Analysis of Propagation of Hydromagnetic Waves and Jeans Instability of Hall plasma in the Presence of Fine Dust Particles

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Abstract - This paper discusses about the instability of propagating hydromagnetic waves through the gaseous plasma in the presence of fine dust particles and under the influence of Hall effect. A general dispersion relation is obtained with the help of linearized perturbation equations using the normal mode analysis method. It is found that the Jeans condition of the instability of propagating hydromagnetic waves is modified due to the presence of various parameters considered in our gaseous Hall plasma. The finite electron inertia is important in the problem of magnetic reconnection processes.

Keywords - Hall effect, porosity, permeability, finite electron inertia, suspended particles, rotation, thermal conductivity and magnetic field.

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1. Introduction -

In recent years numerous investigators have been carried out an investigation on the various features of Jeans instability of infinite homogeneous gaseous plasma in the presence of various parameters. The Jeans instability is the fundamental concept of modern astrophysical plasma and it is connected with the fragmentation of interstellar matter in regard to star formations. The study of gravitational instability of an infinite homogeneous medium has been first carried out by James Jeans [1] and he shows that an infinite homogeneous self-gravitating fluid is unstable for all wave number which is less than critical Jeans wave number. A detailed contribution of self-gravitational instability with different assumptions on the magnetic field and rotation has been given by Chandrasekhar [2]. In this connection, many investigators have discussed the gravitational instability of a homogeneous gaseous plasma considering the effect of various parameters [3-10].

Along with this, the presence of fine dust particles plays an important role in the interstellar medium. The effects of the presence of fine dust particles, on the onset of Benard convection, on an infinite homogeneous gaseous medium has been investigated by a group of authors lead by Sharma [11], Sharma and Sharma [12], Sharma [13]].

It is clear from the above studies that more of the investigators have investigated the problem of gaseous plasma under the combined effects of viscosity, permeability, thermal conductivity, the presence of fine dust particles, finite electron inertia, Hall effect, porosity and rotation of the medium on the Jeans instability of gaseous plasma. Thus, in the present work, we are motivated to investigate the Jeans instability of gaseous plasma in the presence of finite electron inertia, fine dust particles, viscosity, porosity of the medium and thermal conductivity under the influence of Hall effect.

2. Linearized Perturbation Equations:-

We consider an infinite homogeneous gaseous porous medium incorporating thermal conductivity, viscosity, permeability, Hall effect, rotation and finite electron inertia in the presence of fine dust particles and transverse magnetic field. Linearized Perturbation Equations of the Problem are,

$$\frac{\delta v}{\delta t} = -\frac{\nabla \delta P}{\rho} + \nabla \delta \phi + \frac{k_s N}{\rho}(u-v) + \vartheta\left(\nabla^2 - \frac{1}{k_1}\right)v + \frac{1}{4\pi\rho}(\nabla \times h) \times H + 2(v \times \Omega) \tag{1}$$

$$\varepsilon \frac{\partial \delta\rho}{\partial t} + \rho \nabla . v = 0 \tag{2}$$

$$\delta P = C^2 \delta\rho \quad (3)$$

$$\nabla^2 \delta\phi = -4\pi G \delta\rho \quad (4)$$

$$\left(\tau \frac{\partial}{\partial t} + 1\right) u = v \quad (5)$$

$$\lambda \nabla^2 \delta T = \rho C_p \frac{\partial \delta T}{\partial t} - \frac{\partial \delta P}{\partial t} \quad (6)$$

$$\frac{\delta P}{P} = \frac{\delta T}{T} + \frac{\delta\rho}{\rho} \quad (7)$$

$$\frac{\partial h}{\partial t} = \nabla \times (v \times h) + \frac{C^2}{\omega_{pe}^2} \frac{\partial}{\partial t} \nabla^2 h - \frac{C}{4\pi N e} \nabla \times [(\nabla \times h) \times H] \quad (8)$$

Where,

$v(v_x, v_y, v_z), u(u_x, u_y, u_z), N, \rho, P, \phi, H(0,0,H), \Omega(\Omega_x, 0, \Omega_z), T, G, \vartheta, k_1, \varepsilon, C_p, \lambda, R,$ ω_{pe}, $k_s(6\pi\eta r)$ and $h(h_x, h_y, h_z)$ denote respectively, the gas velocity, the particle velocity, the number density of the particle, density of the gas , pressure of the gas , Gravitational potential, magnetic field, rotation, temperature, Gravitational constant, kinematic viscosity, permeability, porosity, specific heat at constant pressure, thermal conductivity, gas constant, plasma frequency of electron, the constant in the stokes drag formula and the perturbation in magnetic field. $\tau = \frac{m}{k_s}$ is the relaxation time where m is mass of a particle and $mN = \rho_s$ is density of particles.

3. Dispersion Relation -

We analyze these perturbations with normal oscillation technique; we find the solution of equation (1)-(8). In a uniform system, we can find a plane-wave solution with all variables varying as,

$$exp\{i(k_x x + k_z z + \omega t)\} \quad (9)$$

Where k_x, k_z are the wave numbers of perturbation along the x and z-axis so that $k_x^2 + k_z^2 = k^2$ and the frequency of harmonic disturbances, Using (2)-(9) in (1), we obtain the following algebraic equations for the components

$$M_1 v_x - \left(\frac{k_z^2 V^2 k^2 A_3}{A_2} + 2\Omega_z\right) v_y + \frac{i k_x}{k^2} \Omega_T^2 s = 0 \quad (10)$$

$$\left(\frac{k_z^2 k^2 V^2 A_3}{A_2} + 2\Omega_z\right) v_x + M_2 v_y - 2\Omega_z v_z = 0 \quad (11)$$

$$2\Omega_x v_y + d_1 v_z + \frac{i k_z}{k^2} \Omega_T^2 s = 0 \quad (12)$$

The divergence of (1) with the aid of (2)-(9) gives

$$\frac{i k_x k^2 V^2 A_1}{A_2} v_x - \left\{\frac{i k_x k_z^2 V^2 k^2 A_3}{A_2} + 2i(k_x \Omega_z - \Omega_x k_z)\right\} v_y - M_3 s = 0 \quad (13)$$

Where $s = \frac{\delta\rho}{\rho}$ is the condensation of the medium,

$\gamma = \frac{C_p}{C_v} = \frac{C^2}{C'^2}$ ratio of two specific heats, $V = \frac{H}{\sqrt{4\pi\rho}}$ is the Alfven velocity,

$A = \frac{k_s N}{\rho}$ has the dimension of frequency, $\tau = \frac{m}{k_s}$ is the relaxation time,

$\beta = \tau A = \frac{\rho_s}{\rho}$ is the mass condensation, $\sigma = i\omega$ is the growth rate of perturbation,

$\vartheta_k = \vartheta\left(k^2 + \frac{1}{k_1}\right)$, $A_1 = \sigma f$, $f = \left(1 + \frac{C^2 K^2}{\omega_{pe}^2}\right)$, $\theta = \frac{\lambda}{\rho C_p}$ is the thermometric Conductivity,

C and C' are the adiabatic and isothermal velocities of sound.

$$d_1 = \left(\sigma + \vartheta_k + \frac{\beta\sigma}{\sigma\tau + 1}\right), \quad d_2 = \left(\frac{k_z^2 k^2 V^2 A_3}{A_2} + 2\Omega_z\right), \quad d_3 = \left(\frac{ik_x k_z^2 k^2 V^2 A_3}{A_2} + 2iM_4\right),$$

$\Omega_{j'}^2 = \left(C'^2 k^2 - 4\pi G\rho\right)$, $\Omega_j^2 = \left(C^2 k^2 - 4\pi G\rho\right)$ $\Omega_T^2 = \left(\frac{\sigma \Omega_j^2 + \gamma_k \Omega_{j'}^2}{\sigma + \gamma_k}\right)$,

$M_1 = \left(d_1 + \frac{V^2 k^2}{A_1}\right)$, $M_2 = \left(d_1 + \frac{V^2 k_z^2}{A_1}\right)$, $M_3 = \left(\varepsilon\sigma d_1 + \Omega_T^2\right)$,

$M_4 = \left(k_x \Omega_z - \Omega_x k_z\right)$, $A_2 = \left(A_1^2 + A_3^2 k_z^2 k^2\right)$, $\gamma_k = \gamma\theta k^2$, $A_3 = \left(\frac{CH}{4\pi Ne}\right)$

For nontrivial solution of equations (11)-(13), the determinant of the matrix obtained from coefficients $of\ v_x$, v_y, v_z and s should vanish, which gives the following dispersion relation.

$$\left(\sigma d_1 + \frac{\Omega_T^2}{\varepsilon}\right)\left(M_1\, M_2 d_1 + 4\Omega_x^2 M_1 + d_1 d_2^2\right) - \frac{k_x^2 V^2 A_1}{A_2}\frac{\Omega_T^2}{\varepsilon}\left(M_2 d_1 + 4\Omega_x^2\right) - 2\Omega_x k_z \frac{\Omega_T^2}{\varepsilon}\left(\frac{iM_1 d_3}{k^2} + \frac{k_x A_1 d_2}{A_2}\right) + \frac{ik_x}{k^2} d_1 d_2 d_3 \frac{\Omega_T^2}{\varepsilon} = 0 \qquad (14)$$

The dispersion relation (14) shows the combined influence of fine dust particles, thermal conductivity, finite electron inertia, magnetic field, viscosity, porosity, and rotation on the self-gravitational instability of a homogeneous Hall plasma. If we ignore the effect of finite electron inertia then (14) reduces to Chhajlani and Vyas (4). The present results are also similar to those of Chhajlani and Sanghvi (5) in the absence of rotation and finite electron inertia neglecting the contribution of finite Larmor radius (FLR) connection and Hall parameter in that case. In the absence of finite fine dust particles (14) give a similar result as are obtained by Prajapati et al.(6) excluding the effects of arbitrary radiative heat-loss functions, permeability, electrical resistivity and Hall effect in that case.

4. Analysis of the Dispersion Relation -

Now we shall discuss the dispersion relation given by equation (14) for different cases of rotation and propagation as follows.

4.1. Axis of rotation parallel to the magnetic field ($\boldsymbol{\Omega} \parallel \boldsymbol{H}$) -

By taking the axis of rotation along the magnetic field i.e. $\Omega_x = 0$ and $\Omega_z = \Omega$, for the convenience, equations (14) reduces to

$$\left(\sigma\varepsilon d_1 + \frac{\Omega_T^2}{\varepsilon}\right)\left\{M_1\, M_2 d_1 + d_1\left(\frac{k_z^2 k^2 V^2 A_3}{A_2} + 2\Omega\right)^2\right\} - \frac{k_x^2 V^2 A_1}{A_2}\frac{\Omega_T^2}{\varepsilon} d_1 M_2 + \frac{ik_x}{k^2} d_1\left(\frac{k_z^2 k^2 V^2 A_3}{A_2} + 2\Omega\right)\left(\frac{ik_x k_z^2 k^2 V^2 A_3}{A_2} + 2ik_x\Omega\right)\frac{\Omega_T^2}{\varepsilon} = 0 \qquad (15)$$

4.1.1. Longitudinal mode of propagation ($\boldsymbol{K} \parallel \boldsymbol{H}$) -

For this case, we assume that all the perturbations are longitudinal to the direction of the magnetic field. $(i.e.\ \ k_x = 0, \quad k_z = k)$.

Thus the dispersion relation (15) reduces to the simple form to give

$$d_1\left[M_1^2 + \left(2\Omega + \frac{k^4V^2A_3}{A_2}\right)^2\right]\left(\sigma d_1 + \frac{\Omega_T^2}{\varepsilon}\right) = 0 \qquad (16)$$

The dispersion relation given by equation (16) has three factors. We will discuss them separately. In the above dispersion relation, the first factor equated to zero gives,

$$\tau\sigma^2 + \sigma\{1 + \tau(A + \vartheta_k)\} + \vartheta_k = 0 \qquad (17)$$

The second factor equated to zero gives,

$$A_7\sigma^7 + A_6\sigma^6 + A_5\sigma^5 + A_4\sigma^4 + A_3\sigma^3 + A_2\sigma^2 + A_1\sigma + A_0 = 0 \qquad (18)$$

The coefficients in above equation are very lengthy. The constant term is

$$A_0 = k^8\vartheta_k^2A_3^4 + 4\Omega^2k^8A_3^4 + 4\Omega k^8V^2A_3^3 + \ k^8V^4A_3^2$$

The third factor equated to zero gives,

$$\sigma^4\tau + \sigma^3\{1 + \tau(A + \vartheta_k)\} + \sigma^2\left[(\vartheta_k + \gamma_k) + \tau\left\{\frac{\Omega_j^2}{\varepsilon} + \gamma_k(A + \vartheta_k)\right\}\right] + \sigma\left(\frac{\Omega_j^2}{\varepsilon} + \vartheta_k\gamma_k + \tau\gamma_k\frac{\Omega_{j'}^2}{\varepsilon}\right) + \gamma_k\frac{\Omega_{j'}^2}{\varepsilon} = 0 \qquad (19)$$

This is four-degree polynomial equations and shows the combined influence of fine dust particles, porosity, viscosity, rotation, magnetic field, thermal conductivity and heat loss functions in the transverse mode of propagation when the axis of rotation is parallel to the direction of magnetic field.

4.1.2. Transverse Mode of Propagation $(\boldsymbol{K} \perp \boldsymbol{H})$ -

For this case, we assume all the perturbations are transverse to the direction of the magnetic field$(i.e. k_x = k, \quad k_z = 0)$. Thus the dispersion relation (15) reduces to the simple form to give,

$$d_1^2\left[\sigma d_1^2 + d_1\left(\frac{\Omega_T^2}{\varepsilon} + \frac{\sigma k^2V^2}{A_1}\right) + 4\Omega^2\sigma\right] = 0 \qquad (20)$$

This dispersion relation is the product of two independent factors. These factors show the mode of propagations incorporating different parameters as discussed below. The first factor of this dispersion relation is stable mode as discussed in the previous case and the second factor of the dispersion relations (20), after simplification can be written as

$$\sigma^6\tau^2 f + \sigma^5\tau f\{2 + \tau(2A + 2\vartheta_k + \gamma_k)\}$$
$$+ \sigma^4\left[\tau^2 f\left\{\frac{\Omega_j^2}{\varepsilon} + A\gamma_k + (A+\vartheta_k)(A+\vartheta_k+\gamma_k)\right\} + 2\tau f\{1 + (A + 2\vartheta_k + \gamma_k)\}\right]$$
$$+ \sigma^3\left[\tau^2 f\left\{(A+\vartheta_k)\frac{\Omega_j^2}{\varepsilon} + \vartheta_k^2 + \gamma_k\left(\frac{\Omega_{j'}^2}{\varepsilon} + A^2\right)\right\}\right.$$
$$+ \tau\left\{\gamma_k\left(2f\frac{\Omega_{j'}^2}{\varepsilon} + k^2V^2 + 4\Omega^2 f\right) + (A+\vartheta_k)\left(f\frac{\Omega_j^2}{\varepsilon} + k^2V^2\right) + f\vartheta_k\left(\frac{\Omega_j^2}{\varepsilon} + \vartheta_k\gamma_k + \gamma_k\right)\right\}$$
$$\left. + f(2\vartheta_k + \gamma_k)\right]$$
$$+ \sigma^2\left[\tau^2(A+\vartheta_k)\left(f\gamma_k\frac{\Omega_{j'}^2}{\varepsilon}\right)\right.$$
$$+ \tau\left\{\gamma_k\left(2f\frac{\Omega_{j'}^2}{\varepsilon} + k^2V^2 + 4\Omega^2 f\right) + (A+\vartheta_k)\left(f\frac{\Omega_j^2}{\varepsilon} + k^2V^2 + \vartheta_k + \gamma_k\right) + \vartheta_k f\left(\frac{\Omega_j^2}{\varepsilon} + \vartheta_k\gamma_k\right)\right\}$$
$$\left. + \left(f\frac{\Omega_j^2}{\varepsilon} + k^2V^2 + \vartheta_k + \gamma_k\right) + f\vartheta_k(\vartheta_k + 2\gamma_k)\right]$$
$$+ \sigma\left[\tau\left\{\gamma_k(A+\vartheta_k)\left(\frac{\Omega_{j'}^2}{\varepsilon} + k^2V^2\right) + \vartheta_k\gamma_k f\frac{\Omega_{j'}^2}{\varepsilon}\right\} + \gamma_k\left(f\frac{\Omega_{j'}^2}{\varepsilon} + k^2V^2 + 4\Omega^2 f\right)\right.$$
$$\left. + \vartheta_k\left(f\frac{\Omega_j^2}{\varepsilon} + k^2V^2 + f\vartheta_k\gamma_k\right)\right] + \vartheta_k\gamma_k\left(f\frac{\Omega_{j'}^2}{\varepsilon} + k^2V^2\right) = 0 \qquad (21)$$

This is six degree polynomial equation and shows the combined influence of fine dust particle, thermal conductivity, viscosity, finite electron inertia and porosity.

4.2. Axis of rotation perpendicular to the magnetic field ($\boldsymbol{\Omega \perp H}$):-

In this case, when the axis of rotation is perpendicular to the magnetic field, we put $\Omega_x = \Omega\ and\ \Omega_z = 0$ in the dispersion relation (14) and this gives,

$$\left(\sigma d_1 + \frac{\Omega_T^2}{\varepsilon}\right)\left\{M_1 M_2 d_1 + 4\Omega^2 M_1 + d_1\left(\frac{k_z^2k^2V^2A_3}{A_2}\right)^2\right\} - \frac{k_x^2V^2A_1}{A_2}\frac{\Omega_T^2}{\varepsilon}\left(d_1M_2 + 4\Omega^2\right)$$
$$- 2\Omega k_z\frac{\Omega_T^2}{\varepsilon}\left\{\frac{iM_1}{k^2}\left(\frac{ik_xk_z^2k^2V^2A_3}{A_2} - 2i\Omega k_z\right) + \frac{k_xA_1}{A_2}\left(\frac{k_z^2k^2V^2A_3}{A_2}\right)\right\}$$
$$+ \frac{ik_x}{k^2}d_1\left(\frac{k_z^2k^2V^2A_3}{A_2}\right)\left(\frac{ik_xk_z^2k^2V^2A_3}{A_2} - 2i\Omega k_z\right)\frac{\Omega_T^2}{\varepsilon} = 0 \qquad (22)$$

4.2.1. Longitudinal mode of propagation ($\boldsymbol{K \parallel H}$):-

For this case, we assume that all the perturbations are parallel to the direction of the magnetic field ($i.e.\ k_x = 0,\ \ k_z = k$).

Thus the dispersion relation (22) reduces to the simple form to give

$$d_1\left[M_1\left(\sigma d_1 + \frac{\Omega_T^2}{\varepsilon}\right)M_1 + 4\Omega^2\sigma + \frac{k^8V^4A_3^2}{A_2^2}\left(\sigma d_1 + \frac{\Omega_T^2}{\varepsilon}\right)\right] = 0 \qquad (23)$$

This dispersion relation is the product of two independent factors. These factors show the mode of propagations incorporating different parameters as discussed below. The first factor of this dispersion relation is stable mode as discussed in the previous case and the second factor of the dispersion relations (23) after simplification can be written as

$$\sigma^9 + A_8\sigma^8 + A_7\sigma^7 + A_6\sigma^6 + A_5\sigma^5 + A_4\sigma^4 + A_3\sigma^3 + A_2\sigma^2 + A_1\sigma + A_0 = 0 \qquad (24)$$

The coefficients in above equation are very lengthy. The constant term is

$$A_0 = k^8 A_3^4 \vartheta_k^2 \gamma_k \frac{\Omega_{j'}^2}{\varepsilon} + k^8 V^4 A_3^2 \gamma_k \frac{\Omega_{j'}^2}{\varepsilon}$$

4.2.2. Transverse Mode of Propagation($K \perp H$):-

For this case, we assume all the perturbations perpendicular to the direction of the magnetic field($i.e. k_x = k,\ \ k_z = 0$). Thus the dispersion relation (22) reduces to the simple form to give,

$$d_1\left(d_1^2 + 4\Omega^2\right)\left(M_1\sigma + \frac{\Omega_T^2}{\varepsilon}\right) = 0 \qquad (25)$$

The dispersion relation given by equation (25) has three factors. We will discuss them separately. The first factor of this dispersion relation is stable mode as discussed in the previous case and the second factor of the dispersion relations (25), after simplification can be written as

$$\sigma^4\tau^2 + 2\sigma^3\tau\{1 + \tau(A + \vartheta_k)\} + \sigma^2\left[\{1 + \tau(A + \vartheta_k)\}^2 + \tau\left(2\vartheta_k + \tau 4\Omega^2\right)\right] + \sigma\left[2\vartheta_k\{1 + \tau(A + \vartheta_k)\} + \tau 8\Omega^2\right] + \vartheta_k^2 + 4\Omega^2 = 0 \qquad (26)$$

The third factor equated to zero gives,

$$\sigma^4\tau f + \sigma^3 f\{1 + \tau(A + \vartheta_k + \gamma_k)\} + \sigma^2\left[f(\vartheta_k + \gamma_k) + \tau\left(f\frac{\Omega_j^2}{\varepsilon} + k^2V^2 + f\gamma_k(A + \vartheta_k)\right)\right] + \sigma\left(\frac{\Omega_j^2}{\varepsilon} + k^2V^2 + f\gamma_k\vartheta_k\right) + \tau\gamma_k\left(f\frac{\Omega_{j'}^2}{\varepsilon} + k^2V^2\right) + \gamma_k\left(f\frac{\Omega_{j'}^2}{\varepsilon} + k^2V^2\right) = 0 \qquad (27)$$

This is a four-degree polynomial equation and shows the combined influence of various parameters such as presence of fine dust particles, viscosity, porosity, rotations, magnetic field, thermal conductivity and heat loss functions in the transverse mode of propagation, when the axis of rotation is perpendicular to the direction of magnetic field.

5. Conclusions:-

In this paper, we have studied about the propagating hydromagnetic waves and Jeans instability of infinite homogeneous gaseous plasma under the influence of thermal conductivity, viscosity, permeability, finite electron inertia, the porosity of the medium, rotation, Hall effect in the presence of fine dust particles and transverse magnetic field. The axis of rotation has been taken parallel and perpendicular to the vertical magnetic field and it is further reduced in the longitudinal and transverse mode of propagation. Owing to the inclusion of the thermal conductivity the isothermal sound velocity is replaced by the adiabatic velocity of sound.

The effects of the permeability and viscosity are found to stabilizing the system in both the longitudinal and transverse mode of propagation. In the transverse mode of propagation, we have obtained Alfven mode which is modified by the presence of finite electron inertia, the presence of fine dust particles, porosity, viscosity, permeability and thermal conductivity. In the absence of fine dust particles with some assumptions such as viscosity and rotational parameters are small the rotational parameter is more dominated for a hydromagnetic wave with the period as compared to the period of revolutions of the system.

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