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Research Summary

Magnetic Confinement Fusion

There are several approaches to developing sustainable fusion, but this paper will focus on Magnetic Confinement Fusion (MCF), specifically inside of tokamak reactors. Tokamaks are the most developed style of fusion reactor, and with ITER being developed, the most relevant as well. Tokamaks are also based on the simplest physical and technical parameters out of all the fusion reactors making it possible for this paper to develop a detailed model. The MHD involved is a mess to look at and will be kept to high level with the detailed model being dedicated to the magnetic confinement.

Tokamaks are a style of stead state MCF reactor that uses a set of toroidal and poloidal electromagnetics to create a magnetic bottle torus that contains fusing plasma. The magnetic containment of the plasma is vital to achieving fusion, because the two most import physical parameters for fusion, temperature and particle density are dependent on it (I.R. Lindemuth and R. E. Siemon). That is, the cross section of fusion is dependent on the number of particles in a given volume and the average energy of the particles, dependent of temperature. Mathematically, this is given by the Maxwellian averaged cross section, σv which is a function of temperature multiplied by the number density of each particle species in the fusion fuel.

$$\frac{dn_1}{dt} = \frac{dn_2}{dt} = -\overline{\sigma v} n_1 n_2,$$

The plasma is primarily heated by a solenoid running through the middle of the reactor torus. The solenoid will induce a current into the plasma which will increase the temperature due to ohmic heating (L.A. Artsimovich). This will heat the plasma up to a temperature where it can fuse, but problems in containment arise. The plasma pressure fighting against the magnetic bottle increases with temperature and attempts to drop the number density of the fusing particles. The current in the electromagnets creating the magnetic bottle is adjusted to contain the plasma, but due to more complicated MHD interactions, containment is still broken after a few seconds of fusion.

Excluding the MHD interactions a simple model can be built for a single charged particle inside the magnetic bottle of a tokamak reactor. For simplicity, the torus is going to be assumed to be perfectly axially symmetric. The set of poloidal and toroidal magnets create a helical field for a charged particle to follow along with the electric field produced by the solenoid.

[First attempt at making a model for particle motion]

By changing the current through the central solenoid, the magnetic field is also being changed, which will create an electric field that induces a current to oppose the change in magnet field. (Lenz's law)

This induced current in the plasma will be in the opposite toroidal direction as the current going through the solenoid. And now we have.

$$F = q(E + V \times B) \quad \text{(Lorentz force)}$$

The particles will be driven in the toroidal direction by qE, and this will always be perpendicular to a component of the helical magnetic field. This will cause the particle to gyrate as it travels in the toroidal direction. The gyration will always steer the particle away from the edges of the field, containing the particle.

There's more to it than this, but I need to find a source that goes into the particle motion more.