IAEA FEC 2012
24th IAEA Fusion Energy Conference
October 8-13, 2012
San Diego, California, USA

The Finite Element Analysis of an Inertial Electrostatic Confinement (IEC) Unit

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Abstract

A new inertial electrostatic confinement (IEC) fusion unit was designed via finite element analysis (FEA) in a 3D electrostatic frame. Finite element method (FEM) was applied to the unit in order to identify the potential and electrical fields inside the spherical reaction chamber. Different material types and cathode geometries were tested, theoretically and the electrostatic responses of the central cathode were determined in the cases of different dielectric materials. The effects of cathode geometries were explored in order to identify the minimal and maximal field values at the vicinity of the cathode and inside the vertical and horizontal rings of the cathode structure. It was found that the number of vertical rings plays an important role to produce circular potential wells near the vertical rings. The increment of vertical rings on the cathode affects the bottom corner of electrical potential, thereby ions may be scattered to the entire region of the cathode. In fact, there should be an optimal number of vertical rings so that a better ion core can be obtained at the middle of the central grid for the confinement. Parallel to our earlier study, the dielectric materials surrounding the cathode also affect the field structure near the cathode rods, too. The dielectric thickness was changed in the entire study and some materials were found to be better in order to form homogeneous field inside the cathode for the ion dynamics.

Keywords: fusion, dielectrics, inertial electrostatic confinement

INTRODUCTION

Inertial electrostatic confinement (IEC) device is a steady-state fusion reactor where ions are accelerated through a spherical cathode under a dc or ac feeding. This device is different from the pulsed plasma devices, since fusion event occurs in the order of nanoseconds in the pulsed fusion devices, whereas an IEC device continuously realizes fusion. According to literature, Elmore and colleagues studied the equilibrium and stability features of an IEC system in 1959. A multi-well potential model is studied both experimentally and theoretically by Hirsh. Hockney performed some 2D simulations on the behavior of virtual electrodes inside a cylinderic geometry. His study proposed a stable virtual electrode, formed by the injection of charged particles. Wong and Krall investigated the potential well structure with the effects of electron injection. Later, an analytical expression is proposed by Nevins for the ion density of a square well potential to determine the feasibility of IEC for the improvements of commercial fusion plants.

According to the earlier studies, it has been known that there exists a correlation between the potential well structure and the neutron production rate in such devices. Therefore many attempts have been made on the identification of potential profiles in different cathode geometries and chamber shapes. It is understood that the dependency of neutron production on the shape of the potential-well is a very complicated process including the effects of virtual cathodes formed by the ions and electrons near the central cathode. In addition to the electrostatic solutions, temporal solutions of the potential wells are also vital in order to include the effects of virtual cathode. In one of his recent work, the author of this paper has introduced a new potential structure via solving the temporal trajectories of ions. He found that ions may create a repulsive effect at the vicinity of cathode rods if the high density ions are positioned around the cathode in a phenomenological manner. According to his results, complex trajectories are observed and while some potential parameters keep the ion inside the cathode, others cause no confinement. In the most recent studies, some spherical IEC device designs have been carried out and 3D field structures have been explored by the authors depending on some material types and cathode shapes. Within this context, some minimal potential regions inside the central grid have been clarified and the effects of dielectric materials on the potential-well have been explored.

In the present study, some other electrostatic features of an IEC fusion device are investigated in a 3D media by using the finite element method. The device which is modeled as the spherical chamber contains a spherical cathode at the center. First, the electric and potential fields are defined. Then, the effects of different dielectric materials such as mica, porcelain, polystyrene, alumina and glass wrapped on the cathode rode are explored. In addition, different geometric arrangements for cathode grid (i.e. the vertical ring numbers on the central sphere) are explored in order to find out the effects to the potential-well.

MODELING

A spherical IEC model is considered and formed by a commercial simulation packet of Ansoft-Maxwell in a 3D media. In this packet, a finite element method (FEM) is used in order to determine the scalar and vector fields inside a well-defined material with electrical and magnetic specifications. Since we focus on the electrostatic features of the IEC device, the electrostatic solution packet has been used in the entire simulations.

The elecrostatic solver mainly calculates the value of the electric potential at each tetrahedron node and at the midpoint of all edges. Following these data, the potential values inside each tetrahedron, which produces a part of the specific volume is interpolated from these nodal values using a second-order polynomial approximation. It should be noted that the accuracy of the solution depends on the volume size of each individual tetrahedrons, therefore a nominal mesh number should be ascertained in all simulations.

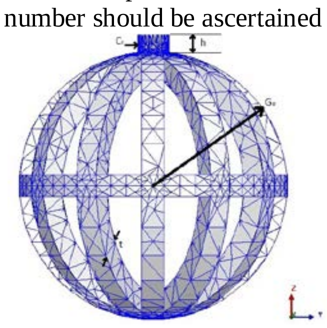
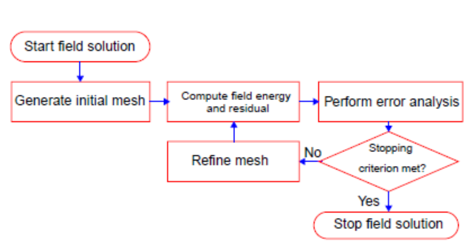


FIG. 1. A sample to mesh structures of the 6 vertical ring cathode

To obtain a value of the field, the system must size each tetrahedron so that it is small enough for thefield to be adequately interpolated from the nodal values. The electrostatic field simulator solves the electric potential from Poisson equation and finds the electrical fields.

Maxwell 3D's electrostatic solver finds the values of electric potential at the nodes and midpoints of the edges of each tetrahedron in the finite element mesh.

FIG. 2. Finite element analysis algorithm



After E is calculated, it produces solution files and performs an error analysis. In the adaptive analysis, it refines the tetrahedrons with the highest error, and continues solving until the stopping criterion is met.

Device Part	Measures
Outer radius of sphere (Ro)	500mm
Skin depth of sphere (d)	5mm
Grid radius (Go)	30mm
Skin depth of grid (t)	5mm
Radius of Copper rod (Cr)	3.5mm
Length of Copper rod (h)	500mm
Vcathode	-25kV
Vanode	grounded
Upper radius of dielectric holder wrapped around Copper rod	5mm
Lower radius of dielectric holder wrapped around Copper rod	2.5mm

Properties	Mica(M)	Porcelain(PR)	Polystyrene(PL)	Alumina (A)	Glass (G)	Unit
Relative Permittivity	5.7	5.7	2.6	9.8	2.3	-
Relative Permeability	1	1	1	1	1	-
Bulk Conductivity	0	0	0	0	0	S/m
Mass Density	2500	2400	1050	3960	2200	Kg/m3

TABLES 1&2. Features of unit and dielectrical properties of holder at cathode.

RESULTS AND DISCUSSION

Below the potential (Φ) and electric field (E) values are represented in the case of 8 vertical rings.

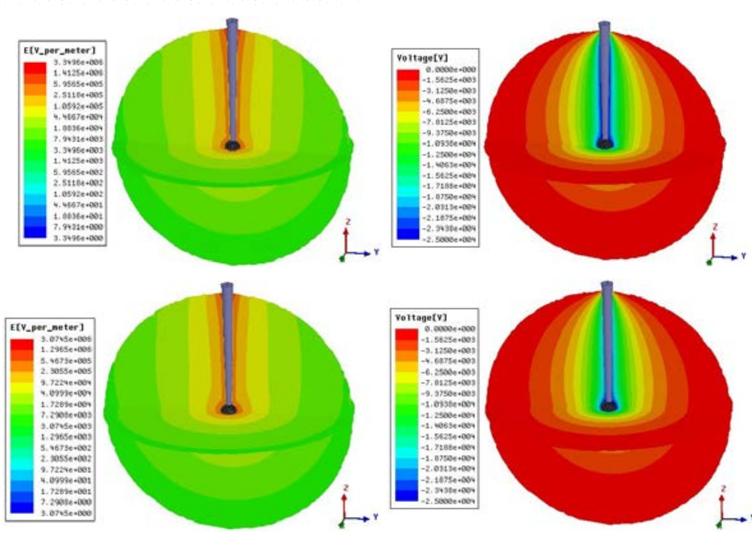


FIG. 3. Electric field ***E*** and potential ϕ surfaces for alumina (above), glass (below) for the inner grid structure including 8 vertical rings.

E and ϕ profiles along the diameter of chamber in the case of 8-vertical-ring grid. The insets show values inside the inner grid.

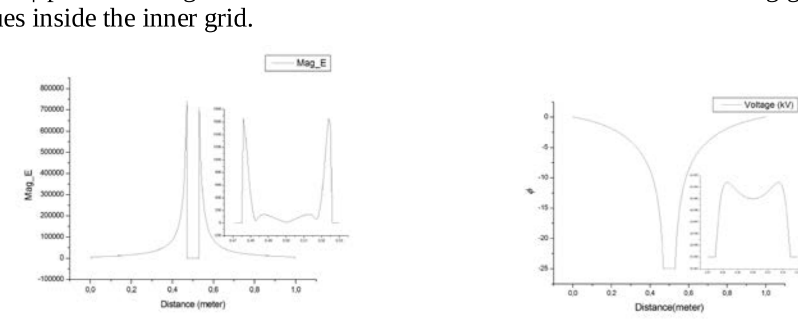


FIG. 4. ***E*** and ϕ profiles along the diameter of chamber in the case of 8-vertical-ring grid. The insets show values inside the inner grid.

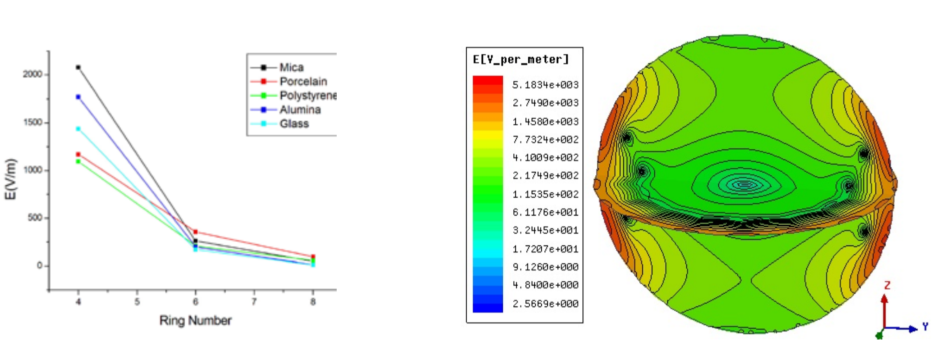


FIG. 5. Maximal ***E*** field at the middle of grid with respect to the ring number (left) and Electric fields with horizontal and vertical components in the cases of A (right).

CONCLUSIONS

A 3D simulation of the inertial confinement fusion device has been carried out. The effects of different cathode geometries are discussed. Two different types of materials (i.e. glass and alumina) have been explored for the cathode holder. It has been found that similar field patterns are generated at the inner part of cathode, however there exist slight differences in the maximal values of horizontal and vertical components in the case of glass (G) and alumina (A). It has been observed that G gives better horizontal and vertical symmetries compared to the A. This reality results a secondary potential well with a sand-clock shape in order to trap ions. The electric field values are higher near the vertical grid positions; in fact, the maximal horizontal E value is obtained for glass. This grid geometry still needs to be improved in terms of the confinement along the vertical direction.

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