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MHD-like plasma equations for hybrid-particle simulations*

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Abstract

In particle simulations of electromagnetic plasma perturbations, the perturbed fields are frequently expressed in terms of the potentials $\delta\phi$, $\delta\mathbf{A}_\parallel$, and the parallel perturbed magnetic field $\delta B_\parallel$. The perturbed potential $\delta A_\parallel$ describes the Magnetohydromagnetic (MHD) plasma response. Ideal MHD plasma behaviour can however be adequately described by fluid equations and it is undesireable to reproduce fluid-like phenomena using numerical simulation. Furthermore, Ampere's law for $\delta A_\parallel$ involves the perturbed parallel component of the plasma current which in turn requires the computation of the first moment of the parallel particle velocity component. Thus to reproduce ideal MHD, the parallel particle trajectory must be determined accurately enough to reflect the fact that the particles and field lines tend to move together. An alternative choice is $\delta\phi$ and $\delta\mathbf{A}_\perp$ or equivalently $\xi = (\mathbf{b}\times\mathbf{A})/B$, with $\mathbf{A}_\parallel = 0$. The two sets of perturbed fields are related by a gauge transformation. The vector ξ is essentially the magnetic field line displacement and $\nabla_\perp \cdot \xi$ describes the field line compression. Plasma kinetic equations are derived for arbitrary perturbed pototentials $\delta\phi, \delta A_\parallel, \delta A_\perp$, and Maxwell's equations are formulated so as to require the evaluation of the plasma pressure rather than the plasma current. Gauge invariant linearised equations are obtained, and in the case where the chosen gauge is $\delta A_\parallel = 0$, they reduce to the conventional linearised MHD fluid equations. Kinetic effects are included by integrating the kinetic drift (or gyrokinetic) equation to calculate that part of the perturbed plasma pressure which depends on the details of the particle guiding center motion. Nonlinearities can be included by adding nonlinear terms quadratic in the field amplitudes. The suitability of these equations as the basis of a hybrid-simulation code is being explored.

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