Geometrical Sizes Change Measuring by a Capacity Sensor

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***Abstract*—Automated system for measuring of change of geometrical sizes with the use of capacity-code convertor is developed. It is explored basic parameters of the system in combination with software and hardware. The relative sensitiveness of the system makes $\Delta l/l=6\cdot10^{-12}$.**

***Index Terms*—capacity sensor, thermal expansion, thermal generator, automated system.**

I. INTRODUCTION

Highly sensitive capacities sensors in different physical researches are widely used. Such type the devices are used for measuring of thermal matters expansion, magnetostrictive and electrostrictive effects research, and also in the automatic measuring systems [1–3]. The distances change or overlap square between the plates of flat capacitor at such methods of measuring is registered, one of which is related with sample, and other is immobile. It requires registrations of parametric capacitor capacity with high exactness [4], especially for samples with the small measured effect.

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II. EXPERIMENTAL PART

In the real terms complete parallelizability of capacity sensor plates it is painful to ensure. Therefore, at planning of capacity sensor it follows to take into account the changes of analytical dependence of capacity from moving. If find analytical dependence of capacitor capacitance on distance between the unparallel rectangular plates (fig.1), then will get the error on unparallelity.

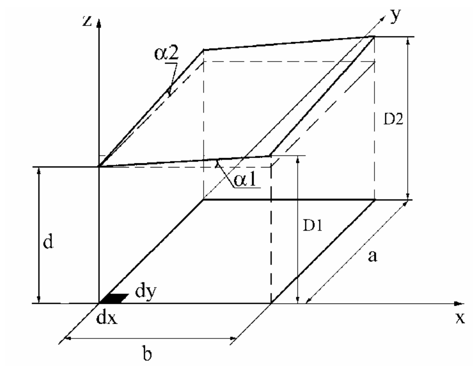

Figure 1. Capacitor with non parallel flat rectangular plates

Capacity value between the plates of capacitor infinitely small area of *dS*, without account of the leakage fields, is evened:

$$dC = \varepsilon\varepsilon_0 \frac{dS}{z} = \varepsilon\varepsilon_0 \frac{dxdy}{z} \qquad (1)$$

Dependence of distance size of *z* between the elements plates can be presented in a kind:

$$z = d + xtg\alpha_1 + ytg\alpha_2 \qquad (2)$$

Integrating equation (1) on *S*

$$C = \iint_S \frac{\varepsilon\varepsilon_0}{d + \frac{D1-d}{b}x + \frac{D2-d}{a}y} dxdy,$$

we obtain:

$$C = ee_0 \frac{ab}{(D1-d)(D2-d)} \times$$
$$\times [(D1+D2-d)\ln(D1+D2-d) -$$
$$- D1\ln D1 - D2\ln D2 + d\ln d] \qquad (3)$$

$$DC = ee_0 ab\left[\frac{(D2-d)\{(\ln(D1+D2-d)-\ln D1)(D1-d)-(D1+D2-d)\ln(D1+D2-d)\}}{[(D1-d)(D2-d)]^2}DD1 - \frac{D1\ln D1+D2\ln D2-d\ln d}{[(D1-d)(D2-d)]^2}DD1 + \frac{(D1-d)\{(\ln(D1+D2-d)-\ln D2)(D2-d)\}}{[(D1-d)(D2-d)]^2}DD2 - \frac{(D1-d)\{(D1+D2-d)\ln(D1+D2-d)\}}{[(D1-d)(D2-d)]^2}DD2 - \frac{D1\ln D1+D2\ln D2-d\ln d}{[(D1-d)(D2-d)]^2}DD2\right] \qquad (4)$$

In the boundary case, at reduction of size of unparallel to the zero a formula (3) grows into a formula for a capacitor with flat parallel plates.

Thus, capacitor capacitance with the rectangular plates placed under some corner, it is possible to define according to a formula (3).

The determination absolute error of capacitor capacitance with unparallel rectangular plates, with the use of methods of differential calculation, is **found after a** formula (4).

In the case of capacitor with the round unparallel plates (Fig.2) size of area of element with width *dy* plate with the radius of *r* at the beginning of frame in the center of one plate, is evened:

$$dS = AC \cdot dy = 2\sqrt{r^2 - y^2}\,dy \quad (5)$$

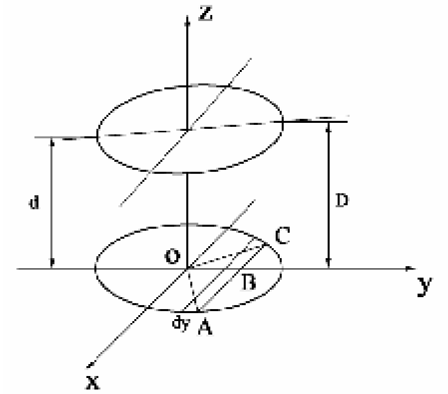

Fig.ure 2. Capacitor with non parallel round plate

After integration we obtain a formula for determination of capacitor capacitance with the unparallel round plates:

$$C = 4\varepsilon\varepsilon_0 \frac{\pi r^2}{\left(\sqrt{d+a} + \sqrt{d}\right)^2} \quad (6)$$

where $a = D - d$.

In the boundary case, at reduction of size of unparallel to the zero a formula (6) grows into a formula for a capacitor with round covers.

The absolute error of capacity determination of capacitor with the unparallel round plates, by the methods of differential calculation, is found as the formula (7).

$$\Delta C = -4\varepsilon\varepsilon_0 \pi r^2 \frac{1}{(\sqrt{d+a} + \sqrt{d})^3 \sqrt{d+a}} \Delta a \quad (7)$$

Capacitor capacitance dependence with the parallel, unparallel round and rectangular plates is represented in fig.3, accordingly curves 1, 2, 3. Overlap area of plates select as unchanging, that is provided by construction of capacity sensor. Theoretical curves built depending on distance between plates of *d* with keeping of parallel (curve 1), with identical unparallel between the round (curve 2) and rectangular (curve 3) plates. From the resulted graphs it is possible to do a conclusion, that with reduction of distance between the unparallel plates the sensitiveness of sensor (curves 2, 3) diminishes and is enough substantially violated linear (curve 3).

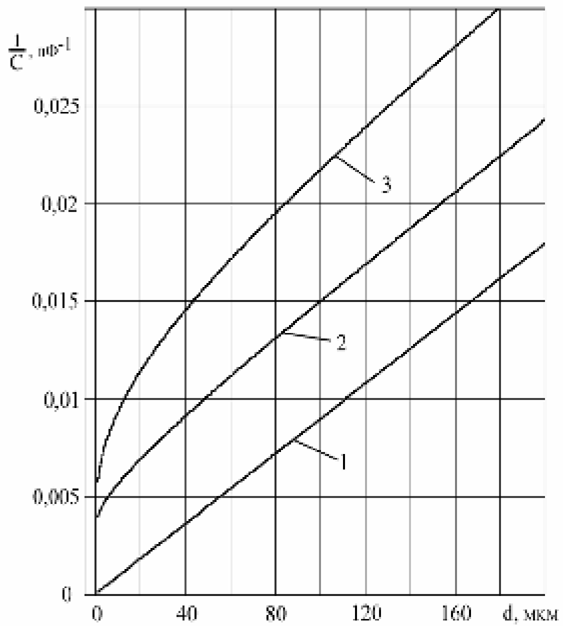

Figure 3. Capacitor sensor capacitance dependence on distance between plates: 1 – plates are parallel; 2 – unparallel round plates; a 3 – unparallel rectangular plates.

The value of error of measuring of geometrical sizes with the help of capacity sensor depend from such factors as a temperature, capacity of bonding wires, regional effects of capacitor. At construction development of geometrical sizes measuring device all measures for the removal of influencing of the higher indicated factors were accepted. In the device a capacity sensor is used with the round plates as technology of their making is simpler. Original appearance of capacity sensor is represented on ris.4.

Figure 4. Design of capacity sensor.

III. FUNCTIONAL SCHEME

The developed automated system allows to register the changes of sensor capacity in the real time on the computer monitor and to write down information in a separate file for subsequent treatment and analysis. Using of capacity-code converter AD7746 to increase of measuring exactness to 4 *fF* [5]. The presence of two capacity measuring channels enables to conduct the differential measuring. The capacity-code converter is micro power, is allow placing him directly near the object of research and connecting wires diminishing.

The microprocessor methods of the data processing are used in equipment part of device, because exchange by information between an integrated circuit AD7746 it is carried out on I^2C protocol. Connecting to the computer can be carried out through serial, parallel and USB ports.

The functional scheme of the small changes measuring device of geometrical sizes is shown on Fig.4.

Piezocrystal is entered in construction of the measuring system the change of linear sizes of which under action of the enclosed voltage is used as calibration. The necessity of calibration at the measuring is conditioned by capacity nonlinear dependence of capacity measuring from distance between plates.

For providing of stabilizing of the regulation speed of temperature change the thermal generator of linearly-variable voltage (GLVV) is used. Temperature of cell is measuring with the help of thermocouple chromel-alumel. Thermal electromotive force of thermocouple amplifies and is given to the analog input of L761-card [6].

Software for the data processing realized in language of Delphi 6.0. The law control of temperature of research object is regulating by program. The managing voltage of heater is formed on the analog output of L761-card.

Scanning speed on a temperature is set by built-in L761 DAC can change programmatic within the limits of 0,1÷12 K/minute. A program interface allows to the operator to set the interval of temperatures, in which it is necessary to carry out research, scanning speed, and amount of scanning cycles “upward-downward” on a temperature. The measured information is saved in a separate data file, and on the monitor screen the graph of dependence of the relative lengthening of standard is represented from a temperature. For the data processing the methods of linear and rationed averaging are used. The value of sensitiveness depends on the initial capacity (initial distance between plates) of sensor. The temperature linear expansion coefficient is determined after the proper mathematical data processing by software.

The developed automated system was used for research of temperature linear expansion coefficient of solids with the use of capacitive sensors of moving. The initial capacity of sensors can be set within the limits from 10 to 50 *pF*. The relative sensitiveness of the system is $\Delta l/l=6\cdot 10^{-12}$.

Typical type of thermo-diagram at research of thermal expansion of compound $BaTiO_3$ is shown on fig.5.

IV. CONCLUSION

The using possibility of the capacity-code converter for measuring of change of geometrical sizes with the help of parametric capacities sensors is shown. The got results testify that parametric capacities sensors owns a high sensitiveness, which can be promoted by application of the vibration-proof systems and additional screening.

The automated system was used for research of thermal expansion of aluminium, copper, $BaTiO_3$. Thus was coinciding of measuring results with literary information. In compound $BaTiO_3$ at a temperature 128 °C phase transition is registered of which by the calorimetry device was confirmed.

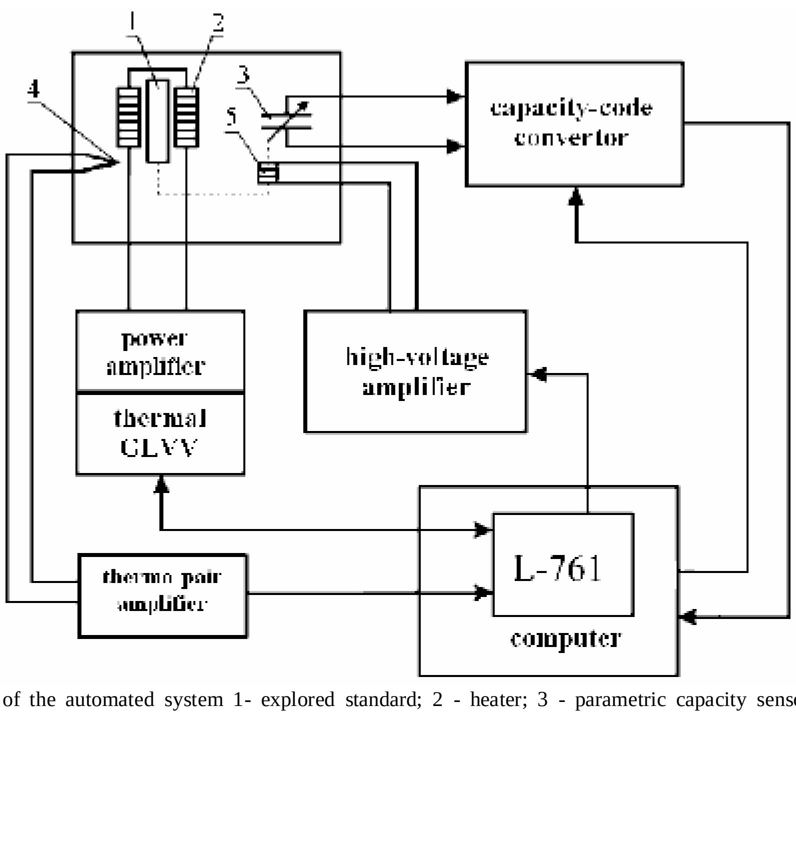

Figure 4. Functional scheme of the automated system 1- explored standard; 2 - heater; 3 - parametric capacity sensor; 4 - thermocouple; 5 - piezocrystal

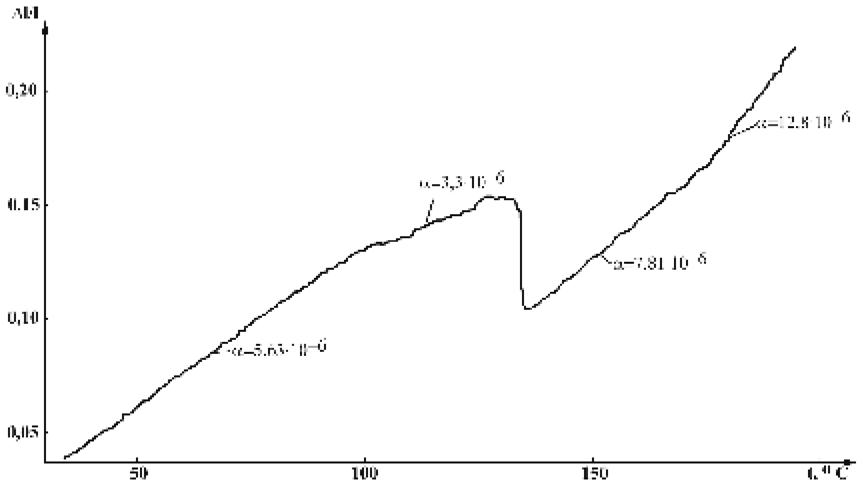

Figure 5. The thermal expansion in compound $BaTiO_3$

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