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MINIATURE DEVICE FOR ENERGY CONVERSION – BASIC BUILDING ELEMENTS IN MECHATRONICS

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Abstract: A prototyping of miniature hyperboloid gear drives and ultrasonic motors is presented. A new type ultrasonic motor is experimentally tested.

Keywords: MECHATRONICS, HYPERBOLOID GEARS, ULTRASONIC MOTORS

1. Introduction

Mechatronics is the leading direction in contemporary industrial sciences and approach to the creation of products in the direction of synergistic integration of various branches of science and techniques as mechanics, electronics, electrical engineering, control theory and computer science.

This work has for objects of research *multibody systems mechanics*, which are mechatronics modulus. It contains a brief review of the development and improvement of the approaches for studying of the energy transformation processes, in order to achieve a regularly defined motions.

The multibody systems with force (regular) determined relations and interactions are developed in such way, so that they as a whole or separate bodies (body parts, respectively) of them to realize a law of energy transformation. In this case, the relations and interactions between bodies exist unlimited in time or duration of their existence is precisely defined. The predominant mechanical motions transformers and energy convertors and machines belong to these systems.

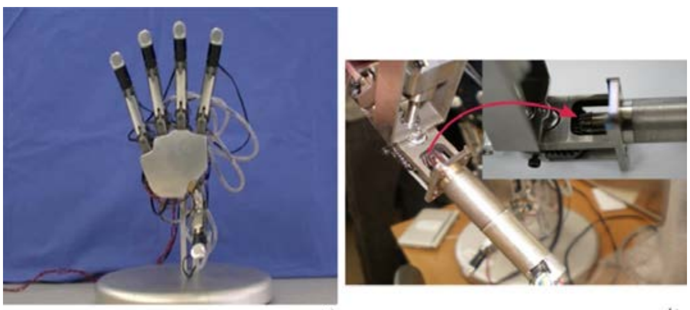
The *mechanical miniature multibody systems*, which purpose are to realize a preliminary defined law of energy transformation, which are the study objects are as follows:

- *miniature hyperboloid gear drives;*
- *miniature ultrasonic motor.*

2. Miniature Hyperboloid Gear Drives

2.1. Background

Typical products of mechatronics are bio-robots. Their transmissions as a rule include miniature transformers of motions and energy (see Fig. 1,a) [1, 2].



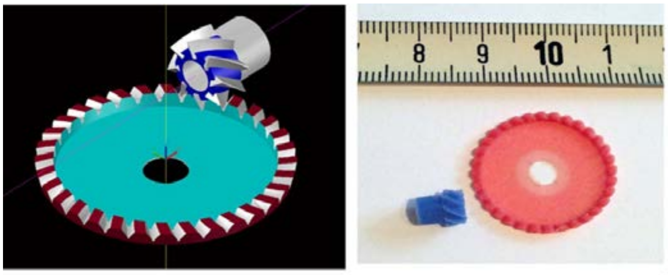
a) b)

Fig. 1. *Model of robot hand: a) whole hand; b) bevel gear with straight teeth with* $i_{12} = 4$; $z_1 = 10$; $z_2 = 40$; $m = 0,5$ *mm*

The current work aims to present the realized by authors activates related with improvement of exploitation properties of the bio-robot hand shown on Fig. 1 [1 - 3]. The tasks related to the mentioned above goal is to find out a solution to the problems connected to the increment of the number of simultaneously contacting active tooth surfaces and also to create preconditions for controlling the backlash between mating gears which are implemented into the fingers of this hand. This is achieved when a plane bevel gear (Fig. 1b) is replaced with kinematically equivalent miniature spatial gear drive of type Spiroid or Helicon [3 - 5] (Spiroid and Helicon are registered trade mark of Illinois Tool Works, Chicago, Illinois.).

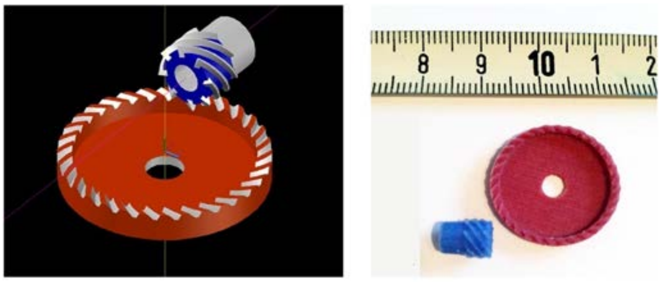
2.2. *Synthesis and Prototyping.*

The gear drives shown in Fig. 2 - Fig. 5 are specially synthesized by choosing the optimal structure and geometrical characteristics and they are CAD modelled. From an exploitation view point these gear drives are suitable for integration into already existing robot hand, which will result in its technical precision.



a) b)

Fig. 2. *Spiroid gear drive with offset 3,25 mm, gear ratio 32/8 (axial module 0. 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)*



a) b)

Fig. 3. *Helicon gear drive with offset 3,25 mm, gear ratio 32/8 (axial module 0. 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)*

The novelty of this design solution is that developed Helicon and Spiroid gears have a boundary small gear ratio. This is a

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challenge both for their optimization synthesis and design in terms of their technical realization. The reason for this is that these gear pairs usually ensure rotations transformation with gear ratio more than 10 [6].

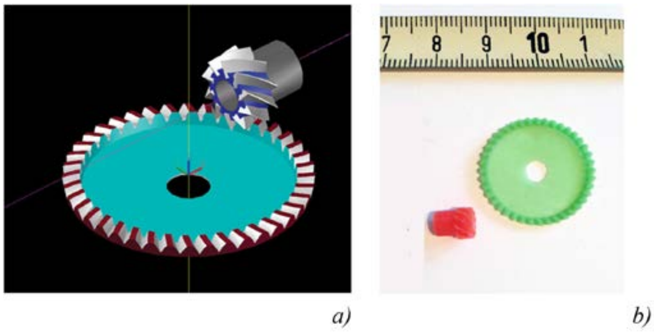

Fig. 4. *Spiroid gear drive with offset 4 mm, gear ratio 40/10 (axial module 0. 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)*

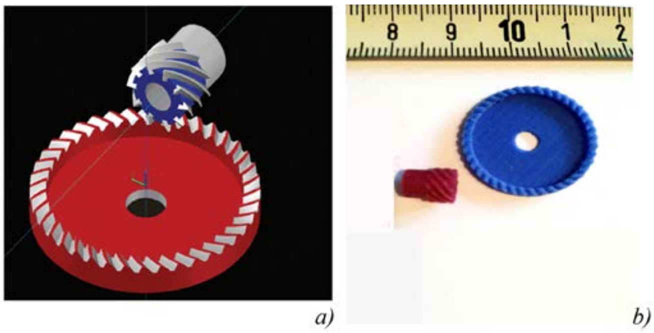

Fig. 5. *Helicon gear drive with offset 4 mm, gear ratio 40/10 (axial module 0. 5 mm): a) 3D CAD model; b) 3D printed model (the shown scale is in mm)*

The extreme difficulty of elaboration with available technical and technological device and the high manufacturing cost, define the reason to use 3D software technology for the elaboration of the above mention gear transmission (see Fig. 2 - Fig. 5).

We will mentioned, that the applied by authors, 3D software technology include the following stages:

- mathematical modeling for optimization synthesis of skew-axes gears upon a „pitch contact point“ [6, 7];
- development of a mathematical model for synthesis upon a „mesh region“[6] (development of a 3D CAD model);
- 3D printing of the synthesized gear drives.

Fig. - Fig. 5 illustrate the last two stages of the 3D software technology.

The use of this technology is a guarantee of :

- Shortening of the cycle "innovative idea - innovative product" ;
- Impetus of the innovative strategies development and increasing the actual quality of the created prototypes by improving their accuracy and a fast realization of various modifications (variants) of a physical prototype;
- Impetus to the process of building a competitive environment;
- Stimulation of the inventive and innovative activity of engineers, designers and scientists.

An essential problem, related to the 3D technology of manufacturing is the optimal choice of 3D printers and materials for the gear sets elaboration. The quality solution of these tasks is a guarantee for the optimal teeth strength, optimal smoothens and hardness of the active tooth surfaces.

2.3. Conclusion

The mathematical models of two Spiroid and Helicon gear drives for incorporation into the robot-hand are elaborated, based on the presented approach. An experimental printing with different alternatives material is forthcoming.

3. Miniature Ultrasonic Motor with a Metallic Plate

3.1. Background

Ultrasonic motor is a mechanical system for transforming an electric energy into a mechanical one. It is a type of electric motor powered by the ultrasonic vibration and friction of a component – the stator, placed against another component – the rotor or slider depending on the scheme of operation (rotation or linear translation). The ultrasonic vibration is generally generated by a piezoelectric element. The first applied in practice, ultrasonic motor is of a rotational type and it is developed in Japan in 1986 [8, 9]. Other motors with different working principle are elaborated after it, but in most cases it is difficult to be downsized [10 - 12].

This study presents a new miniature ultrasonic motor, which combines the operating of the ultrasonic motor with a metal plate [13]. The new ultrasonic motor is characterized with a simple construction, small dimensions and mass. The action of the created prototype is under testing.

3.2. Structure of the Motor.

In Fig. 6 are shown the device and basic dimensions of the stator of the new ultrasonic motor $(2{,}67mm \times 2{,}5mm \times 1{,}2mm)$. Stator's structure includes a piezoelectric element and a J-shaped metal plate. The piezoelectric element is a multilayer – type AM1 (with dimensions $1{,}2mm \times 1{,}2mm \times 2{,}47mm$) and it is elaborated by NEC/Tokin Corp., Japan. The material of the metal plate is phosphor bronze having a thickness of board $0{,}1mm$. Fig. 7 shows the result of the vibration mode by finite element method (FEM) analysis (the first frequency vibration mode is $4{,}7kHz$ and the second mode is $51{,}6kHz$). Through experiments it is verified the obtained rotation of the lowest frequency to high frequency.

The displacement characteristics are measured by the experiment. It is generated a 1 Hz trapezoidal wave from a function generator and it is applied as the driving signal by its amplifying with an amplifier. The horizontal displacement is detected by a laser sensor, and the data are recorded with an oscilloscope. When the voltage of $\pm 4V$ was applied, the maximum displacement was $0{,}26\mu m$ in the horizontal direction.

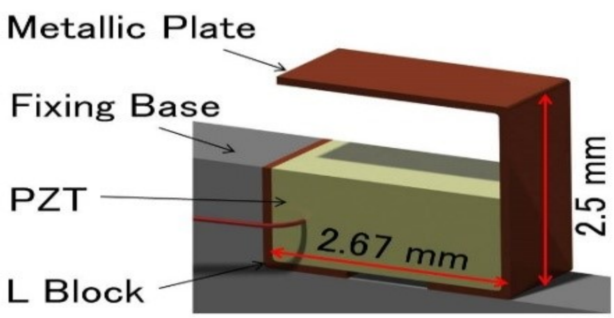

Fig. 6. *Structure of the stator*

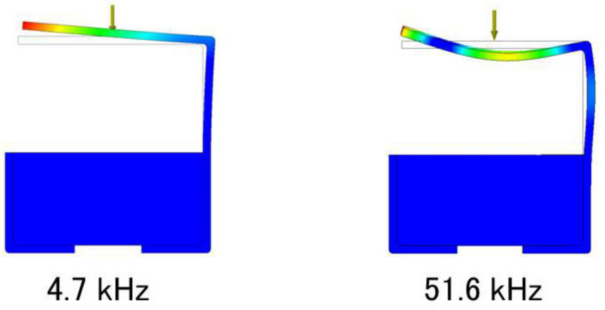

Fig. 7. *Vibrational modes of the stator*

3.3. Operating Principle

On Fig. 8 is shown the operating principle of the new ultrasonic motor. When a driving signal is inputted into the piezoelectric element, the voltage causes the piezoelectric element to stretch in horizontal direction. The extension drives the metallic plate. On Fig. 9 is shown a driving signal: (a) the driving wave for the rotation in the counterclockwise direction; (b) driving wave for the rotation in clockwise direction. The signal is saw-tooth shaped wave and the ratio of the voltage is 1: 8: 1 (see Fig. 9).

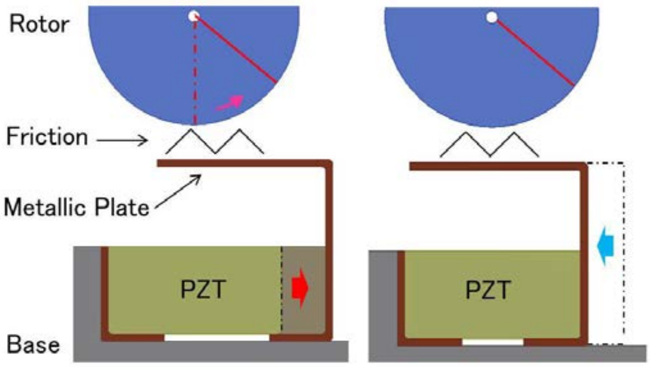

Fig. 8. *Operating principle*

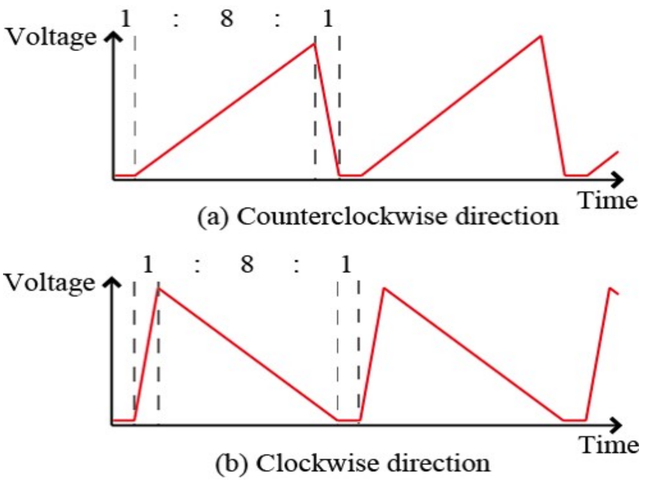

Fig. 9. *Driving wave*

3.4. Experiment

The equipment for the experiment is shown on Fig.10. A rotor is used to verify the rotation characteristics of the stator. The rotor has the miniature bearing with the diameter 3 mm which is made by the stainless. The video image is analyzed in order to measure the rotational speed. Since the bearing is so small, there are is not a measurement method.

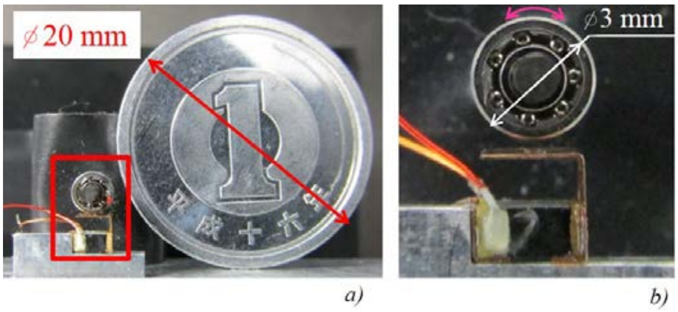

Fig. 10. *Experimental equipment: (a) Comparison of the size of the stator with a coin; (b) A miniature ultrasonic motor*

The conducted experiment is realized by changing the applied voltage to a piezoelectric element: $\pm 2V$; $\pm 3V$; $\pm 4V$. Fig. 11 shows the results from the experiment, when the rotor is rotating in clockwise direction. The vertical axis shows the rotor's rotational speed analyzed in the video image. It is found that when the driving frequency applied to the stator is higher, the resulting rotational speed of the rotor is higher. The maximum speed of rotation is around 360 $\min^{-1}$, when the applied voltage is $\pm 4V$. The miniature motor has a rotation speed of 60-110 $\min^{-1}$ (by driving frequency of $85-175kHz$), and it can driven even with a very low voltage of $\pm 2V$.

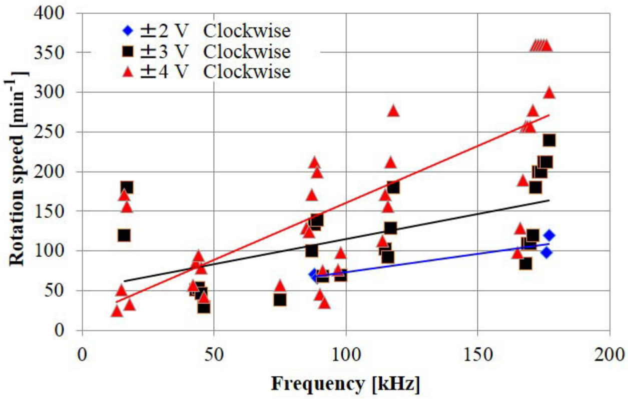

Fig. 11*. Results of the experimental test (rotation into clockwise direction)*

3.5. Conclusion

The study of new miniature ultrasonic motor is presented. Its structure combines multilayer piezoelectric element with a metal plate. It can realize a rotational speed of the rotor over 360 $\min^{-1}$. The futures studies will examine the motor torque by using a force sensor.

4. Generalized Conclusion

The study is dedicated to the offered and applied by the authors of this work, two type miniature mechatronics modulus:

- miniature hyperboloid three-links transmissions with face mating gears of type Spiroid and Helicon, intended for incorporation into bio-robots;
- miniature ultrasonic motor with a driving metal plate, implanted in its stator;

The study contains information about the developed constructions, approaches to the synthesis, prototyping and experimental testing. The perspectives for the development of the created modules, as well as the possibility for their combining in order to establish a mechatronic systems, are declared.

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