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Research of a capacitive distance sensor to grounded surface

In this paper, a review and analysis of capacitive sensors with flat round electrodes for measuring distances to grounded surfaces has been performed. The response characteristic of capacitive distance sensor with coplanar electrodes has been determined. The optimal relationship between the dimensions of the elements of sensor with concentric coplanar electrodes and the measuring range for it has been determined. The recommendations which of types of sensors when to apply are given

Introduction

Automatic distance sensors are commonly used for static and dynamic evaluation of movement for machinery in work. When a part of a tool is grounded the best way to measure displacement is capacitive [1]. Capacitive sensors are not influenced by electromagnetic, magnetic fields and temperature of grounded surface.

Sensors with a centric coplanar electrodes system of electrodes are commonly used for control the dielectric characteristics of materials – during checking the composite materials in aviation industry [5 – 7] or for measuring different kind of non-electrical quantities, such as geometrical dimensions of subjects, displacement and vibration of grounded surfaces, position of object, pressure, force and others mechanical parameters of aerospace equipment. Existing capacitive sensors made in the shape of flat capacitor geometry do have high values of sensitivity, but they also have a notable nonlinear behavior over their whole gauge characteristics [8].

Similar research works about these types of sensors and their usage in measuring distance between the active surface and grounded one were not found during analysis.

The goal of this report is definition of converting function of capacitive sensor with centric coplanar electrodes for measuring distance to grounded surface.

In the Department of Electrical and Magnetic Measurements of the Institute of Electrodynamics of the National Academy of Sciences of Ukraine, in recent years, meters have been created for distances to a grounded surface with a specified system of electrodes of various applications [4].

Principle of design capacity distance sensor with circular electrode

The simplest analogue of a capacitive sensor with concentric coplanar electrodes is a sensor with a circular flat electrode (type 1). This type of sensor are measuring the distance to a grounded surface and it's scheme is shown in Fig. 1. The principle of operation of the sensor is as follows: the working electrode 1.1 and grounded electrode 1.2 are placed on one part of the machine. In this system of electrodes distance is measured to the grounded surface 2. To the measuring device, the sensor is connected by a shielded cable 3. The working capacity of such a sensor (without taking into account the parasitic capacity of the conductive conductors) depends on the distance and definite by formula

$$C = \varepsilon_0 \varepsilon_r \pi R^2 / d \qquad (1)$$

where $\varepsilon_0 = 8{,}8542 \cdot 10\text{-}12$ F/m – dielectric permeability of the vacuum; εr=1,00056 – relative dielectric air permeability; R – radius of the working electrode of the sensor 1.1; d – the distance between the surface of the working electrode of the sensor 1.1 and grounded surface 2.

The disadvantage of this method is a significant impact on the accuracy of measuring edge effects, especially when $d / R > 0{,}1$

The aforementioned disadvantage is practically eliminated by placing in the same plane in the capacitive sensor between the active (working) electrode and the grounded electrode of a guard electrode (type 2), which has a potential of active, but not galvanically connected to it. As a result, in the working gap of the sensor (between the active electrode and ground plane), a uniform electric field with parallel lines of power is created that eliminates the effect of boundary effects. Such a system of electrodes, for example, is used in serial capacitive sensors of the type capaNCDT firm Micro-epsilon (Germany) [2,3].

The sensor circuit with such a system of electrodes (type.2) is shown in Fig. 2. Sensor 1 (fig. 2), using which the distance is measured d to the ground plane 2, consists of an active electrode 3 with a radius of R, security electrode 4 width b and a grounded electrode 5, the size of which is established for constructive reasons. Width b The protective electrode depends on the ratio d / R and for the given error is calculated. Electrodes 3 and 4 separated by a dielectric gap h, which for the greater uniformity of the field should have a minimum width. The capacitance sensor will be equal by a formula (1), where R – radius of the active electrode 3.

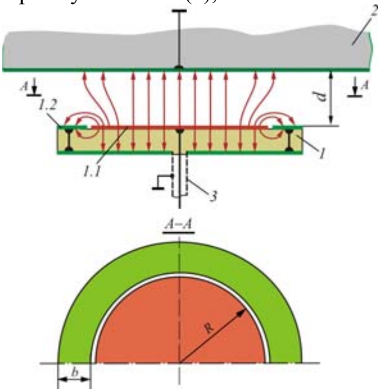

Fig. 1 – The scheme of measuring the distance to a grounded surface sensor with a simple circular capacitive electrode

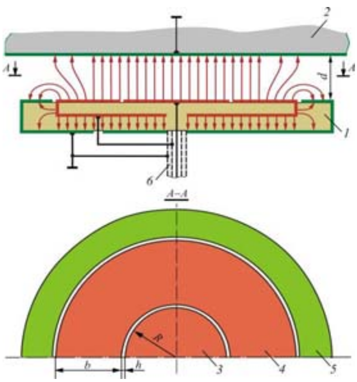

Fig. 2 – The scheme of measuring the distance to a grounded surface to create uniform electric fields in capacitive sensor

The meters of this type have an estimated linear characteristic, and they provide high accuracy and resolution of the measurement. To their disadvantages is a fairly complex scheme of the secondary measuring transducer. In particular, in the meter described in [4], a special transformer is used, the secondary winding is wound with shielded cable, which is not technologically expensive and expensive. In addition, an expensive tri-axial cable (with dual screen) is used between the sensor and the secondary converter.

Basic principle of design capacity distance sensor with concentric coplanar electrodes

Disadvantages of the capacity distance sensor with circular electrode type 1 and 2 are minimized in the scheme of a relatively simple capacitive sensor with concentric coplanar electrodes (type 3) which shown in Fig. 3. Sensor 1 with concentric coplanar electrodes, are measures the distance between the plane of the sensor electrodes and the grounded surface 2. The sensor consists of the following main parts: active high-power electrode 3 with a radius of b, low-power electrode 4 with a width of b, between which a low-potential protective electrode 5 is located with a width of s. Electrodes 3, 4 and 5 separated from each other by thin dielectric spaces in width h, which depends on the technology of manufacturing, usually photolithography. Field between electrodes 3 and 4 in each radial section, will be two-dimensional and will have the same shape when providing a minimum value of the h.

Distance sensor with concentric coplanar electrodes response characteristic

Use the results of research [8,9] we have for response characteristic of sensor with concentric coplanar electrodes next formula

$$C_L = \frac{\varepsilon_0 \varepsilon_{r\Pi}}{\pi} \ln \frac{\left(\mathrm{th}\frac{\pi s}{4d} + \mathrm{th}\frac{\pi\left(s+2b\right)}{4d} \right)^2}{4\mathrm{th}\frac{\pi\left(s+2b\right)}{4d}\mathrm{th}\frac{\pi s}{4d}} \tag{2}$$

where b – width of electrodes 3 and 4; s – distance between electrodes 3 and 4; d – the distance between the plane of the electrodes 3 and 4 and surface 2.

Total working capacity of the sensor $C_{34\text{P}}$ taking into account that the length of the middle line between the electrodes 3 and 4 is $L_{34} = 2\pi R = 2\pi(b + s/2)$, definite as

$$C_{34\text{P}} = 2\varepsilon_0\varepsilon_r \left(b + \frac{s}{2} \right) \ln \left(\left(\mathrm{th}\frac{\pi s}{4d} + \mathrm{th}\frac{\pi\left(s+2b\right)}{4d} \right)^2 \cdot \left(4\mathrm{th}\frac{\pi\left(s+2b\right)}{4d}\mathrm{th}\frac{\pi s}{4d} \right)^{-1} \right). \tag{3}$$

From the analysis of formula (3) as shown in [9], it is determined that the most convenient for use is the plot of the function graph (curve 1, fig. 4) when $b \approx d_{\max}$, and $s = b/6$. Fig. 4 shows the dependency curve of the function

$C_{34P} = f(d)$ (line 1) for the following parameters $1\text{ mm} \le d \le 5\text{ mm},\ b = 6\text{ mm},\ s = 1\text{ mm}$.

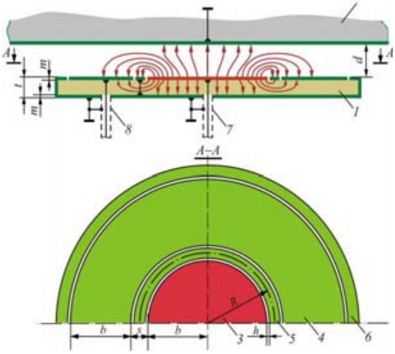

Fig. 3 – The scheme of measuring the distance to the grounded surface by a capacitive sensor with concentric coplanar electrodes

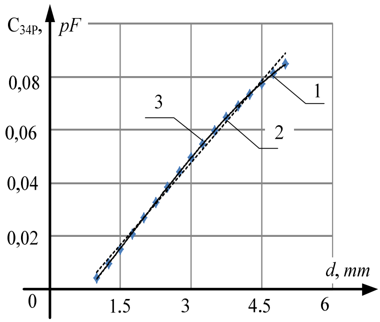

Fig. 4 – Curve of the function change the working sensor capacity C_{34P} and approximation functions

Parasitic capacity $C_{34\Pi}$ through the dielectric of foil glass fiber in thickness t = 1,5 mm (thickness of copper foil m = 35 µm) will be calculate as

$$C_{34\Pi} = 2\varepsilon_0\varepsilon_{rF}\left(b+\frac{s}{2}\right)\times\ln\frac{\left(\mathrm{th}\frac{\pi s}{4(t-2m)}+\mathrm{th}\frac{\pi(s+2b)}{4(t-2m)}\right)^2}{4\mathrm{th}\frac{\pi(s+2b)}{4(t-2m)}\mathrm{th}\frac{\pi s}{4(t-2m)}} = 0{,}0746\ pF \quad (5)$$

For practical use of the obtained dependence, it is necessary to calculate the approximating dependence in accordance with the method shown in [10, 11].

As a result experimental (curve 3, fig. 4) and of the analytical calculations obtained graphs of approximating (functional) dependence: for the linear model (curve 2, fig. 4) $C_{34P} = 0{,}0206d - 0{,}0144$ with a determination factor $R^2 = 0{,}9951$.

Conclusion

The capacitive sensors of different types are described in this report. The most advantageous position for practical use had the capacitive distance sensor to grounded surface with concentric coplanar electrodes. This type of the sensor has the following benefits:

1. On the basis of theoretical studies with help of regressive analysis methods were obtained approximating functional dependences for a capacitive sensor with concentric coplanar electrodes to measure the distance to the grounded surface.

2. The methods of the regression analysis determined the convenient approximation functions of the "distance - electric capacity" transformation.

3. It is established that the smallest approximation error ensures the use of polynomials of the third order (determination coefficient).

4. The sensor can be used to create simple and inexpensive devices in cases where high accuracy of measurement is not required.

5. For the application of the sensor in more high speed devices, it is advisable to use linear approximation.

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