Science and Education a New Dimension. Natural and Technical Sciences, X(34), Issue: 268, 2022 July. www.seanewdim.com

Application of piezoceramic actuators in adaptive interferometry

M. V. Tsyhyka[1], I. I. Chychura[1], A. A. Grabar[1], V. V. Tsyhyka[1], M. V. Stoika[2]

[1] Uzhhorod National University, Ukraine
[2] Ferenc Rákóczi II Transcarpathian Hungarian College of Higher Education, Ukraine
*Corresponding author. E-mail: sztojka.miroszlav@kmf.org.ua

Paper received 08.02.22; Accepted for publication 07.03.22.

https://doi.org/10.31174/SEND-NT2022-268X34-06

Abstract. The features of application of piezoceramic actuators in adaptive interferometry are considered in this work. Methods of power supply of actuators from a sinusoidal voltage source with preservation of positive polarity of a control signal by means of schemes on the basis of operational amplifiers are developed. The possibility of modulating not only for amplitude and frequency but also the phase of mechanical oscillations of the surface of the actuator by using a phase-rotating circuit (FRC) is provided, the method of parameters calculating of FRC elements is also proposed. A two-channel control circuit for piezoceramic actuators has been implemented.
Keywords: *adaptive interferometry, piezoceramic actuators, voltage source, phase rotation, impedance*.

Introduction. Adaptive interferometry is based on the use of dynamic holograms, which are formed in photorefractive crystals [1]. Adaptive interferometers are very promising in the field of non-destructive testing, nanometric measurements, acoustic measurements, etc. [1, 2]. In dynamic interferometry, in particular in adaptive interferometers, it is convenient to use piezoelectric actuators, i.e. piezomechanical devices that provide calibrated movement, including in the sub-nanometer range and are therefore widely used in adaptive optics, as drives for optical phase modulators, in tunneling microscopy, etc. [3 - 5]. Concerning heterodyne dynamic interferometers, actuators are used mainly to modulate the phase of laser radiation, reflected from the studied surface and the phase of reference beam, which allows to synchronize the frequencies of laser beams and determine the parameters of the studied mechanical oscillations [2]. Actuators can also be used, for example, to simulate the mechanical oscillations of the test surface and other applied problems of adaptive interferometry.

Materials and methods. To determine the technical requirements for the power supply, you need information about the electrical parameters of the actuator, and for elimination the phenomenon of repolarization when working in dynamic mode, you must ensure the positive polarity of the control signal. Solutions to these issues for the case of sinusoidal supply voltage of multilayer piezoceramic actuators are considered in this paper. In our experiments, sinusoidal signals in the frequency range 1 Hz – 1 kHz were applied to the piezoelectric elements. If an alternating voltage with a frequency f below the resonant is applied to the actuator, the piezoactuator should in most cases be considered as a purely capacitive load relative to the power supply. Its capacity, unlike a conventional capacitor, depends on the amplitude of the applied voltage, temperature and other factors that cause changes in the dielectric constant of piezoceramics and can increase significantly. Therefore, the specifications of finished products indicate there approximate value.

The response of the actuator to the control voltage is almost linear and theoretically allows to ensure the resolution (minimum possible movement of the actuator body per unit of control voltage), which is limited by factors such as electromagnetic interference, electronic noise, microfriction with devices in contact with sensors. Therefore, the stability of power supplies is subject to strict requirements, as even interference with an amplitude of one microvolt can cause displacement. Under conditions of a small control signal, the tangent of the dielectric loss angle tg $\delta = 0.01 \div 0.02$, i.e. only up to 2% of the electric power flowing through the device, can be converted into heat.

The speed of the actuators is determined by their resonant frequency f_0: the nominal movement is carried out over time $t_{\min} \approx 1/3f_0$ [4], which is usually a few microseconds.

Actuators AE0203D08F from NEC Corporation were used in this work. Their main characteristics: $f_0 = 138\,kHz$, response time $t_{min} \approx 2{,}4\,\mu s$, rated control voltage $U_{nom}=100\ V$, displacement Δl at rated control voltage $\Delta l = (6.1 \pm 1.5)$ *mkm.*

Results. To clarify the static capacitance and the tangent of the dielectric loss angle, the electrical circuit of the series connection of the actuator ZQ and the exemplary resistor *Rz* was used, shown in Fig. 1 (to remove the time dependence of the voltage on the actuator $u_C(t)$ the signal from the output of the oscillator G $u(t)$ was applied to the resistor).

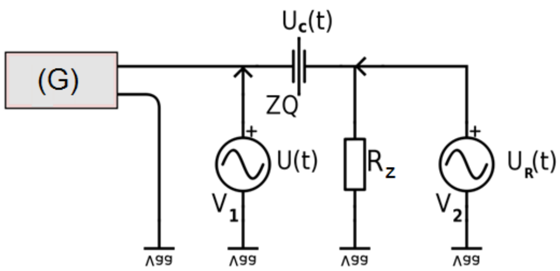

Fig. 1. Diagram for determining the capacitance and dielectric loss angle of the actuator: G - low frequency generator, V_1, V_2 - measuring inputs of the oscilloscope.

The circuit was powered from a sinusoidal oscillator with a voltage amplitude of 4 V and a frequency of 100 Hz. Oscillograms of supply voltage, voltage drops on the resistor and actuator are shown in Fig. 2.

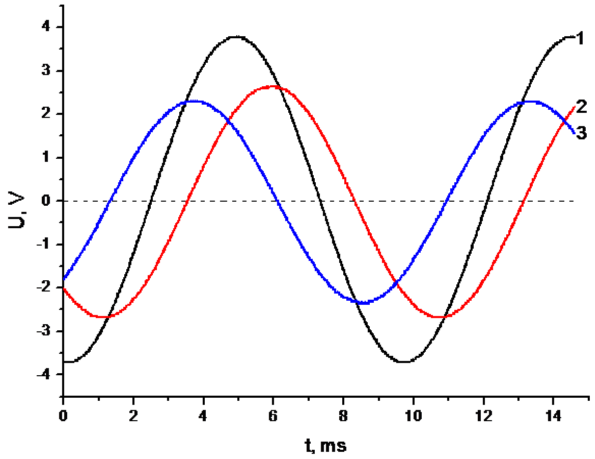

Fig. 2. Oscillograms of voltages: 1 - supply voltage *u(t)*, 2 - voltage drop on the actuator $u_C(t)$, 3 - voltage drop on the sample resistor $u_R(t)$.

According to the obtained oscillograms, phase shifts between voltages, phase shift φ between voltage u_C and current ($\varphi = \alpha_{U_C} - \alpha_{U_R}$), dielectric loss angle $\delta = 90^0 - |\varphi| = 1{,}2^0$, $tg\delta = 0.021$, capacitive resistance and, accordingly, the static capacity of the actuator $C_0 = (0.22 \pm 0.01)mkF$ were determined. The oscillographic method allows to determine electrical quantities with a relative error of not less than 5%.

Switching on the reverse voltage can lead to repolarization and failure of piezoceramics. The value of the negative polarity voltage, which can be connected to the actuator for a short time, should not exceed 20% of the maximum value of the control voltage specified in the specification. Schemes based on operational amplifiers (OA) were used to supply positive bias voltage.

In fig. 3 shows a schematic diagram of the electrical basic device for supplying control signals to the piezo actuator. The sinusoidal voltage from the low frequency generator (G) Uin and the constant bias voltage from the reference voltage source U_{OA} are applied to the input of OA - DA1.

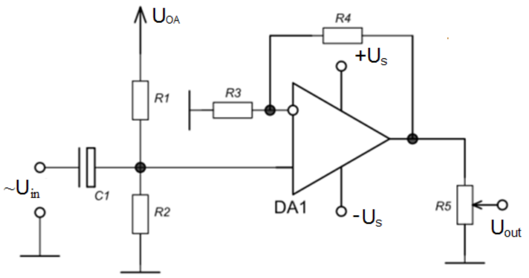

Fig. 3. Actuator control voltage generator.

The voltage divider in the resistors R_1, R_2 sets the bias voltage equal to the amplitude of the output signal of the (G). Resistors R_3, R_4 set the value of the voltage gain $K_U = \frac{U_{out}}{U_{in}}$, which receives the maximum signal amplitude at the output of the OA. Adjustment of the actuator control voltage range is carried out by potentiometer R_5.

Usually the bipolar supply voltage of OA ±Us does not exceed 15 V. To increase the amplitude of the output signal, a circuit of OA TDA2050 with unipolar power supply, the maximum allowable voltage of which is 50 V was used. Its basis is a typical version of the inclusion of this OA with unipolar power supply, given in [6]. The advantage of this inclusion of OA is the presence of only one power supply and the ability to obtain an output voltage above 40 V. However, it turned out that at amplitudes of the output voltage above 20 V there is a distortion of the shape of the output signal. A simpler solution to increase the amplitude of the actuator control voltage is to use a reliable bipolar circuit. 3 and more high-voltage OA, which is, for example, OPA454, product from Texas instruments company. In Fig. 4 shows the basic scheme of inclusion of OPA454 as a non-inverting amplifier. Power can be selected any in the range from ± 5 to ± 50 V while maintaining all the characteristics.

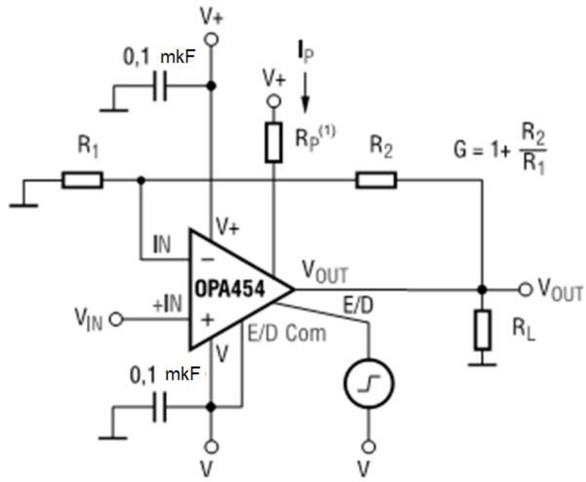

Fig. 4. Basic non-inverting circuit of the amplifier OPA454 [7].

In [7] considered the bridge power supply circuit of the piezoelectric converter based on two OA OPA454 with doubling of the maximum output voltage, which can be up to 195 V.

For some adaptive interferometry problems, there is a need to modulate not only the amplitude, frequency, but also the phase of the mechanical oscillations of the piezoceramic actuator. To control the phase change of the sinusoidal control voltage, a phase-rotating circuit (FRC) in the form of a bridge circuit was used, in the adjacent arms of which resistors of one denomination are included, and in the other two, respectively, variable resistor and capacitor [8]. The diagram of this electric circuit is shown in Fig. 5.

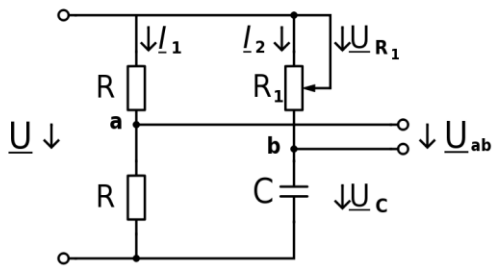

Fig. 5. Phase-rotating circuit diagram [8].

The phase angle between the voltage phasors (rotating vectors) on the resistor $\underline{U}_{R1}$ and the capacitor $\underline{U}_C$ is 90^0, and the phasor sum $\underline{U}_{R1} + \underline{U}_C = \underline{U}$, where $\underline{U}$ is the voltage phasor supplied from the signal generator to the FRC. Therefore, depending on the ratio of resistance R_1 and capacitive reactance X_c, the vertex of the right angle of the voltage triangle formed by the phasor $\underline{U}$, $\underline{U}_{R1}$ and $\underline{U}_C$ will describe a semicircle constructed on the phasor $\underline{U}$ as on the diameter. The voltage phasor $\underline{U}_{ab}$, whose modulus is 0.5 U, is the radius of this semicircle. At $R_1 = 0$ the angle α of the phase angle between the voltages $\underline{U}$ and $\underline{U}_{ab}$ is zero, and at $R_1 » X_C$ we have $\alpha \rightarrow 180^0$.

In the implementation of this scheme there is a question of choosing the values of resistors R and capacitor C, which should be determined taking into account the output resistance of the (G) and the operating frequency range. Calculate the equivalent complex impedance of the phase-rotating circuit at idling mode. We get:

$$\underline{Z}_e = \frac{2R(R_1 - jX_C)}{2R + R_1 - jX_c} = \frac{2R(2RR_1 + R_1^2 + X_C^2)}{(2R + R_1)^2 + X_C^2} - j\frac{4R^2 X_C}{(2R + R_1)^2 + X_C^2} \quad (1)$$

According to this relationship, in the extreme case $R_1 = 0$ the modulus of equivalent impedance:

$$Z_e = \frac{2RX_C}{\sqrt{4R^2 + X_C^2}}. \quad (2)$$

One of the options for calculating the FRC elements is to set the value of Ze equal to the nominal value of the output resistance of the (G), set the value $X_c \approx R_{1max}/10$, and the nominal value R is determined according to relation (2).

To study the dynamic holograms, a two-channel piezoceramic actuator control circuit was implemented using an LM2904 analog chip consisting of two independent operational amplifiers with a maximum bipolar supply voltage of ± 13 V, which provides maximum displacement of the working surface of the applied actuators $\Delta l = (0.78 \pm 0.18)$ mkm. Calibration of movement should be carried out by measuring instruments with high resolution. Examples of implementation of such measuring systems are considered in [9], where, in particular, the characteristics of the digital control and measuring stand are given, the optical part of which is based on the Michelson interferometer.

Conclusions. This paper considers the features of the use of piezoceramic actuators in adaptive interferometry. The method of determining the capacitance and tangent of the angle of dielectric loss of piezoelectric elements by means of the oscilloscope is applied. Variants of power supply of actuators from a sinusoidal voltage source with preservation of positive polarity of a control signal by means of schemes on the basis of operational amplifiers are developed. The possibility of modulating not only the amplitude, frequency but also the phase of mechanical oscillations of the surface of the actuator by using a phase-rotating circuit is provided, the method of calculating the parameters of the FOC elements is proposed. A two-channel control scheme for piezoceramic actuators has been implemented.

REFERENCES

1. R.V. Romashko Adaptive holographic interferometry: technique, progress and applications. Vestnik of the FEB RAS, 2021, № 4, p. 40- 47. DOI: 10.37102/0869-7698_2021_218_04_03
2. M. V. Tsygyka, A. A. Kohutych, I. I. Stoika, A. A. Grabar (2017). Dynamic interferometer on the base of Sn2P2S6 photorefractive crystal modified by indiffusion of Cu. Scientific Herald of Uzhhorod University.Series Physics. DOI:41. 14-19. 10.24144/2415-8038.2017.41.14-19.
3. http://www.americanpiezo.com
4. http://www.elpapiezo.ru
5. http://www.physikinstrumente.com.
6. http://www.st.com TDA 2050 32 W hi-fi audio power amplifier.
7. http://www.ti.com Texas Instrumemts OPA454 sbos391b – december 2007– revised march 2016.
8. Bessonov L.A. Teoreticheskie osnovyi elektrotehniki. Elektricheskie tsepi. – M.: Gardariki. 2002 – 638 s. (ru).
9. Bobtsov A. A., Boykov V. I., Byistrov S. V., Grigorev V. V. Ispolnitelnyie ustroystva i sistemyi dlya mikroperemescheniy. - Sankt-Peterburg, GU ITMO, 2011, 131 s. (ru).