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# INFLUENCE OF GEOMETRIC PARAMETERS ON CHARACTERISTICS OF INTERDIGITAL DIELECTROMETRY SENSOR FOR MEASURING MATERIALS WITH DIELECTRIC ANISOTROPY

# ВЛИЯНИЕ ГЕОМЕТРИЧЕСКИХ ПАРАМЕТРОВ НА ХАРАКТЕРИСТИКИ МНОГОСЕКЦИОННЫХ ЭКРАНИРОВАННЫХ ЭЛЕКТРОЕМКОСТНЫХ ПРЕОБРАЗОВАТЕЛЕЙ ДЛЯ ИЗМЕРЕНИЯ АНИЗОТРОПИИ МАТЕРИАЛОВ ПО ДИЭЛЕКТРИЧЕСКОЙ ПОНИЦАЕМОСТИ

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*<u>Key words:</u> anisotropy, dielectrometry, nondestructive testing, edge effect, capacitive sensors.*

*<u>Ключевые слова:</u> анизотропия, диэлектрометрия, неразрушающий контроль, краевой эффект, емкостные датчики.*

*Abstract. Capacitive transducers are widely used for non-destructive testing (NDT) of a great number of polymer materials. The input data for NDT tasks applied for the testing of composition and structure, strength and deformation properties are presented as the complex of electrical characteristics. This paper focuses on the principles of design of MSAIC (Multichannel shielded attachable instrument capacitors) and mirror-symmetrical SAIC. In addition, the analysis of the following characteristics is presented: depth of a control zone, service capacity, sensitivity to the anisotropy of dielectric properties.*

*Аннотация. Электроемкостные преобразователи широко применяются для неразрушающего контроля полимерных материалов. Входные данные для задач неразрушающего контроля, применяемых для контроля состава и структуры, прочностных и деформационных свойств представляет комплекс электрических характеристик. В статье рассматриваются принципы проектирования многосекционных экранированных и многосекционных зеркально-симметричных измерительных конденсаторов. Кроме того, анализируются следующие характеристики: глубина зоны контроля, рабочей емкости, чувствительности к анизотропии диэлектрических свойств.*

The efficiency of NDT of composites and polymers mainly depends on the precise measuring of anisotropy of their physical and mechanical properties which is characterized by the permittivity tensor components. Permittivity tensor components provide information on density, composition, structure, and humidity. They are a part of the input data complex for the quality inspection of materials with low anisotropy [1, 2, 3].

The control methods of anisotropy of dielectric properties of polymers are based on the formation of parallel plate fields in objects to be tested with the help of two types of transducers - the Maxwell's parallel-plate capacitor which requires destruction of the tested object, and the attachable instrument capacitor (AIC) which does not destroy the tested object [4]. However, the use of AIC is not always effective because the fields at the faces of strip electrodes of AIC differ from parallel plate ones [5], which, in their turn, lead to procedural errors in measurement of anisotropy of dielectric properties. The error may go well beyond 10%. Moreover, the edge effect at the faces of electrodes is impossible to determine as opposed to the control of isotropic media [6]. In addition, the sizes of the electrodes should be selected so that the penetration of the transducer’s electric field is less than the minimum thickness of the material [7] and, consequently, any change in the thickness does not affect the measurement results. The absence of effective means and methods of NDT of anisotropy of polymer materials leads to low efficiency of testing of strength and deformation properties of polymers, water content measurement of materials with anisotropic structure.

The mathematical models of the sensors are constructed by an integral equation method where potential electrodes are presented as mirror-symmetrical equipotential surfaces spaced apart at the electrodes thickness [7]. The models of mirror-symmetrical SAIC and SAIC are of a universal nature and in a particular case, if shield is removed, it turns into the model of the AIC [5]. The calculation of electric fields of capacitive sensors (Fig. 1a, 1b) filled with an anisotropic material was performed by the method of isotropizing coordinate transformation.

When coordinate axes coincide with axes of material anisotropy the indices of reflection and transmission are replaced with similar indices for isotropic medium considering that material permittivity equals: $\varepsilon = \sqrt{\varepsilon_x \varepsilon_z}$. For anisotropic medium, distances between electrodes h, and electrode thickness d are changed as well:

$$h_1 = h\sqrt{\varepsilon_x / \varepsilon_z}, \quad d_1 = d\sqrt{\varepsilon_x / \varepsilon_z}.$$

Values of specific constants εx, εy and εz vary insignificantly for most anisotropic materials. Thus, errors resulted from non tight contact of electrodes with the inspected surface, and errors caused by edge effect at the electrode faces where the field is not parallel-plate may lead not only to quantitative but also qualitative changes in the idea of anisotropy of the tested material. Solution of this problem relates to the design of sensors which enable to create fields mainly along the axes of material anisotropy in the ZOX and ZOY planes [6].

In case of difference the high sensitivity of the measuring device can be achieved by differential measuring method. When determining the values of constants of permittivity tensor to remove errors caused by edge effect two capacitive transducers of different length but with the same configuration of strip electrodes at the faces shall be used. The difference between capacitances of transducers, measured for various electrode lengths, L1 and L2, reflects capacitance per electrode length without edge effects at the faces [6]. Figure 3 shows calculated dependences of the difference of normalized capacitances Cx/C0 and Cy/C0, for differential mirror-symmetrical AIC, SAIC and AIC, which enable to create fields along anisotropic axes of a material. C0 is capacitance of a capacitive transducer in the air. Field force lines of the first sensor are closed in ZOX plane and those of the second one - in ZOY plane. Values of material permittivity in direction of axis are εx = 1.9 and in perpendicular directions are εy = εz =1.2 [7]. In contrast to AIC, mirror-symmetrical AIC and SAIC demonstrate a clear maximum on the relative capacitance difference curves (Cx – Cy)/C0 from a relative gap dr/h. Moreover, the smaller the thickness of transducers substrates is, the higher the sensor sensitivity to anisotropy. It is caused by the fact that the shields at the base of substrates accumulate the larger part of the flow of electric field intensity. Z-type field bending takes place in the space between electrodes. It increases which results in the increase of the share of the flow closed between the potential electrodes through the inspected anisotropic material, isotropic material of the substrate, and in the decrease of the share of the flow closed between potential electrodes in the substrate. The loss of sensitivity to anisotropy for small gaps dr is caused by the decrease of the share of horizontal component of field intensity. The fields, to a greater extent, are coupled to shields making force lines protrude which decreases capacitive transducer sensitivity to anisotropy.

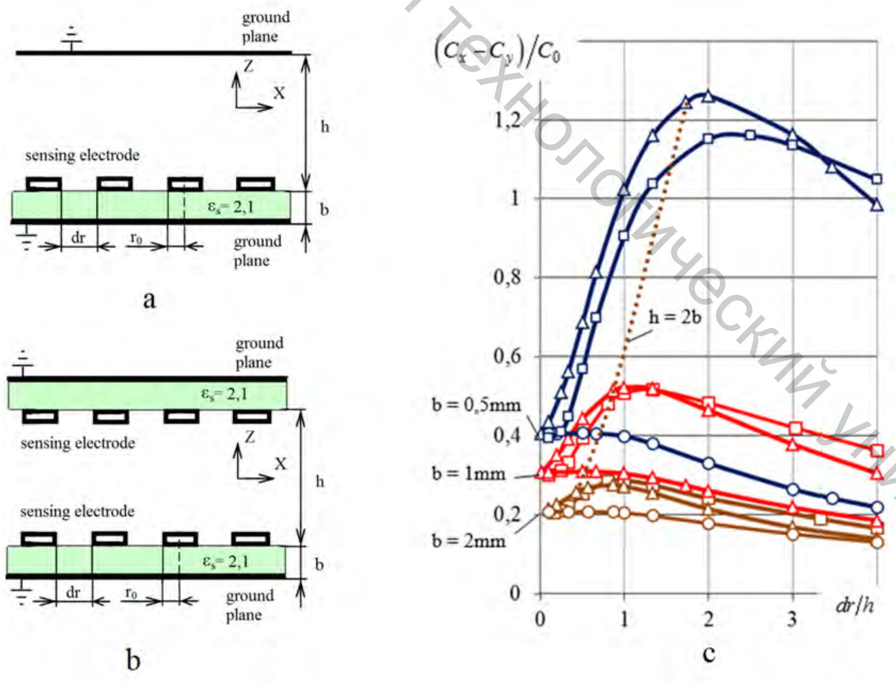


Figure 1 – Characteristics of capacitive sensors:
a - design of mirror-symmetrical SAIC; b - design of mirror-symmetrical SAIC
c - Calculation pattern of dependency of relative capacitance difference on a relative gap $dr/h$ : Δ – SAIC; □ – mirror-symmetrical AIC; ○ – AIC.

The sensitivity to anisotropy of capacitive transducers produced on relatively thin substrates b ≈ dr (upper curves in Fig. 1c) is higher than that of capacitive transducers on thick substrates. However, small capacitance values of capacitive transducers bring to naught this advantage. Figure 1c shows the changes in capacitances between electrodes of mirror-symmetrical AIC and SAIC which are observed as long as the gap between electrodes, dr, decreases. The electrodes of capacitive transducers abrade during the period of exploitation. The thickness loss of the electrodes results in the loss of sensitivity to dielectric anisotropy of a material. The loss of relative difference of capacitances, which create the fields along the anisotropy axes, equals to 0.5 % when the loss of electrode thickness ranges from 5 μm to 35 μm. When the size increases $h \to \infty$ relative differences (Cx – Cy)/C0 tend to the values of relative differences of capacitances of multichannel AICs. They do not depend on the size h (thickness of the inspected material). The maximum difference (Cx – Cy)/C0 is observed for sensors when the thickness of an inspected material equals h ≈ 2b.

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## COMMODITY NOMENCLATURE OF SHOES QUALITY INDICATORS

## ТОВАРОВЕДНАЯ НОМЕНКЛАТУРА ПОКАЗАТЕЛЕЙ КАЧЕСТВА ОБУВИ

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