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ULTRASONIC ROTARY MOTOR. DESIGN AND SIMULATION

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Abstract: The article presents the authors research in the field of the ultrasonic motors, especially of the rotary ultrasonic motors. The basics of the analytic calculations, the vibration movement simulation of the active piezoceramic element and the constructive scheme of the motor are presented. Finally, the authors focus on the output characteristics and the advantages of the ultrasonic motors.

1. INTRODUCTION

The paper presents research and practical aspects of the authors experience regarding a relatively new research field that refers to the ultrasonic motors. These systems can have different application in various fields starting with the military industry, new materials technology, for example intelligent composite materials, and finishing with the goods industry (rotation of the focus lens). The paper is structured in 3 chapters that briefly presents the steps followed to realize such devices. First chapter presents theoretical elements that contain the main functional parameters of these motors based on high frequency vibrations, second chapter depicts design elements for the ultrasonic motor and the last one presents some functional characteristics of the realized system.

2. THEORETICAL ELEMENTS REGARDING THE ULTRASONIC MOTORS FUNCTIONING

The ultrasonic motors represent at this time a relatively new research field, very complex and interesting. The practical realization dates from the beginning of the years ‘70 in Japan. The developing of these kind of devices was remarked because of their characteristics and advantages like:

- a very precise control displacements in the field of 10^{-4} mm;
- very good start – stop characteristics;
- high rotational torque;
- simplicity in design;
- no interference with other external fields;
- possibility of movement control with the PC.

All these advantages are represented in a relatively simple construction, compact and not heavy. Also it is important to notice some disadvantages like low efficiency and in time (hundred of hours) non-constancy of characteristics.

The functioning of this motor type is based on the vibrational movement transfer of a piezoceramic active material to a mobile activated element. This transfer is done on the interface of the two elements by the frictional phenomenon thus, the motor functioning is the result of the electric energy produced by an ultrasonic generator (20 – 100 kHz) transformed into vibrational energy that is transformed after this in a controlled movement of an activated element.

In the ultrasonic motors construction, different ways to transmit the movement from the piezoelectric active element to the mobile activated element are presented in the figure 1 it is presented the principle scheme used in the presented motor. This principle is named with oblique impact.

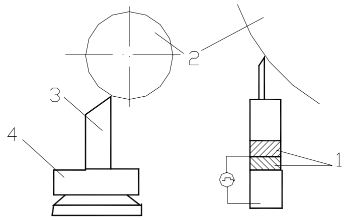

Fig. 1. Scheme of an oblique impact ultrasonic motor
1. Active piezoceramic element; 2. Mobile activated element; 3. Vibration horn; 4. Active piezoceramic element

The ultrasonic motor with high impact frequency is based on the superimposed of the tangential impact impulse. Considering the viscous frictional hipothesis, the tangential component impact impulse is dependent on the normal component and is defined by the instantaneous frictional coefficient f_l. This, depends of the contact surfaces properties and conditions. Considering the dry frictional hipothesis, the tangential component of the dry friction is proportional with the normal component , and the proportionality coefficient is equal with the dry frictional coefficient f_f. In the case of the oblic impact ultrasonic motor 2 categories are defined. This article present the category with one active element in the contact zone, and with 2 coordinates movement of the active element that defines the normal and tangential impact speed. Figure no. 2 presents the scheme of this method in which the active element 2 is elastically pressed on the activated element 1.

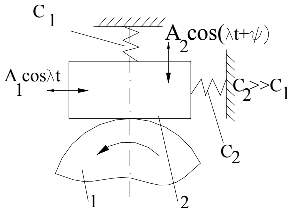

Fig. 2. Displacement scheme of an ultrasonic motor with one element in the contact zone

In the figure 3, A represents vibration amplitude, λ - wave length, ψ - phase shift.

As it can be seen, at limit, the oscillating movement of the piezoceramic element can be divided in 2 perpendicular oscillations with the fase shift ψ . On the two vibrations directions the following equations can be written:

$$\begin{aligned} x &= x_0 \cos(\varpi t) \\ y &= y_0 \cos(\varpi t + \varphi) \end{aligned} \tag{1}$$

The combination of the 2 equations has the result of an elliptic movement equation that represents the locus of the one point situated on the surface of the active element

$$\frac{x^2}{x_0^2} + \frac{y^2}{y_0^2} = 1 \tag{2}$$

In the first moment the design and construction of this ultrasonic system is a relatively simply thing but, one has to take into account that a minimal background consist in the following elements: an ultrasonic generator, a signal amplifier and an oscilloscope.

3. DESIGN ELEMENTS FOR THE OBLIC IMPACT ULTRASONIC MOTOR

To realise the ultrasonic motor the authors proposed the scheme presented in the figure 3. The basic element is the piezoceramic disk with Φ_{piezo}= 24,7 mm. and h = 0,3 mm. To magnify the vibration amplitude ant to protect the active element surface the piezoceramic plate was glued on a very thin copper disk, h = 0,1 mm, and Φ_d = 41 mm. This element has the possibility of vertical adjustment very useful to find the contact point where the elliptic movement is obtained. At the same time the activated element (the disk) has the possibility to be moved horizontally for a elastic preload adjustment. This is very important in order to get the optimal friction coefficient between the active and activated element. This tribologic problem is of great importance and itself is a separate problem.

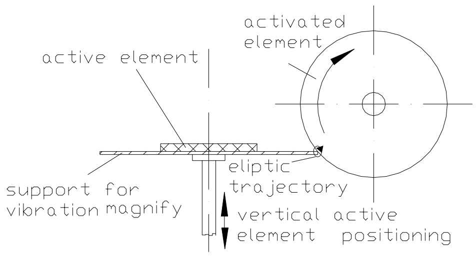

Fig. 3. Constructive scheme of the ultrasonic motor

4. VIBRATION STUDY OF THE PIEZOCERAMIC ELEMENT USING THE FINITE ELEMENT SOFTWARE ANSYS

This method is very useful to predict the vibration frequency, to shorten the design time and to understand the vibration mode shapes. In the following picture is presented the vibration mode for the frequency f = 32421. In the experiments, the rotative movement was obtained very near of this frequency.

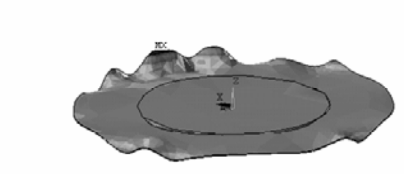

Fig. 4. Vibrational mode of the piezoceramic disk glued on the copper support disk

At this stage it is very interesting to observe that the vibration shape isn't constant on the whole circumferential zone, because of the discretisation process which is not uniform.

5. Practical realisation of the ultrasonic motor

In figure 5 depicts the constructive elements of the system that consists in the piezoceramic disk, the support disk, and the activated element. Mathematical modelling offers the input parameters of the ultrasonic system. One of the most important problems to be solved in this kind of design is to determine the electrical potential to be applied on the surface of the piezoceramic disk:

$$V = \tfrac{1}{A_z}\sqrt{\left(F_z + \tfrac{F_\theta \cdot A_z}{A_\theta}\right) + (\ r_m \upsilon_{\ z}\ )}^2 \tag{3}$$

where:

$$F_z = \frac{n\,\omega_d}{2}\int_a^b p_{(x)}\cos(2\pi x\ \ /\lambda)dx \tag{4}$$

$$\begin{aligned} F_\theta = {} & \frac{\mu\omega_d}{2}\int_a^b p_{(x)}\,\mathrm{sgn}\left[\upsilon_\theta\cos(s\pi x/\lambda) - \frac{2\pi RN_{R0}}{60}\right]\cdot\cos(2\pi x/\lambda)dx + \\ & + \frac{\mu\omega_d}{\upsilon_\theta}\int_a^b p_{(x)}\,\mathrm{sgn}\left[\upsilon_\theta\cos(s\pi x/\lambda) - \frac{2\pi RN_{R0}}{60}\right]\times \\ & (\ \upsilon_\theta\cos(s\pi x/\lambda) - \frac{2\pi RN_{R0}}{60}\ )dx \end{aligned} \tag{5}$$

where ω_d represents the width of the contact zone between the two elements measured on radial direction and ν_θ represents the maximal vibration speed on the tangential direction on the surface of the active element. This speed can be determined from the equation no. 6

$$\int_a^b p_{(x)}\,\mathrm{sgn}\left[\upsilon_\theta\cos(s\pi x/\lambda) - \frac{2\pi RN_{R0}}{60}\right]dx = 0 \tag{6}$$

where:

$$\lambda = \frac{2\pi\ R}{n} \tag{7}$$

represents the wave length. From the studied literature, the vibration speed can be considered ν_z = 0,24 m/s where a and b represents contact points between the active and activated element. For these values it was considered that the length of the (a b) segment is about aproximativ 1/3λ. N_{R0} represents the requested rotational speed in the motor design R represents the contact radius between the active and activated elements. Considering all these, it was obtained by using the MathLab software, the value U = 70 V for the electrical potential which was further experimentally applied.

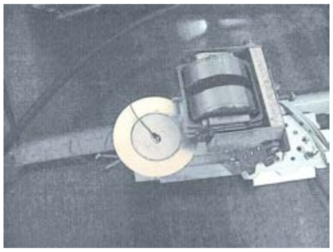

Fig. 5. View of the ultrasonic motor

Using the defined values the output power can be calculated with the relation:

$$P_{iesire} = \frac{2\pi\ R N_R\ F_d}{60} \tag{8}$$

where F_d represents the output force of the motor calculated with the following equation [2]:

$$F_d = n\ \omega\ {}_d\int_a^b p_{(x)} \operatorname{sgn}\left[\upsilon_{\theta} \cos(s\pi\, x/\lambda) - \frac{2\pi\, R N_{R0}}{60}\right] dx \tag{9}$$

$p_{(x)}$ represents the contact pressure aproximated by the equation:

$$\begin{aligned} p_{(x)} = {} & -\frac{E}{2(1-\upsilon^2)\sqrt{1+\mu^2\left(\frac{1-2\nu}{2-2\nu}\right)^2}} \left(\frac{\sin \pi\theta'}{(\ x-a\ )^{\theta'}(b-x)^{1-\theta'}}\right) \\ & \cdot \int_a^b \frac{f_{(t)}dt}{(t-a)^{-\theta'}(b-t)^{\theta'-1}(t-x)} + \\ & + \frac{c}{(x-a)^{\theta-1}(b-x)^{1-\theta'}} \end{aligned} \tag{10}$$

where:

$$\theta' = \frac{}{2} - \left(\frac{1}{\pi}\right) \tan^{-1} \mu \frac{1-2\mu}{2-2\mu} \tag{11}$$

and E represents the Young modulus of the active element, ν is the Poisson coefficient and

$$f_{(x)} = A[\cos(2\pi x/\lambda) - \cos(2\pi b/\lambda)] \tag{12}$$

where A is the normal direction movement amplitude that was aproximed with the help of the finite element method applied by the ANSYS software. In the motor construction process it is useful to determine the preload force between the two elements. The equation for this force is the following:

$$F_c = \omega_d\ n \int_a^b p_{(x)} dx \tag{13}$$

Using this equation the numerical value F_c = 0,2 N. From experiments the applied force at which the movement appears was about $F_{c\ real}$ = 0,02 N.

A frequency generator was used to generate the signal in the ultrasonic domain that offered a low sinusoidal signal amplified by an amplifier, special designed for this application.

6. Conclusions

After many experiments it was obtained a rotation frequency of the activated element n = 0,02 rot/ min. As it can be seen the system has viable applications in very precise mechanisms. One of disadvantages of the system is, on this stage of development, the very low output torque. After these first experiments the work will continue considering different vibration frequencies, different materials pair for the active and activated elements or different applied electric potential.

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