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Stability of three-dimensional dust acoustic waves in a dusty plasma with two opposite polarity dust species including dust size distribution

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Propagation of dust acoustic waves (DAWs) with the effect of power law dust size distribution (DSD) in a magnetized dusty plasma with opposite polarity dust is studied. Using a reductive perturbation method, a Zakharov-Kuznetsov equation appropriate for describing three-dimensional DAWs is derived. The compressive and rarefactive solitons are possible in the present model. Due to the DSD effect, a soliton with a smaller amplitude and width and a larger velocity is observed. The stability criterion for obliquely propagating DAWs in such plasma using small-*k* expansion method is investigated. The growth rate of instability is derived and analyzed under the effect of power law DSD. It is found that the growth rate of instability is strongly affected by the power law DSD. The relevance of these findings to space plasma phenomena is briefly discussed.

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I. INTRODUCTION

In the last decades, dusty plasma began to have a great interest for researchers because of its important role in explaining many space and astrophysical phenomena, as well as many industrial and physical applications [1]. In dusty plasmas, the presence of charged dust particles influences significantly the plasma characteristic features. The dust grains play a significant role in plasma wave dynamics [1]. It is normal to consider the dusty plasma model with negatively charged dust only; however, there are many cases in which dust particles have both negative and positive charges [2–5]. Dusty plasmas with two opposite polarity dusts have been found in different regions of space, e.g., Jupiter's magnetosphere [3,4], cometary tails [4], Earth's mesosphere [5], etc. The consideration of negatively charged dust is due to the fact that in low-temperature plasmas, the collection of plasma particles (electrons and ions) is the only important charging process. However, there are some other more important charging processes by which dust grains become positively charged [2,6–8]. The principal mechanisms of such processes are photoemission in the presence of a flux of ultraviolet photons [6], thermionic emission induced by radiative heating [7], secondary emission of electrons from the surface of the dust grains [2,8], etc. Using Sagdeev potential analysis (SPA) [9], Ivlev and Morfill [10] investigated the role of the ion distribution (Boltzmann or highly energetic cold ions) in the characteristics of dust acoustic waves (DAWs) with negative dust species. They stated that the allowed solitons are supersonic, and in dense clouds the width of the Mach number range remains finite for the Boltzmann ions but tends to zero for highly energetic ones. Also, they concluded that the charge variation is not important in rarefied particle clouds but becomes crucial if the particle number density is sufficiently high. Later on, Popel *et al.* [11] presented a study of arbitrary-amplitude DAWs in a three-component dusty plasma including the possibility of changing the dust species polarity (either positive or negative dust grains). Their model is applied to interpret the features of two different layered structures known as noctilucent clouds (NLC) and polar mesosphere summer echoes (PMSE) in Earth's mesosphere. However, they [11] started their analysis with SPA to examine the possible Mach number regime where DAWs would propagate; in the end, they expand the Sagdeev potential for the small-amplitude limit to get the analytical expression for the produced solitons. The final equation has the form of a Korteweg–de Vries (KdV) equation. Verheest and Hellberg [12] studied a fully general description of nonlinear electrostatic modes in plasmas with an arbitrary number of constituents. They showed that arbitrary-amplitude modes can be described by a SPA, although explicit expressions will be available for some simpler power law dependency constituents. On the other hand, weakly nonlinear modes can be treated by the reductive perturbation technique (RPT) [13], which leads to nonlinear evolution equations. The nonlinear evolution equation enables us to study the basic characteristics of the nonlinear waves [11,12,14]. Also, from the first step of the RPT, the linear dispersion relation is obtained, from which the pressure and inertial effects needed to sustain the wave modes can be defined [12]. When a comparison between the SPA and the RPT is carried out [12,14], full agreement is found between the two descriptions when the difference between the linear phase velocity and the velocity of the nonlinear structure is small [12].

On the other hand, Chow *et al.* [2] have shown that due to the size effect on secondary emission, insulating dust grains with different sizes can have opposite polarity, with smaller ones being positive and larger ones being negative. The opposite situation, i.e., massive positive and lighter negative dust grains, is also possible by triboelectric charging [7,15]. This is predicted from the observations of dipolar electric fields perpendicular to the ground, with the negative pole at higher altitudes, generated by dust devils [16] and sand storms [17]. The formation of these dipolar electric fields means that negatively charged dust particles are blown upward with convection, while positively charged dust particles remain at the surface due to gravity. The coexistence of opposite polarity charged dust particles is also observed in laboratories [18–20]. It may be noted here that the case of same sized

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