Modified two-stream instability at perpendicular shocks: Full particle simulations

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A full particle simulation study is carried out for studying micro-instabilities generated in perpendicular collisonless shocks. Recent self-consistent kinetic simulation studies revealed that there exist various types of micro-instabilities at the shock front of supercritical perpendicular collisionless shocks. The modified two-stream instability (MTSI) is known as one of these micro-instabilities and is commonly exited at lower-Mach number (MA$<$10) perpendicular shocks where incoming/reflected ions can interact with obliquely propagating electromagnetic whistler mode waves. Previous one-dimensional (1D) full particle simulations showed that the MTSI was generated at quasi-perpendicular shocks but not at exactly perpendicular shocks. This is because incoming/reflected ions could not interact with oblique whistler mode waves in the 1D system taken in the direction perpendicular to magnetic field. Recent two-dimensional (2D) full particle simulation with a local model suggested that two-dimensionality and a higher ion-to-electron mass ratio were quite essential for the generation of the MTSI. These studies suggest that multi-dimensional full particle simulations with a high ion-to-electron mass ratio are necessary for studying at exactly perpendicular shock. In the present study, we performed 2D full particle simulations of exactly perpendicular shocks with a high ion-to-electron mass ratio. The present simulation showed that various types of plasma waves are excited at the shock front. The Fourier analysis shows that the one of these waves corresponds to electromagnetic whistler mode waves propagating in the direction oblique to magnetic field. From the comparison with linear analysis, it is confirmed that the MTSI is generated at self-consistently excited perpendicular shock due to the interaction between incoming/reflected ions and the oblique whistler waves.