ELECTRONICS

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ELEKTRONIKA

Capacitive Transducers in Granulometry

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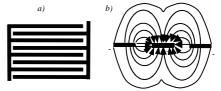
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Introduction

Evaluation of some certain physical parameters of analyzed object by performing non-destructive testing or contactless measurements is often required in practice. For example, old-known and well-established capacitive methods can be used in order to verify the quality of products, to ascertain that they are without cavities, to evaluate material anisotropy, to measure pressure, displacement, thickness, acceleration and humidity. They allow evaluation of physical magnitude according to the change of transducer capacitance. However the application of capacitive transducers in granulometry is a new problem.

Electrode system is required to measure parameters of the analyzed object (for example granule) using capacitive transducers; the capacitance of this system should vary according to the variation of the analyzed parameter. Also a system for measurement of capacitance change is needed. In most cases it is accomplished by transforming electrical capacitance into some other electrical quantity, for example frequency of electrical signal. A generator in the contour of which one capacitor is replaced by capacitive transducer is used for this purpose. The change of its capacitance also changes the output signal frequency. This frequency can be easily measured using counters. Transducer capacitance can be transformed into voltage by application of capacitive voltage dividers, in which one of capacitors is replaced by the capacitive transducer, or to use the bridge circuit – the bridge imbalance voltage will be proportional to the transducer capacitance.

The potential of known and established methods is most often limited by the possibilities of capacitance transformation to some other electrical quantity. Achievements of modern technology and science allow to model electrical field using finite element techniques, to construct the capacitance measurement systems, which are distinguished by especially high discrimination threshold [2]. This particularly expands the possibilities of current application methods of capacitive transducers and development of new methods. This is also relevant when investigating the application of capacitive transducers in granulometry in order to assess the size of the granule or other characteristics [3].

"Comb" type electrodes can be used to evaluate the flow of granules of their size in this flow by using the capacitive transducers. These consist of *n* (For the comb depicted in Fig. 1,a parameters *n*=7) capacitors-transducers connected in parallel, which are made of two metal strips-electrodes. The lines of electrical field between these strips are distributed as it is shown in Fig. 1,b. The analyzed object should be placed in this environment. Parallel connection of capacitors allows to obtain higher changes of the capacitance. The bigger distance between the electrodes, the wider area is covered by the electrical field.

Fig. 1. "Comb" type electrodes consisting of 7 strips and electrical field between 3 strips

The size of one granule can be evaluated when it rolls on the electrodes or falls between them. The bigger the granule is, the higher the change of electromagnetic field and the capacitance consequently. Slot-type (Fig. 2,a: arrows indicate the possible direction of the granule movement) or standard (Fig. 2,b) transducer can be applied for such measurements. Slot transducer is similar to the "comb" type transducer consisting of 2 electrodes; however the electrodes of the slot transducer are considerably wider compare to the gap between them. Standard transducer is a planar capacitor, when the analyzed object is placed between its electrodes.
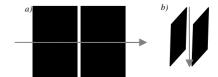

Fig. 2. Electrodes of aperture and standard transducers

In order to prove these assertions the finite element modeling using software "Ansoft Maxwell v10" and several practical experiments are performed.

Influence of granule flow thickness on the "comb" type transducer capacitance

Transducer capacitance is linearly proportional to the permittivity of the material used to fill the environment of the electrodes. If this environment is non-homogeneous, e.g. there are materials with different permittivity, the lines of electric field are distorted: the higher material permittivity, the more lines of electric field fall into material boundaries, and the electric field lines on the interfacing surface of materials with different permittivity are distributed according to the boundary conditions. All this may be evaluated by the use of the conception of the average permittivity. Average permittivity is considered as such permittivity of the material when the capacitance of electrodes the environment of which is homogeneous and filled with this material is equal to the capacitance of the electrodes the environment of which is non-homogeneous (the analyzed case). If there are only two materials with different permittivity in the environment, the coefficient k of environment (first material) filling using the second material can be used instead of the concept of average permittivity. It is considered that the permittivity of the second material is higher.

$$k = \frac{\varepsilon_{vid}}{\varepsilon_{m1}\varepsilon_{m2}} ; \qquad (1)$$

here k – coefficient of filling using the second material, ε_{vid} – average permittivity of the environment, ε_{m1} – permittivity of the first material, ε_{m2} – permittivity of the second material.

On the basis of the notion of filling coefficient the capacitance of a plain capacitor can be rewritten as

$$C = \frac{\varepsilon_0 \cdot k \cdot \varepsilon_{m1} \cdot \varepsilon_{m2} \cdot S}{d} . \qquad (2)$$

According to (3) it is possible to propose, that the higher the coefficient of filling k, the higher capacitance of the electrodes is.

Assume that air is the environment of the electrodes, and it is filled using round granules of equal diameter, when they are placed in layers one on the other. With the bigger thickness of this layer it will take up the bigger part of the electrodes environment, therefore k and capacitance of the electrodes C will be higher.

This consumption was verified by modeling. Software package "Ansoft Maxwell 2D v9" is used for this purpose. Two-dimensional model of the system is given in Fig. 3 [1].
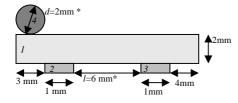

Fig. 3. System model. 1 – textolite plate, 2, 3 – electrodes, 4 – granule: distance between electrodes and granule diameter are varied

Electrodes are formed on the surface of the textolite plate *1*: the positive *2* and the negative *3*. Granules *4* are placed in layers on the other side of the plate (one granule

is depicted in Fig. 2). Granule diameter and distance between electrodes are varied. Modeled distribution of the electric field magnitude is given in Fig. 4.

"Required" amount of granules is added onto the surface of the textolite plate, required distance between electrodes is selected and the modeling is performed, the aim of which is to determine the capacitance of such transducer.
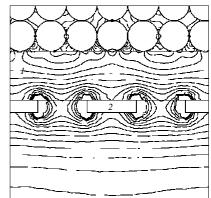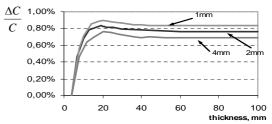

Fig. 4. Distribution of electric field magnitude in the analyzed model

Modeling results – dependence of the relative change of the capacitance of the electrodes on the thickness of the granule layer – is presented in Fig. 5 (distance between electrodes is 6mm).

Fig. 5. Dependence of the relative change of the capacitance of the electrodes on the thickness of the granule layer when granules of different diameter are used

It can be seen from the obtained characteristics, that with the increase of the thickness of the granule flow up to 9mm the electrode capacitance increases linearly. When the thickness of the layer increases further, capacitance increases non-linearly and when the thickness of 20mm is reached, the capacitance maximum is obtained. When flow thickness increases even more, the capacitance slightly decreases and the variation stops. This shows that the granule flow takes up the entire environment of the electrodes and increase of its thickness beyond the boundaries of this environment does not influence the capacitance. It can be also seen that the change of capacitance depends on the size of the granules. The smaller the granules, the higher change of the capacitance is observed with the increase of the flow thickness.
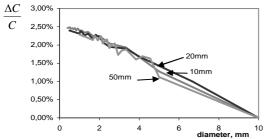
Influence of granule diameter on the capacitance of the transducer

When placing granules of the equal diameter one on the other in layers, the ratio of their occupied volume and general volume of the environment is the constant quantity, not related to the diameter of granules. Thus the coefficient

of the environment filling using granules of equal diameter k should not vary with the alteration of the diameter of all granules. This assumption contradicts the modeling results presented in the previous section.

The environment of the electrodes illustrated in Fig. 1,b in which the lines of electric field are present has the form of the ellipsoid. Non-homogeneities of the environment disturb the lines of the field. The closer the electrodes the more lines of electric field are there, and the more electric field is distorted; consequently the electrode capacitance depends on the non-homogeneity location in the environment of the electrodes. There are less granules in the layer consisting of the bigger granules, compare to the one consisting of smaller granules, even they occupy the same volume. The more granules the higher interface area between materials of different permittivity, therefore electric field is distorted more. So the k and the capacitance of the electrodes C should increase with the decrease of the diameter of granules.

This assumption was verified by modeling. The same model of the system given in Fig. 3 is used.

Modeling results are shown in Fig. 6, if distance between electrodes is 6mm. It can be seen from them that the smaller the granules are, the higher capacitance of the electrodes is; when granules of the diameter of 10mm in the flow are replaced with the granules of 0.1mm, the capacitance of the electrodes increases by 2.5%. This change does not depend on the thickness of granule flow. The jumping character of the curves is conditioned by different modeling tolerance. Considering this the size of the granules in the flow can be evaluated according to the relative change of the capacitance, irrespective of the flow thickness; however it should remain constant. If the flow thickness varies, the size of the granules may be evaluated only for the flow which is thicker than 20mm, when the variation of the flow thickness does not influence the capacitance of the electrodes.

Fig. 6. The dependence of the relative change of the capacitance of electrodes on the diameter of granules under various thicknesses of the flow

The influence of the geometry of electrodes

Distance between electrodes also influences the electrode capacitance. The larger it is, the larger volume is spanned by the electrode environment. Previous modelings were repeated with the altered distance between electrodes. Received results are given in Fig. 7 (diameter of granules is 0.5mm) and Fig. 8 (flow thickness is 5mm). It can be seen from them, that the larger distance between the electrodes, the bigger capacitance changes are observed both when varying the flow thickness and granule diameter.
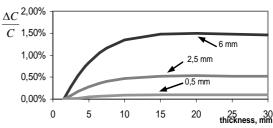

Fig. 7. Influence of granule flow thickness on the capacitance change under various distances between the electrodes
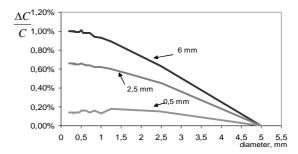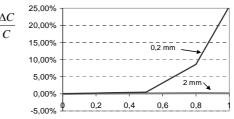

Fig. 8. Influence of granule diameter on the capacitance of the electrodes under various distances between the electrodes

Influence of various-sized granule flow on the capacitance of the electrodes

According to the modeling results presented in Fig. 5 it can be proposed, that the electrode capacitance becomes higher with the decrease of the size of the granules in the flow. On the base of this assertion, if several bottom layers of the flow would be replaced by smaller granules, the capacitance of the electrodes should also increase. The thicker layer of the smaller granules would be, the larger capacitance of the electrodes should be. This assertion was verified by modeling. Model depicted in Fig. 3 is used. Required number of layers of granules with diameter of 0.1mm is placed on the textolite plate, and 24 layers of larger granules with diameter of 2mm are placed on them additionally. Overall athickness of granule layer is already sufficient and occupies entire environment of the electrodes; its variation does not influence the electrode capacitance. Capacitance should be influenced only by the composition of the lower layers of the flow. Distance between electrodes was 2mm and 0.2mm. Modeling results – the dependence of the relative change of the electrode capacitance on the thickness of the layer of smaller granules is given in Fig. 9.

Fig. 9. Influence of the layer thickness of the smaller granules on the electrode capacitance when distances between the electrodes are 2mm and 0.2mm
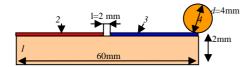
On the base of modeling results it can be proposed that when the distance between the electrodes is large, smaller granules at the bottom of the flow do not influence

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the capacitance, whereas the capacitance of the electrodes the distance between which is small varies according to the change of amount of smaller granules at the bottom of the flow. Distance between the electrodes should be close to the diameter of the smaller granules. This fact can be applied for determination of amount of the small defective granules, but only when they are at the bottom of the flow. For this purpose two pairs of "comb" shaped electrodes are required. Difference of their relative capacitances is higher when there are more smaller granules at the bottom of the flow.

Analysis of the slot transducer

Granule rolls on the textolite plate, on which two wide long electrodes with the small gap between them are formed. The largest amount of electromagnetic field lines of the electrodes are located near this gap. When the granule enters this environment, it will distort the electromagnetic field of the electrodes and the capacitance of the transducer will increase, since the permittivity of the environment is less than the permittivity of the granule.

If granule rolls on this surface, then it will stay for longer time at the region of the gap; the time is longer the larger the size of the granule is. Furthermore it will fill larger part of the environment, therefore the environment fillinf coefficient k will be higher and consequently the transducer capacitance will be higher.

Modeling was performed to determine the capacitance variation pattern. System model illustrated in Fig. 10 is used.

Fig. 10. System model:1 – textolite plate, 2 – positive electrode, 3 – negative electrode, 4 – granule (its size is not varied)

Granule location, its size is varied and capacitance of such system is modeled. Modeling results are given in Fig. 11.
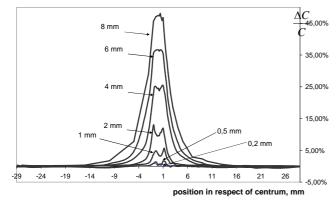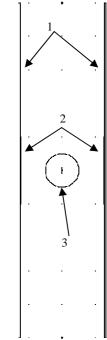
Fig. 11. Dependence of electrode capacitance on the location of the granule for different sized granules

It can be seen from the modeling results, that the bigger the granule, the wider is the pulse and the higher its amplitude is. If granule roll velocity is known, its permittivity is also known, then its size could be evaluated using slot transducers.

Additionally the highest transducer capacitance is achieved when the granule is near one of the edges of the electrodes. When granule rolls closer to the center of the slot, the transducer capacitance decreases and the smaller the granule, the higher this decrease is. It is related to the distance between the electrodes. If it is smaller than the diameter of the granule, there is no capacitance decrease.
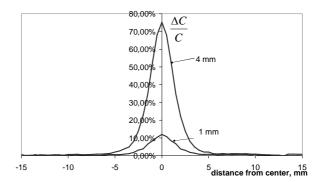
Analysis of the standard transducer

Roll of the granule can be substituted by its air fall in between of two flat parallel electrodes. Most part of the electromagnetic field lines generated by these electrodes are situated between these electrodes. When the granule enters this electromagnetic field it distorts the field and the capacitance of the transducer increases. The more of the space is taken up by the granule, the larger the capacitance is; furthermore, the larger granule will stay longer in this environment during its fall compare to the smaller one, thus the capacitance change pulse will be wider.

To determine the pattern of the cpacitance variation the modeling was performed. Model illustrated in Fig. 12 was used.

Fig. 12. System model: 1 – textolite plates, 2 – electrodes formed on the surface of plates, 3 – granule (solid)
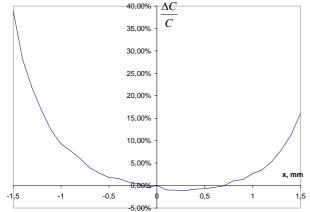
Fig. 13. Relative change of the electrode capacitance during the fall of the granule, when the size of the granule is 1 and 4mm

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Location of the granule is selected between the electrodes on the x and y axes; size of the granule is also selected and the capacitance magnitude of such electrical system is modeled. Modeling results are given in Fig. 13, where width of the electrodes is 1mm, distance between the electrodes is 5mm.

As it can be seen, the larger the granule, the higher amplitude of the pulse is, but the pulse duration does not depend on the granule diameter.

The dependence of the electrode capacitance on the granule location on the *x* axis is presented in Fig. 14. From this figure it is obvious, that the granule fall trajectory location on the *x* axis has a large impact. It must fall as precisely as possible through the center in equal distances from each of the electrodes.

Fig. 14. The dependence of the electrode capacitance on the granule location on the *x* axis. Diameter of the granule is 1mm, width of the electrodes is 1mm, distance between the electrodes is 5mm. Granule is at the center on the *y* axis

Experimental investigation of influence of amount of smaller granules on the transducer capacitance

A conclusion was proposed in the subsection 2.4 that the transducer capacitance depends on the amount of smaller granules in the flow of large granules; it is verified experimentally.

Comb-type electrodes are formed. Distance between the electrodes is 1mm. Other electrode dimensions are selected so that their capacitance would be equal.
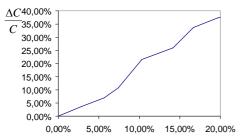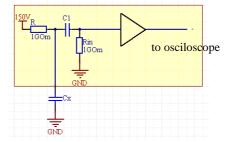

Fig. 15. Dependence of the electrode capacitance on the mass amount of the smaller granules in respect of the larger granules

Large granules with diameter of 3mm are poured onto the electrodes; their amount is sufficient to fill entire environment of the electrodes. Granules are distributed chaotically and not as during the modeling, when they were placed regularly one by the other. Then the known amount of the smaller (diameter 0.5mm) granules is poured

in, they are mixed in order for them to reach the bottom and the capacitance of the electrodes is measured. Results of the experiment are shown in Fig. 15. It is obvious from them, that the more of the smaller granules are present, the larger the transducer capacitance is. That proves the modeling results.

Shape of the pulse during granule roll through the slot transducer

The transducer is made from the copper plated textolite plate with dimensions of 20x50mm by forming 3 electrodes on its surface. One of them is not connected to anything and is used for the granule placement. If the granule was placed directly onto the electrode, the interfering pulse would be received. Transducer is connected to the scheme given in Fig. 16. Its output is connected to oscilloscope. It is used to observe the time variation of the capacitance (which is transformed to the voltage) during the granule roll between the electrodes.

Fig. 16. Scheme of capacitance transformation into voltage. C_x – transducer capacitance

Typical oscillogram is shown in Fig. 17. The higher transducer capacitance is, the less output voltage of the transformation scheme is obtained. The biggest capacitance is received during the fall of the granule into the slot. This moment is depicted in the oscillogram at the time $t=11$μs.
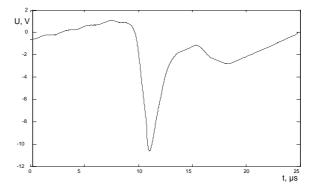

Fig. 17. Voltage variation during granule roll over the electrodes

Such transducer could be effective if the granule would roll over the surface of the electrodes. In most cases the granule bounces when it hits the surface irregularities or due to its imperfect round shape, and the less change of the capacitance is observed. Furthermore in many cases the granule gets electrified and two pulses are received – one when the granule reaches the first electrode and the second when it crosses the slot between the electrodes.

Shape of the pulse during fall of the granule through the standard transducer

Biggest problem of the applications of the slot transducers in granulometry is posed by the bouncy character of the granule roll instead of the perfect roll over the surface of the transducer and its electrification. These problems could be avoided if the type of the granule movement would be free-fall between two planar electrodes. Two electrodes of the size 4x10mm are formed. Gap between them is 4mm. Granule is thrown through this gap from the highest possible height. Measurements of the previous subsections are repeated, only in this case the granule is not rolled but released for free fall.
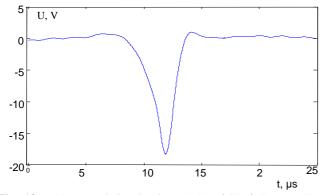

Fig. 18. Voltage variation in time during fall of the granule between the electrodes

Typical voltage variation in time is given in Fig. 18. In this signal the pulse is more obvious and the interfering pulses are weaker since the granule falls uniformly, does not bounce and does not get electrified. If the granule touches the electrodes during its fall, two pulses of almost equal shape are obtained. However the evaluation of the granule size is being complicated by the fact that the closer to the electrodes the granule flies, the higher amplitude of the pulse is; only it can be used to determine the granule diameter. Sharp ascending front of the voltage pulse is influenced by increasing velocity of the granule, which is determined by the free-fall acceleration.

Conclusions

1. When using "comb" type transducer it is possible to evaluate the thickness of the granule flow, if it consists of equal-sized granules. It is also possible to evaluate the size of the granules if the flow thickness remains constant.

2. Amount of small defective granules in the flow can be also assessed using "comb" type transducer. It is required that the flow thickness would be sufficient and the size of good granules would be similar.

3. It would not be possible to achieve high precision using such transducer since after the change of defective granules by 1% the transducer capacitance also changes by 1%. Such capacitance change can be also influenced by other factors, e.g. changes in granule composition, humidity.

4. Implementation of the slot and standard transducers is complicated by the requirements of system precision.

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3. **Augutis V., Styra D.** Analysis of Discrimination Threshold of Small Capacitance Measuring Chains // Measurements. Kaunas University of Technology. – 2005. – Vol. 33, No.1. – P. 36–39.

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Investigations of possible applications of capacitive transducers dedicated to the measuring of granule flow thicness, measurement of the size of individual granules for evaluation of amount of small defective granules in the flow are presented. Also possible construction of the electrodes is discussed, dependences of the transducer capacitance on the listed parameters are modeled. Presented experimental results are analogous to the results of the modeling. Ill. 18, bibl. 3 (in English; abstracts in English, Russian and Lithuanian).

В. Аугутис, В. Стадалюс. Емкостные преобразователи в гранулометрии // Электроника и электротехника. – Каунас: Технология, 2009. – № 3(91). – С. 21–26.

Представлены исследования емкостных преобразователей, предназначенных для измерения толщины потока гранул и величины отдельных гранул, а также оценки количества малых гранул в потоке. Представлены варианты конструкций электродов и соответствующие результаты моделирования. Эксперименты подтверждают правильность результатов расчетов и моделирования. Ил. 18. библ. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

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Pateikiami talpinių keitiklių, skirtų granulių srauto storiui ir atskirų granulių dydžiui matuoti bei mažų nekokybiškų granulių kiekiui sraute nustatyti, tyrimai. Aprašomi elektrodų konstrukcijos variantai ir modeliavimo rezultatai. Eksperimentiniai tyrimai patvirtina skaičiavimo ir modeliavimo rezultatų teisingumą. Il. 18, bibl. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).