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Inertial Piezoelectric Stepping Motor

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ABSTRACT

The article proposes an inertial piezoelectric stepping motor that does not have friction nodes in its design, which greatly increases its reliability and operating time. The description of the principle of operation and the theoretical basis of the action of the engine are given.

Keywords: inertial, piezoelectric, stepper motor, bimorph plate.

1. Introduction

In various branches of engineering, to solve a number of tasks electromagnetic servomotors are commonly used. However, there are cases where their electromagnetic fields disrupt the operation of other units and elements of the devices integral components, which is undesirable. In these cases, piezoelectric motors are currently widely used [1,2,3].

2. Statement of the research problem

The basis of the work of these engines is a frictional connection between the active element - the piezoelectric plate and the propeller - tape or rotor - mass flywheel. However, during the operation abrasion occurs due to parts rubbing within the mechanism that causes a change in the engine output characteristics and limits their lifetime [1,2,3].

3. Solving problem

The proposed lower inertial piezoelectric stepping motor (IPSM) has no friction components in its design, which greatly increases reliability and operating time.

Figure 1 shows one embodiment IPSM structure.

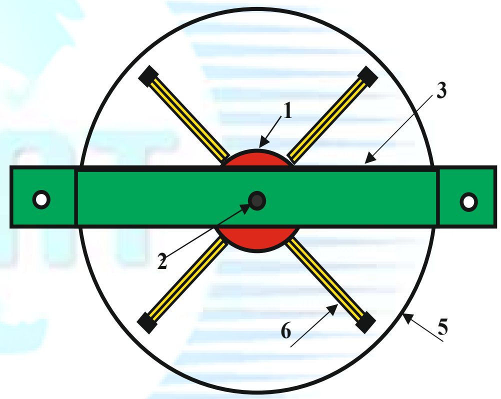

Fig.1,a.

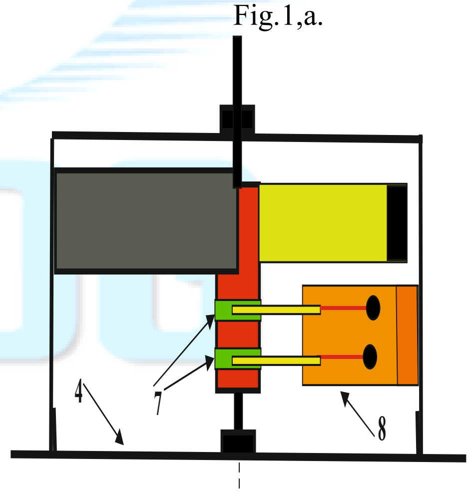

Fig.1,b.

IPSM consists of the following elements and components: 1- rotor body; 2 - the output shaft; 3 - base armature; 4 - fixing bearing no. 2; 5- guard ring (part of the basic fittings); 6- piezoceramic plates with inertial nozzles; 7- collector; 8- node collector brushes.

Construction of IPSM presupposes p pairs of piezoceramic plates. Limiting the quantity p determined by the design of the rotor body parameters and dimensions of piezoceramic plates.

The power supply generates a sawtooth voltage, the amplitude and the clock frequency can be controlled and thereby regulate engine speed. To reverse the polarity a switch is used on the node collector brushes.

4. Mathematical modelling

The physical basis IPSM is the generation of a difference driving force for inertia during the working and return stroke of piezoceramic plates. When applying a control voltage U_y bimorph piezoceramic plates on the last bend [4,5,6] together with the inertia of the nozzles and the time t_1 create momentum forces. As a result, there are inertial forces $F_1 = m_0 * a_1$, which creates the appropriate moment M_1.

The value of the acceleration a1 is determined from the expression:

$$a_1 = \frac{d^2\Delta}{dt^2}$$

Δ- where the value of the deflection of the piezoelectric plate in time t_1. There m_0 - reduced mass (the mass of the bimorph plate + packing weight).

Idle (return bimorph plate to its original state) takes place during the time t_2. Thus $t_2 \gg t_1$. As a consequence, the corresponding value of acceleration $a_2 \ll a_1$. Hence $F_1 \gg F_2$. Thus, the resulting inertia force $\Delta F = F_1 - F_2$, and the corresponding torque is $\Delta M = \Delta F * R$. There R- radius rotor. In this case the total shaft power is defined as:

$$M = p * \Delta M \quad (1)$$

As stated above, for each period of the control voltage U_y rotor is rotated by a certain angle φ, i.e., a certain "step". The angle φ is dependent on the load torque on shaft M_H, the values of the amplitude and frequency of the control signal pulses. It follows that engine speed n will depend on the M_H).

n_{xx} value determined torque idling M_{xx}, which in turn, depends on the amount of friction torque in bearings of the output shaft and torque strength of the aerodynamic resistance to movement of the BP:

$$M_{xx} = M_{TP} + M_{AT}, \quad (2)$$

If the value of $M_T \geq M_{MAX} - M_{xx}$ motor rotor is in the braking mode. Here M_{MAX}- the maximum point on the motor shaft. In terms of the mechanics' piezoceramic plate motor assembly -head " is a vibratory element and is given by [7]:

$$F_I + F_D + F_J = F_E \quad (2)$$

Or

$$m_0 * \frac{d^2\Delta}{dt^2} + b * \frac{d\Delta}{dt} + K * \Delta = F_E \quad (3)$$

Where: $m_0 = m_k + m_I$; $m_k -$ weight bimorph piezoceramic plate; m_I- inertial mass lining. b– damping coefficient- "viscous" friction piezoceramic material. According to [8] its meaning, for example, piezoelectric ceramics PZT-19 grade is 0.07 - 0.09.

$$\Delta C = K * U_y \quad (4)$$

According to the literature [4], the magnitude of the bending bimorph plate (BP) in static mode ΔC overall dimensions of its constituent plates l_1, l_2, l_3 and physical parameters ε, E_p, E_y will depend on the applied control voltage U_y:

$$m_0 * \frac{d^2\Delta}{dt^2} + b * \frac{d\Delta}{dt} + K * \Delta = F_E \qquad (3)$$

where: K- is the coefficient of proportionality; l_1, l_2, l_3 - length, width and thickness of one of the forming of the bimorph plate [m]; ε - relative permittivity of piezoelectric ceramic; E_p– electric field polarization of the piezoelectric ceramics [B/m]; E_y– Poisson's ratio of piezoceramic, , $[\frac{H}{m^2}]$; B- bimorph plate anisotropy coefficient [2].

$$U_{op} = U_y$$

In the formula (4) and the component K_{op} *u* U_{op} have the following expression:

$$U_{op} = E_{op} * l_3;\ K_{op} = 2{,}2 * 10^{-2} * \varepsilon^2 * E_p * l_1^2/(l_3 * E_y). \qquad (5)$$

From the above expression it follows that within the limits of applicability of Hooke's law BP Δ bending depends directly on the amplitude of the signal U_y.

As is well known [2], bimorph plate consists of two piezoceramic plates connected by gluing with epoxy resin or low-melting solder spikes $(t \leq 100^0C)$. Depending on the type of piezoelectric ceramics, it retains its piezoelectric properties up to temperatures $130^0C - 150^0C$ [7,8].

The piezoceramic plates comprising the bimorph in IPSM have The following compound (Fig.2):

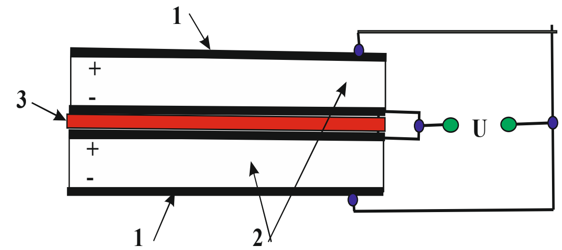

Рис.2.

In case the average dielectric electrode connecting seam is formed as shown in Fig. 4. Here: 2 - piezoceramic; 1 - plate electrodes (silver plating); 3 - a connecting joint.

When the ramp as the control pulse

$$U_y = K_u * t, \qquad (6)$$

Where $U_{ymax} = K_u * t_1$.

To estimate Δ dynamically into the equation (1) substitute values K_J *u* F_E, where $F_1 = F_E$,

$$F_E = 2 * F_0 * \frac{l_3}{l_1}, \qquad (7)$$

$$F_0 = 2{,}2 * 10^{-12} * \varepsilon^2 * S_0 * E_p * E_{op} \qquad (8)$$

Substituting in the formula (8) values S_0 и E_{op} :

$$F_0 = 2{,}2 * 10^{-12} * \varepsilon^2 * E_p * 12 * U_y, \quad (9)$$

Where $S_0 = l_2 * l_3$.

Substitute F_0 value in the expression for the F_E:

$$F_E = 4{,}4 * 10^{-12} * \varepsilon^2 * \mathrm{E_p} * l_2 * l_3 * U_y/l_1 \qquad (10)$$

When replacing $\mathrm{K}_E = 4{,}4 * 10^{-12} * \varepsilon^2 * \mathrm{E_p} * \frac{l_2 * l_3}{l_1}$, $U_y = K_u * t$ get:

$$F_E = \mathrm{K}_E * \mathrm{K}_I * t = K_y * t \qquad (11)$$

$$K_y = K_E * \mathrm{K}_и;\ [K_y] = \left[\frac{H}{c}\right]; \qquad (12)$$

The expression [2] $F_y = E_y * S_E * \frac{\Delta}{l_1}$ determine:

$$К_J = \frac{F_y}{\Delta} = E_y * S_E * \frac{1}{l_1} = E_y * l_1 * l_2 * \frac{1}{l_1} = E_y * l_2. \quad (13)$$

Substitute the expressions (13) and (11) into equation (2), we obtain:

$$m_0 * \frac{d^2\Delta}{dt^2} + b * \frac{d\Delta}{dt} + K_J * \Delta = K_y * t. \quad (14)$$

The solution of this differential equation is the sum total of their differential equation and a particular solution.

If we consider the process during the power stroke as the transition process, the function $\Delta = f(t)$ in the form of the operator takes the following form:

$$\Delta = K_1 * t \,/ (T_2^2 * p^2 + T_1 * p + 1, \quad (15)$$

Where: $K_1 = \frac{K_y}{K_J}$; $T_2^2 = \frac{m_0}{K_J}$; $T_1 = \frac{b}{K_J}$.

The equation shows the balance of power in the power supply in BP, operating in dynamic mode:

$$F_и + F_{вт} + F_J = F_E \quad (16)$$

Here: $F_и$- inertial force; $F_{вт}$– the force of viscous friction; F_J– strength hardness BP; F_E– strength of the electric field BP.

4. Conclusion

The article considers the design of an inertial piezoelectric stepper motor. Analytical analysis of the proposed device showed high efficiency of the engine. The inertial piezoelectric stepping motor is simple in construction, has high speed and reliability. The pitch of the motor is regulated by the controller.

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