OPTIMIZATION OF THE SIZES OF THE CYLINDRICAL MEASURING TRANSDUCER

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Abstract. In this paper, questions of determination of the sizes of electrodes of capacity measuring transducers depending on tolerated relative error of measurement are considered. Dependences of ways of laying of grain materials on their electrical conductance are analyzed. It is established that the problem of optimization can be solved by the determined and statistical methods. At the determined method, it is accepted that all particles of the contacting layer with an electrode of bulk materials are located in order. At the statistical technique, the arrangement of particles is accidental, submitting to any distribution law, for example, normal. The example of calculation of the sizes of electrodes, near-optimal determined, and static ways are shown.

Keywords: measuring device, area of electrodes, humidity, bulks, grain, laying form, tolerated reliable error, the determining method, the statistical technique, the equivalent scheme.

Introduction

When developing the measuring devices (MD) one of the main questions is the calculation of their sizes. At first, the area of MD electrodes depends on humidity, a form and particle sizes of the bulks (B), and their conductivity (EDS) and a way of particles laying in operating volume. Here, the EDS between particles and electrodes has a significant effect on the general EDS MD, its influence of subjects is more than the EDS of particles, their humidity, and the sizes is more [7,9,10].

The dimensions of the MD will be considered optimal if the change in the state of the contacting layer of the B with a constant method of laying does not lead to a change in its parameters by more than the permissible \( \delta_{\text{don}} \) value of the relative error of the MD, i.e.

\[
\delta_0 \leq \delta_{\text{don}}
\]

2. The determining method

With a determining approach, the area of the MD electrodes does not matter; therefore, the determining size will be at the distance between the electrodes.

Since we have developed a measuring transducer cuvette with a cylindrical shape, then according to [5] for a cylindrical capacitor the determining size \( Z_u \) will be as following

\[
Z_u = \frac{d_1}{2} \left( \sqrt{\frac{d_2}{d_1}} - 1 \right),
\]

where, \( d_1 \) and \( d_2 \) — respectively the diameters of the inner and outer electrodes.

In the general case, it can be assumed that the determining size of the MD is the averaged distance between the equipotential corresponding to 100 and 50% of the field strength since the zero equipotential has its own contacting layer.
Possible options of laying (placement) of the bulks in a ditch, for example, grain materials:

![Diagram 1](image1.png)

*Fig. 1. The maximum dense placement of soft granular (grain) elliptic materials at the vertical direction consolidation: a - horizontal placement; b - vertical placement.*

![Diagram 2](image2.png)

*Fig. 2. The maximum dense placement of soft granular (grain) elliptic materials at the horizontal direction consolidation: a - horizontal placement; b - vertical placement.*

![Diagram 3](image3.png)

*Fig. 3. Ways of particles contact - vertical consolidation.*

![Diagram 4](image4.png)

*Fig. 4. Equivalent circuit of a particles chain:*

\[ r \text{ - the particle resistance; } E \text{ - electrode; } Z_K \text{ - total resistance of the second (contact) zone of the particle; } Z_n \text{ - total resistance of the first zone (particle body); } Z_r \text{ - the total resistance of half of the second zone of the particle in contact with the electrode of the MD; } n \text{ - the ratio of the determining size to the particle diameter.} \]

Consider the limiting method of cellular packing of particles. Since we have developed a cylindrical ditch, grain materials are most of all placed on a cellular packing. For cellular packing, there are two most different ways of contact (Fig. 3, a, b). The replacement scheme for cellular packing can be represented in the form of Fig. 4.

It is obvious that for the first way of the contact shown in fig. 3, a, \( Z_r = \frac{Z_K}{2} \), for the second way of
laying shown in fig. 3, \( Z_r = Z_K \). Then relative error will be as following

\[
\delta_c = \pm \frac{n(Z_{II} + Z_K) + \frac{Z_K}{2} - n(Z_{II} + Z_K)}{2n(Z_{II} + Z_K)} = \pm \frac{Z_K}{4n(Z_{II} + Z_K)}
\]

At a low frequency, where the Q-factor of the B is many times less than 1, the capacitive conductance can be neglected and the impedance of the particle is approximately equal to \( Z_K \), and then

\[
\delta_{KH} \leq \pm \frac{1}{4n}
\]

At a high frequency, where the Q-factor of the B is greater than 1, the quantities \( Z_K \) and \( Z_{II} \) are usually of the same order of magnitude, but if \( Z_{II} \gg Z_K \) (for example, the gaps between the particles are filled with water), then

\[
\delta_{KB} \approx \pm \frac{Z_K}{4nZ_{II}}
\]

For cellular laying, two extreme cases are shown in Fig. 3, a, b. In the first case \( Z_r = Z_K / 2 \), in the second \( Z_r = Z_K \sqrt{3/2} \).

In accordance with expressions (1-3), we obtain the relative error \( \delta_c \) in general form

\[
\delta_c = \pm \frac{(\sqrt{6} - 1)Z_K}{4n(Z_{II} + Z_K)};
\]

At a low frequency

\[
\delta_{CH} \approx \pm \frac{(\sqrt{6} - 1)}{4n}
\]

and at high a frequency

\[
\delta_{CB} \approx \pm \frac{(\sqrt{6} - 1)Z_K}{4nZ_{II}}.
\]

3. The statistical method

We consider the arrangement of particles in the layer contacting an electrode accidental. If both extreme cases are equally probable, then at the infinitely big area of electrodes that is equivalent to an infinite number of experiments with each contacting group, the number of the particles contacting one way or another is almost constant and parameters of MD will not change from measurement to measurement.

With the actual dimensions of the electrodes, the MD parameters can change due to a change in the ratio between the contacting cases. In this case, with a decrease in the size of the MD, the ”weight” of each contacting group increases.

Let’s consider that the difference \( q \) of numbers of the groups contacting in the different ways submits to the normal distribution law, then the probability \( y(q) \) of emergence of this difference at the total number of the contacting groups \( m^2 \) can be determined on a formula of probability density function [6], and is set by the value of the reliability of results on the known average quadratic deviation \( \delta_o \), and tolerated relative error \( \delta_o \), it is possible to define Student's coefficient

\[
t_a = \frac{\delta_o}{\Delta S},
\]

on which value (the number of the contacting groups – as the number of experiments) is determined by the
known tables. At the same time as average square deviation accept the following value as for a series of measurements.

$$\Delta S = \frac{\delta}{m}$$

(8)

Thus, in this case, it is advisable to determine the dimensions of the MD electrodes by the method of successive approximations, first setting certain dimensions and checking whether the resulting error at a given confidence interval fits within the specified limits.

Being set by the area of a smaller electrode of MD at cellular laying, the number $m^2$ can be determined by the following ratio according to [6,8,11]:

$$m^2 = \frac{S}{6r^2}.$$  

(9)

Example 1.

Let us calculate the size of the electrodes for cellular laying using the determined method. The calculation is carried out for an acceptable error of ± 1%. Then, for materials with a low figure of merit, the determining size for cellular laying will be $Z^C = 72.2r$ accordingly.

Taking the radius of the particles $r = 2$ mm, we get for the cylindrical MD, taking the inner electrode $d_1 = 40r = 80$ mm, we get the diameter of the outer electrode $d_2^C = 980$ mm and $d_2^C = 1700$ mm.

Example 2.

Let’s carry out the calculation of the size of electrodes for cellular laying when using a static approach.

We set a tolerated relative error of $\delta_o \pm 1\%$. For the radius of a particle $r = 2$ mm, we will put $m^2 = 100$ (i.e. at cellular laying of particles $S^C = 2400$mm$^2$, for example, 60x40 mm), reliability coefficient is $\alpha = 0.99$, Student's coefficient is $t_a = 2.63$. At the same time, the value should not exceed

$$\Delta S \leq \frac{\delta_0}{t_a} = \frac{0.01}{2.63} = 0.0038,$$

(10)

hence, $\delta_o \leq 0.038$.

Then for B with a low Q factor and $d_1^x = 80$ mm we get

$$Z^C \approx 19r \quad d^C \approx 76 \text{ mm} \quad d_2^C \approx 380 \text{ mm}$$

For B with a high Q factor, counting $Z_{\mu} = 2Z_{\mu}$, we get

$$Z^C \approx 6.33r \quad d^C \approx 12.67 \text{ mm} \quad d_2^C \approx 138 \text{ mm}$$

Therefore, given the admissible error of the MD and the parameters of the particles, it is possible to determine the dimensions of the electrodes.

If the dimensions are set from other considerations, then by solving the inverse problem, it is possible to determine the MD error.

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