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A MULTI ELECTRODE FIELD OPTIMIZATION STRATEGY BASED ON THE OPTIMIZED CHARGE SIMULATION METHOD

استراتيجية لامثلة المجال الناتج عن اقطاب متعددة باستخدام طريقة التمثيل بالشحنات الامثلية

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الخلاصـــــة :

يقدم البحث استراتيجية لتصميم الاقطاب الكهربيــة فى نظم الجهد العالى متعــددة الاقطاب بحيث يتم امثلة المجال الكهربى الناتج عن هذه الاقطاب وبالتالى رفع كفاءة استغـــلال المجـــال .

تعتمد الطريقه المقدمة على استخدام طريقة التمثيل بالشحنات الامثلية فى حساب المجال الكهربى وكذلك فى عمل تغييرات على اشكال اقطاب الجهد العالى للحصول على المجال الكهربى الامثل للنظام .

تعتمد الاستراتيجية المقدمة على استخدام التتابع فى تصميم الاقطاب الكهربية نظرا لتغير شـــدة المجال الكهربى على سطح القطب مع تغير توزيع الجهود داخل النظام . لذا فأن الطريقة المقترحة تأخذ بعين الاعتبار توزيع الجهود المؤدى لاعلى شدة مجال كهربى لكل قطب عند التصميم لهذا القطب مما يؤدى فى النهاية الى افضل استغلال للمجال الكهربى الناتج عن مجموعة اقطاب فى نظام جهد عالــى .

تم تطبيق الاستراتيجية على نموذج لقاطع SF_6 يحتوى على عازل تعضيد واظهرت النتائج القدرة الكبيره لهذه الاستراتيجية على تحسين شدة عزل النظام بعد امثلة مجاله .

ABSTRACT

The paper introduces a multi electrode field optimization strategy from the point of view of efficient utilization of the electric field space. The calculation method is based on the application of optimized charge simulating systems, as they can be determined for an accurate simulation by means of minimizing algorithms. The insertion of such optimized charge simulating systems in the field optimization process will be enabled by means of a potential approach, in a rational manner, so that the optimization of electrodes can be undertaken following the electric field calculation within a safely converging and accurate computational process. Thereby, every electrode is to be optimized for the case at which the electrode underlies the highst possible field stress. By this means, subsequent electrode optimization leads to the best utilization of the electric field caused by a multi high voltage electrode system.

1. INTRODUCTION

The continuosly increasing voltage level of high voltage apparatus requires to utilize the field space as well as possible. This goal requires to design the field systems for optimal electrode forms having the lowest possible electrical field stress, so that allowed maximum field strengths are not exeeded.

The solution of this problem is normally undertaken by calculating the electrical field strength of known electrode contours. Quite often the desired electric field strength can only be achieved by repeated alteration of electrode contour and renewable field calculation. Therefore, it has been necessary to devlop computer aided design methods for the design of optimal electrode forms.

It has been shown that the charge simulation method is the best qualified calculation method regarding the optimization of electrode contours [1-4]. With the help of this method, the potential distributions as well as the electric field lines can be easily calculated and altered. However, the work done in this area is limited for the person who has a high degree of experience, specially by the placement of the simulating charges which can strongly affect the accuracy of solution. On the otherhand, increasing the number of simulating charges may not only lead to storage problems but also to bad conditioning solutions, instead of increasing the simulation accuracy [3,5].

To overcome problems associated with the conventional charge simulation method, optimized charge simulating systems have been developed [3,5]. These systems lead to a great improvement of the accuracy of the field computation within a safely converging computational process without great computing expense [3,5]. Thereby, the optimal placements and amounts of the charges are determined by means of minimizing algorithms, that an accurate simulation results with the help of only few simulating charge number.

By means of a novel potential approach, the optimization of electrode systems could be formulated as a special case of the potential simulation [3,6-8]. It became possible to undertake the optimization of electrode systems following the electric field calculation in a rational manner. Thereby, the minimizing algorithms take over the task of changing the placements and amounts of the simulating charges automatically and thus releave the developing engineer strongly.

Since the optimization of electrode forms can be understood as a special part of the field calculation area, more interest has been attained to the optimized charge simulation method [9,10] than to the field optimization one. The application of the field optimization method, based on the optimized charge simulating method, has mainly been demonstrated on single electrode optimization exampies[3,6,8]. Whether and how can this method be applied to a multi electrode field optimization problem, is the main goal of this paper.

2. FIELD OPTIMIZATION METHOD

2.1 General

The goal of the field optimization in this work is the design of electrode configurations with a constant field strength distribution value on their surfaces. To this extent, the electrode contours are to be formed such that the minimum possible constant value of the field distribution can be attained. Only in this case an optimal utilization of the electric field is achieved. The optimization is here foreseen for space charge free fields [3,5].

The necessary foundation for the optimization of electrode systems is thereby the knolledge of the potential and field distributions on the electrode surfaces as well as in the field space. The method of calculating and optimizing the electric field strength used in this paper is based on the application of optimized discrete charge simulating systems, as they can be determined for an accurate simulation by means of minimizing algorithms. The insertion of such optimized charge simulating systems in the field optimization process will be enabled by a potential approach. By this means, optimization of electrode systems can be undertaken following the electric field calculation in a very rational manner.
In this work the methodology of using the minimization techniques for achieving optimized charge simulating systems will be shortly noted, because it is published in details elsewhere [3,5-7]. More details are dedicated to the optimization strategy applied on a multi electrode system.

2.2 Conventional Charge Simulating Method

The conventional charge simulating method expresses the Laplace's equation as a superposition of particular solutions due to discrete ficticious charges. These charges must be placed outside the field space in which the field is to be computed. The magnitude of these charges have to be calculated so that their integrated effect satisfies the boundary conditions exactly at a selected number of contour points on the boundary equal to the number of the simulating charges. This can be presented by the following linear system of equations, which must be solved for the unknown column of the amounts of the charges (Q). After this, these charges describe, with their equipotential surfaces, the field space.

$$(P) \cdot (Q) = (\Phi) \qquad (1)$$

Hereby (P) illustrates the matrix of the potential coefficients of the charges related to the contour points and (Φ) is the column of the boundary conditions, which must be satisfied. The most used kinds of discrete charges are the point charges, the line charges and the ring charges.

Boundary layers and thin tied surface forms can be simulated by means of surface charges. In this work,the representation of the influence of dielectric materials by the simulating process is undertaken by means of a combined numeric - analytic surface charge simulation method simplifying the most complicated surface charge simulation method of Singer [11] as detailed in [2,8].

The simulation of two dielectric fields by means of the surface charges can be regarded through the fulfilling of the dielectric boundary conditions and leads to the following equation instead of eqn. (1)

$$\begin{pmatrix} P \\ F \end{pmatrix} \cdot (Q) = \begin{pmatrix} \Phi \\ 0 \end{pmatrix} \qquad (2)$$

where (F) is an electric field coefficient matrix determined by dielectric boundary conditions at a selected number of points on the boundary surfaces equal to the starting and end number of the surface charge densties [2,8].

2.3. Optimized Charge Simulating Systems

An accurate simulation of electrode systems can be interpreted as the proposition of minimizing the following function of potential error e:

$$\text{minimize } e, \; e = \frac{1}{\ell} \int_{\ell} \left(\Phi_a - \Phi_r \right)^2 dl \qquad (3)$$

where Φ_a corresponds to the potentials along the simulated contour l due to the excitation of the system of simulating charges and Φ_r are the rated boundary potentials. The minimization of the above error function e corresponding to a system of n simulating charges can only be realized by means of varying the geometrical placement $\vec{r}_1, \ldots, \vec{r}_n$ and the amounts $Q_1, \ldots, Q_n$ of these charges which represent the independent variables of the function. Hence, the error function e under minimization can also be written as:

$$e = e(x); \; (x) = (\vec{r}_1, \ldots, \vec{r}_n, Q_1, \ldots, Q_n)^T \qquad (4)$$

The use of simple geometrical forms to define the allowable charge placement zones enables the transformation of these zones into unconstrained regions. Thus highly efficient converging unconstrained minimizing algorithms can be applied [3,5].

When the fault in the boundary potential is sufficiently reduced such that an adjustment of the locations of the simulating charges is no longer necessary, the rest-fault will be further minimized in an easy manner with the use of multiple linear regression. This is possible, because the potential error function (4) will be a linear function, if it is reduced to be only dependent on the amounts of the simulating charges as follows

$$e = e \ (x); \ (x) = (Q_1, \ \ldots, \ Q_n)^T \qquad (5)$$

The resulting simulating charge system after minimizing the potential error is the so called optimized charge simulating system.
A practical application of the optimized charge simulation method can be achieved, if the employment of these systems would be limited on the high stressed regions only, while less stressed zones may be simulated in the conventional way. Such a procedure is possible according to the fact, that the charge simulation method is based on the superposition of particular solutions [3,5-7].

2.4. Field Optimization Strategy

The use of a potential approach detailed in references [3,6-7] enables an iterative changing of the form of the electrode in the direction of the unknown, but wanted optimal form. This form is then achieved, when the electric field on the electrode contour gets a uniform value.

The potential approach transforms the deviation between the existing electric field value due to charge excitation at the i th interval E_i and the desired field value E_d into a potential error $\Delta \varphi_i$, where

$$\Delta \varphi_i = k \ (E_d - E_i) \ / \ E_d \ , \ i = 1,2,\ldots,n_o \qquad (6)$$

Thereby, k is a constant proportional to the highst potential difference within the electrode arrangement [3] and n_o is the number of contour intervals. By this means optimization of electrode systems can be undertaken following the electric field calculation in a very rational manner.

2.5. Multi Electrode Field Optimization Strategy

The field optimization by means of the potential approach can be undertaken as a special case of potential simulation of electrode contours. By this means, a field optimization strategy is changed into a special potential strategy, which is adapted to the special features of the field optimization.

Starting point of an optimization calculation is the field computation of an appearantly suitable electrode contour. Thereby, the potential distribution which causes the highst possible field stress should be taken into consideration.

Beginning with only one electrode to be optimized, potential changes will be calculated from the potential approach.These changes will be superposed to the acual rated potentials of the contour interval points of the starting electrode contour. Thus, a new equipotential contour having the rated potential will be produced. the new contour serves then as a start contour for a new optimization iteration.

After optimizing the first electrode, the field distribution of the next, to be optimized, electrode should be also calculated for the potential distribution corresponding to the highst stress case. The optimization procedure is then to be execuded as by the exceeding electrode. Such a subsequent electrode optimization is necessary, since the potential distributions are to be altered for each electrode optimization process.

For a practical application, the optimized charge simulating systems will be only limited to the critical regions of high field stress, which are to be optimized. Moreover, the use of the powerful and fast converging methods for the unconstrained optimization of eqn. (4) has been only limited to the first field optimization iteration. The experience shows that the charge positions after the first optimization iteration are satisfactory, that the less time consuming linear regression analysis can be employed to eqn. (5) for the continuity of the optimization [3,6,8].

3. APPLICATION EXAMPLE

The multi electrode field optimization strategy will be applied to the capsulated single phase SF_6 circuit breaker illustrated in figure 1. The cylindrical enclosure H of the system is earthed and thus having zero potential. A potential distribution of 105 kV on one of the electrodes and -17 kV on the other electrode will be considered in the calculation. The geometries of the arrangement as well as the potential distributions have been chosen reffering to [2] illustrating real dimensions with real possible high stresses. The whole arrangement is rotationally symmetric. The optimization takes place for the case of open contacts (contact electrode is inside the right electrode E2). The solid insulating spacer between the left elctrode E1 and the enclosure H, as illustrated in the figure, is of a relative permittivity of $\varepsilon_r = 4$. Since the permittivity of the spacer differs from that of SF_6 ($\varepsilon = \varepsilon_0$), surface charges have been used to regard these dielectric boundaries. 8 linear surface charges for each spacer side have been used for this purpose. For the critical, to be optimized, region of E1 8 ring charges have been used and for the other critical region of E2 10 ring simulating charges have been used. The simulation of the whole uncritical regions "fixed regions" of the electrode system have been simulated by means of 62 ring charges; 18 rings for the uncritical part of E1, 24 rings for the uncritical part of E2 and 20 rings for the enclosure H.

A conventional simulation has been firstly applied to simulate the whole arrangement for getting basic informations about the field distribution on the critical electrode parts. It has been found, that the maximum field stress on the same electrode surface is higher under positive potential stress (105 kV) than under -17 kV. This is expected, since the spacer influences the field space in an unsymmetrical manner. Thatfor, a subsequent electrode optimization has been forseen in this paper to regard the highst possible stresses and thus to obtain a best utilization of the electric field.

The optimization has been started firstly for the electrode E1, because the maximum field stress of this electrode was found to be higher than that of electrode E2. With a potential distribution of 105 kV for E1 and -17 kV for E2, the optimization method has been applied to E1. Thereby, the charge amounts resulting from the conventional solution have been taken as start values in the optimized charge simulating system. After the first field optimization iteration, the placements of the optimized charges have been kept constant and the regression analysis algorithm has been used for continuing the optimization.

After optimizing electrode E1, the procedure has been applied to electrode E2 in the same manner.

Fig.2 illustrates the initial critical zone of electrode E1 as well as the final optimized contour. Fig. 3 illuetrates the courses of the electric field intensities, corresponding to the two contours mentioned above in an unrolled demonstration.

Fig. 4 illustrates also the initial critical zone of the electrode E1 as well as the final optimized form, while Fig. 5 illustrates the coressponding electric field intensities.

Comparing the maximum electric fields of both electrodes E1 and E2 for the same potential distribution shwos that the initial as well as the final maximum stress of E1 is slightly higher than that of E2. This can be attributed by the fact, that the initially chosen contour of E1 is of higher curvature than E2. Aleo, the influence of the dielectric spacer on the field of E1 is more than on E2.

4. CONCLUSION

The paper introduces a multi electrode field optimization strategy based on the optimized charge simulation method. The strategy considers the potential distributions, which cause the highst possible field stresa, in the optimization strategy. By this means, subsequent electrode optimization leads to the best utilization of the electric field caused by a multi high voltage electrode system. The strategy has been applicated to a capsulated single phase SF_6 circuit breaker containing a solid dielectric spacer. The results illustrate the highly improvements in the dielectric strength of the arrangement, which can be attained by this field optimization strategy.

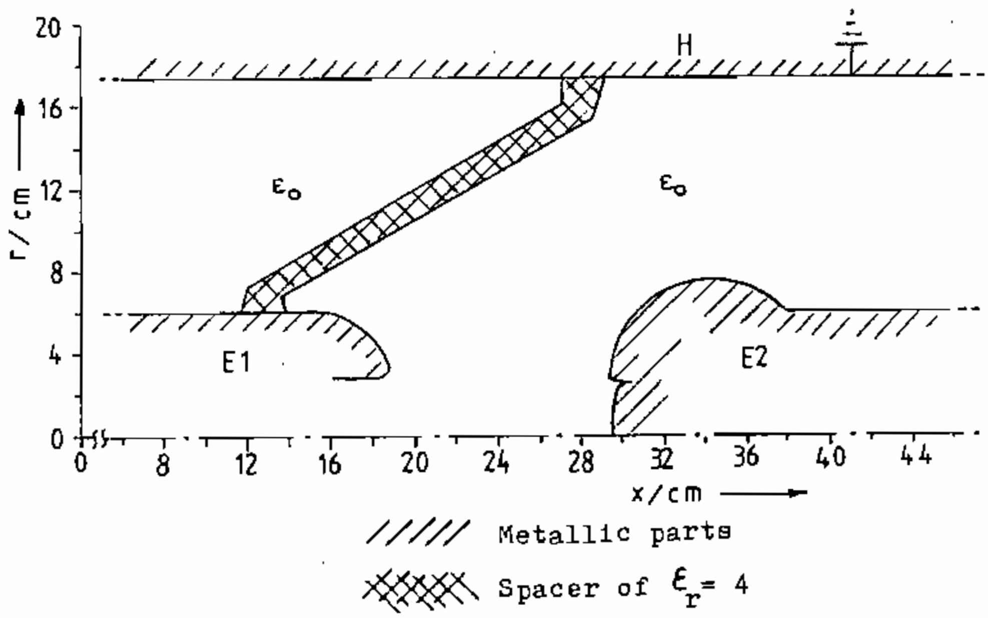

Fig.1 Example of a rotational symmetric capsulated single pbase SF_6 circuit breaker.

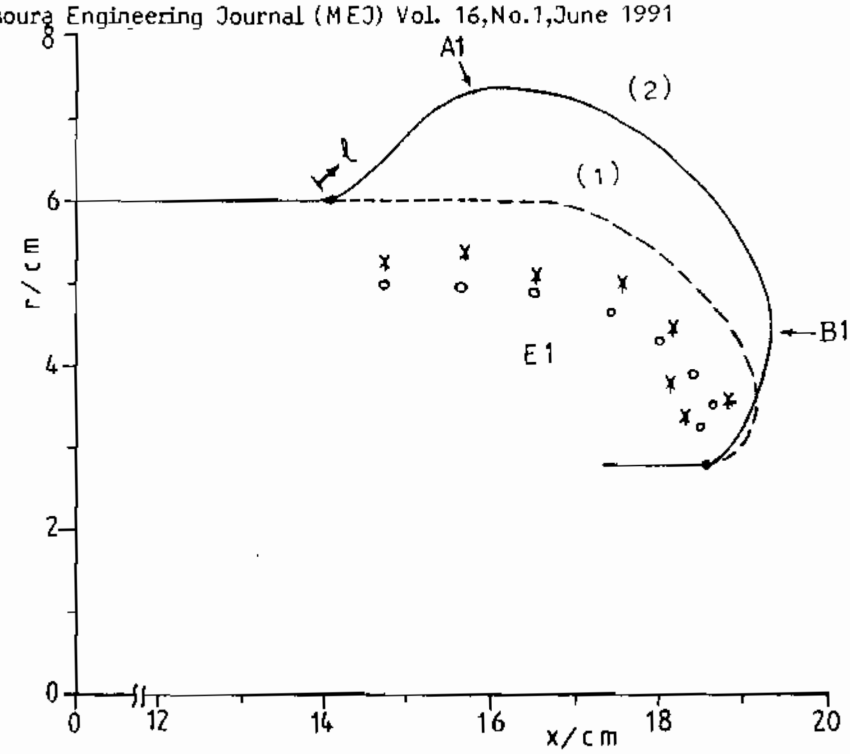

Fig. 2 High stressed region of electrode E1. [(1) initial form, (2) optimized electrode. o initial charge placement and x placement after optimization]

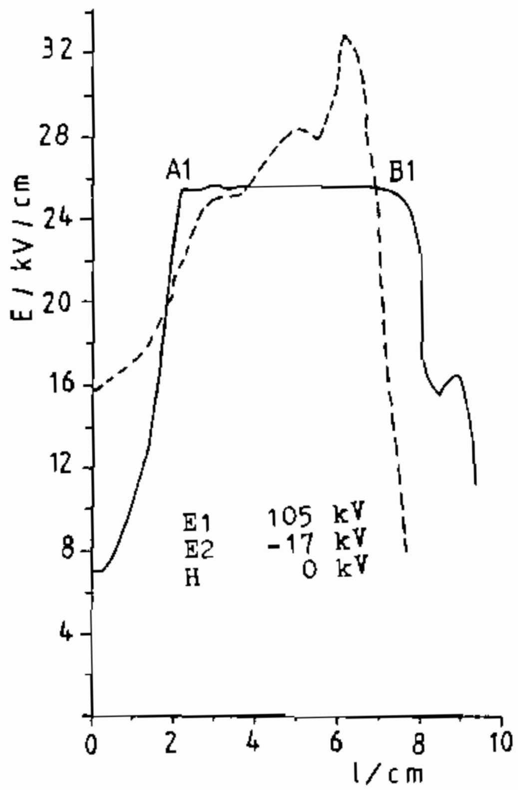

Fig. 3. Electric field course in an unrolled illustration, corresponding to electrode forms in Fig.2.

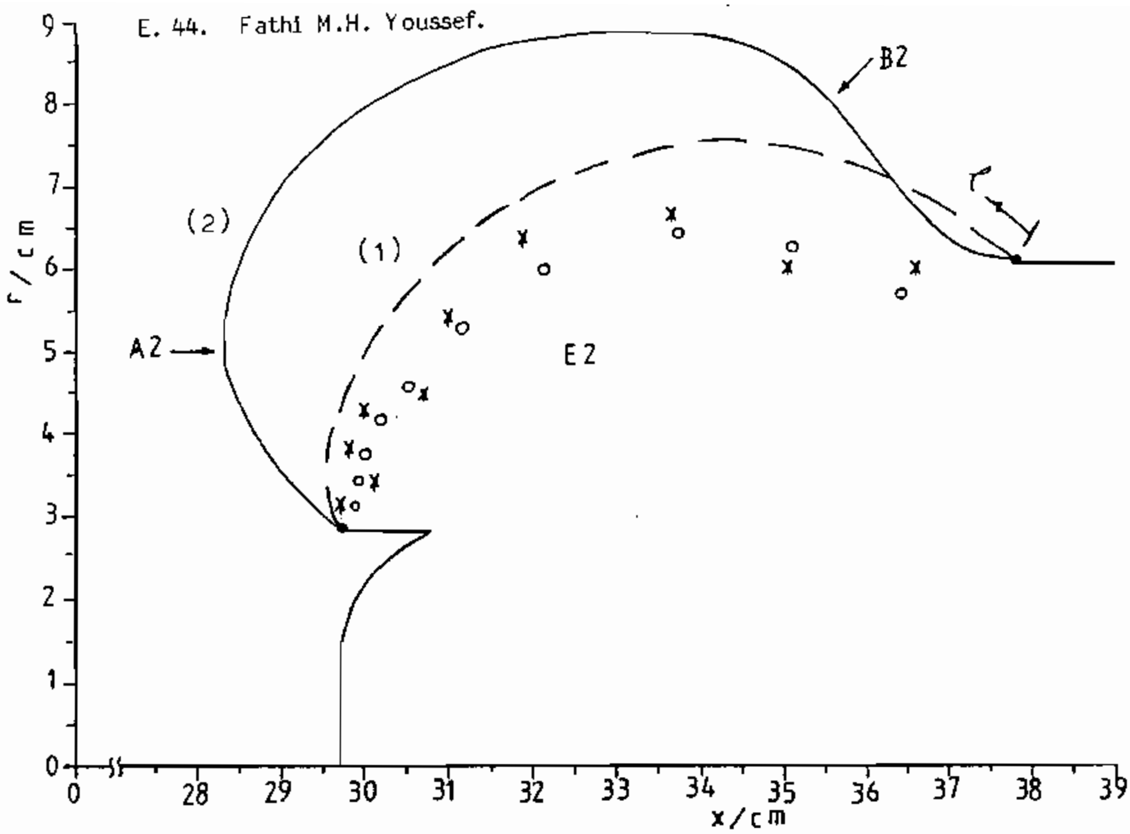

Fig. 4. High stressed region of electrode E2. (Symboles as in Fig. 2.).

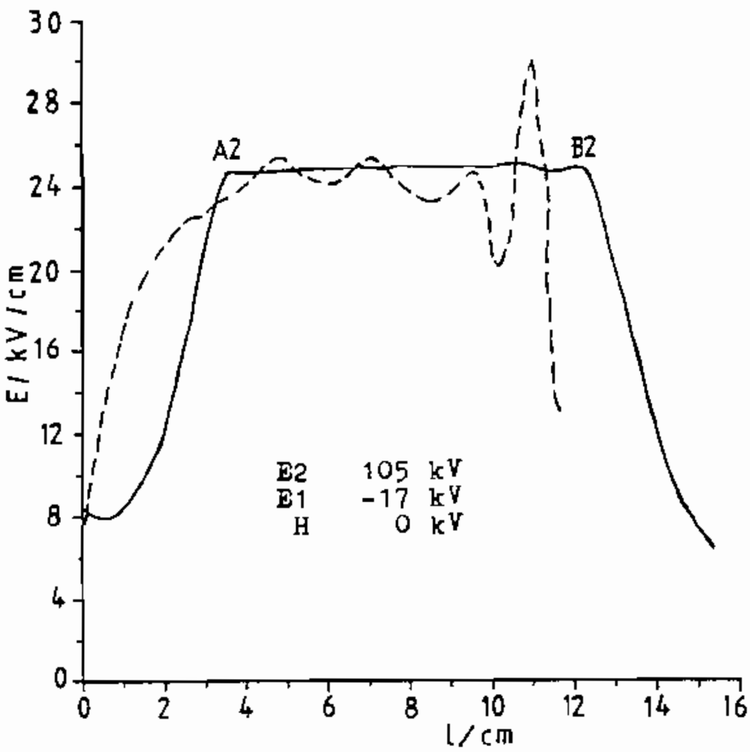

Fig. 5. Electric field course in an unrolled illustration, corresponding to electrode forms in Fig.4.

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