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The zero gap conjecture

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ABSTRACT

The conjecture asserts that one electron optical device modeled having no gaps and another in which there are arbitrarily small gaps between the contacting elements are equivalent. It is verified using as an example a high resolution cylindrical mirror analyzer having contacting elements at different potentials. The verification proceeds by showing the equivalence between an air gap separating the elements and that of a small segment separating the elements at voltage V. Next use is made of this small segment at ever decreasing lengths in order to complete the assertion. Lastly the net charge located in the vicinity of the contact point is numerically calculated and it is found that this net charge becomes vanishingly small as the mesh point density surrounding the contact point becomes increasingly large. Thus there is no net charge in the contact region that can affect trajectories, a result consistent with the conjecture itself.

1. Introduction

Electron spectrometers increasingly use segmented geometries to produce their desired solution. Solution here refers to a particular result such as the energy resolution for a certain pass energy, spectrometer voltages. The design may be a model for a completed spectrometer or may exist simply to add to the knowledge concerning spectrometer design. These designs typically go through stages before one with desired properties is obtained. Before the final phase which is spectrometer construction finite gaps need be inserted in the model between the segments under the considerations of voltage breakdown. The question is “will the zero gap solution be the same as a finite but an arbitrarily small gap solution similar to one present in the final design?” If not true, small gaps need be inserted at every design stage at the cost of modeling complexity which can significantly burden the design process. It is the purpose of this report to show that no change in the spectrometer properties from the zero gap solution result from sufficiently small gaps inserted between the contacting elements.

It may be useful to remark that the path to a high resolution design involves many trials until one finds an optimized solution. If there is artifact in the calculation such as if the zero conjecture were false and yet one persisted in finding an optimized solution using no gaps between the elements, the solution would likely not be an optimized one and the designer would have been lead down a false path. Thus the conjecture has practical implications.

2. A statement of the zero gap conjecture

Defining *precision* as the value of |solution parameter (gap = g’) – solution parameter (gap = 0) | where solution parameter can refer to the resolution of the device, the end point of a trajectory or the spot size of a group of rays on a suitably defined plane, the conjecture can be stated as follows:

There exists a gap g such that for all separations g’ < g, the precision of the finite gap solution will be the same as the precision of the zero gap solution.

In effect this states that all parameters (segment voltages, pass energy, etc.) of the device resulting in a solution for a sufficiently small gap will be identical to those of the zero gap solution; i.e. the two situations will have equivalent precisions.

3. The treatment of singular points

Fig. 1 shows four situations in which select points on the boundary are singular. These occur at the endpoints of connected segments.

The first represents a situation in which there is no gap between the adjacent elements which are at different potentials and result in a step discontinuity of the potential on the boundary at point A. The representation of a gap consisting of a line segment whose potential varies linearly between the adjoining elements is shown in the second pane. In this situation there is no discontinuity of the potential at the points at which the line meets the elements. However the derivative of the potential in the z direction is discontinuous causing the points B and C to be singular. (This linear gap pane was included only to show that

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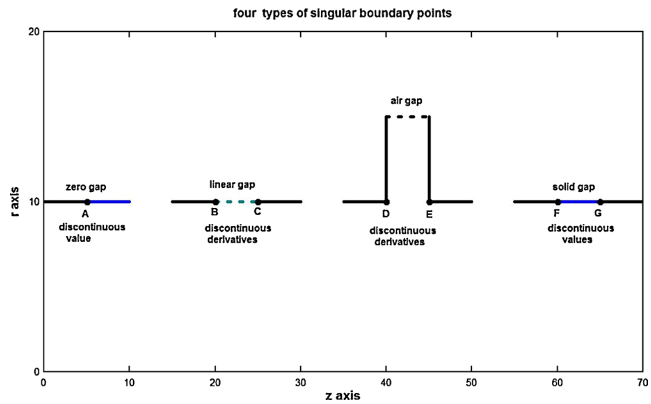

Fig. 1. The four types of possible singular boundary points.

the end points of it were singular points. No further use of it will be made.) The third pane shows the gap separated by an air or vacuum interface between the two elements which is a realistic model for a gap construction [1]. In this pane the corner points of the electrodes are singular for the same reason as in pane 2, namely discontinuous derivatives. The last pane - solid gap - is a representation of the gap replaced by a small segment at its own potential, the two singularities being of the same type as in the zero gap pane. Thus all the points explicitly labeled in Fig. 1 are singular having either a discontinuous value or discontinuous derivative along a horizontal line. The question is of course “do singularities change the nature of the solution?”

3.1. The simulated geometry

The geometry used to demonstrate the conjecture is taken from one of the recent segmented CMA designs [2] and is shown in Fig. 2. This design has the property of having a high resolution of ~0.040% and thus provides a somewhat stringent test of the conjecture.

The parameters specifying the design together with ray tracing results are given in Table 2 of reference [2]. It is noted that while the design of Fig. 2 has no gaps inserted between any of the contacting segments, derived examples will have a gap inserted between the segments labeled out1 and outer postsegment. The potential distribution with specific potential values placed on the segments is found by a process called superposition in which the voltage on a particular segment is set to 10 V with 0 V on the remaining segments and the potential distribution for this geometry or component is found by standard FDM techniques [3]. The production of the final potential distribution prior to the tracing of rays through the design is made by adding all component distributions scaled by Vcomponent/10 where Vcomponent

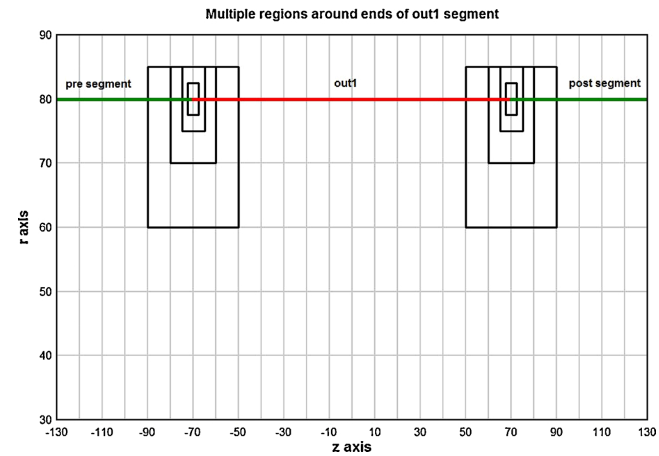

Fig. 3. The multi-region structure around the singular points of the out1 component in the CMA geometry is shown.

is the actual voltage of the component in the design. Thus in certain sections below components rather than the complete segments of the spectrometer are used in the simulations.

3.1.1. Neutralizing singularities with multi region FDM

All singularities present essentially the same dilemma to FDM, namely for a meshpoint one unit from the singular point there is no algorithm that can determine the value of its potential with any accuracy. Further this imprecision or potential error spreads with little diminution throughout the entire geometry [4]. The remedy found was to either create ever increasing mesh densities over the entire geometry or equivalently to effect enhanced densities only in the vicinity of the singular point [4]. The latter is the process employed here. As an example the multi-region structure used in the creation of the out1 component of Fig. 2 is shown in Fig. 3. (Highlights of the multiregion FDM process may be found in the Appendix A.)

Seen is the creation of telescopic regions with focii on the two singular points of the segment. For the purposes here it is only necessary to note that in each child region of its immediate parent the number of meshpoints in the horizontal and vertical directions is the same as its parent with their respective distance being ½ of that of the parent (in parent units). This will increase the mesh density of the child by a factor of 4 over the parent. In Fig. 3 the height and width of each region was set at 20 and for illustration purposes the number of regions surrounding each singularity was set to 4. In the simulations below the number of regions was set between 10 and 30 while the width was taken between 20 and 50. It is noted that within any particular child region the resultant potential after mesh relaxation is equivalent to the

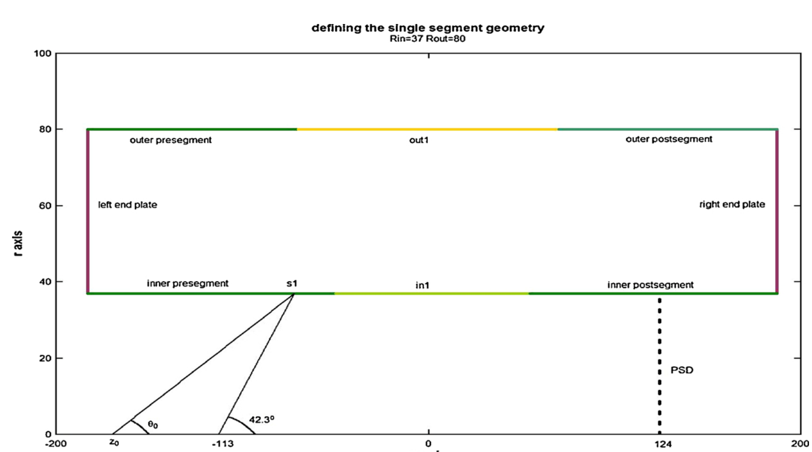

Fig. 2. The simulated CMA geometry.