Annotated Bibliography

1. Tokamak devices

L.A. Artsimovich 1972 *Nucl. Fusion* **12** 215

This paper is a survey of tokamak function and design. It starts with the general idea of what a tokamak is and how it confines plasma and then breaks it down to the details. First the paper details the movement of single particles in a tokamak and then reviews the theoretical work on equilibrium, transport coefficients and plasma stability. The design of the various Tokamak devices is described, as are the methods of plasma diagnostics employed with them. Finally, main experimental results are summarized and compared with theory.

The theoretical model used in the paper assumes perfect toroidal symmetry in the magnetic field causing particles to take a perfect- mathematically clean spiral around the reactor. The need for the spiral comes from the ExB drift of the plasma particles that would cause them to leave containment if their direction was not constantly changed. The paper continues with explaining the parameters needed to maintain plasma stability. It sums them up in the “q” factor which is a measure of how well fusion is sustained. It is dependent on confinement time, temperature, and plasma density.

I need to dig into the math a bit more to really understand what is going on. But, at face I understand conceptually how a tokamak contains plasma- it's basically a magnetic bottle donut. The q parameter makes sense though. The plasma density and temperature define the rate of fusion, and the containment time is how long the fusion lasted.

2. The fundamental parameter space of controlled thermonuclear fusion

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This paper gave a framework to compare multiple approaches to fusion by outlining the parameters for all of them. The three approaches are magnetic confinement fusion, inertial confinement fusion, and magnetized target fusion. The parameters for each type of fusion differ because of the different set ups, but they all operate under the same basic principles.

The basic parameter to measure fusion is Qfus, the fusion energy production rate, which is dependent on the rate of fusion and energy released per reaction. This is further broken down into ion density, fusion cross section, and temperature. It’s like the tokamak devices paper; defining the basic, but it explains how these parameters apply to the other fusion approaches as well.

Magnetic confinement fusion is what tokamaks (and stellarators) do, make a magnetic bottle to contain the plasma while heating it. Inertial confinement fusion is setting up a pellet of fusion fuel and shooing it with lasers, so it implodes and fuses. Magnetic target fusion is a combination of the two that created a magnetic bottle to contain plasma and then squeezing it to get the temperature and density needed for fusion.

3. Commercial tokamak reactor potential with advanced tokamak operation

J.D. Galambos et al 1995 Nucl. Fusion 35 551

This paper explores the commercial viability of tokamak reactors by mapping the physics and engineering parameters of fusion to cost/profit. The point of the study is to point to the physics areas that can be leveraged to make tokamak fusion the most economically viable. There are many physics parameters addressed, but primarily they are summed up in confident time and beta- a measure of fusion performance. Intuitively, making fusion economically feasible means making the power it generates worth more than the startup up cost and the upkeep cost. This will primarily be determined by confinement time and beta- how long fusion can be sustained and how effective the fusing plasma is at making energy.

The study found that beta optimization is the most important parameter to optimize. Maximizing beta maximizes the fusion power density and can lower the overall cost of fusion by using the least amount of fuel and electricity in for the most amount of power out. Beta is defined as

$$\beta = \frac{\langle p \rangle}{B^2/2\mu_0}$$

Which is the ratio of the plasma pressure to the magnetic pressure. The magnetic pressure is broken down into toroidal and poloidal components and plasma pressure is equal to the density * temperature * Boltzmann Constant.

The other factor of confinement time is used a lot, but not well explored. I'm pretty sure plasma confinement is an MHD nightmare and that's why it was glossed over, but it's something I need to explore further.

4. Study of in-vessel nonaxisymmetric ELM suppression coil concepts for ITER

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Unfortunately, my assumption was correct and plasma confinement is a huge MHD nightmare. This paper is a proposal on how to improve plasma confinement on ITER, soon to be the world's largest fusion reactor, by adding a set of external perturbation coils outside of the reactor. These coils will create a magnetic field to make the plasma better behaved. This paper was very technical, and I would have to do some more background work to understand it, but I think I got the general idea.

The main problem with trying to confine plasma is that we cannot make a perfect axisymmetric toroidal field. There will inevitably be small variations in the field that will cause problems. The plasma is a system of charged particles that produces its own magnetic field. When the plasma hits a variation in the external field containing it, its path around the reactor is skewed, thus skewing the magnetic field it produces. This happens to the plasma near the edge of the magnetic bottle, and the outside misshaped field will create an internal misshaped field that will progressively change the bulk flow of the plasma. This will quickly lead to a break in containment. It is a positive feedback cycle where when the plasma toroid is slightly misshapen, it will start to misshape itself more and more until stability is lost.