Results in Physics 6 (2016) 873–876

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.journals.elsevier.com/results-in-physics

New results on structure of low beta confinement Polywell cusps simulated by comsol multiphysics

B. Mahdavipour, A. Salar Elahi *

Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

Article history:
Received 15 October 2016
Received in revised form 1 November 2016
Accepted 2 November 2016
Available online 4 November 2016

Keywords:
Low beta confinement
Polywell
IEC
Comsol multiphysics

ABSTRACT

The Inertial electrostatic confinement (IEC) is one of the ways for fusion approaches. It is one of the various methods which can be used to confine hot fusion plasma. The advantage of IEC is that the IEC experiments could be done in smaller size facilities than ITER or NIF, costing less money and moving forward faster. In IEC fusion, we need to trap adequate electrons to confine the desired ion density which is needed for a fusion reactor. Polywell is a device which uses the magnetic cusp system and traps the required amount of electrons for fusion reactions. The purpose of this device is to create a virtual cathode in order to achieve nuclear fusion using inertial electrostatic confinement (Miley and Krupakar Murali, 2014). In this paper, we have simulated the low beta Polywell. Then, we examined the effects of coil spacing, coils current, electron injection energy on confinement time.

Introduction

The Polywell is a nuclear fusion reactor which developed by Bussard. It is a hybrid device which combines specs and elements of inertial electrostatic confinement (IEC) and cusped magnetic confinement fusion [1]. Gridded IEC systems use spherical cathode grids to create radial electric fields which perform as the deep electrostatic potential wells. The radial electric field causes the ion confinement and acceleration for fusion reactions in central grid region [1]. The weakness of these gridded systems is that they lose lots of energy because of ion collisions with the metal grid. The Polywell Device uses a system of magnetic cusps to achieve the necessary electron trapping and create a virtual cathode instead of the physical cathode. By using a virtual cathode there is no longer a loss surface embedded within the plasma. The outer grid which contains the magnetic field coils is effectively isolated by the magnetic field it creates [2]. Polywell consists of the six current coil positions of a cube which are three orthogonal pairs of opposing current loops. The overall system of coils causes magnetic point cusps centred on the cube faces and corners. Magnetic mirror effects and reflects electrons towards the magnetic null which causes Electron confinement [3]. In this paper, we study the confinement time for single particle electron as a function of Coil current (I), electron energy (K) and the distance of pair coils (coil spacing) for low beta Polywell device. These calculations have been done with simulation by Comsol Multiphysics software.

* Corresponding author.

Theoretical approach

The magnetic fields were calculated from the Biot-Savart law with contributions summed over each coil

$$B = \frac{\mu_0 I}{4\pi} \sum_{\text{Coils}} \int \frac{dl \times r}{r^3} \tag{1}$$

the magnetic fields are time varying, So E, which is calculated from the magnetic vector potential, A is:

$$E = -\frac{dA}{dt} \tag{2}$$

$$A = \frac{\mu_0 I}{4\pi} \sum_{\text{Coils}} \int \frac{dl \times r}{r} \tag{3}$$

We assumed that the confinement time scale is small compared to the rate of change of current in the coils, such that the E and B fields were approximately constant. From the Lorentz force, the radial position, R, of an electron within the device is given by [4]

$$R = R_0 + r_g \sin(\varphi_0 + \omega_c \Delta t)\hat{e}_1 - (r_g \cos(\varphi_0 + \omega_c \Delta t) - \frac{E}{B}\Delta t)\hat{e}_2 + v_{\|}\Delta t\hat{e}_3 \tag{4}$$

Here, Δt is a small time interval, ω_c is the cyclotron angular frequency, r_g is the gyro-radius, $v_\perp$ and $v_{\|}$ are the velocity components perpendicular and parallel to the direction of the local magnetic field, respectively, and R0 and φ_0 are the initial position and phase,

http://dx.doi.org/10.1016/j.rinp.2016.11.003
2211-3797/© 2016 The Authors. Published by Elsevier B.V.

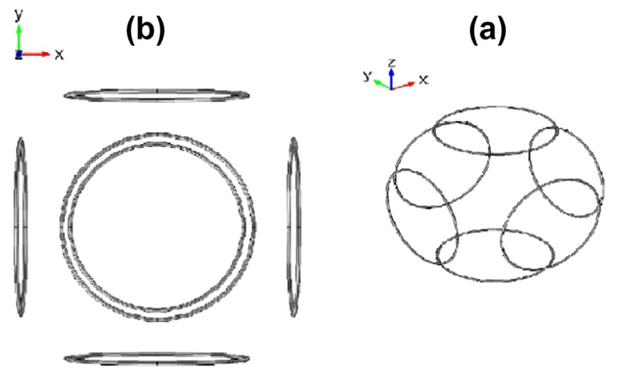

Fig. 1. (a) Je_Kollasch polywell Model designed and simulated by Comsol Multiphysics software. (b) From another view.

respectively, which were both determined by the initial conditions. The unit vector along the magnetic field direction is given by $\hat{e}_3$ and $\hat{e}_1$ is the resultant unit vector perpendicular to $\hat{e}_3$. The unit vector, $\hat{e}_2$, is in the direction of $\hat{e}_1 \times \hat{e}_3$. The co-ordinates used in this derivation were chosen such that $\hat{e}_1$ and $\hat{e}_3$ define the direction of the local x and z axes, respectively. The electron velocity is obtained from time derivative of Eq. (4):

$$v = v_\perp \cos(\varphi_0 + \omega_c \Delta t)\hat{e}_1 + (v_\perp \sin(\varphi_0 + \omega_c \Delta t) - \frac{E}{B})\hat{e}_2 + v_\parallel \hat{e}_3 \quad (5)$$

were $v_\perp = r_g \omega_c$ [3,4] .

Comsol multiphysics

COMSOL Multiphysics® is a general-purpose software platform, based on advanced numerical methods, for modeling, simulating

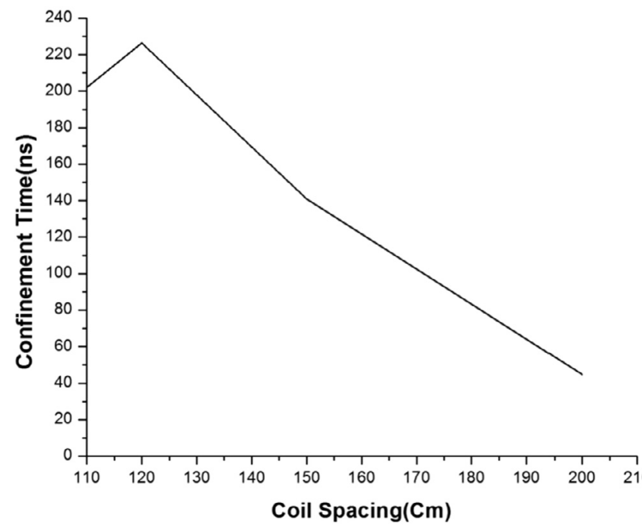

Fig. 3. Polywell confinement time based on different coil spacing.

and scientific and engineering problems. COMSOL Multiphysics, enable to account for coupled or multiphysics phenomena, also further expanding the simulation platform with dedicated physics interfaces and tools for electrical, mechanical, fluid flow, and chemical applications. COMSOL is a flexible platform that allows users to model all relevant physical aspects of their designs. Advanced users can go deeper and use their knowledge to develop customized solutions, COMSOL gives you the confidence to make the model you want with real-world precision. Certain characteristics of COMSOL become apparent with use. Compatibility stands

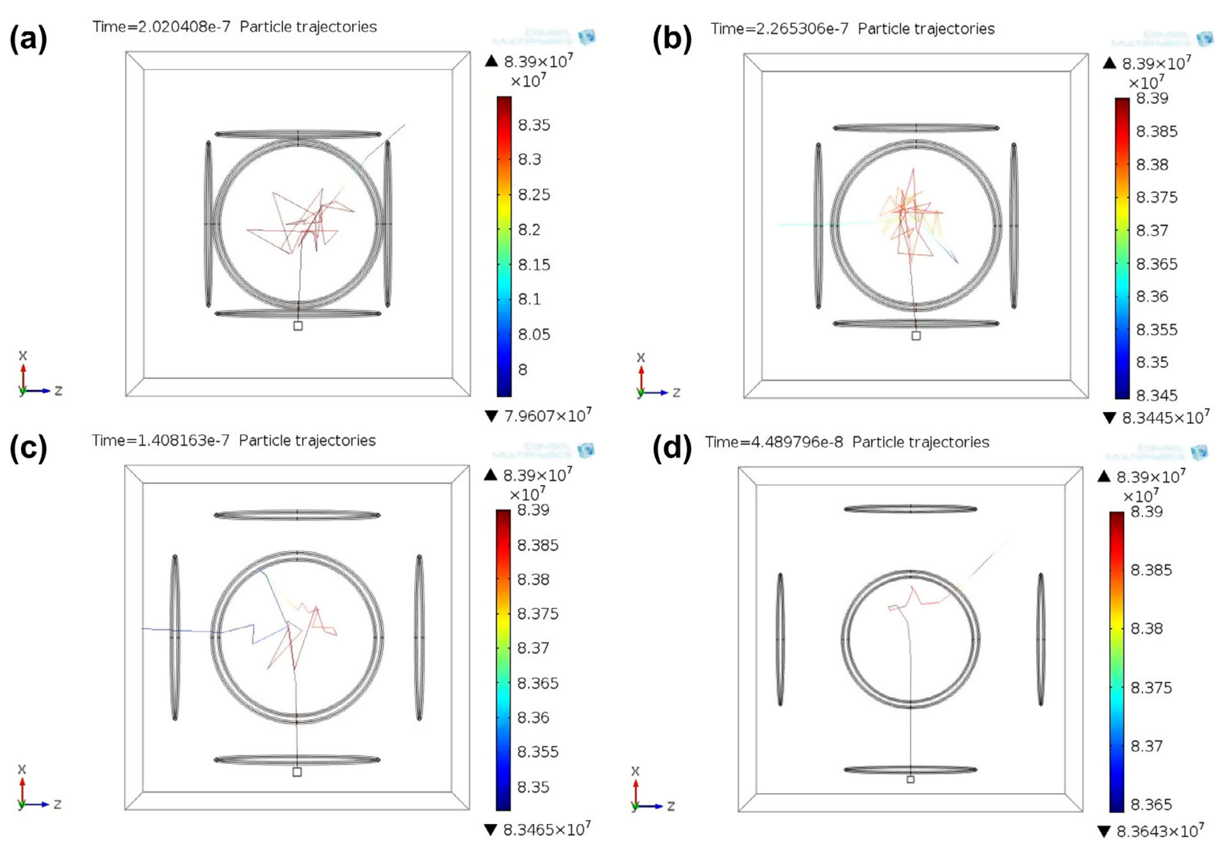

Fig. 2. Particle trajectory simulated by Comsol Multiphysics with different coil spacing (a) 110 cm (b) 120 cm (c) 150 cm (d) 200 cm.

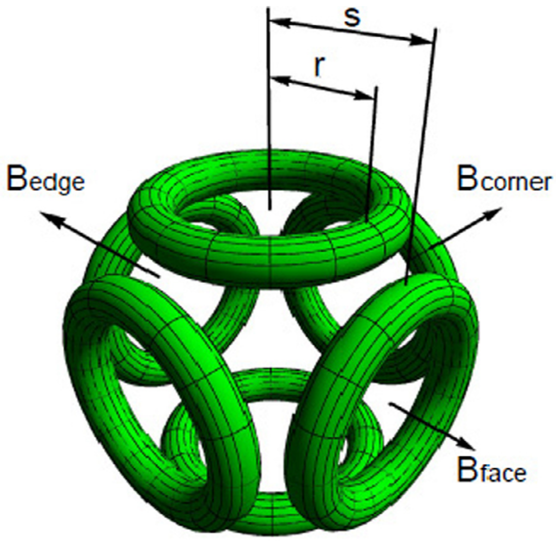

Fig. 4. Shows the parameters of S, r, B_{corner}, B_{face} and B_{edge} [2,8].

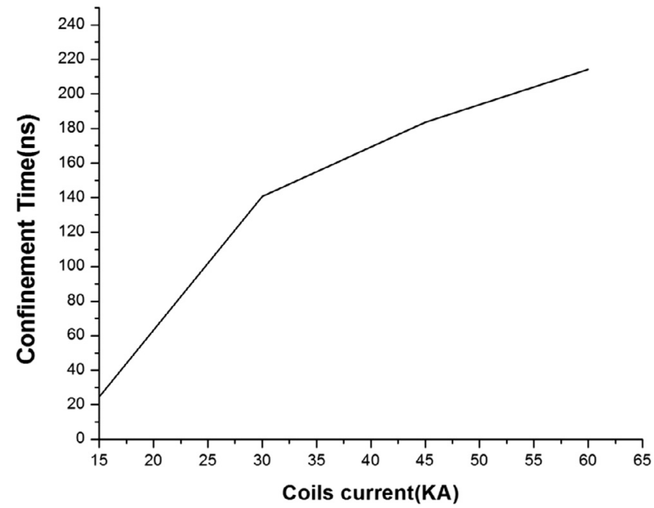

Fig. 6. Polywell confinement time based on different coil current.

out among these. COMSOL requires that every type of simulation included in the package has the ability to be combined with any other. This strict requirement actually mirrors what happens in the real world. Also it is adaptable with other softwares. If you need of including another physical effect it can be added. If one of the inputs to your model requires a formula, you can just enter it. Using tools like parameterized geometry, interactive meshing, and custom solver sequences, you can quickly adapt to the ebbs and flows of your requirements. Comsol Multiphysics can be installed on windows, Linux and Mac OS X [5,6].

Simulation and results

In this paper, we simulated the low-density polywell Based on Je_Kollasch Model [7] by Comsol Multiphysics software. According to Fig. 1, each coil radius is 50 cm, Coil spacing is 150 cm. Each coil

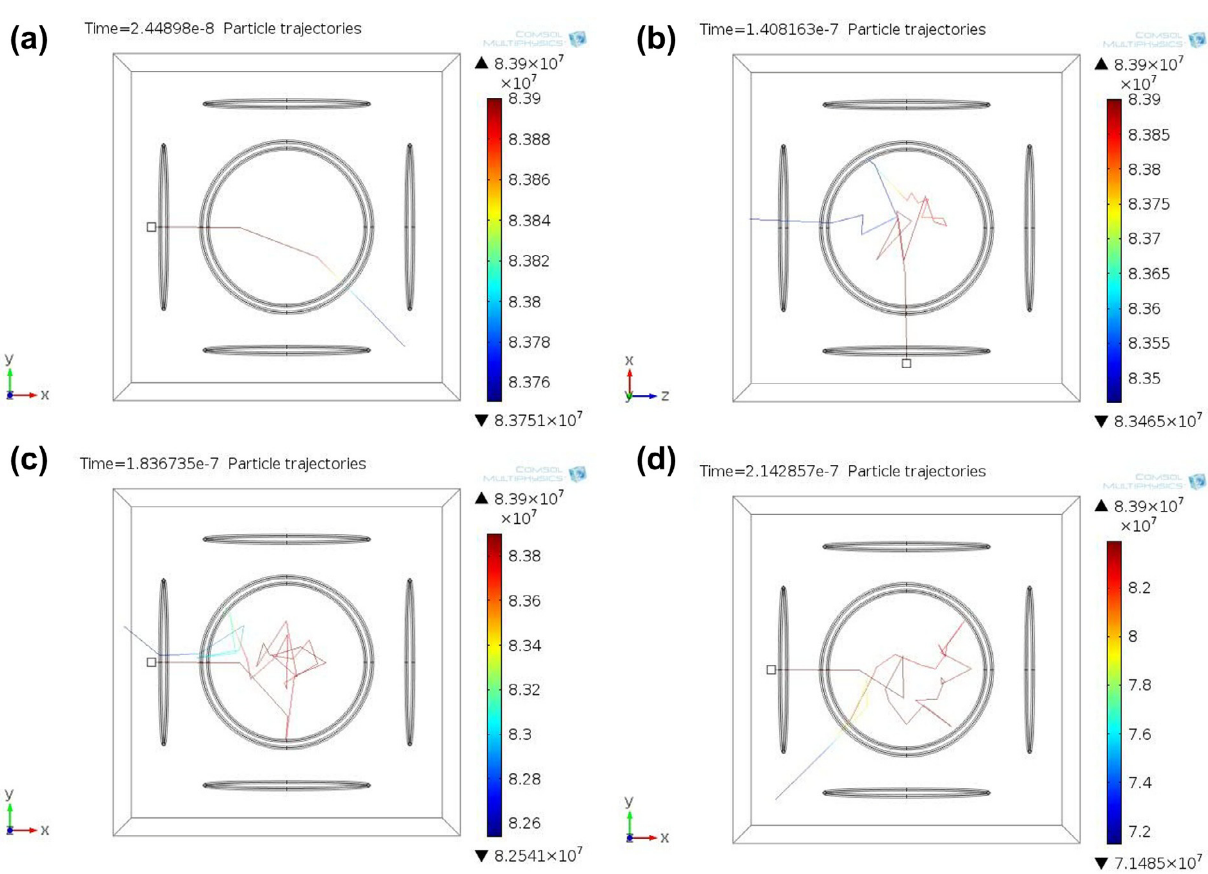

Fig. 5. Particle trajectory simulated by Comsol Multiphysics with different coil current (a) 15 KA (b) 30 KA (c) 45 KA (d) 60 KA.

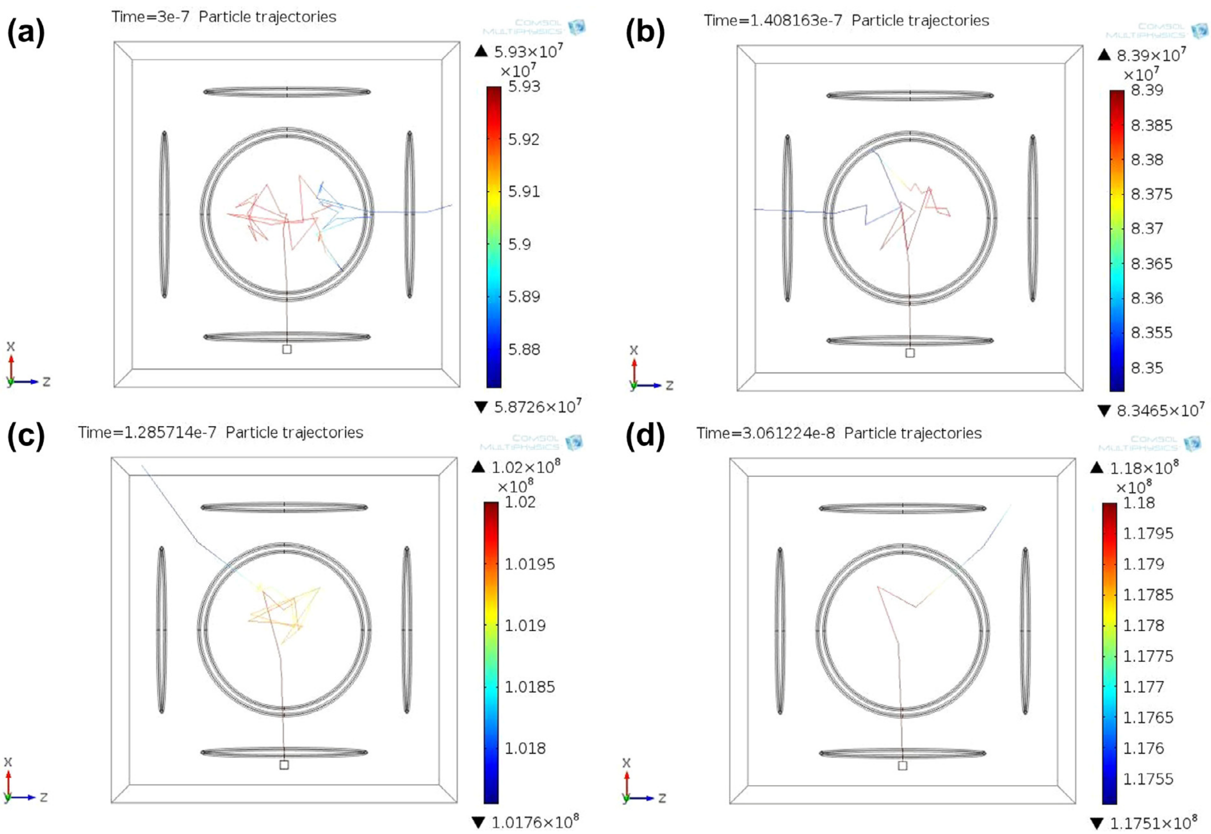

Fig. 7. Particle trajectory simulated by Comsol Multiphysics with different electron injection energy (a) 10 keV (b) 20 keV (c) 30 keV (d) 40 keV.

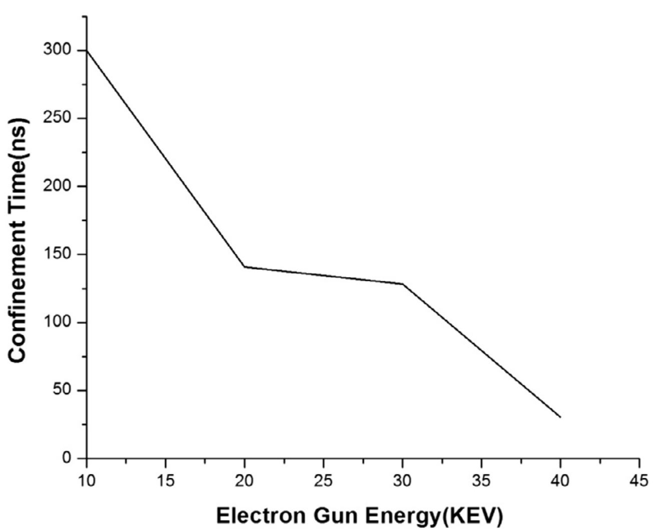

Fig. 8. Polywell confinement time based on different electron injection energy.

loop has the 30 KA current. Electron Injection source is a 5 cm upward shift with 20 keV energy [5]. Also, we study the effect of coil current, coil spacing and electron injection energy variations on confinement time.

Figs. 2 and 3 shows that confinement time depends on coil spacing. 4models were designed with different coil spacing of 110 cm, 120 cm, 150 cm, and 200 cm. The confinement time decreases by increasing the coil spacing. But in 120 cm spacing, we have the best confinement (s = 60, r = 50. when "S" is 1.2 times "r", $B_{face} = B_{corner}$ and B_{edge} is an order of magnitude larger than both which is the ideal spacing for confinement (Fig. 4) [2,8].

4 models were simulated with the different coils current 15 KA, 30 KA, 45 KA, 60 KA. Based on the Figs. 5 and 6, the confinement time enhancement depends on the coils current increase.

Also, 4 Models of polywells with different electron injection energy were simulated. The results of confinement time upon to electron injection with the energy of 10 keV, 20 keV, 30 keV, and 40 keV are shown in Figs. 7 and 8. Based on the figures, the confinement time is decrease by the electron injection energy increasing.

Conclusions

In this paper, we have simulated the low beta Polywell. Then, we examined the effects of coil spacing, coils current, electron injection energy on confinement time. Based on results, we can conclude that particle confinement time strongly depends on coil spacing, coil current, and electron injection energy. Generally, the confinement time increases by increasing the coils current, decreasing the coil spacing and electron injection energy.

References

[1] Miley George H, Krupakar Murali S. Inertial electrostatic confinement (IEC) fusion. New York: Springer Science+Business Media; 2014.
[2] Carr Matthew, Gummersall David, Cornish Scott, Khachan Joe. Phys. Plasmas 2011;18:112501.
[3] Gummersall David V, Carr Matthew, Cornish Scott, Kachan Joe. Phys Plasmas 2013;20:102701.
[4] Chen F. Introduction to plasma physics and controlled fusion. Plenum press; 1984.
[5] Comsol Multiphysics software users guide (version 4.3); 2012.
[6] Comsol Installation and operation guide (Version 4.3); 2012.
[7] Je Kollasch, Carl Sovinec, John Santarius. Vlasov-Poisson calculations of electron confinement times in Polywell devices using a steady-state particle-in-cell method. In: 2014 US-Japan workshop at UW-Madison.
[8] Matthew Carr, Joe Khachan, Conventional point cusp theories applied to the polywell, The university of Sydney