Boundary element method analysis of the electric field of electrostatic separators

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Abstract

The efficiency of the various electrostatic technologies of air purification, powder deposition or paint spraying is intimately related to the optimisation of the employed electrode configurations. The analysis of the electric field has already proven its utility in this respect. The aim of this paper is to demonstrate that the boundary element method (BEM) is appropriate for the study of roll- and plate-type electrostatic separators, two groups of devices which are characterised by intricate electrode configurations. A BEM program, developed at Worcester Polytechnic Institute (USA) and provided with interactive data input, error checking facilities and procedures for plotting equipotential and/or flux lines, was successfully employed for the evaluation of field uniformity and breakdown conditions in various electrode arrangements. The computed results showed how the electric field distribution can be modified by changing the electrode shape, size and position. The program was used as an effective design tool for developing several models of industrial electrostatic separators at the Technical University of Cluj-Napoca (Romania). Nevertheless, the role of computer modelling should not be overestimated: numerical analysis of the field provides useful data for an appropriate design, but cannot serve as a complete substitute for experimental testing of new technical ideas.
Introduction

Electrostatics is no longer a dusty chapter of physics. During the last thirty years, it has become a rapidly progressing branch of electrical engineering. The electrostatic forces purify the air, paint practically all the automobiles sold worldwide, produce billions of copies of documents per year, spray substances which protect vegetation in the fields, in the orchards, in the greenhouses [1-5]. These forces are of help to the researchers who study the human genom [6]. They proved to be effective in the beneficiation of minerals and in the recycling of granular industrial wastes [7-9].

The dust precipitators, the paint guns, the copying machines and the electrostatic separators have one thing in common: the electric field. The efficiency of all these electrostatic devices depends on the configuration of electrodes which generate the adequate field distribution. The analysis of the electric field and the optimisation of the electrode system which generate it represent topics of utmost interest at this stage of development for all the above-mentioned devices [10, 11].

Various methods of field analysis have been employed for the study of electrostatic air filters, liquid sprayers or powder guns [12, 13]. A review of this domain of research is beyond the scope of this paper, which will strictly aim at demonstrating the usefulness of the BEM for the analysis of the electrostatic field in a specific group of applications: roll- and plate-type separators for granular mixtures of solids.

Electric field of electrostatic separators

The wide diversity of electrostatic separators is reflected in hundreds of patents [14]. Nevertheless, most of the commercially-available units can be classified in one of the following categories: free-fall, roll-type or plate-type separators. In the first group of separators, the granular materials to be sorted, most frequently charged by triboelectification, fall freely between two vertical plate electrodes of opposite polarities. The electrode configuration of such an installation is very simple, more or less similar to a parallel plate capacitor, and the use of numerical methods of field analysis is not needed.

In the other two types of electrostatic separators, the material to be separated is fed onto the surface of a grounded roll or plate electrode. The electric field is generated between this electrode and one or several high-voltage (active) electrodes, of various shapes (Fig. 1).
Figure 1. Roll-type electrostatic separator; 1: vibratory feeder; 2: high-voltage "corona" electrode; 3: high-voltage "electrostatic" electrode; 4: grounded rotating roll electrode; 5: collecting boxes.

The electrode configuration is very complicated and no analytical solutions can be proposed for the study of the electric field of these devices. Analogue modelling [15] and graphical methods of mapping the electric field cannot be integrated in the structure of a computer-aided design algorithm. These facts explain the need for developing a numerical model of the electric field in an electrostatic separator.

**Numerical method of field analysis**

No matter how complicated the electrode shapes may be, the parallel-plane symmetry of the configuration authorises the use of a two-dimensional model. As a matter of fact, a three-dimensional study is necessary only for evaluating electrode-end effects, a problem which is most frequently solved by testing experimental models of the various technical ideas.
The intricate boundaries of the two-dimensional field domain represent an important argument in favour of using BEM for the study of roll- and plate-type electrostatic separators [16]. Another important point in choosing this method is related to the simplicity of interfacing it with the algorithms of trajectory computation, which require the evaluation of the electric field in successive points along the path of the particle in the active zone of the electrostatic separator.

Even if reducible to a two-dimensional formulation, modelling of the electric field in an actual separator remains a redoubtable problem. A first difficulty is to model the field non-homogeneity due to the presence of the granular material to be separated. The granules carry electric charges and are characterised by different dielectric constants and electric conductivities. Nevertheless, in most if not all industry applications, the granules form a mono-layer on the surface of the electrode and their dimensions are small as compared with the air gap between the electrodes. Under these conditions, their influence on field distribution can be neglected.

A second and more consistent difficulty is related to the air ionisation produced by the electrodes in certain types of electrostatic separators [17]. Indeed, the corona discharge which occurs from wire- or needle-type electrodes produces a ionic space charge which affects the distribution of the electric field. Several algorithms have been proposed for solving the problem of such mono-ionised fields, in simple wire-plane or needle-plane electrode configurations. No computer program is yet available for the analysis of more complicated electrode systems. Work is in progress at the Technical University of Cluj-Napoca (Romania).

As the ionic space charge is confined to a relatively small region of the inter-electrode space, treating only the electrostatic aspect of the field does not represent a major limitation for the validity of the results obtained with the existing programs, which can solve only the Laplace equation.

With the BEM-based program developed by Prof. Levin and his group at Worcester Polytechnic Institute [18], both Dirichlet and Neuman conditions can be imposed on the boundaries (Fig. 2). The program includes a pre-processor module which simplifies the task of specifying the geometry of the electrode system and the respective boundary conditions. Besides interactive data input, the program is provided with error checking facilities, with procedures for plotting equipotential and/or field lines.
Typical results of field analysis

Roll-type separators

The equipotential line plot (Fig. 3,a) is suggestive for the electric field distribution. The comparison of such plots obtained for electrodes of various shapes, sizes and positions can guide the designer in choosing the most adequate solution (i.e. the one which ensures the largest extension of the electric field. A quantitative characterisation of the field distribution, in relation with the peculiarities of this application, has been proposed in [11]. Thus, in order to compare the different electrode configurations, the electric field is computed in 100 points, along a line situated in the operating zone (Fig. 3,b). The line represents a segment of the most probable trajectory of a particle. The average magnitude of the electric field along this line:

\[ E_a = (E_M + E_m)/2 \]

and the coefficient of field non-uniformity:

\[ k = (E_M - E_m)/E_M \]

\[ (1) \]

\[ (2) \]

\[ E_M \] and \[ E_m \] being, respectively, the maximum and minimum values of the electric field along the considered line, are two criteria that might be employed for the evaluation of various design solutions.
For instance, by changing the axis $A_2$ of the lower electrode from the location $(0.7, 0.72)$ to $(0.75, 0.67)$ does not alter significantly the average value of the field (less than 1%), but modifies the coefficient of field non-uniformity, which decreases from 0.65 to 0.52.

Figure 3. BEM analysis of the electric field in a roll-type separator; (a) equipotential lines plot; (b) electrode location [11]; $A_1$: axis of the upper electrode; $A_2$: axis of the lower electrode; $C$: axis of the roll electrode. All dimensions are in meters.
Plate-type separators

A systematic study of the electric field generated by various electrode arrangements has been carried out. The shape (circular or ellipsoidal) and the position of the tubular high-voltage electrodes have been the parameters under investigation. A typical example is shown in figure 4, which points out the significant modification of the electric field distribution as an affect of changing high-voltage electrode position.

BEM field analysis as design tool for industrial separators

Numerical analysis of the electric field in an electrostatic separator provides useful information for a propitiate design. It can be used to estimate critical dimensions (such as spark gaps), maximum electrode potential before breakdown, insulation strength, etc. It can also guide the designer in choosing the optimum shape, size and position of the electrodes.

Nevertheless, the role of computer modelling should not be overestimated: no final decision can be adopted without a thorough examination of all technical and manufacturing criteria, most of which are very difficult or impossible to include in a mathematical model.

The industrial-metal electrostatic separators manufactured by Electromures Inc. of Targu-Mures (Romania) benefited of the results of BEM analysis of the electric field carried out by the author [11]. At the first stage of the project, the numerical modelling provided arguments in favour of using an original two-electrode arrangement (Fig. 5). Then, it was of help in establishing the optimum size/position of the electrodes, and in validating the overall dimensions of the separation chamber.

Conclusions

BEM can be advantageously employed for the analysis of the electric field in electrostatic separators. Two arguments sustain the choice of this method: (i) the intricate boundaries which characterise this specific application can be easily handled; (ii) the evaluation of the electrical field in distinct points between electrodes requires less computational-time than with other methods (as, for instance, the finite element method, which cannot avoid the computation of the field in each node of a mesh).
The results presented in this paper show the capability of BEM to answer the basic needs of the designer of a new electrostatic device. Even if the presentation is limited to a specific group of devices, the approach would be similar for other electrostatic applications.

Figure 4. BEM computed equipotential and flux lines in a plate-type electrostatic separator, for the upper (a) and lower (b) position of the tubular high-voltage electrode.
Figure 5. Optimised electrode configuration of an industrial roll-type electrostatic separator engineered by the Technical University of Cluj-Napoca and Electromures Co. of Targu-Mures (Romania).

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