Development and Research of a Capacitive Transducer for Angular Displacement Measurement

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***Abstract*— The report presents the methodology and difficulties in developing a capacitive transducer for angular displacement. Experimental studies of the developed converter are presented, as the measurement of the capacity is performed by two independent methods. Mathematical models are derived giving the relationship between the value of the capacitance and the area of overlap and the distance between the electrodes.**

Keywords—angular, capacitive, mathematical model

I. Capacitive Transducers

Capacitive measuring transducers are capacitors whose capacitance changes under the influence of the measured non-electric quantity. It contains two parallel metal plates. These plates are separated by a dielectric medium, which is either air, material, gas or liquid. In a normal capacitor the distance between the plates is fixed, but in a capacitive converter the distance between them is different. [1,2,3]

$$C = \frac{\varepsilon s}{\delta} = \frac{\varepsilon_0 \varepsilon_r s}{\delta} \quad (1)$$

Where ε is the dielectric constant of the medium between the electrodes, s - their area, δ - the distance between them, ε_0 = 8.854,10-12 F/m the dielectric constant of the vacuum, ε_r - the relative dielectric constant of the medium between the electrodes (for air ε_r = 1.0006).[2]

Therefore, the capacity C can be changed by changing ε, s and δ. In the developed capacitor we can change simultaneous 2 parameters – the distance between the electrodes and their area of overlap. [2,3]

II. Development of Capasitive Transducer

For the development of the capacitive transducers are used 2 aluminum plates as shown in fig. 1.

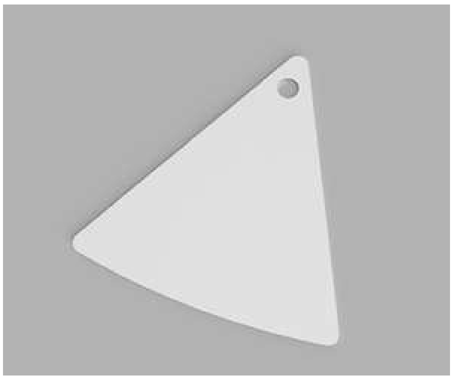

Fig. 1. Aluminum capacitor plate

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One of the capacitor plates is static and is put on the bottom of a wooden box. A special hole with a diameter of ϕ11.5 is drilled in the box, in which a tube with an external thread with a diameter of ϕ12 and a stud are inserted, in which enters the tube and stops in the drilled hole. The second capacitor plate has a hole through which the thread passes (Fig.2). With nuts the plate is moved up and down thus changing the distance between the 2 plates. The rod and nuts are plastic. (Fig.3)

Fig. 2. Connection between the aluminum plate and the wooden box

Fig. 3. Plastic rod connected to an aluminum plate

One of the plates has a scale that is showing the angle. The range of it is from 0 to 50 degrees, which corresponds to from 0 to 100 % cross area between the plates. Because we don't know the actual cross area we will use this scale instead to set the parameters.

III. EXPERIMENTAL SETTING

The measurements are done by using 2 of the integrated 12 instruments of NI Educational Laboratory Virtual Instrumentation Suite 2 (NI ELVIS 2) – the digital multi meter (DMM) and the impedance analyzer.

The capacitor plates ate connected to the instrument through a cable with pinch ends from one of the ends and are connected to the plates and the instruments as shown in fig.4.

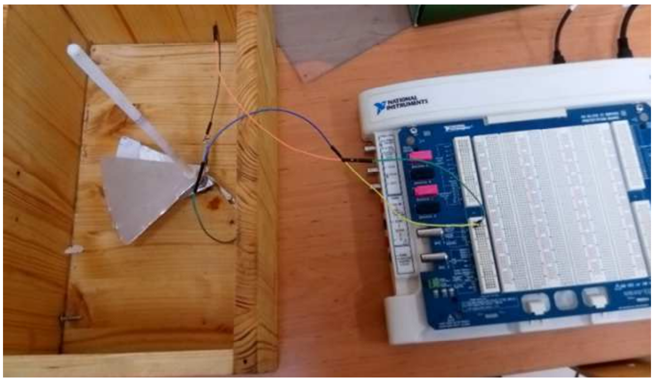

Fig. 4. Test equipment

The results are visualized on a computer with NI ELVIS 2 virtual instrument installed on.

IV. EXPERIMENTAL DATA

The experiments are done with changing the distance between the plates with nuts and by changing the cross area between the plates.

The experiments are reproduced 5 times in each distance between the plates and in different angular displacement (from 0 to 50 degrees with a step of 10 degrees).

On fig.5 are shown the results of the test measured with the DMM.

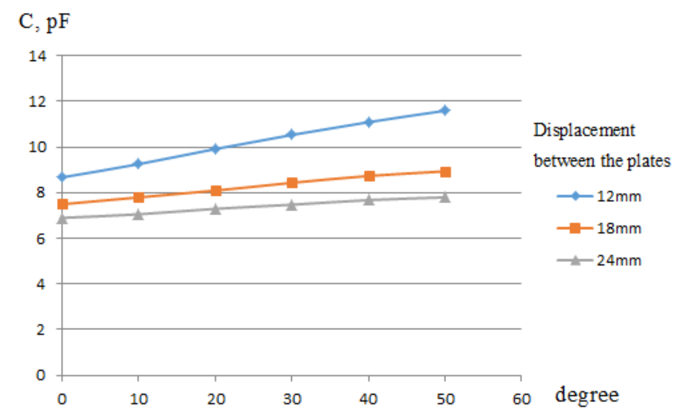

Fig. 5. Result from the measurements with DMM

On fig.6 are shown the results of the test measured with the impedance analyzer.

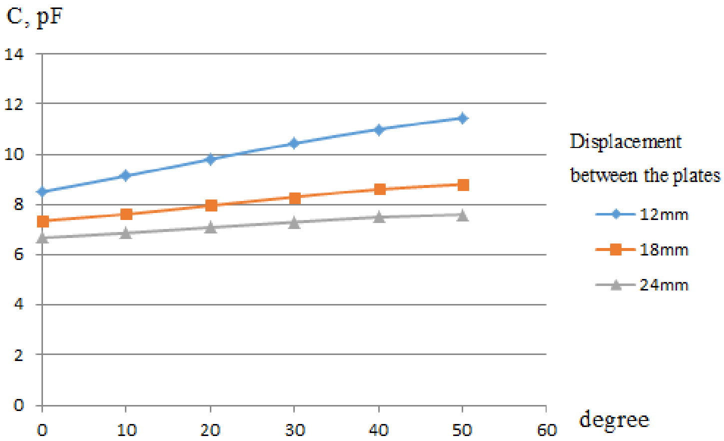

Fig. 6. Results from the measurements with the impedance analyzer

The results are basically the same. The results from the impedance analyzer are calculated with formula 1 and shows a difference it the range from 0,05 to 0,22 pF less than the ones measured with the DMM. The difference is bigger when the displacement between the plates is 24mm.

$$C = -j\frac{1}{\omega Z} \quad (1)$$

It is obvious from fig. 5 and 6 that the results at each displacement between the plates are changing linear with the change of cross area.

By the method of least squares the following mathematical equations are derived describing the change of the capacity at change of cross area for the measurements done by the DMM (eq. 2 for 12mm, 3 for 18mm and 4 24mm) and impedance analyzer (eq. 5 for 12mm, 6 for 18mm and 7 for 24mm). It must be marked that in the following equations "s" is the cross area between the plates but it is given with the angular displacement.

$$C = 0{,}0593.s + 8{,}7019 \quad (2)$$

With correlation coefficient – 0,9982

$$C = 0{,}0296.s + 7{,}5133 \quad (3)$$

With correlation coefficient – 0,9958

$$C = 0{,}0187.s + 6{,}8029 \quad (4)$$

With correlation coefficient – 0,9935

$$C = 0{,}0597.s + 8{,}57219 \quad (5)$$

With correlation coefficient – 0,9964

$$C = 0{,}0303.s + 7{,}3559 \quad (6)$$

With correlation coefficient – 0,9946

$$C = 0{,}0191.s + 6{,}6981 \quad (7)$$

With correlation coefficient – 0,9925

Values were calculated with above equations and were checked with real data in position with different cross area between the plates than the one the equations were derived from. Equations from 2 to 7 give good results.

From equations 2, 3 and 4 a formula was derived for calculating the capacitance form the cross area and the distance between the plates.

$$C = (0{,}0003d^2 - 0{,}0128d + 0{,}1751)s + (0{,}008d^2 - 0{,}439d + 12{,}814) \quad (8)$$

Where d – is the distance between the plates and s - is the cross area.

The same is done with equations 5, 6 and 7.

$$C = (0{,}0003d^2 - 0{,}0125d + 0{,}1731)s + (0{,}0078d^2 - 0{,}4358d + 12{,}685) \quad (9)$$

The results from these formulas aren't satisfactory (formula 8 – for DMM and formula 9 – for impedance analyzer). In some cases the errors are between 1 to 2 pF.

After some further investigations a conclusion was derived that the results in the measurement when the distance between the plates is 24 mm are not good, because the change in the capacitance is too low and the measuring device doesn't have a better resolution. Due to this it was decided that new equations will be derived without the data from the measurement done at 24 mm distance.

From equations 2 and 3 a formula was derived for calculating the capacitance form the cross area and the distance between the plates.

$$C = (-0{,}005d + 0{,}1187)s + (-0{,}1981d + 11{,}079) \quad (10)$$

From equations 5 and 6 a formula was derived for calculating the capacitance form the cross area and the distance between the plates.

$$C = (-0{,}0049d + 0{,}1185)s + (-0{,}2028d + 11{,}007) \quad (11)$$

Results were taken using formulas 10 and 11 in points different than the ones used for creating the formulas and were compared with a real data form the test equipment (table 1 and 2).

The result show that at 18 mm where the data for developing the formulas are taken in different angular positions than the one used for the formulas the error between the calculated and measured values are insignificant.

TABLE I. MEASUREMENTS DONE WITH THE DMM

Displacement = 18 mm			
Angle, degree	***Capacitance Calculated with the derived formula, pF***	***Capacitance measured, pF***	***Error, pF***
22,5	8,3	8,3	0
45,0	8,8	8,8	0
Displacement = 14 mm			
Angle, degree	***Capacitance Calculated with the derived formula, pF***	***Capacitance measured, pF***	***Error, pF***
20,0	9,28	9,3	-0,02
40,0	10,25	10,2	0,05
Displacement = 16 mm			
Angle, degree	***Capacitance Calculated with the derived formula, pF***	***Capacitance measured, pF***	***Error, pF***
20,0	8,68	8,8	-0,12
40,0	9,46	9,5	-0,04

TABLE II. MEASUREMENTS DONE WITH THE IMPEDANCE ANALYZER

Displacement = 18 mm			
Angle, degree	***Capacitance Calculated with the derived formula, pF***	***Capacitance measured, pF***	***Error, pF***
22,5	8,19	8,21	-0,02
45,0	8,72	8,70	0,02
Displacement = 14 mm			
Angle, degree	***Capacitance Calculated with the derived formula, pF***	***Capacitance measured, pF***	***Error, pF***
20,0	9,17	9,18	-0,01
40,0	10,13	10,11	0,02
Displacement = 16 mm			
Angle, degree	***Capacitance Calculated with the derived formula, pF***	***Capacitance measured, pF***	***Error, pF***
20,0	8,56	8,65	-0,09
40,0	9,37	9,42	-0,05

Other tests were done at distances between the plates 14 mm and 18 mm (as shown in table 1 and 2). The results show that the calculated and the measured values are almost the same. This leads to the conclusion that the derived formulas can be used to calculate the values in advance.

V. CONCLUSIONS

The cables that connect the plates of transducer with the measuring device should be screened, otherwise every disturbance will lead to change in the output signal.

If cables with different parameters are used the output signal will be different. This is due to the inner capacitance of the cables.

The developed transducer is appropriate for education of students. The experimental set will be used in the subject “Non electrical measurements” to upgrade the already existing exercise.

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