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HYBRID PIEZOELECTRIC MOTOR BASED ON ELECTROACTIVE LUBRICATION PRINCIPLE

A novel conception of hybrid piezoelectric motor is presented in this paper. Proposed conception required synchronized work of quasi-static and resonant piezoelectric actuators that results in a rotary movement. The motor's working principle is explained and the main characteristics are described. Studied topology is compared to the existing piezoelectric motors with regards to its field of applications. The assembling process of the motor is briefly explained with emphasis put on the frequency and impedance tuning of the piezoelectric actuators. Next, the power supply system is described. Finally, conclusions are presented concerning the features of the hybrid piezoelectric motor and possible solutions of the faced problems.

1. INTRODUCTION

The described studies are continuation of work carried out at the Electrodynamics research group of LAPLACE laboratory in Toulouse. The purpose of those efforts was to develop a new actuator dedicated for the embedded applications. For the chosen structure different piezoelectric topologies, working in synchronization, have been used. In this paper a verification process of the novel prototype of piezoelectric motor has been described.

In general, piezoelectric phenomena can be divided into two effects: generation of electric charge when subjected to mechanical stress and production of strain when the voltage is applied to the material. They are respectively: direct and inverse piezoelectric effects. Since its discovery, in the late XIX century, the piezoelectric materials

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have found a lot of applications. Nowadays, PZT (lead zirconate titanate) ceramics are being used in a variety of technical fields. Piezoelectric structures are especially desired in nano-positioning stages or medical robotics. They can be utilized both as sensors and as actuators which is a great quality for embedded applications [1, 8].

Modern piezoelectric motors are generally built using either quasi-static or resonant actuators. The detailed comparison of those structures will be discussed in the following paragraphs. When working in a step mode those actuators rarely generate rated torque greater than tens of Nm. However they exhibit interesting properties in terms of torque per mass ratio and small dimensions. Combination of these two topologies can result in further advantages [2].

2. COMPARISON OF DIFFERENT MOTOR TOPOLOGIES

The piezoelectric actuators, as it has been said, can be divided into two categories as shown in Fig. 1 and Fig. 2.

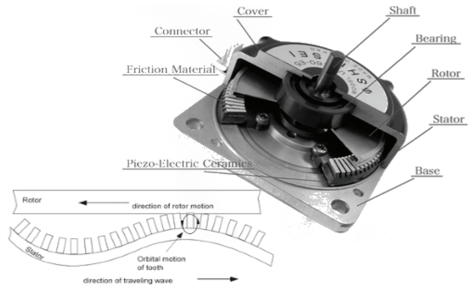

Fig. 1. Ultrasonic motor (Shinsei type) [8]

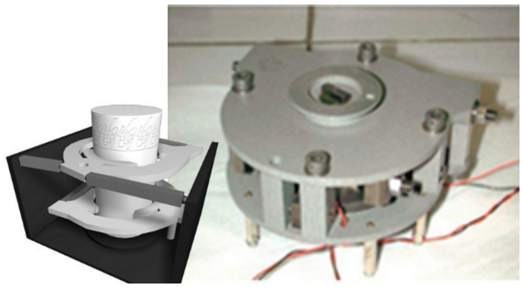

Fig. 2. Quasi-static actuator [6]

The resonant structures. The small deformations (a few μm) produced by the piezoelectric ceramics are amplified by the resonance of the mechanical structure. The rotor is driven by friction. Kinematics used at the level of interface between the rotor and the stator impose the dynamic friction coefficient. Produced forces are a priori weaker. The points at the rotor/stator contact surface are oscillating in an elliptic way The tangential velocity generated on the stator surface of these motors (≈ 0.5 m.s^{-1}) is considerably greater than that of quasi-static structures and their operating area is located in the ultrasonic frequencies, which results in a silent functioning. Nevertheless, they are less accurate than the quasi-static motors.

Quasi-static structures. Their principle is based on the deformation of ceramics, such as multilayer ceramics, of the order of a few microns, which are supplied with the low frequencies (below the hundreds of Hz). The multiplication of these micro displacements results in movements of larger amplitudes. This type of motors is used primarily for their nano displacement, precision and substantial generated forces. Moreover, the used kinematics is the type of a solid, low frequency ($V \approx 3$–10 mm.s^{-1}). Thus, the contact imposes the coefficient of a static friction [2].

For the intended application the choice was to implement quasi-static structure benefiting from modification of the operating principle to overcome recurring problems of conventional structures (sensitivity to wear, poor accommodation surfaces). The electro-active lubrication between rotor and stator was also included due to the use of resonant piezo actuators [2], in order to disengage rotor and stator in the return phase.

3. HYBRID PIEZOELECTRIC MOTOR – WORKING PRINCIPLE

The presented piezoelectric motor was developed to be used in embedded applications. This imposes characteristics such as: a high torque/mass ratio, small overall dimensions and light weight. Moreover, the blocking torque when the motor is not powered is also desired [10].

The studied motor has a basic structure composed of grippers containing resonant actuators and the exciters equipped with the multilayer ceramics (Fig.3). The hybrid nature of the motor is a result of utilising two different types of piezoelectric actuators in order to generate a rotational movement.

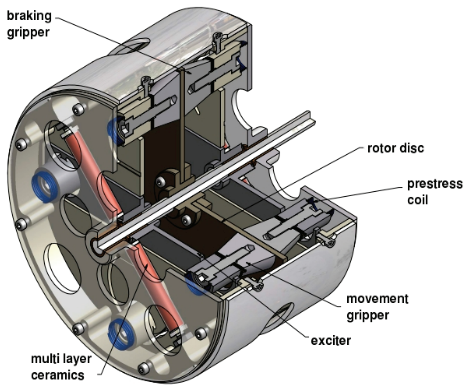

Fig. 3. Structure of the completed hybrid piezoelectric motor [6]

The driving force is generated by the exciters equipped with the quasi-static actuators. They produce small deformations due to the operation of the high voltage multilayer ceramics. The basic step is then multiplied and drives the rotor. The purpose of the grippers is to lock and unlock the rotor of the motor in specific time intervals and to provide the electro-active lubrication. With the use of resonant actuators working in the bending mode, the vibrations are being injected on the level of the rotor/stator interface.

This leads to lowering the parasitic friction of the structure and give the piezoelectric motor, a behavior independent of the evolution of ambient temperature, and enables better control over motor's performance [2, 6]. The half of the motor consists of one exciter (using two multi layer ceramics) and two sets of grippers. The complete structure consists of those two halves and a rotor sandwiched between them.

One work cycle contains the following operations:

- movement grippers hold the rotor when exciter pieces move with the rotor;
- exciter pieces reach the high position so the movement grippers can release the rotor;
- brake grippers lock the rotor and exciter pieces return to the low position;
- brake grippers unlock the rotor.

4. ASSEMBLY PROCESS

The assembling process was divided into following steps:

Preparation of the ceramics. PZT ceramics were sectorized using laser and then polarized in high electric field (2 V.mm^{-}) and elevated temperature (95 ˚C). Total of 32 ceramics were prepared.

Assembling of the resonant actuators and frequency matching. The process included: arranging piezo ceramics in a specific direction of polarization to maintain the bending deformations (Fig. 4); bolting the stack of PZT to the metal cylinders and adjusting the pre stress force in order to set the proper working frequency. For this task an impedance analyzer was used. By detecting the minimum impedance the resonance frequency was obtained. As a result, the mechanical resonance of the grippers was set to 17.6 kHz and 18.6 kHz, respectively, for the exciters.

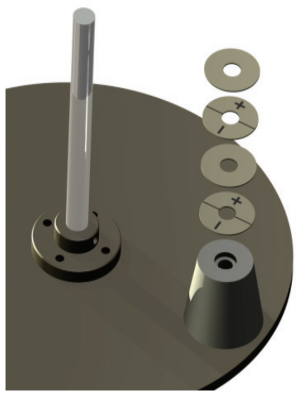

Fig. 4. Orientation of the ceramics and the electrodes

Assembling of the complete structure. The formation process of the motor included the positioning of exciters and grippers in relation to the rotor disc as well as to the housing. The motor's characteristics were regulated mostly by minor changes in the position of the multilayer piezo ceramics: their angle with respect to each other and the force with which they acted on the exciters.

Fig. 5. Disassembled hybrid piezoelectric [6]

The final setting of multi ceramics provided the displacement of 0.097 mm in one direction. All measurements were done with the Laser Vibrometer which detected vibrations of the exciter. The view of motor's parts is presented in Fig. 5.

5. POWER SUPPLY DESCRIPTION

Requirements of the power supplies for piezoelectric machines are very different from conventional electric motors, due to higher operating frequencies and capacitive behaviour of the piezoelectric motor.

The DS1005 Controller, a power converter and DS2004 High-Speed A/D Board were used to supply the hybrid piezoelectric motor. The DS1005 processor board provided the possibility for real-time monitoring and also functioned as an interface to the I/O boards and the host PC. The used power supply was based on the voltage fed, resonant, full-bridge topology. It consisted of four inverters which could work in synchronization or independently and were supplied by a DC voltage source [11].

MATLAB along with dSPACE application have enabled the control of the power supplied to the piezoelectric hybrid motor. In this way, the synchronization of the multilayer ceramic's supply with the duty cycle of the piezo ceramic grippers was possible. The main program is consisted of four function blocks, where the power switching process for each channel of the converter was controlled. According to the work cycle presented earlier, when exciters were working, breaking grippers should not be fed by voltage and vice versa. Additionally, the control of four frequencies of the movement and braking grippers was essential to maintain them in a resonant mode and to ensure the proper work of the machine. The voltage waveforms supplied to the motor are shown in Fig. 6. It represents the synchronization of alimentation between the multiceramic and the grippers containing resonant actuators. In this mode of supply, the amplitude of voltage supplying for the piezoceramic grippers is about 200 V at the frequency of 17.6 kHz and 18.6 kHz and the excited frequency of multiceramic are about 90 Hz.

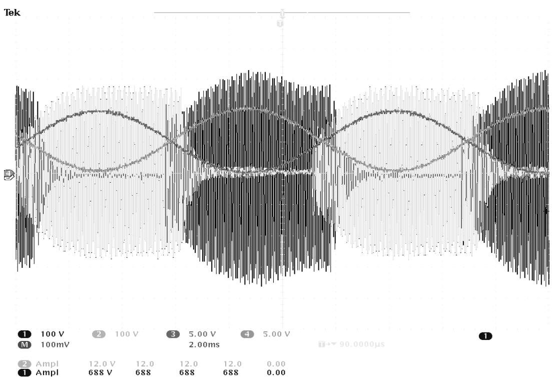

Fig. 6. Motor's voltage waveforms: dark – braking grippers;
bright – movement grippers; Sinusoidal – multilayer ceramics

6. CONCLUSIONS

In this paper, the operating principle and assembling process of the hybrid piezoelectric motor have been presented. The current prototype is built using the patented solution [6]. The main concept of this motor was based on utilising quasi-static piezoelectric actuators that are well-described in the literature [3, 5, 10]. To overcome several mechanical flaws such as: parasite movements and frictions, as well as to ensure better control over motor's performance, the piezoelectric resonant actuators were introduced. Their main task was to provide electro-active lubrication, and in effect improving the contact surface between rotor and the stator.

The hybrid piezoelectric motor was developed as a multicellular structure, which permits adopting the motor's performance to desired specifications. The current version, with two sets of grippers, reached the torque of 3.5 Nm with blocked rotor. By increasing the number of the grippers, it is possible to increase the developed torque. Another advantage of this solution is increased security and possibility of redundancy.

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