Investigation of Dust-Ion Acoustic Waves in a Magnetized Collisional Dusty Plasma with Kappa Distribution Function for Electrons

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ABSTRACT— The propagation of arbitrary amplitude dust ion acoustic waves (DIAWs) in a magnetized collisional dusty plasma including hot electrons, with kappa velocity distribution for electrons, warm ions and dust particles has been studied. In the presence of immobile massive dust particulates, DIAWs have been investigated through the Sagdeev pseudo-potential method. It is demonstrated that the amplitude and width of the pseudo-potential are increased with the ion density and also with Directional cosines. It is shown that the behaviors of the amplitude and the width of the wave in terms of all of plasma parameters is similar to the our recently work, and the spectral index has a little effect on the wave.

KEYWORDS: magnetized dusty plasma, Dust ion acoustic waves, Sagdeev pseudo-potential method.

I. INTRODUCTION

Nowadays, the study of dusty plasmas properties has received a great deal of attention both theoretically and experimentally. In the presence of massive and highly charged dust particulates in an usual electron ion plasma new types of waves, such as dust acoustic (DA) waves and dust-ion-acoustic (DIA) waves are excited. These dusts can be regarded as static or mobile particles [1]. The nonlinear waves particularly, the DIA solitary waves (DIASW) have been theoretically investigated by several authors [2-6].

In the most of the above mentioned investigations, Maxwellian or Maxwellian Boltzmann distribution functions have been used. However, a lot of theoretical observations of space plasmas are often characterized by a non- Maxwellian particle distribution function. In these plasmas, superthermal particles which are produced due to the effect of wave particle interaction or external forces. Superthermal plasmas are relativistic pulsar wind, solar wind, magnetosphere, interstellar medium, auroral zone plasmas, plasmas produced during an ultra-intense laser pulse interaction with matter. [7, 8]. These kinds of a plasma, can be characterized by generalized Lorentzian or kappa distribution function [9, 10]. This Lorentzian (kappa) velocity distribution is used to model the electrons in magnetosphere and electromagnetic ion cyclotron waves in equatorial ring protons [11, 12]. Using a kappa distribution for plasma particles, many authors have studied the propagation of ion acoustic waves in a magnetized plasma using Sagdeev potential method. The one dimensional kappa velocity distribution is

$$F_\kappa(v)=\frac{1}{\left(\pi\kappa\theta^2\right)^{3/2}}\frac{\Gamma(\kappa+1)}{\Gamma(\kappa-1/2)}\left(1+\frac{v^2}{\kappa\theta^2}\right)^{-(\kappa+1)} \qquad (1)$$

where θ is the most probable speed (effective thermal speed), related to the usual thermal velocity $V_t = \left(K_B T / m\right)^{1/2}$ by $\theta = \left[(2\kappa - 3)/\kappa\right] V_t$, T is the characteristic kinetic temperature, κ is spectral index and K_B is the Boltzmann constant. The most probable speed, and hence the κ-distribution, is defined for κ>3/2 [7, 8, 11]. Nonlinear propagation of ion acoustic waves in a magnetized plasma, electron acoustic waves in a two temperature electron plasma and linear and nonlinear propagation of these sound waves again with the presence of hot electron component and so on have been already studied [13].

Recently, we have investigated the propagation of dust ion acoustic wave in a dusty plasma in the presence of nonthermal electrons [14]. In this paper, the previous work has been extended with the warm ions and hot electrons. In the second section, the governing basic equations are presented similar to our previous paper [14]. The resultant dispersion relation and as well as the Sagdeev potential are derived in the third section. Finally, the numerical investigations are presented in the last section.

II. BASIC EQUATIONS

The continuity and momentum equations for ions and also Poisson equation are:

$$\partial_t n_i + \nabla \cdot (n_i \mathbf{v}_i) = 0, \qquad (2)$$

$$\partial_t \mathbf{v}_i + \left(\mathbf{v}_i \cdot \nabla\right) \mathbf{v}_i = \frac{e}{m_i}\left(\mathbf{E} + \frac{B_0 \mathbf{v}_i \times \mathbf{e_z}}{c}\right) - \nabla \mathbf{p}_i - m_i n_i \mathbf{v}_i \upsilon, \qquad (3)$$

$$\nabla^2 \varphi = -4\pi\left[-e n_e + e n_i - e z_d n_d\right], \qquad (4)$$

where n_e, n_i, and n_d are electron, ion, and dust densities respectively. $\mathbf{v}_i$, υ, and m_i indicating the ion velocity, collision frequency and its mass. qd $=-$ezd where φ is the plasma potential, z_d is the dust charge number, so that the charge of the dust is given by $qd = -ezd$, with **e** being the elementary charge. Here, electrons are assumed to be kappa distributed and the expression for the electron density is as follows:

$$n_e = \frac{1}{\delta_1}\left(1 - \frac{\varphi}{\kappa - 3/2}\right)^{-(\kappa - 1/2)}, \qquad (5)$$

where, $\delta_1 = \dfrac{n_{i0}}{n_{e0}}$.

We assume that the wave is propagating in the x-z plane. After normalization, the above system of equations is reduced to:

$$\partial_t n + \partial_x (n v_x) + \partial_z (n v_z) = 0 \qquad (6)$$

$$\partial_t v_x + (v_x \partial_x + v_z \partial_z) v_x = -\partial_x \varphi + v_y - \gamma \frac{\partial_x n}{n} + \upsilon v_x \qquad (7)$$

$$\partial_t v_y + (v_x \partial_x + v_z \partial_z) v_y = -v_x - \gamma \frac{\partial_y n}{n} + \upsilon v_y \qquad (8)$$

$$\partial_t v_z + (v_x \partial_x + v_z \partial_z) v_z = -\partial_z \varphi - \gamma \frac{\partial_z n}{n} + \upsilon v_z \qquad (9)$$

$$(\partial_{xx} + \partial_{zz})\varphi = \beta\left[\frac{1}{\delta_1}\left(1 - \frac{\varphi}{\kappa - 3/2}\right)^{-(\kappa - 1/2)} - \delta_1 n + \delta_2\right] \qquad (10)$$

where, $\beta = r_g^2 / \lambda_e^2$, $\delta_1 = n_{i0}/n_{e0}$, $\delta_2 = n_d z_d / n_{e0}$. $r_g = C_s/\Omega$ is the ion gyro radius and $\lambda_e = \left(T_e / 4\pi n_{e0} e^2\right)^{1/2}$ is the electron Debye length. $C_S = \left(T_e / m_i\right)^{1/2}$ is the ion acoustic velocity, and $\Omega = e B_0 / m_i c$ is the ion gyro frequency. n_{e0} and n_{i0} are unperturbed electron and ion densities, respectively.

The normalizations are:

$\Omega t \to t$, $\left(C_s / \Omega\right)\nabla \to \nabla$, $v_i / C_s \to v$,
$n_i / n_{i0} \to n$, and $e\varphi / T_e \to \varphi$,

To derive the dispersion relation for low frequency waves, we write the dependent variables as sum of equilibrium and perturbed parts. Assuming $n = 1 + \bar{n}$, $v_x = \bar{v}_x$, $v_z = \bar{v}_z$, $v_y = \bar{v}_y$, Eqs. (5) - (9) can be rewritten as:

$$\partial_t \bar{n} + \partial_x \bar{v}_x + \partial_z \bar{v}_z = 0 \qquad (11)$$

$$\partial_t \bar{v}_x = -\partial_x \bar{\phi}_x + \bar{v}_y - \gamma \frac{\partial_x \bar{n}}{1+\bar{n}} + \upsilon v_x \tag{12}$$

$$\partial_t \bar{v}_y = -v_x + \bar{\upsilon v}_y \tag{13}$$

$$\partial_t \bar{v}_z = -\partial_z \bar{\phi} - \gamma \frac{\partial_z \bar{n}}{1+\bar{n}} + \upsilon v_z \tag{14}$$

$$(\partial_{xx} + \partial_{zz})\bar{\varphi} = \beta\left[\frac{\kappa - 1/2}{\kappa - 3/2}\bar{\varphi} - \delta_1 \bar{n}\right] \tag{15}$$

We assume that the perturbation is of the form $\exp i(k_x x + k_z z - \omega t)$, where k_x and k_z are the wave numbers in x and z directions, respectively. Hence, the dispersion relation for ion acoustic wave can been obtained as

$$\begin{aligned}&\beta_4(i\omega(\nu+i\omega)^3 + k^2(\nu+i\omega)^2\gamma + i\omega(\nu+i\omega)\\&+\gamma k_z^2 - \delta_1 k^2(\nu+i\omega)^2 - \delta_1 k_z^2 = 0\end{aligned} \tag{16}$$

$$\begin{aligned}&\left(\gamma\nu^2k^2 - (\gamma\omega^2-\gamma)k_z^2 - 3\upsilon^2\omega^2 + \omega^4 - \omega^2\right)\\&-\delta_1\left(\left(\upsilon^2+\omega^2\right)k^2 - k_z^2/\beta_4 + i(2\gamma\upsilon\omega k^2\right.\\&\left.+\upsilon^3\omega - 3\upsilon\omega^3 + \upsilon\omega) - 2\delta_1\upsilon\omega k^2\right) = 0\end{aligned} \tag{17}$$

where $\beta_4 = k^2/\beta + \frac{\kappa-1/2}{\kappa-3/2}$. By assuming $\omega = \omega_r + i\omega_i$, the above equation reads as

$X + iY = 0$, where

$$\begin{aligned}X =\ &\beta_4\left(\left(1+3\upsilon^2\right)\lambda + \gamma k_z^2 + \gamma k^2\left(\upsilon^2+\lambda\right)\right.\\&\left.-\omega_i\upsilon\left(\upsilon^2+1-6\omega_r^2+3\lambda+2\gamma k^2\right)\right)\\&+\delta_1 k^2\left(\upsilon^2 - 2\upsilon\omega_i\lambda\right) - \delta_1 k_z\end{aligned} \tag{18}$$

and

$$\begin{aligned}Y = &-2\omega_r\omega_i k^2\left(1+3\upsilon^2\right)\left(\gamma+\delta_1\right)\\&+\beta_4[\upsilon^3\omega_r - 3\upsilon\omega_r^3 + 9\upsilon\omega_r\omega_i^2\\&+\upsilon\omega_r\left(1+2\gamma k^2\right) + 2\delta_1\upsilon\omega_r k^2\end{aligned} \tag{19}$$

Here $\lambda = \omega_i^2 - \omega_r^2$ introducing a new variable $\eta = l_x x + l_z z - Mt$, where l_x and l_z are directional cosines and M is the Mach number. Equations (5)–(9) can be written as ordinary differential equations in terms of η:

$$\mathrm{M(1-n) + n(l_x}v_x + l_z v_z) = 0 \tag{20}$$

$$\begin{aligned}&-M\frac{dv_x}{d\eta} + \left(v_x l_x\frac{d}{d\eta} + v_z l_z\frac{d}{d\eta}\right)v_x\\&= -l_x\frac{d\varphi}{d\eta} + v_y - \gamma l_x\frac{dn}{nd\eta} + \upsilon v_x\end{aligned} \tag{21}$$

$$\begin{aligned}&-M\frac{dv_y}{d\eta} + \left(v_x l_x\frac{d}{d\eta} + v_z l_z\frac{d}{d\eta}\right)v_y\\&= -v_x\gamma\frac{dn}{nd\eta} + \upsilon v_y\end{aligned} \tag{22}$$

$$\begin{aligned}&-M\frac{dv_y}{d\eta} + \left(v_x l_x\frac{d}{d\eta} + v_z l_z\frac{d}{d\eta}\right)v_y\\&= -v_x\gamma\frac{dn}{nd\eta} + \upsilon v_y\end{aligned} \tag{23}$$

$$\begin{aligned}&-M\frac{dv_z}{d\eta} + \left(v_x l_x\frac{d}{d\eta} + v_z l_z\frac{d}{d\eta}\right)v_z\\&= -l_z\frac{d\varphi}{d\eta} - \gamma l_z\frac{dn}{nd\eta} + \upsilon v_z\end{aligned} \tag{24}$$

Substituting Eq. (19) in Eq. (20), we have:

$$\frac{M}{n}\frac{dv_x}{d\eta} = l_x\frac{d\varphi}{d\eta} - v_y + \gamma l_x\frac{dn}{nd\eta} + \upsilon v_x \tag{25}$$

Using Eq. (19), Eqs. (21) and (20) are rewritten as:

$$\frac{M}{n}\frac{dv_y}{d\eta} = v_x + \upsilon v_y \tag{26}$$

$$\frac{M}{n}\frac{dv_z}{d\eta} = l_z\frac{d\varphi}{d\eta} + \gamma l_z\frac{dn}{nd\eta} + \upsilon v_z \tag{27}$$

$$G(\varphi) = \int_0^{\varphi} n\, d\varphi \tag{28}$$

$$v_z = b_1\varphi + b_2\varphi^2 + b_3\varphi^3 + ... \quad (29)$$

Considering Eq. (23), we get:

$$\frac{1}{2}\left(l_x^2 + l_z^2\right)\left(\frac{d\varphi}{d\eta}\right)^2 = \beta\left[1+\varphi+\frac{\kappa-1/2}{2\left(\kappa-3/2\right)}\varphi^2 - \delta_1 G(\varphi) + \delta_2\varphi\right] \quad (10)$$

Comparing the coefficients of equal powers of φ in Eqs. (26) and (28), up to the second order, one can obtain:

$$\left(\frac{1}{3}\frac{\left(-2\gamma a_1 l_z + Mb_1 - l_z\right)A_2}{\sqrt{A_1}} + \left(-6\gamma a_2 l_z + 2Mb_2 - 2a_1 l_z\right)\sqrt{A_1} - 2a_1\upsilon b_1 - \upsilon b_2\right)\varphi^2 + \left(\left(-2\gamma a_1 l_z + Mb_1 - l_z\right) + \sqrt{A_1} - \upsilon b_1\right)\varphi = 0 \quad (21)$$

III. PSEUDO-POTENTIAL APPROACH

The Eq. (29) can be written as

$$\frac{1}{2}\left(\frac{d\varphi}{d\eta}\right)^2 + V(\varphi) = 0 \quad (32)$$

The above equation is an “energy integral” of an oscillatory particle with unit mass, pseudo-velocity $\frac{d\varphi}{d\eta}$ at the pseudo-position φ in a pseudo-potential well $V(\varphi)$. To obtain an equation for $G(\varphi)$, one can expand $G(\varphi)$ and v_x in terms of φ:

$$G(\varphi) = \varphi + a_1\varphi^2 + a_2\varphi^3 + ... \quad . \quad (33)$$

$$v_x = A\varphi + B\varphi^2 + C\varphi^3 + ... \quad (34)$$

To find the coefficients, one can substitute the Eqs.(31) and (32) in Eq. (29) to get,

$$\left(\frac{d\varphi}{d\eta}\right)^2 = \frac{2\beta}{l_x^2 + l_z^2}\left[\left(1+\delta_1-\delta_2\right)\varphi + \left(\frac{2(\kappa-1/2)}{\kappa-3/2} + 4\delta_1 a_1\right)\varphi^2 + \left(\frac{\kappa^2-1/4}{(\kappa-3/2)^2} - 6\delta_1 a_2\right)\varphi^3 + ...\right], \quad (45)$$

And up to the second order we have

$$\frac{d^2\varphi}{d\eta^2} = A_1\varphi + A_2\varphi^2 = -\frac{dV}{d\varphi} \quad (56)$$

$$\frac{d^2\varphi}{d\eta^2} = A_1\varphi + A_2\varphi^2 = -\frac{dV}{d\varphi} \quad (67)$$

where,

$$A_1 = \frac{\beta}{l_x^2 + l_z^2}\left[\frac{2(\kappa-1/2)}{\kappa-3/2} + 4\delta_1 a_1\right] \quad (38)$$

and

$$A_2 = \frac{\beta}{l_x^2 + l_z^2}\left[\frac{\kappa^2-1/4}{(\kappa-3/2)^2} - 6\delta_1 a_2\right] \quad (79)$$

Eqs. (24) and (25) can be solved as

$$M\frac{dv_x}{d\varphi}\frac{d\varphi}{d\eta} = v_x G'(\varphi) + \upsilon v_y G'(\varphi) \quad (40)$$

$$v_y = l_x\frac{d\varphi}{d\eta} + l_x\frac{\gamma}{G'(\varphi)}\frac{dG'(\varphi)}{d\eta} + \upsilon v_x - \frac{M}{G'(\varphi)}\frac{dv_x}{d\eta} \quad (41)$$

Equating the coefficients in the Eqs. (36) and (37), and expansion of $\left(\frac{d\varphi}{d\eta}\right)$ and substituting in Eq. (39) one can obtains up to second order.

$$
\begin{aligned}
&\left(\frac{10 l_z a_1 b_1}{l_x}-\frac{16 M \upsilon^2 a_1^2}{l_x}-\frac{3 M \upsilon^2 a_2}{l_x}+\frac{\upsilon^2 b_2 l_z}{l_x}\right.\\
&+8 M a_1 l_x A_1+\frac{8 M^3 A_1 a_1^2}{l_x}-\frac{12 M^3 A_1 a_2}{l_x}-\\
&\frac{2 M^3 A_2 a_1}{l_x}-\frac{2 l_z b_2 \sqrt{A_1}}{l_x}-10 \upsilon a_1 l_x \sqrt{A_1}-\\
&\frac{1}{3} \frac{\upsilon l_x A_2}{\sqrt{A_1}}+\frac{M^2 l_z A_2 b_1}{l_x}+\frac{4 M^2 l_z A_1 b_2}{l_x}+\frac{10 \upsilon^2 a_1 b_1 l_z}{l_x}-\\
&12 M \gamma a_2 l_x A_1-2 M \gamma a_1 l_x A_2-\frac{1}{3} \frac{b_1 l_z A_2}{l_x \sqrt{A_1}}+\\
&\frac{16 M^2 \upsilon a_1^2 \sqrt{A_1}}{l_x}+\frac{12 M^2 \upsilon a_2 \sqrt{A_1}}{l_x}-\frac{4 l_z a_1 b_1 \sqrt{A_1}}{l_x}+\\
&16 \gamma \upsilon a_1^2 l_x \sqrt{A_1}+6 \gamma \upsilon a_2 l_x \sqrt{A_1}-12 M \gamma a_1^2 l_x A_1+\\
&\frac{4 M^2 l_z a_1 b_1 A_1}{l_x}+\frac{4}{3} \frac{M^2 \upsilon a_1 A_2}{l_x \sqrt{A_1}}+\frac{2}{3} \frac{\gamma \upsilon a_1 l_x A_2}{\sqrt{A_1}}+\\
&\left.\frac{l_z b_2}{l_x}-\frac{16 M a_1^2}{l_x}+M l_x A_2-\frac{3 M a_2}{l_x}\right) \varphi^2+\\
&\left(-\frac{2 M a_1}{l_x}-\frac{2 M \upsilon^2 a_1}{l_x}+2 \gamma \upsilon a_1 l_x \sqrt{A_1}-\frac{2 M^3 a_1 A_1}{l_x}+\right.\\
&\frac{4 M^2 \upsilon a_1 \sqrt{A_1}}{l_x}+\frac{M^2 l_z b_1 A_1}{l_x}+M l_x A_1-2 M \gamma a_1 l_x A_1+\\
&\left.\frac{\upsilon^2 b_1 l_z}{l_x}-\frac{b_1 l_z \sqrt{A_1}}{l_x}+\frac{b_1 l_z}{l_x}-\upsilon l_x \sqrt{A_1}\right) \varphi=0
\end{aligned}
\tag{42}
$$

The coefficients a_1, a_2, b_1 and b_2 can be determined by solving the Eqs. (30) and (39). From equation (34), as like as [14], we get:

$$\varphi=-\frac{3 A_1}{2 A_2} \sec h^2\left(\sqrt{A_1}\, \eta / 2\right) \tag{43}$$

IV. NUMERICAL INVESTIGATIONS

The above results i.e. Eqs. (35)–(41), show that all coefficients are dependent to the spectral index and all plasma parameters. So for investigating the plasma parameters effects on the wave propagation, we use parameters written in Table 1:

$$\beta=\frac{r_g^2}{\lambda_e^2}\ ,\ \delta_1=\frac{n_{i0}}{n_{e0}}$$

TABLE 1: PLASMA PARAMETERS USED IN NUMERICAL INVESTIGATION.

Plasma parameters	β	δ_1	Mach number (M)	Directional cosines (l_z)	Spectral index (κ)
Range of Values	0.46, 0.49, 0.55	1.54, 2.54, 3.54	2, 2.1, 2.25	0.1, 0.4, 0.58	5/2

The variation of the pseudo-potential versus ion to electron density ratio is shown in Fig. 1. It is seen that the amplitude of *V(φ)* increases with increasing the density ratio. It is concluded that increasing the ion density can lead to higher amplitude waves and also it can be said that for all positive values of φ, *V(φ)* is positive and vice versa.

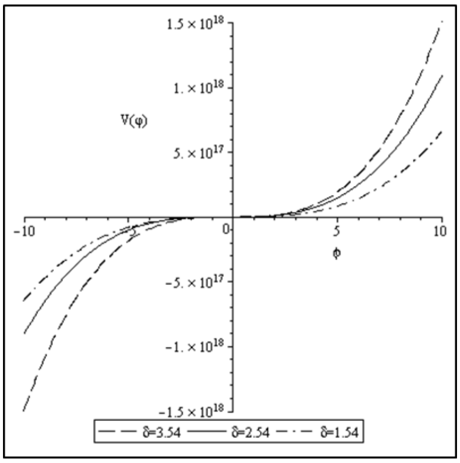

Fig. 1 Variation of Sagdeev potential with plasma potential for different values of δ_1 and for $l_z=0.1$, $M=2.25$, and $\beta=0.46$.

From Fig. 2, it is concluded that the behavior of the pseudo-potential is the same for all β values and only their amplitudes increases slightly. In other words, it can be said that the behavior of the potential is linearly dependent to the electron temperature.

In Fig. 3, the pseudo-potential is plotted as a function of φ. It is clear that for fixed value of the φ, the amplitude of the Sagdeev potential is increasing with l_z.

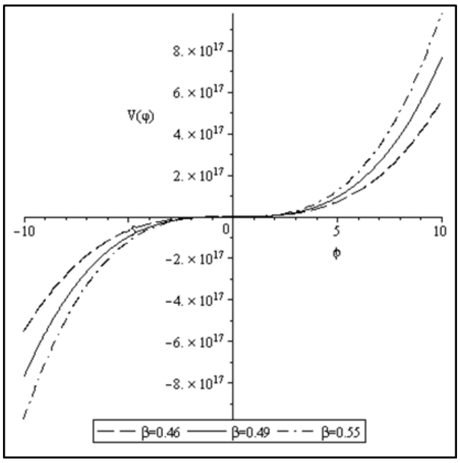

Fig. 2 The plot of $V(\varphi)$ vs. φ, for $l_z = 0.1$, $M = 2.25$, and $\delta_1 = 2.54$ for different values of β.

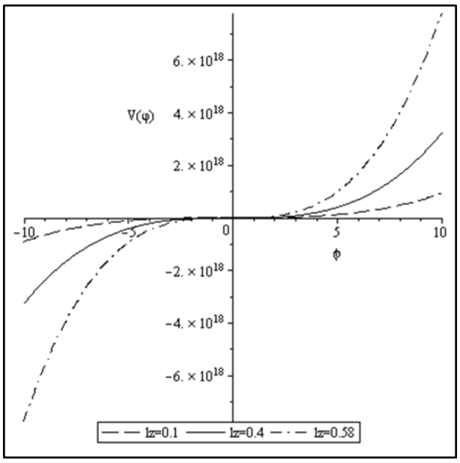

Fig. 3 The plot of $V(\varphi)$ vs. φ, for $M = 2.25$, $\delta_1 = 2.54$, and $\beta = 0.46$ for different values of l_z.

Figure 4 shows the plot of pseudo-potential amplitude versus plasma potential for different values of Mach number.

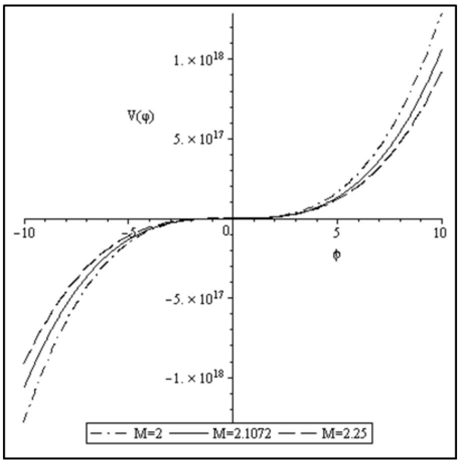

Fig. 4 The plot of $V(\varphi)$ vs. φ, for $l_z = 0.1$, $\delta_1 = 2.54$, and $\beta = 0.46$ for different values of M.

In Fig. 5 the pseudo-potential, φ is plotted versus the η, for $l_z = 0.1$, $M = 2.25$, and $\beta = 0.46$ for different values of δ_1. It is concluded that increasing the δ_1 may increase the plasma amplitude. Also this is negative for negative values of φ, and vice versa. Figure 6 shows that for all values of δ_1, i.e. the ratio of ion density to the equilibrium electron density, the plasma potential is negative. It is also seen that the amplitude and the width of the potential increases as δ_1 increases. Comparing the results for high magnitudes of δ_1, it can be said that the slope of the amplitude is decreased with increasing the ion density.

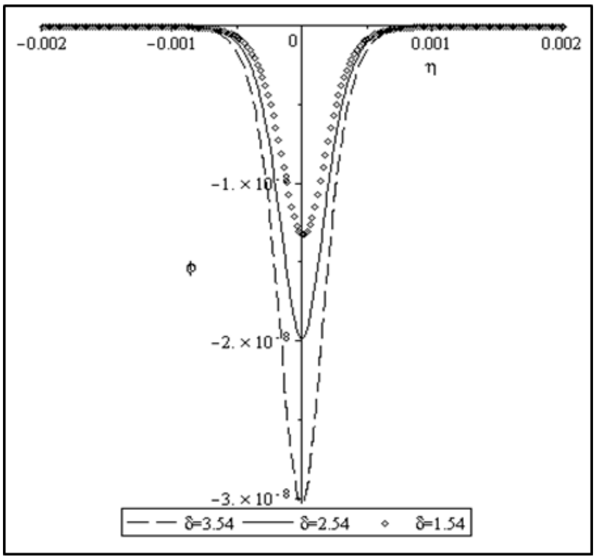

Fig. 5 The variation of φ vs. η, for $l_z = 0.1$, $M = 2.25$, and $\beta = 0.46$ for different values of δ_1.

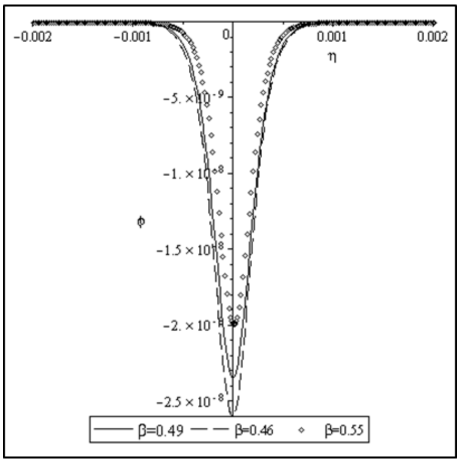

Fig. 6 The plot φ vs. η, for $l_z = 0.1$, $M = 2.25$, and $\delta_1 = 2.54$ different values of β.

The variation of plasma potential is plotted as a function of η for $l_z = 0.1$, $M = 2.25$, and $\delta_1 = 2.54$ for different values of β in Fig. 6. It is seen that decreasing the magnitude of β may increase the width and amplitude of the potential.

In Fig. 7, we have illustrated the variation of plasma potential as a function of η for $M = 2.25$, $\delta_1 = 2.54$, and $\beta = 0.46$ for different values of l_z and for values of δ_1. It is seen that the amplitude is negative and that the negative amplitude and the width of the potential are increased by increasing l_z.

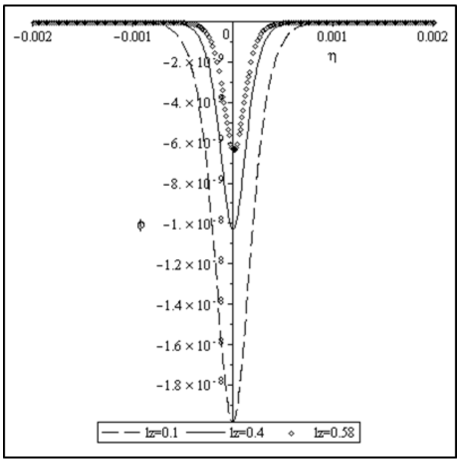

Fig. **7** The plot of φ vs. η, for $M = 2.25$, $\delta_1 = 2.54$, $\beta = 0.46$ for different values of l_z.

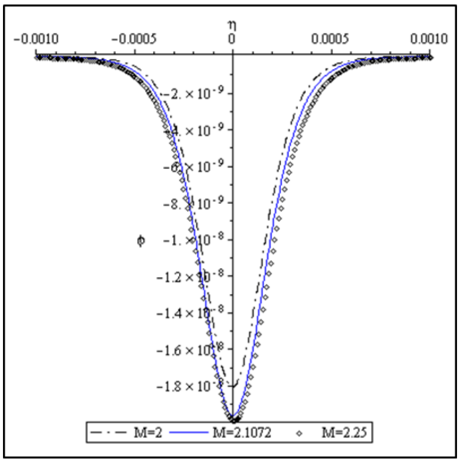

Fig. 8 The plot of φ vs. η, for $l_z = 0.1$, $\delta_1 = 2.54$, and $\beta = 0.46$ for different values of *M*.

In Fig. 8, we have illustrated the variation of plasma potential as a function of η for $l_z = 0.1$, $\delta_1 = 2.54$, and $\beta = 0.46$ for different values of Mach number.

V. CONCLUSION

Using Sagdeev potential, the dispersion relation of dust ion acoustic wave in a collisional magnetized dusty plasma is obtained in the presence of warm ions and hot electrons. It is shown that the amplitude and the width of the wave is dependent on the plasma parameters such as plasma particles density and temperatures, plasma potential, Mach number and etc. The behavior of the amplitude and the width of the wave in terms of all of these parameters is similar to that in our previous work [14]. However, the values of these two variables are different. It is shown that the Sagdeev potential has negative value for positive plasma potential and vice versa. We have also shown that increasing δ_1 and decreasing β can lead to the increasing of wave amplitude and also they can cause an increase in the width and the amplitude of the potential. Finally, it is found that the spectral index, i.e. the quantity when goes to infinite, the kappa distribution changes to Maxwellian one, has little effect on the propagation properties of the wave.

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