Non-contact surface charge/voltage measurements

Fieldmeter and voltmeter methods

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Abstract Methods of measurements of surface electric charges and potentials using electrostatic fieldmeters and voltmeters are discussed. The differences and similarities between those methods are presented. The AC-feedback voltmeter is also described as an unique method that combines advantages of both fieldmeters and voltmeters.

1 Introduction

There is a broad variety of instruments that can measure an electric charge and/or voltage on a dielectric or conducting surface. Electrostatic fieldmeters and voltmeters belong to the category of the most popular devices. This paper focuses particularly on the differences and similarities between electrostatic voltmeter and electrostatic fieldmeter methods. Both measurement techniques come with many variations due to an extraordinary effort put into developing of low-cost, accurate devices [1–10]. Which method is better? Hopefully, the answer can be found in this application note.
In order to make the comparison easier, consider a voltmeter and a fieldmeter, both using the Kelvin vibrating capacitive sensor as the detecting element. Assume that the sensor and the surface under test can be modelled as a parallel-plate capacitor. In this configuration an electric current I is being induced in the sinusoidally vibrating sensor [11, 12]. This current is proportional to the value of the electric potential present on the surface under test [12]:

$$\begin{aligned} I &= U \cdot \frac{dC}{dt} \\ &= U \cdot \frac{d}{dt}\left(\frac{\epsilon\epsilon_0 A}{D_0 + D_1 \cdot \sin(\omega t)}\right) = \\ &= -U \cdot \epsilon\epsilon_0 A \cdot \frac{D_1 \omega \cos(\omega t)}{[D_0 + D_1 \sin(\omega t)]^2} \qquad (1) \end{aligned}$$

U is the difference of potentials between the tested surface and the vibrating probe, [V],

D_0 is a constant representing the separation between electrode and the tested surface when the electrode is not vibrating, [m],

D_1 is the amplitude of vibrations, [m],

ω is the circular frequency of vibrations, $\omega = 2\pi f$ [rad/s], where f is a frequency in [Hz],

A is the surface area of the sensing electrode, [m^2],

ϵ is the relative electric permittivity of the material between the electrode and the surface under test, $\epsilon \approx 1$ for air,

ϵ_0 is the electric permittivity of vacuum, $\epsilon = 8.85 \cdot 10^{-12}$ [F/m].

The current signal I is amplified and demodulated using a phase-sensitive demodulator circuit (Figures 1 and 2) to produce a voltage V_p directly proportional to the amplitude of the current. Electrostatic voltmeters and fieldmeters utilize this method of detecting and conditioning of the signal. The difference is in the way the processed signal V_p is utilized.

2 Electrostatic fieldmeters

Figure 1 presents an electrostatic fieldmeter. A fraction of the detected and processed voltage V_p is inverted and fed back to a screening electrode. At this point the sensing electrode is influenced by two electric fields: one created by the tested surface and one generated by the screen. Therefore, the greater the surface voltage, the greater the inverted voltage on the screen. Fields created by these two voltages cancel each other. Potentiometer P is used to establish a constant ratio between V_s and the measured voltage V_p. When

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the sum of the two fields equals zero, the stability of the signal detected by the vibrating sensor is greatly enhanced. However, the potential difference between the surface and the sensor can lead to the discharge and damage of the equipment if spacing D_0 becomes too small. The value of measured V_s is also sensitive to the changes of the distance D_0.

3 Electrostatic voltmeters

An example of the electrostatic voltmeter circuit is shown in Figure 2. In this voltage-following device the output of the integrator drives a high voltage amplifier circuit to replicate the voltage on the tested surface. The amplified voltage is then applied to the sensor thus nullifying the electric field between the tested surface and the sensing electrode. Potential on the electrode "follows" the potential on the surface. In this case there is no threat of the eventual discharge between the probe and the surface under test, even at close spacing. This ability of following the voltage makes the electrostatic voltmeter measurement independent of the distance D_0 - at least within a certain range of D_0. If the span between the surface and sensor is too big, the probe becomes influenced by other electric fields present in the vicinity.

4 AC-feedback voltmeter

The AC-feedback voltmeter uses a different technique to achieve spacing independent surface voltage/charge measurements [6]. Rather than cancelling the Kelvin current I by use of a feedback DC voltage which follows the surface test voltage to produce zero electric field, the AC feedback method utilizes a nullifying current I' to zero the Kelvin current I. The current I' is produced by external generator circuit tuned to the frequency of the Kelvin sensor oscillations:

$$I' = C \cdot \frac{dV_t}{dt} \qquad (2)$$

Therefore, when currents I and I' cancel each other,

$$\begin{aligned} I' &= I \\ U \cdot \frac{dC}{dt} &= C \cdot \frac{dV_t}{dt} \end{aligned} \qquad (3)$$

As both I and I' currents are inversely proportional to spacing D_0, the ratio of the amplitude of V_t to U (the DC test surface voltage) remains constant over the large range of D_0. As shown in Figure 3, the V_t signal is obtained by amplification of the current I converted to a voltage at the preamplifier. At high gain the current I is being cancelled to a very small value.

5 Summary

Figure 4 presents a comparison of measurement errors for a standard fieldmeter and the Trek model 520 electrostatic voltmeter. The data indicate that it is important to keep the appropriate spacing between the fieldmeter sensor and the tested surface in order to consider the measurement reliable. Table shows a brief comparison between fieldmeter, electrostatic voltmeter and AC-feedback electrostatic voltmeter. Because of their principle of operation, the electrostatic fieldmeters are suitable for measurements conducted on relatively large areas. They are also not as accurate as electrostatic voltmeters. Since the results provided by the fieldmeters depend strongly on the probe-to-surface distance D_0, it is more convenient to read them as the electric field intensity values (thus the name, fieldmeter). Magnitude of fields measured this way is usually high, therefore there is a risk of discharges between the probe and the tested surface. Fieldmeters are less expensive than electrostatic voltmeters, since they do not require high voltage circuitry to produce proper feedback to the sensor. There are also

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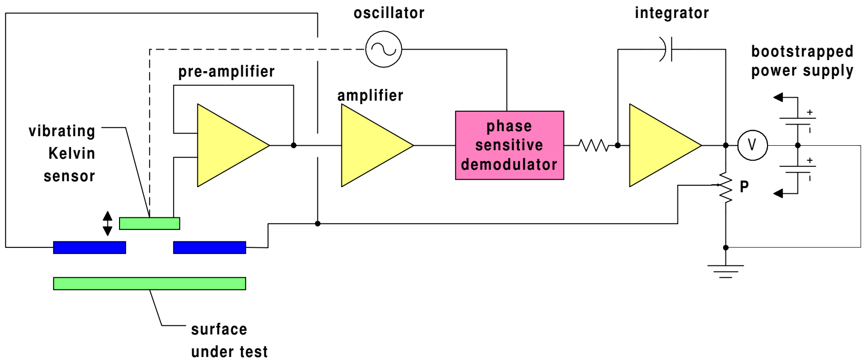

Figure 1: Electrostatic fieldmeter [13].

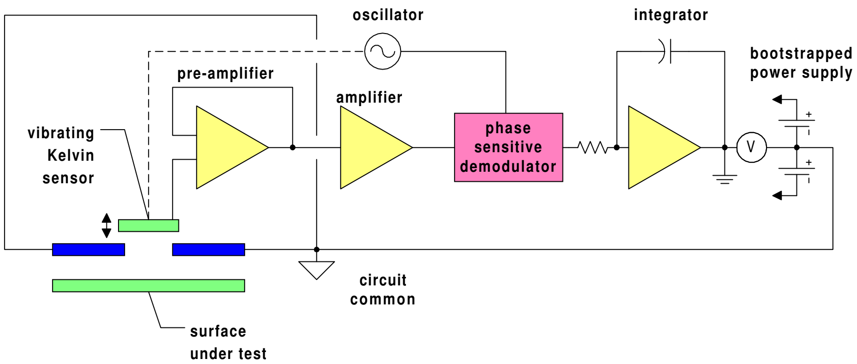

Figure 2: Electrostatic voltmeter (voltage follower) [13].

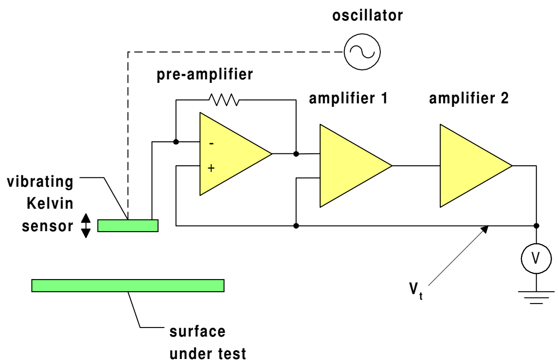

Figure 3: AC-feedback electrostatic voltmeter [6, 10].

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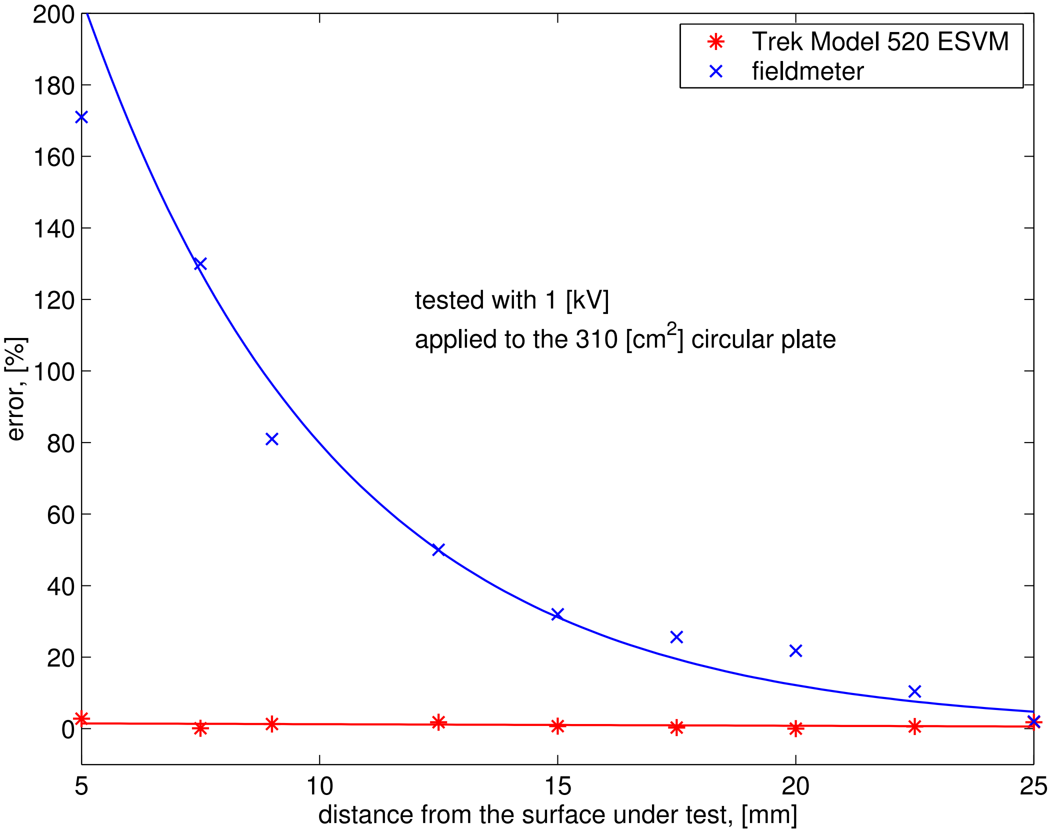

Figure 4: Comparison test between electrostatic voltmeter and fieldmeter.

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other types of fieldmeters available, for example radioactive fieldmeters, rotating vane units. Even though their construction and principle of operation are relatively simple, they suffer from disadvantages such as presence of the radioactive material, poor accuracy and high power consumption by the drive motor of the rotating vane device.
Electrostatic voltmeters, particularly the voltage followers, can be employed for tests of relatively small charged areas - they have much better resolution than fieldmeters. Voltmeters are also very accurate over a certain range of distances D_0. Since the potential on the sensor during the measurement is theoretically equal to the potential of the tested surface, there is no hazard of discharge. However, the person conducting measurement has to be aware of the high voltage present on the probe and proceed with caution.
AC-feedback voltmeter is a low-cost alternative for the voltage follower type voltmeter. It does not have high voltage circuitry and is accurate within a certain specified range of distances D_0. For example Trek's model 520 holds the 5% accuracy over the distance between 3 and 30 [mm] [10, 14]. There is a risk of discharges between the probe and the tested surface, so the resolution of the AC-feedback voltmeter is limited by the distance D_0. Table 1 summarizes features and disadvantages of the electrostatic fieldmeters and DC and AC-feedback voltmeters.

	Electrostatic fieldmeter	DC-feedback ESVM	AC-feedback ESVM
general recommendation	for tests of large surfaces	large and small surfaces	large and small surfaces
measured variable	electric field intensity	voltage	voltage
cost	low	high	medium
spatial resolution	poor	very good	good
accuracy	good at the large probe-to-surface distance	excellent at the small probe-to-surface distance	very good within the specified probe-to-surface distance
probe potential	ground (possibility of arcing)	potential of the tested surface	ground (possibility of arcing)
distance independent	no	within a certain, specified range (depends on the probe type)	within a broad range (depends on the probe type)

Table 1: Overview of features

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