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Trajectories of a dust particle in a magnetic field with magnetic average component

M. Negrea
Department of Physics, Association Euratom-MEdC, Romania,
University of Craiova, 13 A.I.Cuza Str., 200585 Craiova, Romania

Abstract

The dust particles diffusion induced by a magnetic field with magnetic average component and without turbulence is studied. The solutions of the Newton -Lorentz equation of dust particles are obtained for physically relevant parameter values; we obtained also the trajectories for different values of the magnetic average component parameter and the Larmor frequency.

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1 Introduction

One of the most important feature in plasma physics (the impact of dust particles on tokamak walls can create a deterioration of the latter and in consequence it is very important to study the transport of dust grains at the edge of the plasma) and astrophysics is the study of the dust grain in a tokamak and in solar flares [2]. In the current paper we use a magnetic field with a constant magnetic average component specific to astrophysics; in plasma fusion the linear dependence of the magnetic average component term on the radial coordinate is used. In this paper we studied the trajectories of the dust grains influenced by the magnetic average component parameter and by the Larmor frequency.

The paper is organized as follows. The equations of motion for the dust particle in a sheared magnetic field with magnetic average component are established in section 2. In section 3, the velocities and the trajectories for the dust particles were calculated and represented. The conclusions are summarized in section 4.

2 Equations of motion for the dust particle

The electric field is considered to be irrelevant in our analysis and only the unperturbed magnetic field with constant magnetic average component is considered. The Lorentz force is:

$$m\frac{d\mathbf{V}}{dt} = q\left(\mathbf{V}\times\mathbf{B}\right) \tag{1}$$

where the unperturbed magnetic field with magnetic average component is given by the expression:

$$\mathbf{B}\left(\mathbf{X}\right) = B_0\left[\mathbf{e}_z + b_{av}\mathbf{e}_y\right] \tag{2}$$

where $X \equiv (X,\ Y,\ Z)$ and the magnetic average component parameter has the order of magnitude of $b_{av} \in [10^{-3}, 2]$ [3]. The scalar equations corresponding to eq. (1) are:

$$m\frac{dV_x}{dt} = q\left(V_y B_z - B_y V_z\right) \tag{3}$$

$$m\frac{dV_y}{dt} = -q\left(V_x B_z - B_x V_z\right) \tag{4}$$

$$m\frac{dV_z}{dt} = q\left(V_x B_y - B_x V_y\right) \tag{5}$$

The particular choice of the magnetic field, (2) gives the following particular form for system of equations (3- 5):

$$\frac{dV_x}{dt} = \frac{qB_0}{m}\left(V_y - b_{av}V_z\right) \tag{6}$$

$$\frac{dV_y}{dt} = -\frac{qB_0}{m}V_x \tag{7}$$

$$\frac{dV_z}{dt} = \frac{qB_0}{m}b_{av}V_x \tag{8}$$

The magnitude of the magnetic field is:

$$B{=}B_0\left(1 + b_{av}^2\right)^{1/2}$$

and correspondingly the unit vector along the (total) magnetic field $b = B/B$ has the form:

$$\mathbf{b} = \left[\mathbf{e}_z + b_{av}\mathbf{e}_y\right]\left(1 + b_{av}^2\right)^{-1/2}$$

If $b_{av} \ll 1$ than $b \approx e_z + b_{av}e_y$. We use the following dimensionless quantities:

$$\frac{\mathbf{V}}{v_0} = \mathbf{v} \quad , \quad \frac{t}{t_0} = \tau \tag{9}$$

where $v_0 \equiv v_{th} \simeq 10^3 ms^{-1}$, $\ t_0 \equiv t_s \simeq 10^4\,\text{sec}$. The dimensionless equations that we obtain is:

$$\begin{aligned}
\frac{dv_x}{d\tau} &= \frac{qB_0t_0}{m}\left(v_y - b_{av}v_z\right) \equiv \Omega\left(v_y - b_{av}v_z\right) \\
\frac{dv_y}{d\tau} &= -\frac{qB_0t_0}{m}v_x \equiv -\Omega v_x \\
\frac{dv_z}{d\tau} &= \frac{qB_0t_0}{m}b_{av}v_x \equiv \Omega b_{av}v_x
\end{aligned} \tag{10}$$

We will consider that the masses are in the range from $[10^{-11},\ 10^{-10}]\ kg$ and the electric charges are in the range from $[10^{-14},\ \ 10^{-13}]\ C$ [1]. The order of magnitude of the magnetic field is considered to be of order $10\ T$. In the interstellar cloud of dust, i.e. in a nebula, the thermal velocity v_{th} is of order $10^3\ m/s$ and the stopping time $t_0 = t_s$ is of order $10^4 s$ if the dimension of the dust grain is $10^{-2}m$. Ω is considered to be of order $[10, 100]$.

3 The trajectories for the dust particle

In this section we represented the solutions and the trajectories for the dust particle for different values of the Lorentz frequency Ω and the magnetic average component parameter b_{av}. We developed a numerical Matlab code in order to evaluate the sistem of equations (10) . In figure (1) were represented the solutions of the system (10) for $\Omega = 30$ and $\Omega = 60$ and a fixed magnetic average component parameter $b_{av} = 0.5$. We also represented the corresponding trajectories in figure (2). It is obviously that for the same time-interval $\tau \in [0,\ 0.1]$ an increase of the Larmor frequency from $\Omega = 30$ to $\Omega = 60$ gives finally a closed trajectory as we can observe from the figure (2). Correspondingly the number of oscillations of the solutions increase if the Larmor frequency increase as we can observe from figure (1).

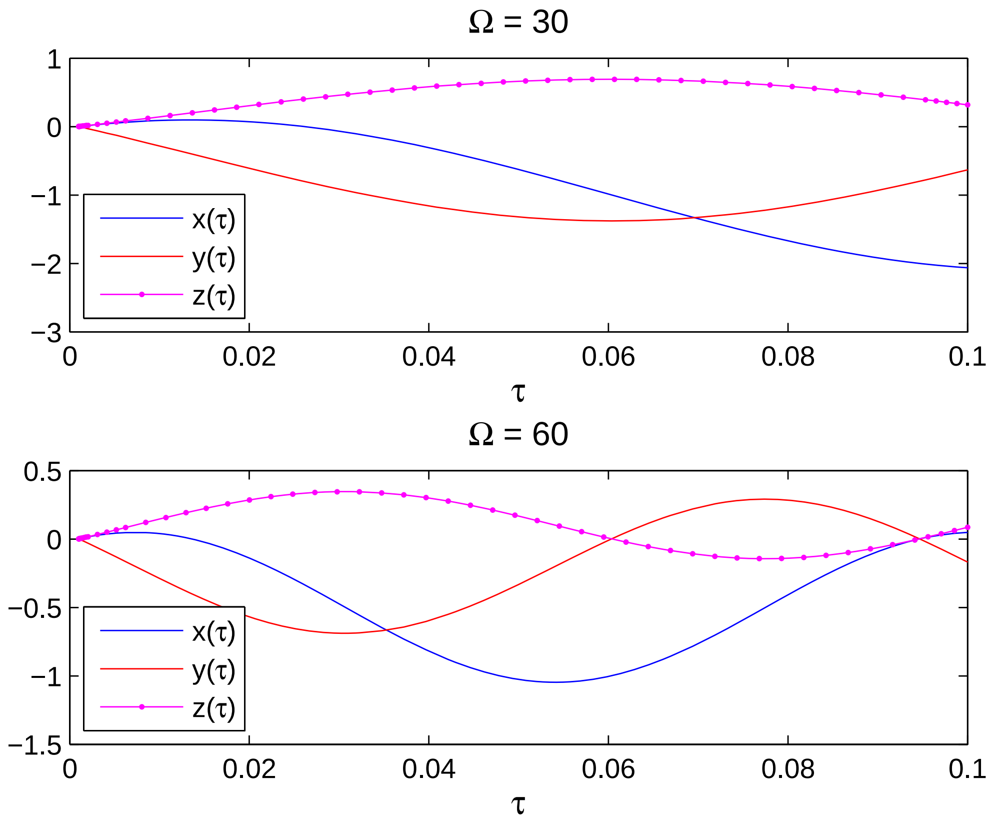

Figure 1: The solutions of the system for $\Omega = 30$ and $\Omega = 60$ and for a fixed magnetic average component parameter $b_{av} = 0.5$.

In figure (3) were represented the solutions of the system (10) for $\Omega = 10$ and $\Omega = 25$ and a fixed magnetic average component parameter $b_{av} = 2.5$. We also represented the corresponding trajectories in figure (4). It is obviously that for the same time-interval $\tau \in [0,\ 0.1]$ an increase of the Larmor frequency from $\Omega = 10$ to $\Omega = 25$ gives finally a closed trajectory as we can observe from the figure (4). Correspondingly the number of oscillations of the solutions increase if the Larmor frequency increase as we can observe from figure (3). .

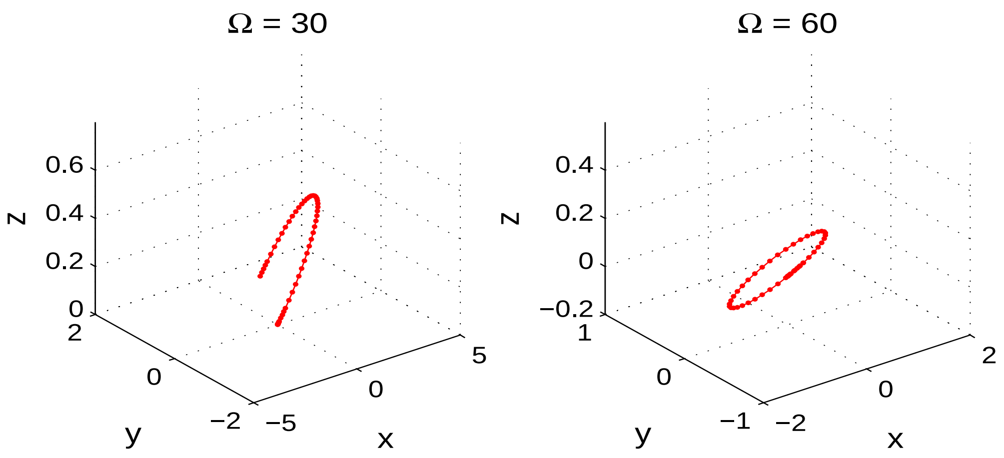

Figure 2: The trajectories for $\Omega = 30$ and $\Omega = 60$ and for a fixed magnetic average component parameter $b_{av} = 0.5$.

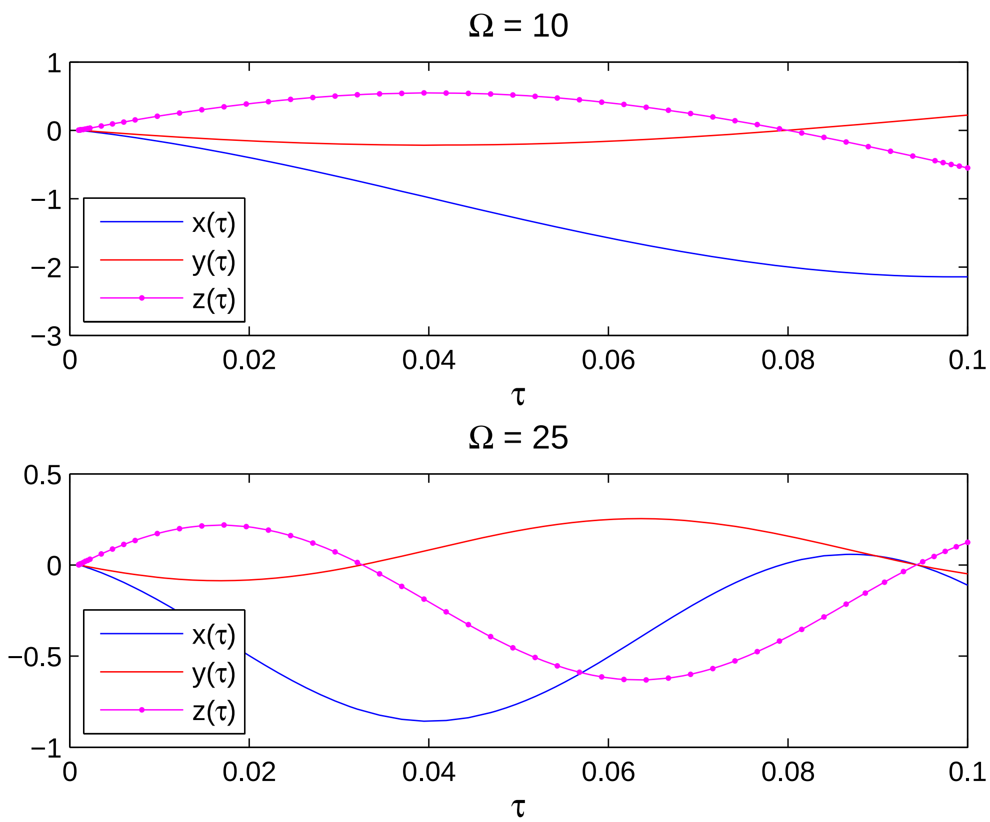

Figure 3: The solutions of the system for $\Omega = 10$ and $\Omega = 25$ and for a fixed magnetic average component parameter $b_{av} = 2.5$.

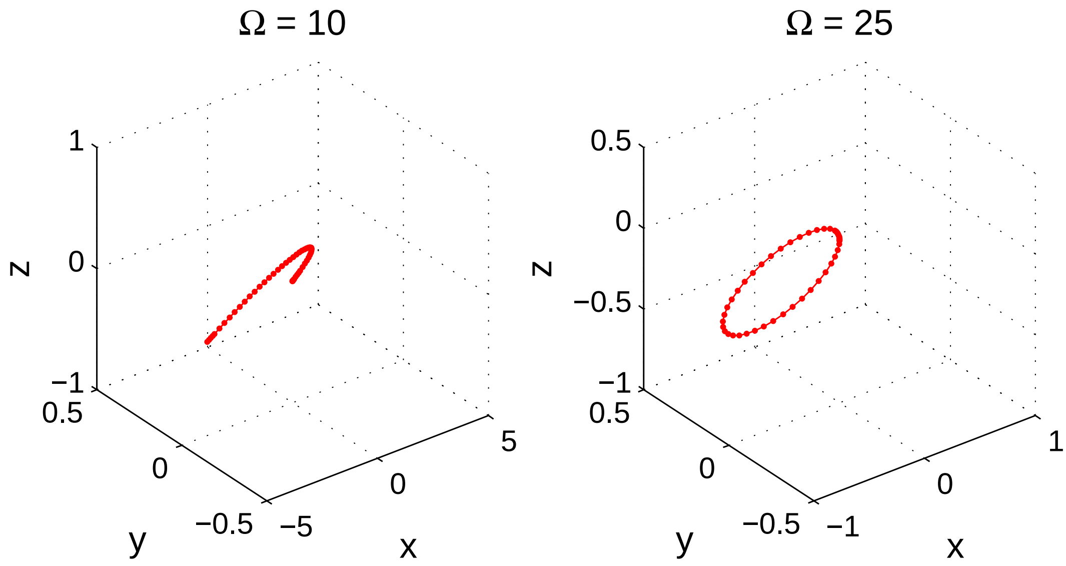

Figure 4: The trajectories for $\Omega = 10$ and $\Omega = 25$ and for a fixed magnetic average component parameter $b_{av} = 2.5$.

4 Conclusions

The dust particles motion was studied and their trajectories were calculated for a class of Larmor frequency and magnetic average component parameter. The increase of the Larmor frequency and of the magnetic average component parameter produce closed trajectories.

Acknowledgments

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