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FINDING VIBRATION MODES FOR A PIEZO DRIVEN ROBOT STRUCTURE

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Abstract: The modes of vibration of a piezoelectric-driven small scale robot are experimentally identified. The structure is excited harmonically by using a sinusoidal waveform in a wide frequency band by using a particular command module based on a microcontroller or by using dedicated excitation approaches. Fine sand spread over the flat structure is showing the structural resonances and approximately the nodes of vibration. The finite element modal analysis is helping to find the modal shapes and consequently the legs attachment spots on the vibrating robot structure.

Keywords: *piezoelectric ceramic, miniature mobile robot, modes of vibration, modal shape, resonance.*

1. INTRODUCTION

Small or micro locomotion robots with efficient walking are of interest in the last decade. This is caused by the large field of mini manipulation and fabrication, precise positioning or even the minimally invasive surgery [4]. Approaches for locomotion, like the so called 'vibration driven robots' are preferred for the conventional wheeled or legged versions (used for large scale robots) because of the simpler mechanical structure and control. In the class of 'vibration driven micro-robots' one can mention systems actuated by conventional internal linear or rotational motors, electromagnetic actuators and piezoelectric actuators (which offer the most in terms of the potential for miniaturization).

In most of the cases the piezoelectric actuator excites at the mechanical resonance the robot whole structure. Hence, a small actuation output (coming from the piezoelement) is natural amplified, resulting generally in an open-loop dynamics of the whole structure. The robot limbs are passive elements simple attached to the actuated body. A piezoelectric unimorph beam with two attached custom-designed legs resulting a falling-ahead unidirectional motion, can be mentioned [7]. A piezoelectric beam with three legs attaches and actuated in two modes of vibration is able to

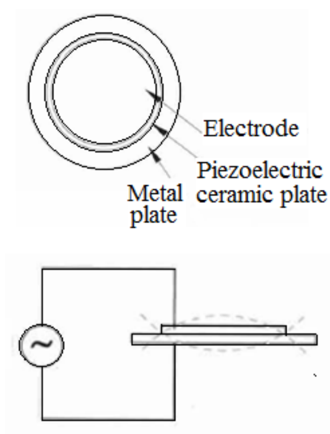

Fig. 1 Piezoelectric circuit

provide a forward and a backward motion [5].

In this paper the piezoelectric-driven small scale robot with simple structure is of interest.

The structural substrate is in general a metal to which a thin piezoelectric film actuator is attached. The thin piezo film is sandwiched between two thin film electrodes. The mini robot with attached legs is driven at the mechanical resonance of the whole structure. The displacement and the velocity of the minirobot can be improved by optimizing the shape and the mechanical resonant modes or modes of vibration of the whole robot structure [6]. The piezoelectric-driven mini robots are a class of a larger micro - electro - mechanical - systems (MEMS) based actuators family.

The piezoelectric element consists of a piezoelectric ceramic plate with electrodes on both sides (Fig. 1). This component is connected/attached to a metal plate by adhesive [10]. When to the electrodes an electric tension is applied the piezoelectric layer and the substrate metal bend in function of the polarity (Fig. 1).

To be able to control the robot structure its geometry and material properties have to be known in order to generate a good finite element model of the whole structure. The geometry of the element (Fig. 2) is defined by the following values: D=35mm, d=25mm, t=0.3mm, T=0.56mm. The total mass is 0.003kg, The modal analysis of the structure

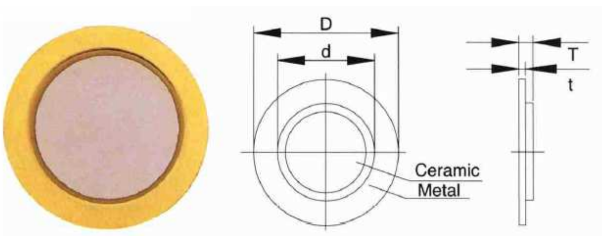

Fig. 2. Piezoelement geometry

will show the structural vibration modes, each one characterized by the modal shape and modal or resonant frequency. The modal model (shapes and associated frequencies) has to be validated by experiment. In this approach we started with the experimental approach.

2. IDENTIFICATION OF THE STRUCTURAL VIBRATION MODES BY EXPERIMENT

An EPZ piezoelectric ceramic element disc has been chosen for vibration modes investigation. The mentioned disc is commonly used to generate sound pressure when is mounted in a resonant (Helmholtz) cavity, potential working as a buzzer.

For the piezoceramic excitation, with fine tuning in the frequency band from 1.kHz to 50.kHz, a Versatester E 0502 device has been used (Fig. 3). Vrms max value used is 9Vrms.

Fig. 3. Excitation set up - fine tuning of the excitation frequency

The disc structure is placed horizontally on o soft structure, covered by fine grains of sand and excited by a sinusoidal signal. At specific frequencies (resonance) the structure will generate standing waves with a multitude of

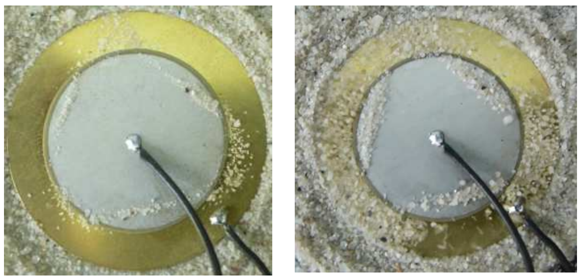

Fig. 4. Vibration mode at 2940 Hz

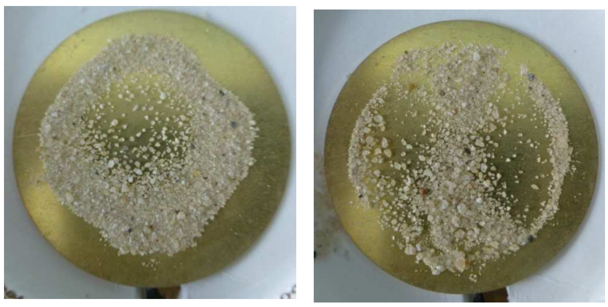

Fig. 5. 4500Hz and 5300Hz vibration modes

fixed nodes. These nodes will form lines on the plate. The fine sand grains that are pushed out of the vibrating regions will settle into nodes or are free to jump out of the plate. Additional sand can be sprinkle on top of the plate. Hence, sand is moving to the nodal areas or is leaving the disk surface. The experiment output is similar to that of the plate of Ernst Chladni.

The node patterns can be seen in the following figures indicating the mode shapes of some modes of vibration. Hence, we will find some of the modes of vibration of the structure.

Fig. 6. Vibration mode at 8550Hz

Each mode of vibration will be known by its frequency indicated by the excitation device and by the sand pattern. A line of nodes will separate two zones vibrating in antiphase. Because the plate is relatively small with respect to the sand grains and the structure thickness, some vibrating out of phase regions will not be well separated. An important mode of vibration with the maximal displacement response at 2940 Hz excitation signal, can be observed in figure 4. In the first image the sand grains are resting in nodes observing a central antinode zone and the exterior ring area moving in opposition of phase with the central area. In the second image the same mode of vibration is shown with the grains in the exterior ring jumping and unable to leave the area because of the large amount of sand on the exterior of the disk. The mode exhibits an important displacement response between 2500 Hz and 3200 Hz on both sides of the response peak at about 2940 Hz.

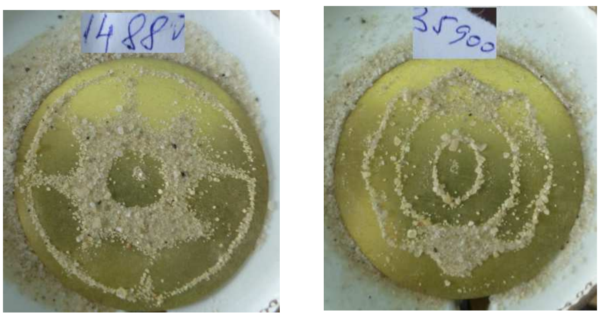

Fig. 7. High frequency modes: 14880Hz and 35900Hz

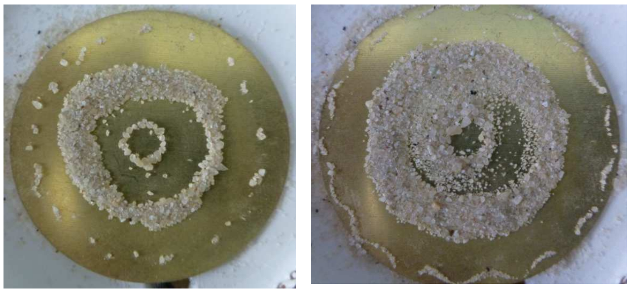

Fig. 8. High frequency vibration modes

We are looking for large areas with adjacent structural points vibrating in phase in order to attach the robot legs to them.

Another mode of vibration is visible with a peak response about the frequency of 5300Hz.

A mode of vibration is visible in figure 6 with a peak response about the frequency of 8550Hz.

Higher modes like those shown in figure 7 and figure 8, can be visualized as well.

3. MICROCONTROLER FOR VIBRATION DRIVEN MINI ROBOT

The command module is made using an ATtiny2313, 8-bit, AVR RISC microcontroller (Fig. 9). To generate the excitation frequencies with the best accuracy, the clock frequency of the microcontroller is provided by an external quartz with a frequency of 16MHz.

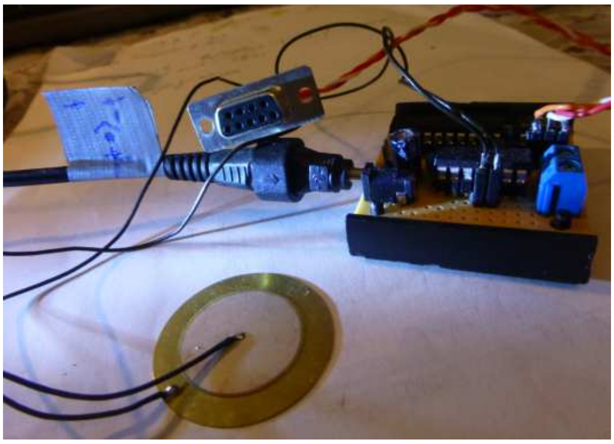

Fig. 9. Structure excitation set up

The setting of output frequencies is controlled from a computer on the RS232 series interface. Also from the computer (IBM-PC in our experiments) Out1 and Out2 outputs are activated to excite the piezoelectric ceramic element disc. The experimental block scheme (computer-command module assembly) is shown in figure 10.

If the calculator does not have a serial interface (COM1 or COM2) then a USB-RS232 converter can be used. The signals on the serial

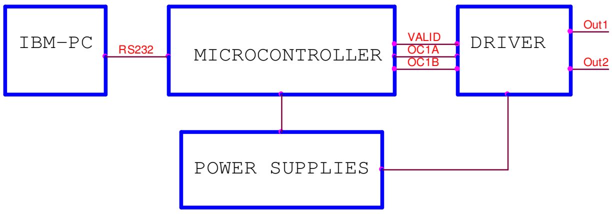

Fig. 10.

interface generated by the microcontroller (RXD and TXD) have TTL levels and a TTL to RS232 level adjustment module must be used.

The electrical diagram of the microcontroller-circuit driver assembly is shown in figure 11. The OC1A and OC1B

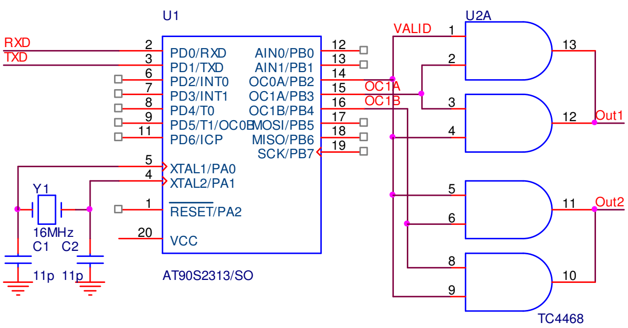

Fig. 11. Microcontroller-circuit driver assembly

command signals are generated by the timer/counter1 of the microcontroller. The timer is set to CTC mode with changing output state to comparison (Mode 4) [11]. The same numeric values are set in the OCR1A and OCR1B registers. Starting from the clock frequency of 16MHz, we can generate excitation signals in a very wide range of frequencies [1]. For very low frequencies (below 100Hz), we can use the timer/counter1 prescaler which allows additional divisions (8, 64, 256 and 1024). A software mechanism monitors that the two output signals OCR1A and OCR1B are complementary. Activation of the Out1 and Out2 signals is done by the VALID signal.

To amplify the excitation signals of the piezoelectric disc we used the TC4468 driver circuit. To increase the output current we connected two outputs in parallel (maximum peak current of 2.4A) [12]. Hence, all four gates of the circuit are used.

Another feature of the TC4468 circuit is that to be able to generate output signals with amplitude equal to the supply voltage. So, we can vary the excitation power of the piezoelectric disc by changing the supply voltage of this circuit.

4. MODAL ANALYSIS SIMULATION OF THE ROBOT STRUCTURE

The geometry of the robot structure is modeled and meshed by using solid finite elements separately for the substrate and for the piezoceramic disk. Small nodal masses are

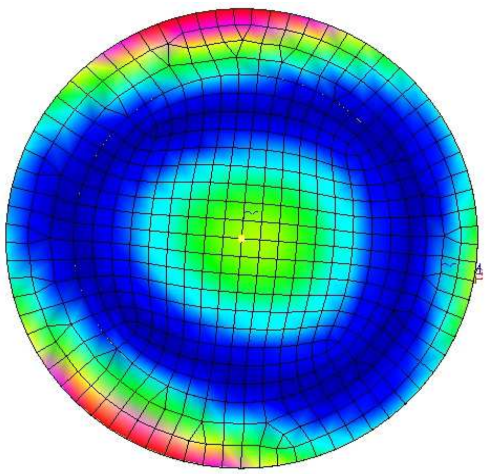

Fig. 12. Simulated mode shape associated to the experimentally found mode at 2940Hz

attached where the wires are connected to the structure in order to excite electrically the piezoelectric ceramic disk (Fig. 12). A Normal modes analysis is set up (Lantzos version) and the modes of vibration in the frequency band from 1kHz to 50kHz are found. The mode shapes and the movement for each mode of

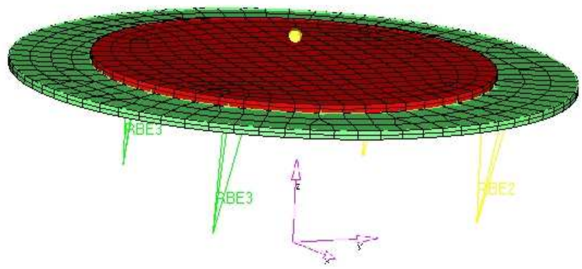

Fig. 13. FEA - piezo disc with attached legs

vibration can be observed. The finite element modes have to be validated following the experimentally found natural frequencies and the sand locations. In figure 12 the mode of vibration which shows a large central antinode zone moving in antiphase with the disk peripheral area. This is the same mode in which the disk without the connecting wires is vibrating like a buzzer, in some applications. Here, the nodal area is showing a triangle. This mode is similar and associated to the mode depicted in figure 4, experimentally found at 2940Hz. In the finite element simulation, legs (Fig.13) can be attached to the vibrating structure.

4. CONCLUSIONS

In the article the modes of vibration of a piezoelectric-driven small scale robot are experimentally identified. The structure is excited harmonically by using a sinusoidal waveform in a wide frequency band. Fine sand spread over the flat structure is showing the structural resonances and approximately the mode shapes. A microcontroler is introduced for vibration driven mini robot to be used after the resoanances identification. The finite element modal analysis is helping to find more exactly the modal shapes and the legs attachment spots on the vibrating robot structure. Smaller grain of sand will be used for the mode shapes identification, hence antinodes zones will be better identified. The study will continue with the proper spots identification where the legs should be attached in order to perform movements and rotations.

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Consideraţii cu privire la determinarea experimentală a modurilor de vibraţie a structurii unui robot actionat piezoelectric

Rezumat: In articol sunt deduse experimental modurile de vibraţie ale unui robot miniatural cu deplasare bazată pe efectul piezoelectric. Structura robotului este excitată armonic folosind semnal sinusoidal într-o bandă largă de frecvenţe. Nisipul cu granulaţie fină este folosit la indicarea nodurilor structurii când se află la rezonanţă. Pentru excitarea robotului în funcţionare este introdus un microcontroler. Analiza modală cu elemente finite este folosită pentru o mai uşoară identificare a modurilor de vibraţie a structurii in vederea găsirii celor mai potrivite zone pentru ataşarea picioarelor robotului miniatural.

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