Effects of modified two-stream instabilities on formation of forward and reverse shock waves in a magnetic field

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Shock waves can be generated from strong disturbances, such as solar flares and supernova explosions and are believed to play an essential role in production of high energy particles. Particle simulations have demonstrated that a large-amplitude magnetosonic shock wave can accelerate hydrogen ions [1], heavy ions [2], electrons [3], and positrons [4] through various nonstochastic mechanisms. Because these processes are caused by strong electromagnetic fields near a shock front, the studies of shock acceleration were mainly concerned with a small region near there. However, recently, a much larger region has been simulated by means of a one-dimensional electromagnetic particle code, and formation of forward and reverse shock waves [5] and of large-amplitude Alfven waves and acceleration of electrons in these waves [6] have been reported. These magnetohydrodynamic waves were generated from a collision of two plasmas in an external magnetic field \( B_0 \); one plasma (exploding plasma) has a high velocity \( v_0 \) while the other (surrounding plasma) is at rest with a lower density.

In this study, we investigate formation of forward and reverse shock waves in a magnetized plasma using two-dimensional (two spatial coordinates and three velocities), electromagnetic particle code with full ion and electron dynamics. We analyze interaction of exploding and surrounding plasmas for a case in which \( v_0 \) is perpendicular to \( B_0 \). After the penetration of the exploding ions, the plasma density and the magnetic field increases near the initial boundary of the two plasmas. The intensified magnetic field reflects the surrounding ions forward and exploding ions backward, which generates forward and reverse shock waves. This time is of the order of the ion gyropoint. In this period, there is a region where the exploding and surrounding ions coexist. Relative ion motion across the magnetic field can excite modified two-stream instability through the interaction of whistler waves propagating obliquely to \( B_0 \). The whistler wave instabilities and the compression of the magnetic field due to the collision of the two plasmas generate current filaments near the peak of the magnetic field. Because of the nonlinear interaction of the current filaments, the variation of magnetic field along \( B_0 \) is enhanced. This causes the variation of the strength of ion reflection, which influences the multi-dimensional structures of forward and reverse shock waves.