Uncertainty of potential measurements of Q-constant objects

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Abstract. Direct and compensating methods of non-contact potential measurements on constant charge objects are distinguished and discussed in the paper. It is well known that in case of potential measurements using direct method the measured voltage value is lower in comparison to that in a non disturbed state. However in case of application of a compensating method, values of measured potential are higher. It is shown that in both of discussed cases approaching of the conducting object by the particular voltmeter (probe) leads to changes of the total capacitance of the object. Approximated relations for estimation of relative error of potential measurements for both of distinguished groups of methods were also given.

1. Introduction

Description of a particular object or an environment from the point of view of electrical field distribution may require field or potential measurements of the particular charged objects which creats the field. Contactless potential probes (voltmeters) are usually applied for potential measurements of extremely high resistance objects [1-7]. All of the methods applied for non-contact potential measurements can be divided into two basic groups, namely "direct" and "compensation" methods. In the case of direct methods the measured quantity (potential or field intensity) is derived and determined directly from the values of "other quantities" unequivocally related to the field intensity in the vicinity of the investigated object. "Other quantities" could be considered as: force (electrostatic voltmeters), current (radio-active or ion-path field-meters); electric charge induced on the measuring electrode (induction methods) or changes in the refractive index (Kerr or Pockel's electro-optic phenomena). Each of the mentioned variants of the "direct" methods may be used in a compensation system – with an automatic or hand-driven setting of the compensation state [5]. It is generally established that approaching of an investigated object with any earthed meter may change its potential trough its additional capacitive loading (increase the effective capacitance) [2, 3, 6]. This phenomenon leads to reduction of the potential of the investigated object (when conducting) or to a local potential reduction in case of weakly conducting or insulating objects [e.g. 6] in comparison to the values expected in a non disturbed state.

Compensating voltmeters also change the field distribution in the vicinity of an investigated object and, finally, may influence both, its effective capacitance and potential. The last may be of special importance in case of low capacitance objects as well as during potential measurements on 3D dielectric objects [5].

2. Potential measurements using direct method

An insulated conducting object with constant charge Q, total own capacitance to the earthed surrounding C_O and potential U will be considered. In case of potential measurements with a non-contact method, e.g.

using an earthed field meter FM, the electric field E is disturbed mainly in the space between the field-meter and the investigated object. The space is limited by a surface S_F as shown in Fig. 1. Due to additional capacitance C_M , introduced by the field-meter, the measured potential of the object will be decreased to U_D value given by:

$$U_D = U \frac{C_O}{C_O + C_M} \tag{1}$$

The equivalent capacitance of the object C_{ED} will be determined by the formula:

$$C_{ED} = C_O + C_M \ . \tag{2}$$

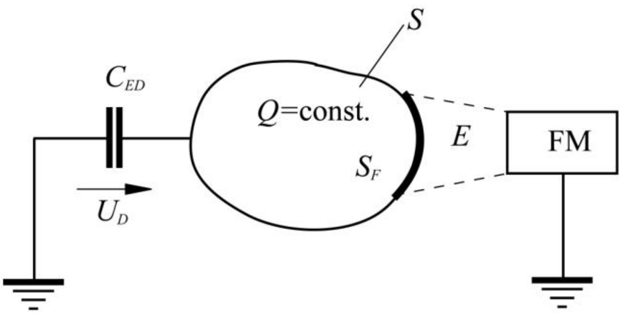

Figure 1. Potential measurements using non-contact direct method. FM – field meter.

Error ΔU_D and relative error δU_D values of potential measurement for direct method are determined by equations, respectively:

$$\Delta U_D = U_D - U \tag{3}$$

$$\delta U_D = -\frac{\Delta U_D}{U} = -\frac{C_M}{C_O + C_M} \tag{4}$$

Assuming, that the capacitance C_M can be approximated by a mutual meter-object capacitance, its value can be determined from the approximated relation [1]:

$$C_M \approx \frac{\varepsilon_0 S_F}{l} \tag{5}$$

where ε_0 - electrical permittivity of a free space, S_F - surface determining space of the field distortion, assumed to be equal to the "sensitive surface" (sensitive aperture) of the meter (probe), l – object-meter distance average value (in the space limited by a surface S_F). Generally the range of C_M variability is from 0 to infinity. C_M capacitance is equal to 0 when the electrical field around the object is not disturbed by any meter. Capacitance C_M increases to infinity for infinitely small distance between the meter and the investigated object. Finally, the undisturbed potential U and relative error δU_D values can be determined from the approximated relations, respectively

$$U \approx U_D \left(1 + \frac{\varepsilon_0 S_F}{C_O l} \right) \tag{6}$$

$$\delta_D U = \frac{\Delta U_D}{U} \approx -\frac{\varepsilon_0 S_F}{C_O l + \varepsilon_0 S_F} \tag{7}$$

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The preceding discussion indicates that the measured potential may be strongly influenced by the earthed meter even in case of contactless measurements. In practical situations the effect of potential reduction is easy to observe in case of potential measurements of low capacitance objects. It should be emphasized, that potential measurement by an earthed meter gives (always) lowered voltage values in comparison to the non-disturbed state.

3. Potential measurements using compensation method

Application of a compensation method requires zeroing of the average field value in the space between the probe and the investigated object (in the air gap over the surface S_F), see Figure 2. Zeroing of the electric field in the region S_F means zeroing of the surface charge density in the same area. Charge loss

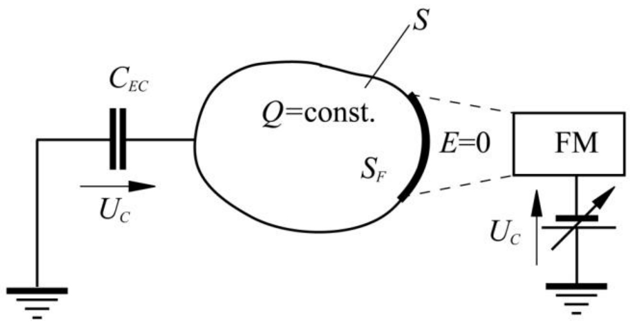

Figure 2. Potential measurements using compensation method

on the surface S_F, implicates an increase in surface charge density on the remaining part of the object (remaining part of its total surface S). Thus, the electric field and potential of the object must increase to the value U_C given by [5]:

$$U_C = U \frac{C_O}{C_O - C_C}, \tag{8}$$

where C_C is the capacitance related to the effect of "cutting out" of the surface S_F from the total surface of the object S. Consequently, the equivalent capacitance of the object will be now given by equation:

$$C_{EC} = C_O - C_C . \tag{9}$$

Capacitance C_C is equal to 0 when the electrical field around the object is not disturbed by any meter or when the S_F surface (more directly the S_F/S ratio) approaches zero. Capacitance C_C increases to C_O when the meter (compensating electrode) completely encloses the investigated object.

In case of a compensation method values of the error ΔU_C and the relative error δU_C of potential measurement are given by equations, respectively [7]:

$$\Delta U_C = U_C - U \tag{10}$$

$$\delta U_C = \frac{\Delta U_C}{U} = \frac{C_C}{C_O - C_C} \tag{11}$$

Assuming field intensity equal to zero in the S_F (compensation) region and uniform distribution of the surface charge on the remaining part of surface S of the investigated object, C_C capacitance can be determined from the approximated equation [7]:

$$C_C \approx C_O \frac{S_F}{S} \tag{12}$$

Thus, the undisturbed potential U and relative error δU_C values can be determined from the equations, respectively:

$$U \approx U_C\left(1-\frac{S_F}{S}\right), \tag{13}$$

$$\delta_C(U) = \frac{\Delta U_C}{U} \approx \frac{S_F}{S - S_F}\,. \tag{14}$$

It should be noted, that the results of potential measurements obtained by a compensating voltmeter will give (always) higher voltage values in comparison to that in a non-disturbed state. Equations (7) and (14) allow determine the relative uncertainty of potential measurements (uncertainty of the applied method) without consideration of accuracy of applied measuring devices. Both of the mentioned equations confirm, that minimal error of potential measurements of conducting objects require application of voltmeters (probes) with minimal "sensitive surface" (aperture) S_F.

Equations (6) and (13) allow to determine the potential value of the object in a non disturbed state and may explain some incompatibilities which can arise between results of measurements made by different meters or by application of different methods.

4. Conclusions

Consideration of the influence of non-contact measuring method on the results of potential measurements of Q-constant and conducting objects, leads to the following conclusions:

- potential and equivalent capacitance of Q-constant objects are changed by a measuring system operating in both, direct and compensation circuitry;
- potential values obtained by application of a direct method are (always) lower than those in a non-disturbed state and the value of the relative error δU_D depends on the distance l between the object and the probe (equation 7);
- potential values obtained by application of a compensation method are (always) higher than that in a non-disturbed state and the value of the relative error δU_C does not depend on the distance between the object and the probe (roughly, see equation 14);
- proper determination of the relative error value requires knowledge of the particular method applied for potential measurement;
- for non-uniform distribution of surface charge density on the investigated object, results of potential measurements may depend on the place of measurement.

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