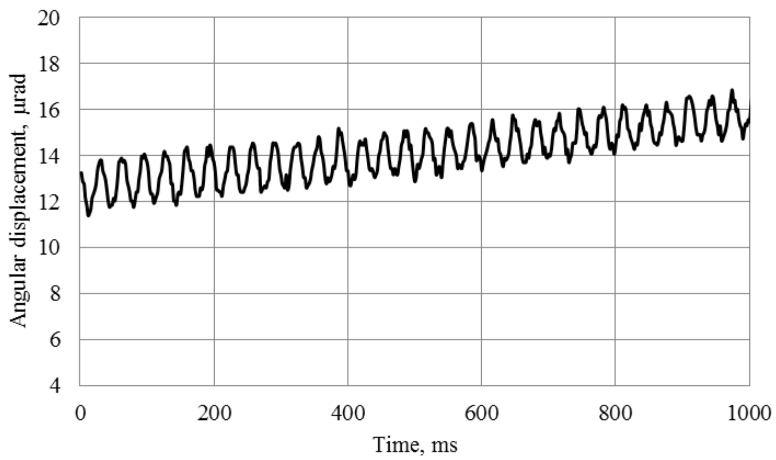

Fig. 7 Waveform of rotation of the rotor with the rotational oscillations at the frequency of 30 Hz (f_1 = 44100 Hz, f_2 = = 44130 Hz), amplitudes of harmonic signals' voltages are U_1 = 25 V, U_2 = 30 V and the rotor angular speed is 3.5 μrad/s

groups of control electrodes. On the contrary, a possibility to combine rotational motion with rotational oscillations of the rotor is presented in Fig. 7. It has to be pointed that the latter opportunity implementation is only feasible, if two harmonic excitation frequencies are not the same and their voltage amplitudes are different (i.e. $f_1 \neq f_2$, $U_1 \neq \neq U_2$). Furthermore, although measured rotor angular speed was 3.5 µrad/s, it can be increased/decreased by setting higher/ lower values of voltage amplitudes. Emphasis should also be placed on capability of bidirectional rotational motion in this case too. Despite this characteristic is not shown in the paper it will definitely be discussed more in details in future work.

4. Conclusions

Developed piezoelectric rotary table driven by two harmonic signals was discussed and analysed in this article. The following conclusions are formed.

1. A new design and operation principle of the rotary piezotable was described.
2. Experimental setup for determination of rotary piezotable resonant frequencies and investigation of major dynamic characteristics was presented.
3. Maximal vibration amplitudes (0.2 rad) and minimal vibration amplitudes (~10 µrad) of the rotor were obtained.
4. Specific regime combining ordinary rotational motion with rotational oscillations was demonstrated to be possible (rotor angular speed 3.5 µrad/s).

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SUKAMOJO STALIUKO, VAROMO DVIEM HARMONINIAIS SIGNALAIS, TYRIMAS

R e z i u m ė

Straipsnyje pateikiama nauja sukamojo pjezostaliuko, varomo dviem harmoniniais signalais, konstrukcija, veikimas ir pirminiai tyrimų duomenys. Varančiojo žiedo formos pjezoelemento ir papildomų komponentų sąveika užtikrina tolygų rotoriaus judesį. Dviejų harmoninių signalų, pasižyminčių skirtingais dažniais bei ampitudėmis, tiekimas į atitinkamai suskirstytus pjezožiedo elektrodus, sukuria specialius sukamojo tipo virpesius išėjimo grandyje. Eksperimentiniai tyrimai suteikia galimybę stebėti du virpesiais pagrįstus darbo režimus ir vieną režimą, integruojantį įprastą sukamąjį judesį bei sukamųjų virpesių efektą.

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RESEARCH OF ROTARY PIEZOTABLE DRIVEN BY TWO HARMONIC SIGNALS

S u m m a r y

This paper presents description of new design, its operation and primary research data of rotary piezotable driven by two harmonic signals. Synthesis of driving ring shape piezoelement and additional components ensures uniform motion of rotor. Supply of two harmonic signals, which are featured by distinct frequency and amplitude, to appropriately sectioned electrodes of piezoelectric ring-shaped transducer initiates specific rotational type oscillations of the rotor. Experimental research provides a possibility to observe two oscillation-based operational regimes and one regime integrating both ordinary rotational motion and rotational vibrations effect.

Keywords: rotary, piezotable, harmonic signals, resonant frequency, amplitude, vibrations.

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