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THE PIEZOELECTRIC TACTILE SENSOR FOR STATIC FORCE MEASUREMENT

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Abstract: The new tactile sensors - based on piezoeffect – have been developed. Piezoceramics PZK 850 is used as the force – electrical signal converter. This sensor is able to measure static force to 50 N without charge amplifier using. Functional principles and sensors properties are described.

Key words: tactile sensors, piezoceramics, static force

1. INTRODUCTION

The paper is focused on the tactile sensors properties. Being used the piezoelectric ceramic material, an active converter force-electrical signal has been realized. Piezocrystals are used only to the vibration scanning to this time. The revolutionary change is realized with the crystal’s vibration - being damped with the acting static force. The mentioned principle enables the static force measurement, what hasn’t been possible with piezomaterials, unless one would have had the great problems. The described sensors are determined for the force measurement up to 50 N.

2. FUNCTION PRINCIPLE

The principle of the tactile sensor with the piezoelectric resonator is characterised by the pressure action on the piezoelectric cut, which is vibrated on the resonance frequency. Its properties are expressed by the equivalent diagram (see Fig. 1). Parameters of these diagrams (L-dynamic’s inductivity, C-dynamic’s capacity and R-equivalent resistor can be calculated as:

$$L = \rho \frac{al}{8b} \frac{\left(s_{33}^{E}\right)^2}{d_{13}^{2}} \qquad (1)$$

$$C = \frac{8bl}{\pi^2 a} \frac{d_{13}^{2}}{s_{33}} \qquad (2)$$

$$R = \frac{\pi^2 a}{4bl} \frac{\left(s_{33}^{E}\right)}{d_{13}^{2}} \qquad (3)$$

$$C_o = \varepsilon_{11}^{s} \frac{bl}{a} \qquad (4)$$

where

ρ	material density	[kgm^{-3}]
a, b, l	piezocrystal dimensions	[m]
d_{13}	piezoelectric coefficient	[mV^{-1}]
s_{33}^{E}	component of the elastic potential tensor by E=const.	[m^2N]
ε_{11}^{s}	component permittivity tensor by constant deformation	[-]

Not only, the geometrical dimensions have to be considered, but elastic and piezoelectric coefficients, too.

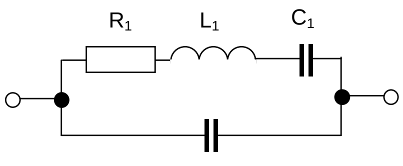

Fig. 1 Equivalent wiring diagram

The equivalent resistor presents the operation of an external influence and the fixation of resonator, too. The equivalent resistor, having been changed by using of the mechanical load, causes the converter vibration damping. The level of the resonator’s vibrating depends inversely proportional on the equivalent resistor. Piezoelectric resonator - being mechanical loaded, or if the density of the inhibitory environment is changed, than the quality factor is decreased, so that to get to the damping oscillation. If we select a suitable inhibitory environment (for example rubber), and if we'll realise any tonic effect on this environment, we influence the properties of the equivalent tuned circuit (particular resistor), and thereby also the factor quality. Having been used the constant load, the parameters of the equivalent circuit are stable, too; and no - the amplitude drops of the oscillations can be registered.

The piezoelectric resonator is the main component of the tactile sensor. The loaded piezoelectric resonator - this one is the controlling element for oscillator. The properties of the sensor are given with the piezoelectric, elastic coefficients and modules, and with the geometrical dimensions of the cut. The parameters are influenced the most of all, by the way of the placement of the piezoelectric resonator in the tactile sensor.

Following material's parameters are important criteria for the selection of the piezoelectric resonator of the tactile sensor:

- coefficient of the electromechanical feed (k_{ij})
- factor of the mechanical quality (Q_m)

The coefficient of the electromechanical feed is required more than 200; in the case of the tactile sensor with the piezoelectric resonator in function of the control element. This coefficient is determining for the geometrical form of the cut. The optimal value is about 0,5 for an existing type of the vibration. We used PZT ceramics PZK 850 for our application.

This material - basic parameters:

density	$7{,}6.10^3$ kgm^{-3}
relat. permittivity	1750
Curie's temp.	360 °C
piezoel. coefficients:	
d_{31}	-180.10^{-12} mV^{-1}
d_{33}	380.10^{-12} mV^{-1}
factor of quality	80
speed of lengthwise wave diffusion	2 833 ms^{-1}
dimensions:	
thickness	1 mm
latitude	2 mm
lengths	2 mm

This piezoelectric differential element satisfies well upon the preservation of the mentioned material properties for the tactile sensor. The Curie's temperature can be as high as possible from the viewpoint technology requirements; and the sufficient temperature stability of the characteristic frequencies, too.

The geometrical dimensions of the resonator are the specific problem, because they have the direct influence on the values of the tuned frequency of the converter. Any unsuitable relationships of the dimensions being used - the conditions are generated for other than thickness vibration. By this way, the higher harmonics get to the area of the basic thickness vibration. This parasite's vibration can get its basic or higher harmonics in the close neighborhood with the geometrical dimension and the disturbing influences are appeared. From this aspect, the circle resonators have to be optimal, and theirs area dimensions have to be several times greater than thickness.

3. COMPUTATION OF SENSORS PARAMETERS

In tactile sensors the piezoelectric ceramics PZK 850 was used. From the next formula we compute the speed of the longitudinal wave diffusion

$$c = \sqrt{\frac{1}{\rho\, s_{11}}} = \sqrt{\frac{1}{7{,}6\,.\,10^3\,.\,16{,}4\,.\,10^{-12}}} = 2832{,}51 \quad \text{ms}^{-1}$$

Now we compute the resonance frequencies, which correspondent with the resonator geometrical dimensions:

Resonance frequency of the thickness vibrations:

$$f_r^{\,t} = \frac{c}{2a} = \frac{2832{,}51}{2\,.\,1\,.\,10^{-3}} = 1\,416{,}255\,.10^3 \ \text{Hz}$$

Resonance frequency of the latitude vibrations:

$$f_r^{\,b} = \frac{c}{2b} = \frac{2832{,}51}{2\,.\,2\,.\,10^{-3}} = 708{,}128\,.10^3 \ \text{Hz}$$

Resonance frequency of the lengthwise vibrations:

$$f_r^{\,l} = \frac{c}{2l} = \frac{2832{,}51}{2\,.\,2\,.\,10^{-3}} = 708{,}128\,.10^3 \ \text{Hz}$$

4. CONSTRUCTION OF SENSORS

The resonator's placement and its conductive connecting with an electrical part of the tactile sensor is the most important problem by the construction design of the sensor.

Our problem being characterized by the damping influences. The resonator will be least damped, if it will be fixed in the node points. There are the points, where meet the direct and reflected vibrations of the lengthwise waves. The node line for thickness vibrations goes along the periphery of the cut in one half of the thickness. This line is in the center, or in the ends of the plate for the stick vibrating, by the lengthwise vibrations in the direct of the length. It's similar for the lengthwise vibration in the latitude dimension.

In both sensors constructions (see Fig. 2. and Fig. 3.) -the special PE elastic joint is used. As resonator the piezoelectric ceramics PZK 850 was used with dimensions 2x2x1 mm.

In variant PZTC-1, showed on Fig. 2, the piezoceramics 1 is horizontal placed between two brass electrodes 5 and 7 and centered by PE elastic joint 6. The vertical axis force touches on the pressure pin 2. This force is transferred on brass electrode 5. The piezoceramics 8 is equally pressured between two brass electrodes 5 and 7, at once kept in axis of pressure - pin 6 in four contact points by PE elastic joint. Every contact point is in the side centre, which is normal to the flat of the brass electrodes 5 and 7. These electrodes are connected by copper wires to oscillator. To the box 1 is pasted the cover 3. Under this cover the stock 4 from cigarette paper is placed. Box, cover and pin are produced from novodur (plastics) and elastic joint from PE.

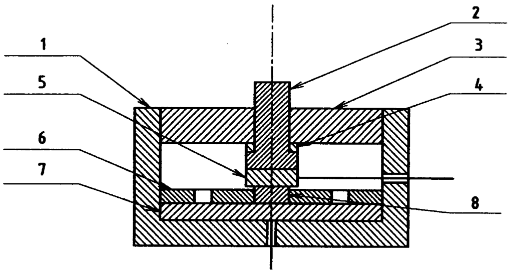

Fig. 2 PZTC-1 tactile sensor construction

The Fig. 3 represents the second variant construction of the tactile sensor PZTC-3. Power wires are direct soldered to the piezoceramic resonator on its metallized flats.

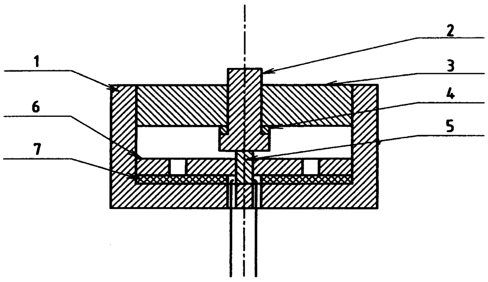

Fig. 3 PZTC-3 tactile sensor construction

The piezoceramics 5 is equally pressured between pressure pin 2 (on this one the measured force touches) and box bottom 1. The piezoceramic resonator 5 is kept by elastic joint 6 and distance ring 7 in the pressure pin 2 axis. This one 7 at once serves as the stock under of the elastic joint 6. The elastic joint 6 keeps piezoceramic 5 in four contact points again. Every contact point is in the side centre, which is normal to the flat of the pressure pin 2. Into the box 1 the cover 3 is pasted. Under the cover 3 the stock 4 from cigarette paper is placed. Box, cover and pin are produced from novodur and elastic joint from PE.

5. ELECTRONIC CIRCUITS

The sensors work with resonator, which is the controlling element of the oscillator - being used the principle - of the change quality factor by an influence of the force action on the resonator electrodes.

The resonators of the sensor serve as the control elements of the oscillator. Clap's oscillator was used in the standard wiring.

6. EXPERIMENTS RESULTS

Fig. 4 shows: The dependence oscillator output voltage vs. The sensor PZTC-1 loading - dependence. The output response isn't linear, which is evocated by range 0 – 5N. The equation: $y = -0{,}0141x^2 - 1{,}6956x + 562{,}28$ by correlation R = 0,996.

The sensor has average sensitivity $C = -2{,}09$ mVN^{-1}. The using loading range is 0 – 50 N. We can suppose, that available loading can be higher – no tests, to this time.

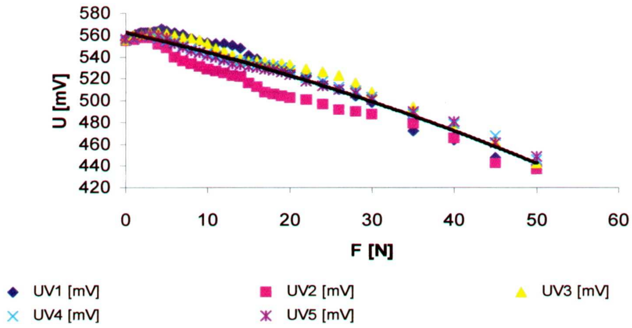

Fig. 4 The dependence U = f(F) for PZTC-1

Fig. 5 shows the dependence: The output voltage vs. The loading - by sensor PZTC-3. This response is linear and described by equation $y = -0{,}676x + 707{,}95$ by correlation R = 0,9383. The unambiguously measurement range is here: 0 – 50 N, by sensitivity $C = -0{,}68$ mVN^{-1}. The upper range border was limited by possibilities of loading equipment capacity, hasn't been tested, to this time.

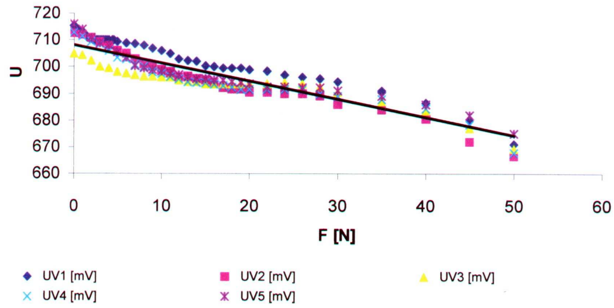

Fig. 5 The dependence U = f(F) for PZTC-3

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REFERENCES

[1] J. Volf, J. Vlček, T. Šemnický, “Tactile Sensors Based on Piezoeffect”, in Czech. Topics in Instrumentation and Control Engineering. CTU in Prague, Herbertov, 2005

[2] A. Pugh, “Robot Sensors Vol. 2 - Tactile and Non-Vision,” IFC (Publications) Ltd., UK, Springer - Verlag, New York 1986

[3] J. Obraz, “Material Testing by ultrasound,” in Czech. SNTL Prague, 1989