IMPLEMENTATON OF ION GYRO-VISCOSITY IN THE NIMROD CODE

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We describe the implementation and validation of the ion gyro-viscous stress in the NIMROD extended MHD code. The ion gyro-viscosity is a non-dissipative finite Larmor radius (FLR) correction to the fluid plasma equations that is ignored as small in both the Hall and MHD parameter regimes. However, in the drift regime, which is relevant to modern tokamaks, it enters at the same order in the gyro-radius as other two-fluid effects, and therefore must be included in any two-fluid model of tokamak plasmas. In this regime, the velocity is often explicitly decomposed into $\mathbf{E} \times \mathbf{B}$ and diamagnetic drifts. In that case, and under certain restrictive conditions, the divergence of the gyro-viscous stress almost completely cancels the advection of the ion velocity by the diamagnetic drift (the so-called gyro-viscous cancellation), leading to a simplified set of equations. However, to attain a more widely applicable and less restrictive model, the equations can be written in terms of the total ion velocity, and the full gyro-viscous stress must be implemented. These new terms introduce dispersive waves that require special numerical treatment. These modes survive the gyro-viscous cancellation, and should be an issue even for numerical models that explicitly employ the drift ordered equations. Here we describe the implementation of the ion gyro-viscous stress in the NIMROD code, using high order finite elements. A semi-implicit time advance of the new dispersive terms removes the restrictive CFL time step limit, and allows the calculation to proceed on the MHD time scale. Details of the numerical algorithm and its validation are described, and initial results including the gyro-viscosity are given.