Abstract

Various schemes have been analysed over the years for extracting energy from Inertial Fusion Energy systems such as laser-driven fusion. The method examined here is to directly convert a part of the plasma kinetic energy into pulsed electrical energy, through the medium of magnetic flux compression. The present work involves a computational study of the physics of flux compression inside a current-carrying coil by an expanding inertial fusion plasma sphere. The numerical analysis has been performed using two-dimensional MHD and FDTD simulations.

The overall efficiency of the system is determined numerically for a typical set of initial plasma and system parameters. It is found that the proposed system is promising in terms of overall efficiency, but the system produces ultrahigh inter-turn voltages in the coil, necessitating the use of magnetic self-insulation to avoid inter-turn breakdown.

The plasma sphere, expanding across a magnetic field, is subject to the Magnetic Rayleigh-Taylor (MRT) instability. For a detailed analysis of this concept, especially plasma dynamics under large deformations, a two-dimensional Eulerian multi-material MHD model has been developed for the first time. The algorithm is found to be capable of accurately handling complex plasma dynamics inside the MFC system. Magnetic field diffusion into the plasma during the expansion phase is found to be negligible. 2D MHD simulations of random, single and multi-mode MRT instability growth have been performed to analyze the MRT instability and its implications for the proposed MFC system. The simulation takes into account the effects of MFC and geometric divergence due to spherical plasma expansion. The dominant modes obtained in the random seed analysis show a progressive transition to the intermediate wavelength regime (~4–8 cm) in the spectrum. Single-mode evolution exhibits linear exponential growth followed by a non-linear phase towards stagnation time. In the multi-mode analysis, with initial amplitudes
(\alpha_{in}) comparable to the perturbation wavelength (\lambda_{in}), there is clear evidence of mode coupling and the generation of harmonic and inverse cascade modes. We also find that near the time of stagnation, the growth in amplitude of the modes, although exponential in nature, is much lower than that predicted by linear theory. Furthermore, the instability amplitudes are not large enough for \alpha_{in} \leq 0.1\lambda_{in} to severely disturb the smooth MFC during the first expansion phase. However, the growth of modes with \alpha_{in} \geq \lambda_{in} causes plasma jetting, especially for longer \lambda modes, and can lead to significant reduction in MFC efficiency.

We have also investigated the application of finite difference time domain (FDTD) schemes, involving direct solution of Maxwell’s equations. The FDTD algorithm has been modified, for the first time, by including motional e.m.f terms in the standard FDTD update equations. This algorithm can be applied to MFC systems with moving parts. This new approach is validated with standard analytical solutions for planar flux compression systems and magnetic field diffusion in moving conductors with non-relativistic velocity. Finally, in order to demonstrate the utility of this powerful scheme to MFC problems, we have applied it to a sample problem involving plasma armatures. To our knowledge, this is the first application of this powerful technique to such systems. We have also identified, through extensive numerical tests, critical constraints that must be satisfied while performing magnetic diffusion problems using FDTD scheme.