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IMPROVING THE METROLOGICAL CHARACTERISTICS OF THE SYSTEM FOR MEASURING AND MONITORING THE PARAMETERS OF THE ELECTROSTATIC FIELD

УЛУЧШЕНИЕ МЕТРОЛОГИЧЕСКИХ ХАРАКТЕРИСТИК СИСТЕМЫ ИЗМЕРЕНИЯ И КОНТРОЛЯ ПАРАМЕТРОВ ЭЛЕКТРОСТАТИЧЕСКОГО ПОЛЯ

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Abstract: The work is devoted to the problem of controlling our environment, which is relevant for modern society. As a component of the environment, we are more interested in electric fields, the effect of tension on the environment, functional changes (of the nervous system, cardiovascular) of the human body. This makes it possible to identify the permissible levels of field strength, operating time in such fields. In some cases, for example, in production and transport, increased values of the electric field strength can lead to catastrophic consequences when working with flammable liquids, explosive mixtures, dust in ventilation systems. This imposes very stringent requirements for controlling the level of tension. Exposure of a stationary measuring plate, lines of force and a moving ground shield is considered a measurement method, which allows the measurement of the potential difference. The main result of the work is a model, algorithm and technique for changing the potential gradient, with alternating, imitation exposure and shielding from the lines of force of the dynamic field and analysis of the effect of the signal electrode on the output signal. Corresponding experiments were carried out using quadratic approximation and harmonic analysis (using the Mathcad package). The structural and functional diagram of the microcontroller device has been developed.

Key words: measuring system, electrostatic field, impact, control of parameters.

Аннотация: Работа посвящена актуальной для современного общества проблеме контроля окружающей нас среды. В качестве составляющей среды нас интересует больше электрические поля, воздействие напряженности на среду, функциональные изменения (нервной системы, сердечно-сосудистой) организма человека. Это позволит идентифицировать допустимые уровни напряженности поля, времени работы в таких полях. В ряде случаев, например на производстве и на транспорте повышенные значения напряженности электрического поля могут привести к катастрофическим последствиям при работе с легковоспламеняющимися жидкостями, взрывоопасными смесями, пылью в системах вентиляции. Это накладывает весьма жесткие требования по контролю за уровнем напряженности. В качестве метода измерения рассматривается экспонирование неподвижной измерительной пластины, силовых линий и движущегося заземленного экрана, что позволяет измерять разность потенциалов. Основной результат работы – модель, алгоритм и методика изменений градиента потенциала, с попеременным, имитационным экспонированием и экранированием от силовых линий динамичного поля и анализ влияния сигнального электрода на выходной сигнал.

Проведены соответствующие эксперименты с использованием квадратичной аппроксимации и гармонического анализа (пакетом Mathcad). Разработана структурно-функциональная схема микроконтроллерного устройства.

Ключевые слова: измерительная система, электростатическое поле, воздействие, контроль параметров.

Introduction

One of the most important tasks of modern society is to control the environment and maintain it in proper condition. The electric field is one of the important parameters characterizing its state. As a controllable parameter, we will consider the electric field strength.

An electric field of great intensity is harmful to humans. With a prolonged stay of a person in such a field, functional changes are observed in the central nervous, cardiovascular and other systems; this is also studied in secondary medical schools (Klyachkin, Vinogradova, 1998).

Permissible levels of electric field strength are established by SanPiN. The task of measuring and monitoring the level of electric field strength in workplaces or dwellings (Gubernskiy, Goshin, et-al 2016) is very relevant today.

Theoretical foundations and literary analysis

In the post-industrial society, a lot of attention is paid to protecting a person from dangerous fields (Grachev, Myrova, 2005). The permissible levels of field strength depend on the electromagnetic compatibility in the environment (Volodina, Karjakin, 2007), the time spent at the workplace (Hygienic requirements, 2003) and are determined by electromagnetic radiation (Titov, 2014).

Natural sources of electromagnetic fields are electrostatic and wave (generated) effects (Titov, 2014) [7]. Many works are devoted to the study of the effect of fields (Oreshina, Savenko, 2021; Edemskiy, Savenko, 2009; Edemskiy, 2019).

Methodology

The measurement method is based on the use of a fixed measuring plate, which is alternately exposed and shielded from the lines of force of the earth's field by a moving grounded shield. The plate is connected to ground through a resistance and capacitance in parallel. The current flowing through them causes the appearance of a potential difference, which is amplified by a selective amplifier tuned to the frequency of the shield movement, and then rectified and measured.

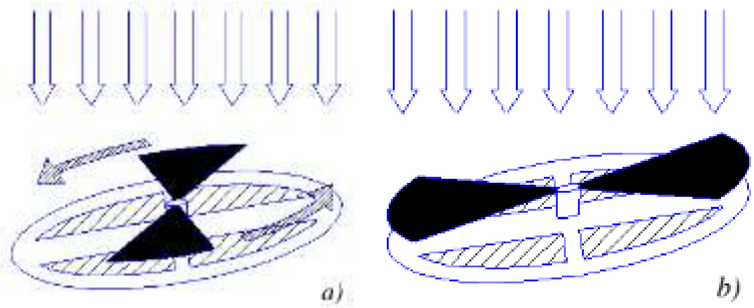

Figure 1. Method for measuring the electric field by rotating the shield relative to a stationary measuring plate

The use of conventional electrostatic devices for measuring very rapid changes in the potential gradient (Skvortsov, 2019) is difficult, since the measuring plate is shielded for half the time of each cycle. To avoid this, the measuring plate in the developed device, according to Figure 1, must be divided into two rows of sectors, which are shielded alternately.

The essence of the principle is as follows: lines of force with an electric field strength *E* act on a horizontal plate with an area S.

$$q = \varepsilon_0 \cdot \mathrm{E} \cdot S_{(t)} ;$$

Differentiating the charge function on time, the value of the ion current *i* on this plate is

$$i = \frac{d}{dt}\oint \varepsilon_0 \mathrm{E} dS$$
,

where i is the electric current (A); *E* is the intensity of the electrostatic field (В/м); ε_0 is electric constant

$$\varepsilon_0 = 8{,}85 \cdot 10^{-12} \frac{Кл^2}{Н \cdot м^2} = 8{,}85 \cdot 10^{-12} \frac{Ф}{м},$$

S is area of a fixed measuring plate, unshielded at a given time by a shield.

Alternately exposed and shielded from the lines of force of the earth's field by a moving grounded shield, the electric current acting on the open part of the plate is calculated by the following formula:

$$i = \frac{d}{dt}\oint_{S_o} \varepsilon_0 \cdot \mathrm{E} \cdot dS_o.$$

As a result of differentiating the expression, we get:

$$i = \varepsilon_0 \cdot \mathrm{E} \cdot \frac{dS_o}{dt}$$

Since the differential of the area of the open electrode over time in the expression is a value directly proportional to the number of revolutions of the shield. Thus, the electric current is a function of the speed.

Then we determine the influence of the shape of the signal electrode on the output signal. The signal electrode is shown in Figure 2.

R is electrode radius

a is distance to center

R1 is radius of the circle

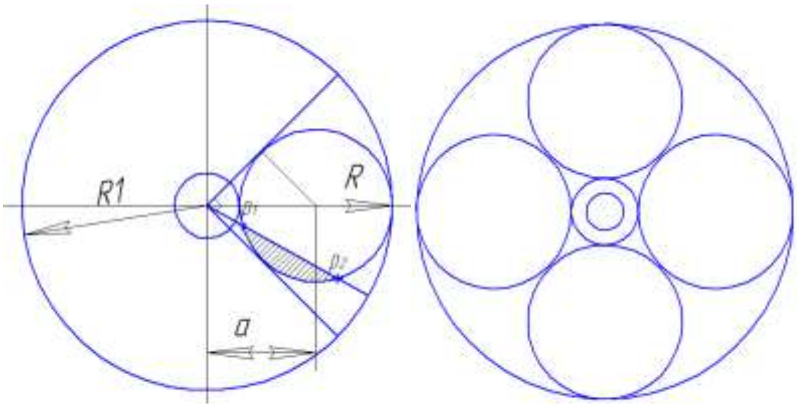

Figure 2

Find the area of the shaded area. It can be found by a double integral (for example, (Kaziev, 2007). Let us write down the electrode equation and find the differential of this expression:

$$\frac{dS}{dt} = 2 \cdot \sqrt{2} \cdot R^2 \cdot \cos\varphi \cdot \sqrt{\cos^2\varphi - \sin^2\varphi} \qquad \varphi = \omega \cdot t$$

$$\frac{dS}{dt} = 2 \cdot \sqrt{2} \cdot R^2 \cdot \omega \cdot \cos(\omega \cdot t) \cdot \sqrt{\cos^2(\omega \cdot t) - \sin^2(\omega \cdot t)}$$

$$\omega \cdot t \in \left[-45^\circ : 45^\circ\right],$$

or

$$\omega \cdot t \in \left[-\frac{\pi}{4} : +\frac{\pi}{4} \right],$$

$2 \cdot \sqrt{2} \cdot R^2 \cdot \omega$ is constant part, then it can be written

$$\frac{dS}{dt} = \cos(\varphi) \cdot \sqrt{\cos^2(\varphi) - \sin^2(\varphi)} =$$
$$= \cos(\varphi) \cdot \sqrt{2 \cdot \cos^2(\varphi) - 1}$$

Using the obtained expression, it is possible to build a graph of this function, draw a trend line for this graph. For an adequate description, a second-order polynomial (i.e., a parabola) was chosen as a mathematical model (Beyer, Boeck, Möller, et-al 1989).

The type and type of radiation from technical devices is also significant (Aleksandrov, Ostapenko, Gentosh, 2014).

Results and discussion

The results of the experiment and simulation are shown in Figure 3:

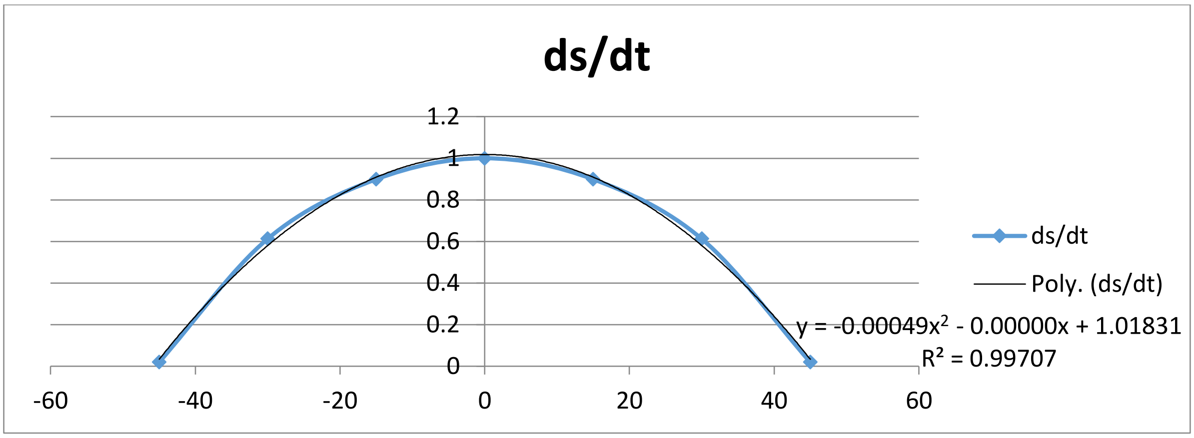

Figure 3. Results of experimental research and modeling

The parabola equation is shown in the graph. The value of the validity of the approximation was 0.997.

Further, with respect to the proposed model, a harmonic analysis was carried out (Skrebkova, Skrebkov, 2019) in the Mathcad package (Shtykov, 2013):

$$y(x) := -0.00049 \cdot x^2 + 1.018$$

$$A1 := \frac{2}{\pi} \cdot \int_{\frac{-\pi}{4}}^{\frac{\pi}{4}} y(x) \cdot \cos(1 \cdot x)\, dx = 0.916$$

$$A2 := \frac{2}{\pi} \cdot \int_{\frac{-\pi}{4}}^{\frac{\pi}{4}} y(x) \cdot \cos(2 \cdot x)\, dx = 0.648$$

$$A3 := \frac{2}{\pi} \cdot \int_{\frac{-\pi}{4}}^{\frac{\pi}{4}} y(x) \cdot \cos(3 \cdot x)\, dx = 6.125 \times 10^{-5}$$

Other packages are also applicable, for example, Maple (Dyakonov, 2011).

It can be seen from the calculations that the amplitude of the third harmonic is negligible, which makes it possible for further processing to use the algorithm of a linear rather than an rms Root Mean Square (RMS) transformation, i.e. minimize third harmonic interference.

According to the proposed algorithm, the development of the structural and functional diagrams of the device was carried out.

The technique for measuring the parameters of the electric field is based on the electrostatic effect. With the help of current meters, implemented on operational amplifiers, informative sinusoidal signals are removed from two electrodes (Ugolnikov, 2019). These signals, having a phase shift of 180 degrees, are fed to the ADC and then to the calculator-microcontroller. A pulse signal from an optical fiber pair with an open optical channel is used as a reference signal for phase detection of signals in a computer and is simultaneously used to control the operation of a microelectric motor, stabilizing its rotation frequency (Makoveev, Berdnikov, 2019). From the output of the microcontroller, the informative signal is sent to the information display device.

The functional diagram of the IMS (Information and measuring systems) is shown in the figure below.

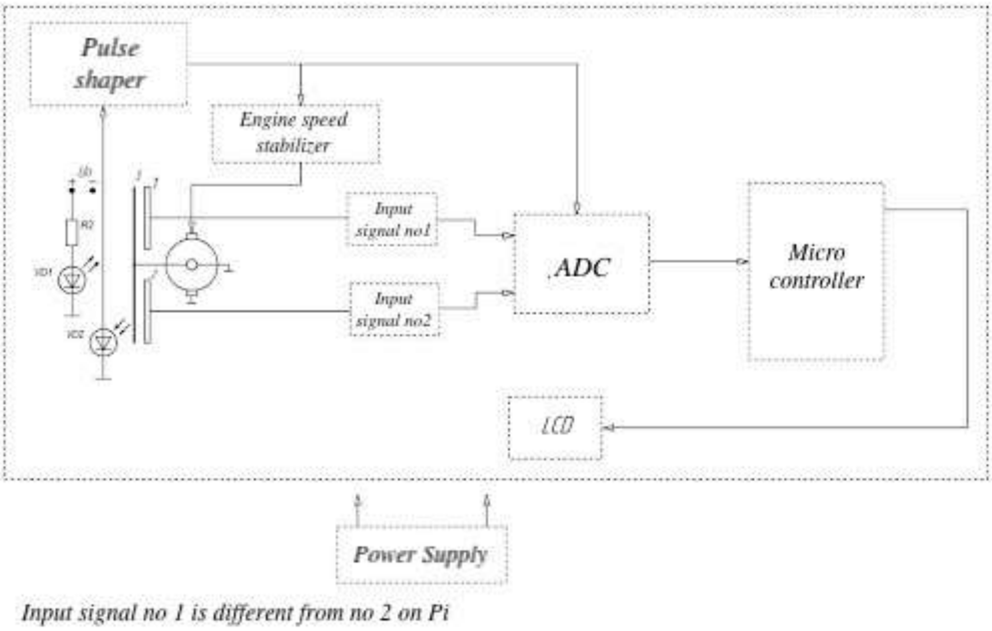

Figure 4. IIS functional diagram

The considered approach will make it possible to estimate, as in (Gubernsky, Goshin, Kalinina, et-al 2016), the levels of exposure to electric fields in the office environment.

Conclusion

Thus, this device makes it possible to control the electric field strength with increased speed, while the accuracy of the analysis is increased due to the use of an electrode of a certain shape in the device and the practical absence of interference from the third harmonic. When using a precision ADC, the measurement path error will depend only on the electrode configuration.

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