NUMERICAL STUDIES OF MAGNETIC FIELD DYNAMICS IN HEMISPHERICAL ELECTRODES PLASMA FOCUS

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ABSTRACT

This study is aimed to numerically and experimentally investigate the magnetic field dynamics in hemispherical electrodes plasma focus. We have initiated the numerical magnetic field propagation by finite difference approach with Taylor expansion for the purpose of each distribution to plasma focus medium but not specified for hemispherical electrodes design. Although the magnetic field profile is still in arbitrary numbers, this model can simply be used to compare with the experimental results. The absorption and attenuation of magnetic field are affected by the plasma medium mainly the production of electron and charged particle movement. However, the code generated for magnetic field attenuation is assumed for dimension and time dependant only.

Keyword*: plasma focus, magnetic field dynamics, hemispherical electrodes*

INTRODUCTION

Dense Plasma Focus (DPF) is a high-voltage high-current pulsed device belonging to a class of pinches (V.A Gribkov, *et al*, 2008) specifically the dynamic Z-pinches family. The term prefix Z means that a plasma column constricts at the z-axis under influence of a magnetic field induced by the axial current flowing through plasma (M.Scholz, *et al*, 2004). Dense plasma focus device are among the brightest representatives of a wide class of systems which are based on Z-pinch phenomenon (V.I Krauz, 2006). The phenomenon of plasma pinching in Z-pinch discharge of a special design has been revealed by Filipov of the Kurchatov Institute in 1954 and has played a key-role in Z-pinch research development on the whole. A similar phenomenon of plasma focusing near the end face of an internal electrode was independently discovered by Mather in Los-Alamos Laboratory in 1961. In some modifications, this chamber may have a built-in gas generator with a heater, which releases gas after its heating. Because of the construction of its discharge chamber, the device is known in three configurations of electrodes as shown in Figure 1. Two of them are named after their inventors; Filippov and Mather type.

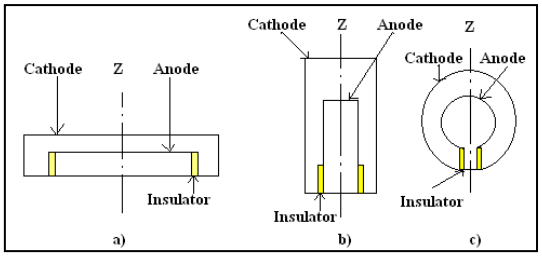


Figure 1: Three types of DPF electrodes configurations: Filippov (a), Mather (b) and Sarov (c) (V.A Gribkov *et.al*,2008)

Figure 1 (a) shows the Fillipov type plasma focus. It was designed Kurchatov Institute for Atomic Energy, Moscow, Russia. It has a flat anode of the disc shape lying directly on the upper edge of a ring-like insulator and a cathode which looks like a pan turned upside down and covers the anode from the top (V.A Gribkov *et.al*,2008). Mather type plasma focus is shown in Figure 1 was elaborated in the Los-Alamos Scientific Laboratory, USA, and has an anode in the shape of a tube, and it encircles the anode tube at its lower end. This construction has a lower diameter compared with Filippov's design and a longer height (V.A Gribkov *et.al*,2008).

The third configuration in Figure 1 was elaborated in the Scientific Research Institute of Experimental Physics, Sarov, Russia, by Dr. N.G Makeev. It has anode and cathode both of spherical shape embedded into one another concentrically. The insulator in this type of plasma focus is a tube enclosing a cylindrical part of the anode which supports its spherical part (V.A Gribkov *et.al*, 2008).

The use of spherical electrodes made the chamber design more compact in comparison with Filippov and Mather chambers. Moreover, such an electrode system provides both the sufficiently long phase of plasma current sheath acceleration in the coaxial gap and the fast radial convergence of the sheath toward the axis (MAA Al-Halim, 2010). For spherical PF chambers, the discrepancy between the simulation results and experimental data of the neutron yield is somewhat larger.

The mechanism for generating charged particles in plasma in the presence of a magnetic field is considered in the framework of an MHD description of the plasma in all the stages. This mechanism operates under definite conditions and is generally similar to the electric field of electrons (S.F Garanin *et al*, 2008). It is well known that electrons with sufficiently high energies are accelerated without limit by an electric field because the Coulomb drag force exerted on a fast electron by ions and other electrons is a decreasing function of its velocity. However, for ions whose velocities are much lower than the electron thermal velocity$V_{TE} = \overline{T_e \ m_e}$and for the

classical resistivity caused by Coulomb collisions, the force exerted by the electron is equal to the electric force and proportional to magnetic field. Therefore, the net force acting on an ion is zero. In addition, each ion is subject to the drag force exerted by other ions (though, for fast ions, this force can be small because it is a decreasing function of the ion velocity), while the forces exerted by electrons are proportional to the velocity of a test ion.

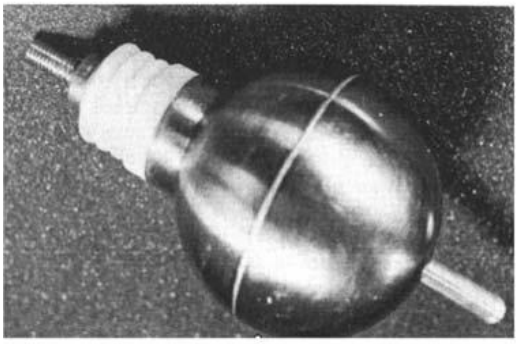
The magnetic field is assumed to be weak enough to not prevent ion acceleration by the electric field. For a plasma focus, this condition is valid near the axis, where the magnetic field is zero. In this case, ion acceleration is limited by the electron drag force, which increases with increasing ion velocity. However, if the electric force *eE* acting on an ion exceeds the maximum drag force exerted by the plasma electrons, then some ions can be accelerated without limit, similar to runaway electrons.

Based on the model of the acceleration mechanism, magnetic field dynamics in a plasma focus is calculated by using a newly developed MHD code for hemispherical electrodes of plasma focus.

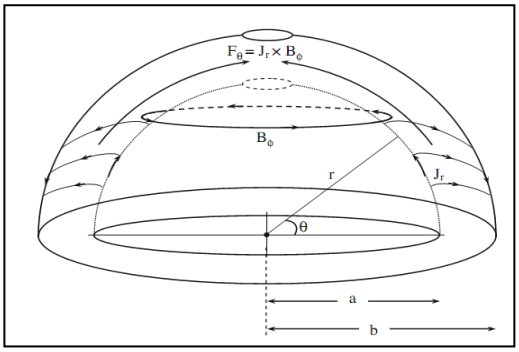
SPHERICAL PLASMA FOCUS

At Russia research institute of experimental physics (VNIIEF), a new type of PF chamber, the so called spherical PF chamber (SPFC), has been developed. It has anode and cathode bothof spherical shape embedded into one another concentrically. An insulator is a tube enclosinga cylindrical part of the anode which supports its spherical part. The use of spherical electrodes made the chamber design more compact in comparison with Filippov and Mather chambers.

The spherical plasma focus device (SPF) is a specialcase between Mather and Filippov configurations. SPFsmachines were suggested for the first time in Russianlaboratories by Makeev in 1996 parallel withEgyptian researches in laboratories of the EAEA (EgyptianAtomic Energy Authority) in 1996.For spherical PF chambers, the discrepancy between the simulation results and experimental data of the neutron yield is somewhat larger. The simulation geometry was similar to the geometry of the SFC-2 chamber (MAA Al-Halim, 2010).



(a)



(b)

Figure 2 (a): Russian spherical plasma focus (MAA Al-Halim, 2010)
(b): Schematic diagram and sheath motion in the SPF device
(MAA Al-Halim, 2010)

The aim of this study is to construct a simulation modelwhich can describe the motion of plasma sheath betweentwo concentric hemisphere electrodes (MAA Al-Halim, 2010). The plasma sheathvelocity and temperature is to be calculated. The dischargecurrent and voltage is to be drawn as a function of thedischarge time. The results of this model are to be comparedwith other results of the other model that designed byLee (S. Lee, 1985) for the cylindrical geometry

MODELLINGOF HEMISPHERICAL ELECTRODES PLASMA FOCUS

A new model has been developed for hemisphere electrodes (MAA Al-Halim, 2010) which describe the motion of plasma sheath between two concentric hemisphere electrodes.After breakdown, the rundown starts with plasmasheath lifting from the insulator surface followed by sheathmotion under the influence of Lorentz force. The streamingvelocity of the plasma is in the $J \times B$ direction.The configuration used where the discharge current J_r flows in the radial direction and the magnetic field is in the azimuth direction so that the Lorentz force, F_θ deflects the sheath to an angle θ. Then finally, the current sheath collapses forming the pinch, which is characterized byextremely high energy density and emission of intenseradiation and high energy particles.

The discharge breakdown starts at insulator forming a plasma sheath, and then the snowplow model is applied to plasma sheath motion. The snowplow model is used to describe the motion of the plasma sheath between two concentric hemispheres (MAA Al-Halim, 2010). Two equations are used during this phase: the equation of motion, which

depends on the rate of the momentum change, and the circuit equation. Values of plasma parameters are obtained by solving these two equations (MAA Al-Halim, 2010).

The force results from the rate of momentum change of the current sheath of mass, m at position θ is given by:

$$F_1 = \frac{d\ mv_\theta}{dt} = \frac{d\ mr\theta}{dt} = \frac{d}{dt}\ \frac{2}{3}\rho f_m \pi\ \ b^3 - a^3\ \ \sin\theta r\theta \qquad (1)$$

So that:

$$F_1 = \frac{2}{3}\rho f_m \pi\ \ b^3 - a^3\ \ \sin\theta r\theta + r\theta^2 \cos\theta \qquad (2)$$

Where b is the outer electrode radius, a is the inner radius, ρ is the initial gas density, $v_\theta$is the tangential velocity, and f_m is the fractions of mass swept by the sheath motion.

When the electromagnetic field is imposed, the magnetic force F_2 exerted on the current sheath is given by,

$$F_2 = \quad PdA = \ \int_a^b \frac{B^2}{2\mu} 2\pi r \cos\theta dr \qquad (3)$$

Where μ is the permeability of space, and the magnetic field B due to the current I at distance r is given by $\frac{\mu I f_c}{2\pi r \cos\theta}$ and $f_c$is the fraction of current flowing in the piston due to the shedding effect.

The magnetic pressure P in Equation 3 is given by:

$$P = \frac{B^2}{2\mu} \qquad (4)$$

And the area A equals to

$$A = \ \int_a^b 2\pi r \cos\theta\ dr \qquad (5)$$

The equation of plasma sheath motion is given by:

$$\theta = \frac{d^2\theta}{dt^2} = \frac{\alpha I^2}{r \sin\theta \cos\theta} - \cot\theta\theta^2 \qquad (6)$$

MAGNETIC FIELD DISTRIBUTION IN PLASMA FOCUS

Hyperbolic partial differential equation for magnetic wave for Figure3 is generally defined as

$$\nabla^2 B = \frac{1}{c}\frac{\partial B}{\partial t^2}\frac{\partial y}{\partial x}$$

Where B is wave amplitude of magnetic field, and c is wave speed.

Considering boundary condition and initial value can be solved by finite difference approach with Taylor expansion Order 2, which gives

$$X_i = i * \hbar, \text{ where } \hbar = L/m$$

$$t_j = j * \hbar\ , \text{ where } \hbar = time\ step$$

Then,

$$\frac{\partial}{\partial t}\frac{\partial B}{\partial t} = \frac{B\ X_i,t_{j+1}\ -2B\ X_i,t_j\ +B\ X_i,t_{j-1}}{\hbar^2}$$

And

$$\frac{\partial}{\partial X}\frac{\partial B}{\partial X} = \frac{B\ X_{i+1},t_j\ -2B\ X_i,t_j\ +B\ X_{i-1},t_j}{\hbar^2}$$

By rewriting the index (i,j) instead of (X,Y) then,

$$\frac{B_{i,j+1}-2B_{i,j}+B_{i,j-1}}{\hbar^2} - c^2\frac{B_{i+1,j}-2B_{i-1,j}}{\hbar^2} = 0$$

Let

$$\lambda = e\hbar/\hbar$$

Then

$$B_{i,j+1} - 2B_{i,j} + B_{i,j-1} - X^2 B_{i+1,j} + 2\lambda^2 B_{i,j} - \lambda^2 B_{i-1,j} = 0$$

By approximation of B to B (X_i, tj_{+1})

$$B_{i,j+1} = 2\ 1-\lambda^2\ B_{i,j} + \lambda^2\ B_{i+1,j} + B_{i-1,j}\ - B_{i,j-1}$$

Using finite difference method of Order 1,

$$\frac{\partial B}{\partial t}\ X_{i,o}\ = \frac{B\ X_i,t_i\ -B\ X_i,0}{\hbar}$$

Then

$$B\ X_i,t_i\ = B\ X_i,0\ + k\frac{\partial B}{\partial t}\ X_i,0 = B\ X_i,0\ + kg\ X_i \quad (9)$$

Or

$$B_{i,1} = B_{i,0} + kg\ X_i \quad (10)$$

where

$$g\ X\ = \frac{\partial B}{\partial t}\ X,0 \quad (11)$$

for $0 \le X \le L$

And $B_{0,j} = V_m, j = 0$ (12)

$$B_{i,0} = f\ X_i \quad (13)$$

Several calculations of magnetic field parameters have been defined and the numerical approach method is also considered. The model of magnetic field profile is not complete yet, however the wave propagation has been determined as shown in Figure 3.

(14)

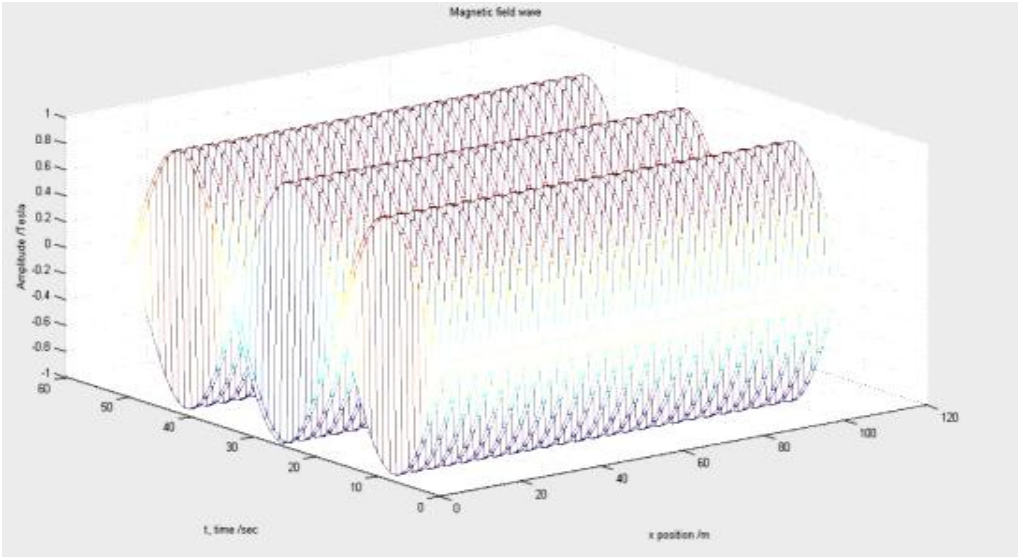


Figure 3: Magnetic field distribution with no absorption and attenuation effect

Figure 3 shows the magnetic field distribution where the period is 18 second to complete the wave group with sinusoidal condition along the plasma medium. The length scale of the dimension is 3 meter over the partition, 50. The wavelength is defined by time step, k multiplied by speed of light, c over the scale length, 3x 10^8 divided over h. Where h is 3/50. At this moment there is no effect of magnetic field to the plasma and vice versa. The magnetic field described is not a resultant from plasma movement along the plasma sheath.

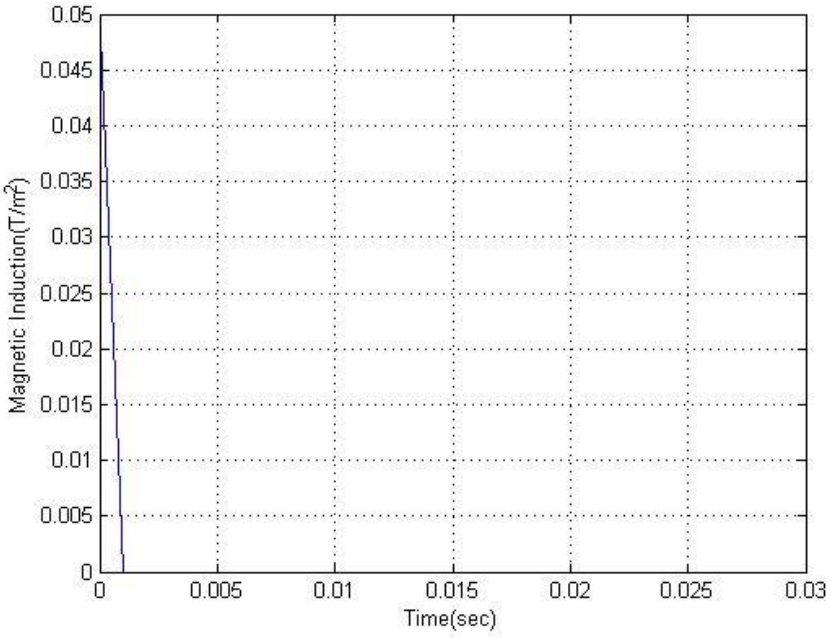


Figure 4: Magnetic field attenuates as effect of position

Figure 4 shows that magnetic field decay rapidly. The magnetic field is exponentially a function of frequency and distance where time is set 0.03 seconds corresponding to distance 0.3 meter. The value of initial magnetic field is set at 0.05 Tesla and frequency, f of 1x10^10 Hz and source wavelength of 1x10^11. This shows that energy of magnetic field is low and particle kinetic energy is more significant rather than magnetic wave. However at initial condition magnetic field is high as effect of current source. This result is not complete yet since some kinetic theory of particle movement is still ignored. The value of magnetic is proportional with current effect and pressure depending with permeability of plasma medium considered.

CONCLUSION

We have initiated the numerical magnetic field propagation by finite difference approach with Taylor expansion for the purpose of each distribution to plasma focus medium but not specified for hemispherical electrodes design. Although the magnetic field profile is still in arbitrary numbers, this model can simply be used to compare with the experimental results. The absorption and attenuation of magnetic field are affected by the plasma medium mainly the production of electron and charged particle movement. However, the code generated for magnetic field attenuation is assumed for dimension and time dependant only.

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