IMPROVEMENT OF REFERENCE ELECTRIC FIELD GENERATION

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Abstract: Based upon the computer-aided numerical field calculations, a methodology to correct and control the reference electric field nonuniformity in an electric field-meter calibration system is described. Using the results of an accurate calculation of the reference electric field nonuniformity, the reduction of traditionally large size of calibration system is proposed, which enables a realization of smaller and more practical calibration system adjusted to the modern field-meters of reduced size.

Keywords: reference electric field, nonuniformity, calibration system

1   INTRODUCTION

While the enormous benefits of using electricity at work and in everyday life are unquestioned, the general public is becoming increasingly concerned about potential adverse health effects of exposure to the extremely low frequency (ELF) electric and magnetic fields, which arise mainly from the transmission, distribution and use of electrical energy at so called power-frequency of 50 Hz (or 60 Hz).

Following the international guidelines and standards [1,2] which are concerning human exposure to electromagnetic fields, more and more countries are including the control of human exposure to power-frequency electric and magnetic fields into their legislation. The legislative control of field levels is based upon the periodic field measurements, where the field-meters must be calibrated regularly. For calibration of electric field-meters the reference electric fields are used, generated by the specially constructed calibration systems.

In the calibration systems used for calibration of electric field-meters of the free-body type (which are portable and allow measurement above the ground plane), the reference field is generated between two parallel conductive plate electrodes, which are energized with the reference voltage using the voltage transformer and a more or less complex arrangement of stabilized voltage generator, precision digital multi-meter, measuring transformers, resistive dividers, grading rings, current-limiting resistors, etc.

In the paper, the electric field between the plates is analyzed, not concerning the outer electrical arrangement. Based upon the PC-aided numerical field calculation, a possibility of improvement in the traditional approach to the reference field generation is proposed.

2   TRADITIONAL WAY OF REFERENCE ELECTRIC FIELD GENERATION

The traditional approach to electric field-meter calibration is based upon the creation of the nearly uniform reference field in the space between two parallel square plates where the field-meter is put for calibration. For that purpose, it is generally recommended [3,4] that plates separation (spacing) d should be sufficiently small relative to the plate width a, and at the same time the separation should be sufficient to avoid substantial field distortion caused by the presence of the field-meter (or its probe).

When the reference voltage U_0 is applied between the plates, than the uniform electric field value

$$E_0 = U_0/d \tag{1}$$

would be established between the plates of infinite size. As the plates have a finite width, due to fringing effects of their edges the nonuniformity of the plate surface charge density occurs, causing the deviation of the reference field value E from the uniform field value E_0. That deviation i.e., the reference field nonuniformity, depends upon the separation/width ratio d/a of the plates.

2.1   Reference field nonuniformity

In the actual standards [3,4] the reference field nonuniformity assessment is based upon the results of numerical calculation of the field E between two parallel semi-infinite plates. The field nonuniformity (i.e., the departure of the calculated value E from uniform field value E_0) at any point is quantified by means of the normalized field value E/E_0.

Analyzing the results of numeric calculation of the field midway between semi-infinite parallel plates,

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in [3] the nonuniformity of 0,1% has been found at a distance of one plate separation from the edge side. It is stated that the nonuniformity due to all four sides can be estimated by superposition when the effect from one edge is less than 0,1%, and that there is a discrepancy of approximately 0,04% between this estimation and the results of numerical calculations of the field between finite-size parallel plates.

For the plates with separation d equal to the half of the plate width a (the separation/width ratio d/a 0,5), the point at the center between the plates would be at the distance d from all four sides of the system. Therefor in [3] a system with the plate width a 1,5 m and the separation d 0,75 m is recommended for field-meters calibration, claiming that the field at the center of such system is within 1% of the uniform field value.

Thus, the maximal field nonuniformity of 1% at the center between the plates is declared, introducing some redundancy in respect to the nonuniformity estimation which would result from the (not quite adequate) semi-infinite plates model and the requested separation/width ratio of 0,5.

2.2   Relation between the plate separation and field-meter size

Besides the finite plate size, there is another potential cause of the reference field nonuniformity. If the field-meter (probe) during calibration comes to close to the plates, it may influence the substantial perturbation of the surface charge distribution on the plates, and thus may cause the additional field nonuniformity.

For the calibration system with plate separation d 0,75 m, proposed in [3], it has been indicated that the influence of the field-meter can be neglected provided that the field-meter, placed in the center, has no diagonal dimension larger than 0,23 m (or 0,3d).

2.3   Large dimensions of calibration systems

As a result of the intention to generate nearly uniform reference field, the usual calibration systems constructed according to [3] and [4] have large dimensions. While in [3] a moderate system with plates 1.5 m wide and separation of 0.75 m is proposed, the laboratory constructions with plates 2 m wide and a separation of 1 m are common, and in [4] a system is presented with plates 3 m wide.

The large size of calibration systems complicates their construction and manipulation. For greater size of the plate system, the plate fixing structure must be more complex, and the high reference voltage must be still higher (e.g., to generate the same reference field as a system with plate separation of 0,75 m, the system with a separation of 1 m should have a 33% higher voltage).

3   CONTROL OF THE REFERENCE FIELD NONUNIFORMITY

In attempt to design a more practical calibration system, adjusted to reduced dimensions of modern field meters (often having detachable probes), the reference field nonuniformity estimation from [3] has been evaluated by means of computer-aided numerical calculation of the real field between two parallel finite square plates.

The numerical field calculation has been conducted, using the method of moments [5]. The plate surface is divided into the rectangles with uniform distribution of surface charge density, and the unknown coefficients of the surface charge distribution are determined from the prescribed reference voltage U_0 applied between the plates.

The theoretical and mathematical framework of the field calculation (performed on a Pentium PC using the software package Mathematica[8]) is described in [6] in a more detailed manner. Here, the results of field calculation are presented and their consequences are discussed.

3.1   Compensation for the field nonuniformity

The value of electric field E_c at the center of the system has been calculated, and the result is for the factor $\hat{e}$ lower than the uniform field value E_0 ($E_0 = \hat{e}E_c$). Therefor, to obtain the reference field of the value E_0 at the center, the reference voltage should be corrected (with the correction factor $\hat{e}$) to the value U'

$$U' = \hat{e}E_0 d \tag{2}$$

Thus, correction factor $\hat{e}$ can be used to compensate for the field nonuniformity due to finite plate size.

Because of the inaccuracy immanent to the numerical calculations, an accurate calculation of the correction factor requires a special methodology which is described in [7]. The magnitude of correction factor $\hat{e}$ is dependant upon the plate separation/width ratio d/a.

For the ratio $d/a = 0,5$ the correction factor $\hat{e}=1,00326$ has been calculated, and the magnitude of correction factor increases with the ratio d/a.

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3.2 Visualization of the field nonuniformity

Numerical field computation enables an analysis of the reference field nonuniformity, not only at the center of the calibration system, but also in the whole space between the plates.

In Figure 1 the field nonuniformity is presented in a quarter of the field space, with the place for the field-meter in the center (a cube of the width 0,3 d). The vertical component of the field E is computed and normalized in respect to the (reference) field value E_c at the center, indicating the field nonuniformity. The plotted surfaces contour the space where the field E is within 1% of the reference field value E_c.
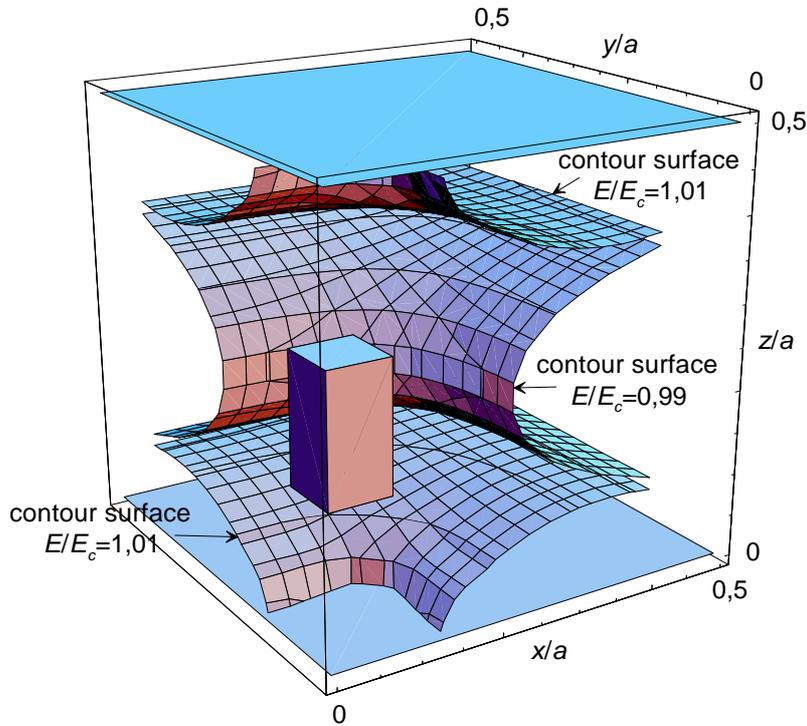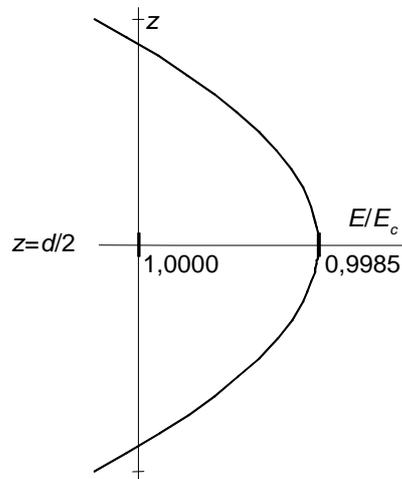

Figure 1. Contour of the space with 1% field nonuniformity for d/a 0,5

Contour surfaces bound the space with the 1% nonuniformity. The distance of the boundary surfaces from the field-meter area clearly shows a redundancy in the reference field nonuniformity estimation from [3], declared as 1% for the proposed calibration system with a separation/width ratio d/a 0,5.

The boundary surfaces are closest to the field-meter area in the plane right midway between the plates (z $d/2$) where, concerning the field-meter area, the highest nonuniformity is at its outer edge.

For the further nonuniformity analysis, the normalized field value E/E_c was calculated along the outer vertical edge of the field-meter area, and the result is presented in Figure 2.
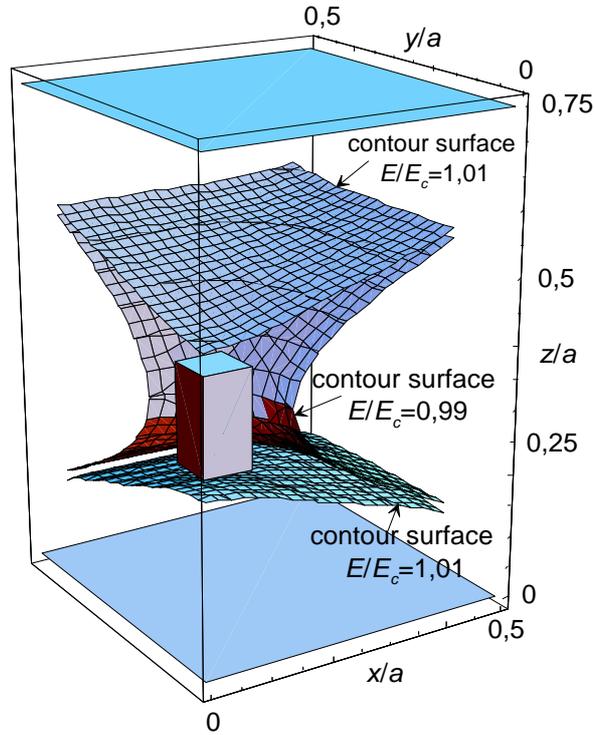

Figure 2. The field nonuniformity along the vertical edge of the field-meter area for d/a 0,5

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Figure 2 shows that nonuniformity at the edge of the field-meter area is greatest midway between the plates where the departure of 0,15% from the field value at the center was calculated. This nonuniformity is lower (due to the applied correction factor), than estimated in [3], suggesting a possibility to increase the separation/width ratio and still preserve the field nonuniformity within 1% in the field-meter area.
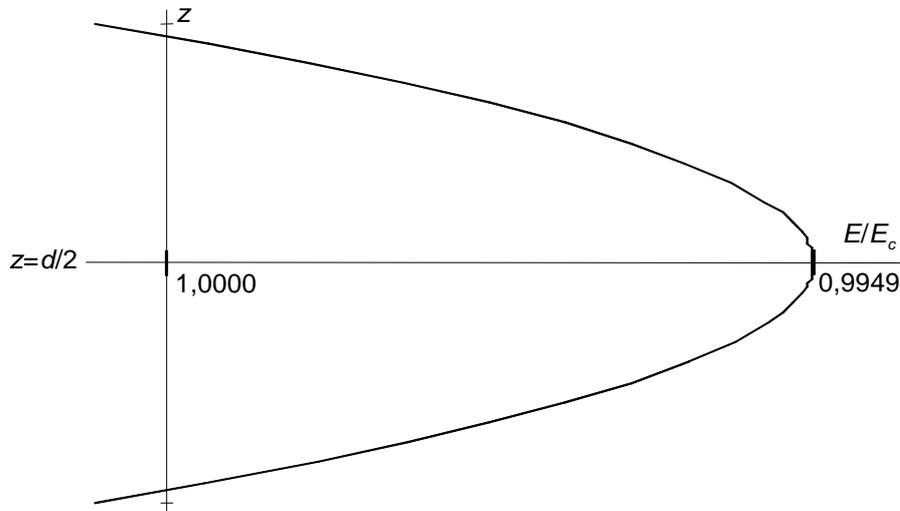
3.3 Increase of the field nonuniformity with the ratio *d/a*

For the increased separation/width ratio *d/a* 0,75 the contours of the space with the nonuniformity within 1% are calculated and plotted in Figure 3. The field-meter area is still inside of the 1% boundary.

Figure 3. Contour of the space with 1% field nonuniformity for *d/a* 0,75

For the same (increased) separation/width ratio *d/a* 0,75 the normalized field value E/E_c along the vertical edge of the field-meter area is calculated and presented by the plot in Figure 4.

Figure 4. The field nonuniformity along the vertical edge of the field-meter area for *d/a* 0,75

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Figure 4 shows that for $d/a \geqslant 0,75$ the greatest departure from the central field value of 0,51% was calculated. That nonuniformity is well below the reference field nonuniformity estimation of 1% proposed in [3] for separation/width ratio d/a 0,5. It is obvious that reference electric fields of the nonuniformity below 1% could be generated between the plates with the increased separation/width ratio, what is important because it can enable the reduction of the calibration system (traditionally large) size.

3.4   Reduction of the calibration system size

The increase of the separation/width ratio can be realized by keeping the constant separation and reducing the plate width. E.g., we can put the plates which are only 1 m wide at the same separation d 0,75 m as proposed in [3], and realize a smaller and more practical calibration system with the ratio d/a 0.75 and with the field nonuniformity (due to finite plate size) as presented in Figures 3 and 4. In such a system the same field-meters can be calibrated as in the system proposed in [3] (because of the same separation), while the smaller plates allow for a simpler mechanical construction and manipulation.

Smaller plates may also facilitate the realization of the interesting concept of calibration system with the variable plate separation, which could be adapted to the reduced size of modern field-meters (often having detachable probes), while the field uniformity can be calculated and controlled as described.

4   CONCLUSION

The proposed methodology for correction and control of the reference electric field nonuniformity enables the construction of simpler and more practical calibration system, which could be adjusted to the modern field-meters of reduced size, and have a sufficiently low level of reference field nonuniformity.

The reference field nonuniformity is a source of a component of the calibration uncertainty which we should be able to calculate and control as a part of the calibration procedures. Therefore, a realization of the proposed smaller calibration system requires an evaluation of the measurement uncertainty due to the reference field nonuniformity. The major components of that uncertainty are: the uncertainty of correction factor calculation, the uncertainty due to field nonuniformity influenced by the presence of the field-meter, and the uncertainty due to field nonuniformity in the field-meter area.

While the uncertainty of the correction factor calculation has been evaluated as presented in [7] (and it is very low), the evaluation of other uncertainty components for proposed system is being prepared.

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