Wire-free method of measurements of weak electrostatic values under stationary and dynamic conditions

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Abstract. Usage of a developed and updated electrometer (EM) allows one, first, to obtain new information on physical properties of materials (glasses and other solids) as well as on the manifestation of the properties in the field of mechanical forces. Second, the applicational significance of such researches could be also important when designing new nondestructive methods of material defects controlling and procedures of their removal. The EM is up to measure both slowly and rapidly varying electric potentials at some distance from a target. EM allows one measure relaxation times of charges in dielectrics, which do not exceed the time constant of discharge time of the amplifier under stationary conditions. Owing to the developed scheme of the EM input circuit, the input capacity of amplifier was decreased with a corresponded increase of its sensitivity.

1. Introduction

With the appearance of chemical fibrous materials and the ever-increasing household and engineering application of plastics, the processes of their electrostatic charging with relevant technological problems and dangers become increasingly important. The charge separation arises, for example, during a paper tape travelling along rolls in fabric industry, in rotary printing machines, in moviemaking, in production of fibrous glass, in liquid flowing through a pipe when filling aircraft fuel tanks and plastic petrol cans, in dust whirls, when splashing aerosols, etc. Nature of electrostatic phenomena is very divers and is not fully cleared up. A prerequisite for suppressing the electrostatic charges formation as well as for designing remedies for their disposal are the measurement instrumentation and methods that provide good reproduction of controlled values and would capable to assess the efficiency of introduced measures. As well as when measuring partial charges, the using of complicated and expensive devices does not ensure the correct results of measurements. The developed EM [1, 2] differs substantially from other similar devices [3,4,5,7]. Its advantages include the compactness, optimal (cylinder) shape, existence of a probe, and a higher sensitivity.

2. Scheme and construction of electrometer

Basing on considered EM described in works [6, 8, 9, 10] a new EM scheme was developed and updated (figure 1).

A distinguishing feature of this scheme is the application of a differential stage at the EM input consisting of two symmetric field - effect transistors T₁ and T₂ with an insulated gate. The T₂ transistor is put into the circuit with the reverse feedback of an operational amplifier erected at A₁.
microchip. Such positioning of field-effect transistors assured the stable EM operation under open $T_1$ gate.

At the second stage erected at $A_2$ microchip, the voltage-sensitive control of the amplifier is performed. The third stage erected at $A_3$ together with a voltage repeater serves for matching with EM loads. Noteworthy, the described above amplifier is noninvertible.

**Figure 1.** Principal diagram of updated electrometric amplifier with differential stage.

Another feature of this EM scheme is the provided functional contact (“K”) at the input of EM, which is connected with its body. This feature assures the switching on of the EM input when being the contact (“K”) at the distance of 5 mm from $T_1$ gate as well as the protection of the EM input from occasional static electricity in disable condition when contact “K” being disconnected from $T_1$ gate. The carried-out test survey showed that when using MT-1 micro switches or relay of zirconia type, there appear parasitic capacities and resistors as well as leakages, which lead to sensitivity breakdown and to the increase of amplifier noise. The EM circuit (radio centers) wiring was performed on a teflon plate. Such choice of material assures the excluding of current leakage, because this material has high resistivity and low wetting ability, which impede appearance of a condensate film on the surface.

A whole structural section of the EM body was manufactured from (nonmagnetic) yellow metal. The EM body was shaped to cylinder (figure 2).

**Figure 2.** Body structure of EM amplifier.

Forward (3) and rear (4) heads of the body (1) are connected by guide stems (2), in which teflon plates (9) are embedded with the EM circuit wiring are embedded. On the forward head (3), a probe construction is fixed (5-8). It contains a shielded flat probe (7) (thin silver disc of 3 mm in diameter) connected with the circuit through a silver wire that pass through teflon insulators (8) along the screen (5). The screen consists of immovable (5) and movable (6) parts equipped with a fine adjusting screw. A position of the latter one can be adjusted with a rotation of the immovable part of the screen (6) relatively the probe (7). A rod (10) serves for performing the mechanical contact of the EM input with its body. Thorough displacement of the rod is performed by outside tubes (11) embedded into teflon plates (9). Rod (10) and tubes (11) are interconnected by a brassy...
wire (12) inside the EM body. EM receives the power supply from a stabilized bipolar source of ± 12 V. The output EM signal to the recording devices is transmitted by a coaxial cable.

3. Parameters of electrometer
The mode of operation of the above - described EM is similar to that of the computer presented in [7,8]. However, it can be believed that some radio - technical parameters might have variations owing to differences in input circuits. Therefore, there required an establishing of the most important parameters, such as the input capacity and resistance, time constant, service band, sensitivity, etc.

Knowledge about these parameters is important for the EM quantitative estimations. A scheme shown in figure 3 (a) was used for determining the radio-technical parameters as well as for EM calibrating.

A sinusoidal signal of frequency f with a constant amplitude was applied to generator (4). The signal was controlled by the oscilloscope ASC-3601 (5). The prove (1, 2) and EM were shielded.

![Scheme used for determining the radio-technical parameters for EM calibrating](image)

**Figure 3.** Scheme used for determining the radio-technical parameters for EM calibrating; probe (1, 2); shield (3); generator S-74 (4); digital oscilloscope ASK-3601 (5).

A clearance d is shown in figure 3a. Using a fine-adjusting screw, the probe (6) was approached to EM and fixed at distance of d (figure 4). In such a way, a shielded parallel-sided capacitor C = ε ε₀ S / d was created. (figure 3a); its capacity was as follows: where S is the area of charge plates; ε₀ = 8.85·10⁻¹² Ф/м is the electric constant; ε is the dielectric constant (for air ε = 1); d is the distance between charge plates (or between proves. In our case, the most important parameter is the d distance (d = 0.2 - 3.0 mm), which should be established with accuracy of 0.05 мм and be controlled by the laser (figure 4 b (5)).
Figure 4. a – A general view of the experimental equipment; b – scheme of distance control between EM (1) and sample; stand (2); sample (3); fine-adjusting screw (4); optical laser (5); probe (6).

Figure 5 shows the EM amplitude-frequency response (AFR) after upgrading; for electrometrical parameters. One can see in Figure 5 that the EM service band covers a range of $10^{-5}$ to $10^5$ Hz (curve 1), which corresponds to AFR (curve 2) obtained under a direct contact of the generator G-74 output (figure 3a) with the EM input in accordance to a scheme shown in figure 3b.

Figure 5. EM amplitude-frequency response after upgrading.

All experiments on determining EM parameters and calibration were carried out under normal conditions ($t = 24 ^\circ C$, relative humidity of 45 %).

4. Discussion

So, the following technical specifications for the given EM were established experimentally under normal environment conditions:

- $C \text{in}$ is the input capacity of $(4 \pm 0.5) \times 10^{-12} \Phi$;
- $R \text{in}$ is the input resistance of $(5 \pm 2.0) \times 10^{15} \Omega$;
- $\tau$ is the time constant of discharge of the input circuit of $(2 \pm 1.0) \times 10^4$ s;
- $L$ is the frequency service band of $10^{-5}$ to $10^5$ Hz;
- $A$ is the sensitivity of $(4 \pm 1.2) \times 10^{15} \text{ C }/\text{ mV}$;
- $f$ is the limit of measurements of
potential $\phi$ value; $\phi = q / C_{in}$; where $q$ value is estimated from relation (1) or through EM sensitivity.

So far as the established EM sensitivity is in good agreement with the relation (1), we obtain: $\phi = K^{-1} U_{out}$ where $\phi^{\max} = 7 \times 10^3$ mV when $K = 1$, $\phi^{\min} = 0.05$ mV; $U_{drift}$ is the drift of zero level, which is equal to $\pm (15 \pm 3)$ mV / h ($\phi = 3 \times 10^3$ mV / s).

Issuing from the given technical specifications, one can conclude that the developed and upgraded EM allows one to measure in contact-free mode both “slowly” and “rapidly” varying electric potentials (EF) at some distance from a target.

One should note that owing to developed by scheme of the EM input circuit, the input capacity of amplifier was decreased with the corresponded increase of its sensitivity. Its value is two orders of value higher than that in EM [7], and an order of value higher than sensitivity in EM [8].

Some parameters of the given EM, such as $R_{in}$, $T_r$, $f_{oper}$, do not differ from similar parameters of EM [7, 8]. Thus, the developed and upgraded EM allows one to measure in contact-free mode both slowly and rapidly varying parameters of the EF as evidenced by its frequency service band. In addition, the EM allows one to measure relaxation times of charges in dielectrics, which do not exceed the time constant of discharge time $T_{dis}$ of the amplifier under stationary conditions [9,10]. Correspondingly, the time of zero level of the EM output does not exceed 15 mV / h.

5. Conclusion
The developed and upgraded EM is capable to perform the contact-free scanning and measure the EF potential of dielectric surface without distortion of signal waveform under condition of respecting constant clearance between the probe and sample [11].

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