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Kinetic Current Convective Instability in a Non-Uniform Dusty Magneto-Plasma

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Abstract

The kinetic current-convective instability (CCI) excited in a nonuniform dusty magneto-plasma is investigated. We use the dielectric constatnt for electrostatic modes in the presence of currents in plasmas and report the modification of the growth rate and threshold of the CCI by the presence of charged dust grains. Also, we assumed that dust grains are magnetized as well.
Two cases are considered, isothermal and non-isothermal plasmas Density and temperature of plasma components have gradients along the x-direction. In the absence of longitudinal current ($u = 0$) and homogeneous temperature the instability, due to dust, is also excited with maximum growth rate much exceeding that obtained in the case of $u \neq 0$. Gradual increasing of the ion temperature over that of the electrons and a large density gradient leads to reduce the growth of instability in the linear stage.

Keywords: Current Convective instability, Dusty plasma.

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INTRODUCTION

Since the pioneering works of Kadmotsev and Nedospasov [1- 4] , the Current Convective Instability (CCI) – alternatively known as the screw, or rippling mode, or the resistive gradient instability – is still considered to be the most dangerous type of instabilities which affecting strongly the confinement scenario at the edge region and Convective transport in the scrape-off layer of tokamaks [5, 6]. It characterized by a large growth rate, and unlikely to let it exist. CCI showed a great interest, for it may have relevance to tokamak edge turbulent [7,8].

CCI is a modification of the $\vec{E}x\vec{B}$ instability when the field aligned currents are included. The mechanism of CCI can be understood as an effect of the resistivity gradient leading to an extra current (which can be also produced by relative motions of electrons and ions streams in plasma), as a sequence of which the magnetic field lines no longer lag behind the plasma motion.

It is noted that this instability arises during the application of constant longitudinal electric and magnetic fields, is manifested in the excitation of helical density waves, and was discovered in both semiconductor and gas-discharge plasmas. It exists also in fully ionized current-carrying plasma, and its modification exists in many plasma devices where the development of this instability has been studied in detail under a wide spectrum of conditions ranging from the limits of linear-wave excitation to strong turbulence.

CCI can be excited in experiments, in which an intense relativistic electron beam is injected into a cylindrical drift tube filled with a low pressure neutral gas (P>1 torr). The instability occurs when the REB space charge is not neutralized [9].

In space physics, CCI play a crucial rolls. Formation of the irregular structure of the high-latitude upper ionosphere causes CCI. The gradient-current instability of inhomogeneous magneto-active plasma in the approximation of double-fluid MHD is investigated by Myasnikov, et al. [10] and Davies et al. [11]. CCI as applied to auroral ionosphere is investigated by Chaturvedi and Ossakow [12].

In the high-latitude upper ionosphere, in the regions containing large-scale currents flowing in and out of the ionosphere along the magnetic field, the gradient-current instability can lead to the appearance of sheet-like irregularities extended predominantly in the plane passing through the geomagnetic-field and regular plasma-drift velocity vectors [10].

When the inhomogeneity size of the density near the layer surface is much smaller than the field inhomogeneity (a sharp boundary model), the flute and current-convective instabilities of a magnetized plasma layer are arises [13].

Many authors considered the suppression of CCI in non-dusty plasma. For examples, Arsenin considered RF-feedback system [14], Tokar [15] suggested suppression using the radial component of external magnetic field, Huba and Ossakow [16] investigated the influence of magnetic shear on the CCI in the diffuse aurora. Hirose [17] indicated that stabilization of CCI in tokamak is due to toroidicity.

Besides, it is found that [18] the velocity shear stabilizes the short wavelength modes and preferentially excites a long wavelength mode.

The effect of finite current channel width on growth rate of the CCI is investigated by Satyanarayana, et al. [19]. Khalil, et. al. [20] investigated the excitation of ICC in inhomogeneous magneto-active clean plasma. Large density gradient and increasing ion temperature over that of electrons are found to decrease the growth rate of instability.

In this paper, we consider the temperature ratio of electrons to ions, in addition to dust, as mechanisms determine growing or depression of CCI.

In fact, the problem investigated in this paper, CCI in dusty plasma, draw a great intention and interest of many theoretical and experimental researchers [21-25]. Dusty plasmas have become a topic of great interest because they provide an excellent tool for exploring many of the fundamental assumptions used in plasma physics.

These references includes more contemporary context and several physics issues related to CCI. For examples to investigate: (1) instabilities in space dusty plasmas, such as cross-field instabilities in both the ion and dust frequency regimes, with application to space shuttle exhaust plumes and meteor trails, (2) Instabilities in laboratory dusty plasmas, such as ion-dust streaming instabilities in a Collis ional plasmas, and dust acoustic waves and instabilities in strongly coupled dusty plasmas. In fact no clear literatures considered the excitation of CCI in dusty plasma, and we believe this article may be the first.

CCI IN PURE PLASMA

We assume an inhomogeneous plasma temperature and density and both have gradient in x-direction. Let the longitudinal current velocity $\vec{u}$ due to relative motion of electrons and ions streams (i.e., $\vec{u} = \vec{u}_e - \vec{u}_i$) be directed along an applied static magnetic field $\vec{H}_0 = \vec{e}_z H_0$. For kinetic theory, $u < V_{Te}$ and we consider the following frequencies ranges $\omega << \omega_{c\alpha}$, $k_\perp V_{T\alpha} << \omega_{c\alpha}$ and $k_{//} V_{Ti} << \omega < k_{//} V_{Te}$. The kinetic dispersion which describes the inhomogeneous magnetized plasma has the form:

$$1 + \sum_{\alpha=e,i} \left\{ \frac{\omega_{p\alpha}^2}{\omega_{c\alpha}^2} \frac{k_\perp^2}{k^2} + \frac{\omega_{p\alpha}^2}{k^2 V_{T\alpha}^2} \left[1 + i\sqrt{\pi} Z_\alpha W(Z_\alpha) + i\sqrt{\frac{\pi}{2}} \frac{V_{T\alpha}^2}{n_0 |k_{//}| \omega_{c\alpha}} \left[\vec{K} \cdot \vec{\nabla} \right]_Z \frac{n_0}{V_{T\alpha}} W(Z_\alpha) \right] \right\} = 0 \quad (1)$$

where, $k_{//}, k_{\perp}$ are the parallel and perpendicular wave vectors with respect to $\vec{H}_0$ ' $\omega_{c\alpha} = (e_\alpha H_0 / m_\alpha c)$ is the cyclotron frequency for particles of type $\alpha = i, e$ (electrons and ions), $\omega_{p\alpha} = (4\pi e_\alpha^2 n_0 / m_\alpha)$ is the plasma frequency, and $W(Z_\alpha)$ is the probability function; $W(Z_\alpha) = \exp(-Z_\alpha^2)\left[1 + (2i/\sqrt{\pi})\int_0^Z e^{t^2} dt\right]$, $Z_i = \dfrac{\omega'}{\sqrt{2}|k_{//}|V_{Ti}}$, $Z_e = \dfrac{\omega' - \vec{k} \cdot \vec{u}}{\sqrt{2}|k_{//}|V_{Te}}$, $\omega' = \omega - \vec{k} \cdot u$

The operator $[\vec{k} \cdot \vec{\nabla}]_z$ is given by:

$$[\vec{k} \cdot \vec{\nabla}]_z \frac{n_0}{V_{Te}} = -k_\perp \frac{n_0}{V_{Te}} \chi_{ne} \left(1 - \frac{\eta_e}{2}\right)$$

$$[\vec{k} \cdot \vec{\nabla}]_z W(Z_i) = -k_\perp \frac{n_0}{V_{Ti}} \chi_{ni} \left(1 - \frac{\eta_i}{2}\right) W(Z_i) + i \frac{k_\perp n_0}{V_{Ti}} \chi_{ni} \frac{1}{\sqrt{\pi}} \eta_i Z_i \left[1 + i\sqrt{\pi} Z_i W(Z_i)\right]$$

where, $\eta_\alpha = \left(\dfrac{\chi_{T\alpha}}{\chi_{n\alpha}}\right)$, $\chi_{(n,T)\alpha} = \dfrac{\partial}{\partial x} \ln(n,T)_\alpha$, $\omega_{(n,T)\alpha} = \dfrac{k_\perp \chi_{(n,T)\alpha} V_{T\alpha}^2}{\omega_{c\alpha}}$, $V_{T\alpha} = \sqrt{T_\alpha / m_\alpha}$.

Assuming for electrons $Z_e << 1$, hence $W(Z_e) \approx 1$; while for ions we consider $Z_i \le 1$. Besides, if we consider dense plasma $\omega_\alpha >> \omega_{c\alpha}$, and neglecting inertial motion of ions along the magnetic field , i.e., $(k^2 \cos^2 \theta \cdot V_S^2 / \omega'^2) << 1$, $\theta = Cos^{-1} \vec{k} \wedge \vec{u}$, $V_S = \sqrt{T_e / m_i}$ the electron acoustic velocity, then after lengthy not complicated calculations, we can find from (1) the threshold frequency of CCI in pure plasma for different temperature regimes (in this case ω' is pure real $(\omega' = \omega_0)$) as follows:

$$\omega_0 = \frac{2k_{//}^2 V_{Ti}^2}{\omega_{Ti}^2}\left[\frac{T_i}{T_e}\right], \quad \text{at} \quad T_i >> T_e \tag{2}$$

$$\omega_0 = \frac{\omega_{ne}}{1 + k^2 \rho_i^2} \quad \text{at} \quad T_i = T_e \;,\; T_i << T_e \tag{3}$$

ρ_i - ion Larmor radius $(\rho_i = V_S / \omega_{ci})$, ω_{ci} is the ion cyclotron frequency..

The CCI is also characterized by a threshold current velocity $u = u_{cr}$ at different temperature regimes. If L is the plasma range along the external magnetic field, then the following condition is fulfilled $V_{Ti} L << (Z_i \omega_{ci} / \chi_n \chi_T)$. This condition is helpful in order to calculate u_{cr}:

$$|u_{cr}| = \sqrt{2} V_{Te} \left(\frac{T_e}{T_i}\right) Z_0 e^{-Z_0^2} \left[\frac{\omega_{ni}}{\omega_0}\left(1 - \frac{\eta_i}{2}\right) + \frac{T_i}{T_e}\right] \quad \text{for } T_i >> T_e \quad \text{at } Z_0 = \sqrt{1/2} \tag{4}$$

$$|u_{cr}| = \sqrt{1/2}\, \eta_i V_{Ti} Z_0 \quad \text{for } T_i = T_e \quad \text{at } Z_0 = \sqrt{10} \tag{5}$$

$$|u_{cr}| = \sqrt{8} V_{Te} \left(\frac{T_e}{T_i} \right) Z_0^3 e^{-Z_0^2} \qquad \text{for } T_i << T_e \quad \text{at } Z_0 >> 1 \tag{6}$$

Above relations leads to the very interesting inequality.

$$u_{cr}(T_e << T_i) >> u_{cr}(T_e = T_i) >> u_{cr}(T_e >> T_i) \tag{7}$$

Which simply shows that CCI appears faster in hot ion plasma compared to isothermal and hot electron plasma?

EXCITATION OF CCI

Let us find the conditions and growing procedure of such instability. As usual we consider a small perturbation in the frequencies, wave number and current velocity, i.e., we set

$$\omega' = \omega_0 + \Delta\omega, \qquad \Delta\omega = \omega_k + i\gamma_k, \quad u = u_{cr} + \Delta u \quad , \quad k = k_0 + \Delta k$$

where ω_k and γ_k are the frequency and growth rate of instability respectively.

Accordingly, after lengthy calculation, we obtain the growth rates of CCI for different temperature regimes as follows:

$$\gamma(T_e >> T_i) = \sqrt{\frac{\pi}{2}} \frac{|\omega_{ne}|}{\left(1 + k^2\rho_i^2\right)^2} \left\{ \frac{u}{V_{Te}} - \frac{|\omega_{ne}|}{|k_{//}| V_{Te}} \cdot \left[\frac{\eta_e}{2} - \frac{k^2\rho_i^2}{1 + k^2\rho_i^2} \right] - \sqrt{2} \frac{T_e}{T_i} Z_{0i} \exp\left(-Z_{0i}^2\right) sign\,\omega_{ne} \right\} \tag{8}$$

$$\gamma(T_e = T_i) = \sqrt{\frac{\pi}{8}} \frac{|\omega_{ne}|}{\left(1 + k^2\rho_i^2\right)^2} \left\{ \frac{u}{V_{Te}} - \frac{|\omega_{ne}|}{|k_{//}| V_{Te}} \cdot \left[\frac{\eta_i}{2} - \frac{k^2\rho_i^2}{1 + k^2\rho_i^2} \right] - \sqrt{\frac{\pi}{8}} \frac{\eta_i |\omega_{ne}| \exp\left(-Z_{0i}^2\right)}{|k_{//}^3| V_{Ti}^3 \left(1 + k^2\rho_i^2\right)^2} \right\} \tag{9}$$

$$\gamma(T_e << T_i) = \sqrt{\pi} \frac{\omega_{Ti}}{\left(1 + T_i/T_e\right)} Z_{0i} \exp\left(-Z_{0i}^2\right) \left[\left(\frac{1}{2} - \frac{1}{\eta_i} \right) - \frac{Z_{0i}^2}{\left(1 + T_i/T_e\right)} \right] \tag{10}$$

It is clear from above relations, that CCI are excited even for plasma with a homogeneous temperature $(\eta_\alpha \to 0)$ and absence of longitudinal current $(u \to 0)$.

To excite CCI the following conditions are satisfied:

$$k^2\rho_i^2 \left(\frac{T_i}{T_e} \right)^{3/2} \left(\frac{m_e}{m_i} \right)^{1/2} \exp\left(Z_{0i}^2\right) \geq 1 \qquad \text{at } T_e >> T_i$$

$$|\omega_{ne}| k^2 \rho_i^2 > 0 \qquad \text{at } T_e = T_i$$

while for the case of hot ion plasma $T_i >> T_e$, we noticed that the growth rate is completely independent from current and the instability is excited when: $\frac{\eta_i}{2} \geq 1 + \frac{\eta_i Z_{0i}^2}{1 + T_i/T_e}$, which restrict existence of ion temperature inhomogeneity.

When calculating the maximum growth rates for the different temperature regimes we get:

$$\gamma_{\max}(T_e >> T_i) >> \gamma_{\max}(T_e = T_i) > \gamma_{\max}(T_e << T_i) \tag{11}$$

This shows that the ratio temperature (T_e/T_i) is a mechanism controlling the excitation and growing of the CCI.

CCI IN AN INHOMOGENEOUS ANISOTROPIC DUSTY PLASMA

We are going here to investigate the effect of dusty plasma on CCI excited in inhomogeneous magnetized plasma. We assume that the current velocity $\vec{u} = \vec{u}_e - \vec{u}_i$, which excites the CCI - due to longitudinal changes in the plasma resistivity or conductivity or the external applied fields - is convected in short range a so that $k_\perp a \approx 1$.

In presence of dust, equation (1) reads:

$$1 + \sum_{\alpha=e,i,d} \delta\varepsilon_\alpha(\vec{k},\omega) = 0, \tag{12}$$

where, $\delta\varepsilon_{\alpha=e,i}(\vec{k},\omega)$ are given by

$$\delta\varepsilon_{\alpha=e,i}(\vec{k},\omega) = \frac{\omega_{p\alpha}^2}{\omega_{c\alpha}^2}\frac{k_\perp^2}{k^2} + \frac{\omega_{p\alpha}^2}{k^2 V_{T\alpha}^2}\left[1 + i\sqrt{\pi} Z_\alpha W(Z_\alpha) + i\sqrt{\frac{\pi}{2}}\frac{V_{T\alpha}^2}{n_0 |k_{//}| \omega_{c\alpha}}\left[\vec{K}\cdot\vec{\nabla}\right]_Z \frac{n_0}{V_{T\alpha}} W(Z_\alpha)\right]$$

while for dust $\delta\varepsilon_d(\vec{k},\omega)$ is given by

$$\delta\varepsilon_d(\vec{k},\omega) = \frac{\omega_{pd}^2}{\omega_{cd}^2} + \frac{\omega_{pd}^2}{k^2 V_{Td}^2}\left[1 + i\sqrt{\pi} Z_d W(Z_d)\right] \tag{13}$$

In (13), we considered weakly magnetized dust, and

$$Z_d = \frac{\omega'}{\sqrt{2}|k_{//}| V_{Td}}, \qquad V_{Td} = \sqrt{\frac{T_d}{m_d}}$$

In the frequencies ranges $\omega << \omega_{c\alpha}$, $k_\perp V_{T\alpha} << \omega_{c\alpha}$ and $k_{//} V_{Ti} << \omega < k_{//} V_{Te}$, and for high density plasma, the following condition $\frac{\omega_{pi}^2}{\omega_{ci}^2} >> 1 + \frac{\omega_{pe}^2}{\omega_{ce}^2} + \frac{\omega_{pd}^2}{\omega_{cd}^2}$ is satisfied.

Accordingly for dusty plasma the dispersion relation describes the CCI reads:

$$1 + \frac{T_i}{T_e} - i\sqrt{\frac{\pi}{2}}\frac{u}{V_{Te}}\frac{T_i}{T_e} - \frac{\omega\omega_{Ti}}{2k_{//}^2 V_{Ti}^2} + i\sqrt{\pi} Z_i W(Z_i)\left\{1 - \frac{\omega_{ni}}{\omega}\left(1 - \frac{\eta_i}{2}\right) - \frac{\omega\omega_{Ti}}{2k_{//}^2 V_{Ti}^2}\right\} + \frac{n_d}{n_i}\frac{T_i}{T_d} + i\frac{n_d}{n_i}\frac{T_i}{T_d}\sqrt{\pi} Z_d W(Z_d) = 0 \tag{14}$$

THRESHOLD VALUES

When ω' is pure real, i.e.,$(\omega' = \omega_0)$, the threshold frequencies for different temperature regimes in dusty plasma reads:

$$\omega_0 = W_T\left[\frac{T_i}{T_e} + \frac{n_d}{n_i}\frac{T_i}{T_d}\right] \qquad \text{at } T_i >> T_e \tag{15}$$

$$\omega_0 = W_T\left[1 + \frac{n_d}{n_i}\frac{T_i}{T_d}\right] \qquad \text{at } T_i << T_e \tag{16}$$

$$\omega_0 = W_T\left[2 + \frac{n_d}{n_i}\frac{T_i}{T_d}\right] \qquad \text{at } T_i = T_e \tag{17}$$

where, $W_T = \dfrac{2k_{//}^2 V_{Ti}^2}{\omega_{Ti}}$.

Also, we can derive the threshold current velocity as:

$$|u_{cr}| = \sqrt{2}V_{Te}\frac{T_e}{T_i}\left[Z_0 e^{-Z_0^2} A - \frac{n_d}{n_i}\frac{T_i}{T_d} Z_d W(Z_d)\right] \tag{18}$$

where, $A = \dfrac{\omega_{ni}}{\omega_0}\left(1 - \dfrac{\eta_i}{2}\right) + \dfrac{T_i}{T_e}\left(1 + \dfrac{n_d}{n_i}\dfrac{T_e}{T_d}\right)$

Separating inhomogeneity in density and in temperature, and taking into consideration $\dfrac{n_d}{n_i}\dfrac{T_e}{T_d} << 1$, A reads: $A = B\left[\chi_{ni} - \dfrac{1}{2}\chi_{Ti} + \dfrac{1}{B}\dfrac{T_i}{T_e}\left(1 + \dfrac{n_d}{n_i}\dfrac{T_e}{T_d}\right)\right]$,

$B = \dfrac{k_\perp V_{Ti}^2}{\omega_{ci}\omega_0}$

Herewith, we shall investigate three cases with respect to the relation between the inhomogeneity in density and temperature.

<u>First case</u>: under the condition $B\chi_{ni} << \dfrac{1}{2}\chi_{Ti}B + \dfrac{T_i}{T_e}$, i.e., inhomogeneity in density much less than in temperature.

Accordingly A reads: $A = A_1 = -\dfrac{1}{2}\chi_{Ti}B + \dfrac{T_i}{T_e}$, and we obtain the following expression for the threshold current velocity:

$$|u_{cr}| = \sqrt{2}V_{Te}\frac{T_e}{T_i}\left[Z_0 e^{-Z_0^2} A_1 - \frac{n_d}{n_i}\frac{T_i}{T_d} Z_d W(Z_d)\right] \tag{19}$$

For different temperature regimes, we get from (19):

$$|u_{cr}| = \sqrt{2}V_{Te}\left\lfloor Z_0 e^{-Z_0^2} - \alpha_1 \Re_1 \right\rfloor \qquad \text{where, } \alpha_1 = \frac{T_e}{T_i} = 1,$$

$$|u_{cr}| = \sqrt{2}V_{Te}\left\lfloor Z_0 e^{-Z_0^2} - \alpha_2 \Re_1 \right\rfloor \qquad \text{where, } \alpha_2 = \frac{T_e}{T_i} >> 1,$$

$$\left|u_{cr}\right| = \sqrt{2}V_{Te}\left\lfloor Z_0 e^{-Z_0^2} - \alpha_3 \Re_1 \right\rfloor \qquad \text{where, } \alpha_3 = \frac{T_e}{T_i} << 1,$$

$$\Re_1 = Z_0 e^{-Z_0^2}\frac{\chi_{Ti}B}{2} + \frac{n_d}{n_i}\frac{T_i}{T_d}Z_d W(Z_d)$$

From above relations, we conclude that:

$$u_{cr}(T_e >> T_i) << u_{cr}(T_e = T_i) << u_{cr}(T_i >> T_e) \tag{20}$$

(20) shows that by increasing the electron temperature over that of ions, the CCI appears faster in the dusty plasma.

Second case: under the condition $B\chi_{ni} >> \frac{1}{2}\chi_{Ti}B + \frac{T_i}{T_e}$, i.e., inhomogeneity in density much greater than in temperature.

Accordingly A reads: $A = A_2 = \chi_{ni}B$, and we obtain the following expression for the threshold current velocity:

$$\left|u_{cr}\right| = \sqrt{2}V_{Te}\frac{T_e}{T_i}\left[Z_0 e^{-Z_0^2}A_2 - \frac{n_d}{n_i}\frac{T_i}{T_d}Z_d W(Z_d)\right] \tag{21}$$

For different temperature regimes, we get from (21):

$$\left|u_{cr}\right| = \sqrt{2}V_{Te}\alpha_1 \mathrm{X}, \qquad \alpha_1 = \frac{T_e}{T_i} = 1$$

$$\left|u_{cr}\right| = \sqrt{2}V_{Te}\alpha_2 \mathrm{X}, \qquad \alpha_2 = \frac{T_e}{T_i} >> 1$$

$$\left|u_{cr}\right| = \sqrt{2}V_{Te}\alpha_3 \mathrm{X}, \qquad \alpha_3 = \frac{T_e}{T_i} << 1$$

where, $\mathrm{X} = \left\lfloor Z_0 e^{-Z_0^2}\chi_{ni}B - \Re_2 \right\rfloor$, $\Re_2 = \frac{n_d}{n_i}\frac{T_i}{T_d}Z_d W(Z_d)$.

From these relations, we simply conclude that,

$$u_{cr}(T_i >> T_e) << u_{cr}(T_e = T_i) << u_{cr}(T_e >> T_i). \tag{22}$$

Opposite from first case, (22) shows that by increasing the ion temperature over that of electrons, the CCI appears faster in the dusty plasma.

Third case: under the condition $B\chi_{ni} = \frac{1}{2}\chi_{Ti}B + \frac{T_i}{T_e}$, i.e., inhomogeneity in density and temperature are equal. It is easy to check out that inequality (22) is still valid.

EXCITATION OF CCI IN DUSTY PLASMA

On setting $\omega' = \omega_0 + \Delta\omega$, $\Delta\omega = \omega_k + i\gamma_k$, $u = u_{cr} + \Delta u$, $k = k_0 + \Delta k$ into (1), and separating real and imaginary parts, we get the frequency ω_k and growth rate γ_k of the instability: following relations:

$$\omega_k = W_n W_T Z\ \Psi\left[D W_n W_T - Z(W_n - W_T)\right], \tag{23}$$

$$\gamma_k = W_n W_T \mathrm{Z}\Psi , \tag{24}$$

where,

$$\Psi = \frac{(\mathrm{M} - \frac{\mathrm{T}\alpha}{\mathrm{Z}})}{(W_n - W_T)[W_n W_T D - (W_n - W_T)\mathrm{Z}] + W_n^2 [1 - W_T D]}, \qquad \mathrm{M} = \omega_0 \left[\frac{W_n + W_T}{W_n W_T} \right] - 1$$

$$W_n = \frac{\omega_0^2}{\omega_{ni}} \left(1 - \frac{\eta_i}{2} \right)^{-1}, \quad \mathrm{Z} = \sqrt{\pi} Z_{0i} e^{-Z_{0i}^2}, \quad D = \sqrt{\pi} \frac{n_d}{n_i} \frac{T_i}{T_d} Z_d W(Z_d), \quad \mathrm{T} = -\sqrt{\frac{\pi}{2}} \frac{u}{V_{Te}}, \quad \alpha = \frac{T_i}{T_e},$$

From (24), we can derive the following inequality, which shows the relations between growth rates of CCI in dusty plasma:

$$\gamma_k (T_e >> T_i) >> \gamma_k (T_e = T_i) > \gamma_k (T_e << T_i) \tag{25}$$

which in agreement with the case of pure plasma, relation (11).

Comparing growth rates in both cases, i.e., dusty and clean plasmas, we came to the conclusion that:

$$(\gamma_k)_{dusty} > (\gamma_k)_{clean} \tag{26}$$

CONCLUSIONS

Both the temperature ratio of electrons to ions, and dust, are found to affect strongly the growing or depression of CCI in clear or dusty plasmas. From (11), a good mechanism to depress such instability is to have hot ion plasmas $T_i >> T_e$.

The relation between the inhomogeneity in density χ_n and temperature χ_{Ti}, are found to play a crucial roll via growing or damping of CCI (relations (20) and (22)).

The result (26) shows clearly that dust in plasma leads to excitation of CCI as it increase the growth rate of instability.

The present results, with dust effect, i.e., high growth rate of CCI, leads to in a tokamak edge plasma dust particles can move with high speed and traverse distances comparable to tokamak radii. As a result, transport of dust particles can represents an important mechanism of fluctuations in tokamak edges [26]

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