Burning Plasma Control

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Excellent work has been done on the simulation of plasmas [1] and on plasma shape control [2]. However, much work needs to be done to control burning plasmas. We propose to develop optimal control strategies for maximizing energy output in burning plasmas and to test these strategies via direct kinetic simulation of small burning plasma regions.

As a first step, we will develop RF-heating/fueling control strategies for one-dimensional electrostatic plasmas where collisions between electrons, reacting ions and alpha particles will be modeled directly via particle-in-cell (PIC) code. The particle equations of motion in this case are

$$\frac{d^2\Phi}{d\tau^2} = -\left(\frac{n_D(\xi)}{n_0} + \frac{n_T(\xi)}{n_0} + \frac{n_\alpha(\xi)}{n_0} - \frac{n_e(\xi)}{n_0}\right) \quad (1)$$

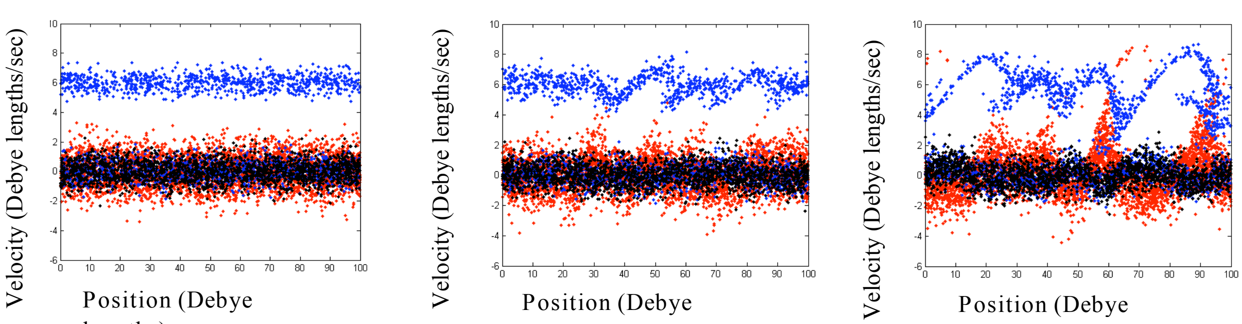
$$E = -\frac{d\Phi}{d\xi}. \quad (2)$$

$$\frac{d\xi_i}{d\tau} = \upsilon_i \quad (3)$$

$$d\upsilon_i = \alpha_i E(\xi_i)dt + d\upsilon_{RF} + d\upsilon_{Coll} \quad (4)$$

where $\Phi = \frac{e}{m_e\lambda_D^2\omega_p^2}\varphi$, $E = \frac{e}{m_e\lambda_D\omega_p^2}\mathrm{E}$, $\upsilon = \frac{v}{\lambda_D\omega_p}$, $\xi = \frac{x}{\lambda_D}$, $\tau = t\omega_p$ and $\alpha_i = \frac{q_i}{m_i} \div \frac{e}{m_e}$ are the dimensionless potential, electric field, velocity, position, time and charge-to-mass ratio. Further, $d\upsilon_{RF}$ and $d\upsilon_{Coll}$ are random dimensionless velocity increments due to RF-heating and collisions. The collision term includes alpha, electron and ion interactions. Also, $n_i(\xi)$ is the velocity integrated number density for the ith species.

Without alpha generation, electron collisions or RF heating, this scheme currently shows well-known two-stream instability when the $\alpha = 2$ ions (blue) are injected into a thermal plasma of $\alpha = 3$ ions (black) and $\alpha = -1$ electrons (red).



Velocity phase space after 0, 1 and 2 plasma periods for $\alpha = 2$ ions (blue), $\alpha = 3$ ions (black) and $\alpha = -1$ electrons (red).

Based on this framework, we will search for optimal control strategies involving the fueling density and velocity profiles for deuterium and tritium $n_D(x,v,t)$ and $n_T(x,v,t)$ and the RF-heating time profile. The author believes that it will be discovered that alpha heating alone will be insufficient to maintain burn and some portion of the electrical output of the reactor will have to be recycled back into the reaction in the form of RF-heating in order to produce sustained burns. The object of these control strategies will be to maximize the energy output of the reactor.

References

[1] *Full Torus Electromagnetic Gyrokinetic Particle Simulations with Kinetic Electrons*, Y. Nishimura, Z. Lin and L. Chen, *Commun. Comput. Phys*. **5**, 183-194 (2009).

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[3] Richard Fitzpark. (2006, March 29th). *Particle-In-Cell Codes*. Retrieved May 22, 2009, from http://farside.ph.utexas.edu/teaching/329/lectures/node96.html