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ADVANTAGES OF IRON CORE IN A TOKAMAK*

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Summary

Several of the experimental tokamak fusion devices to date have used iron cores to reduce the power supplied to the poloidal field coils. As the machines grow in size, iron cores are not receiving emphasis in the U.S. Planned tokamak programs in other countries, e.g. JET, include iron cores in their designs. It is felt that this de-emphasis of the iron core has stemmed primarily from the expediency of using the more costly power supplies rather than having to deal with the relatively involved effects that iron cores have on the poloidal fields and the plasma MHD equilibria.

Recent design studies of the Joint European Torus (JET)[1] have indicated substantial savings of the power supplies in the plasma start-up phase by the use of an iron core, without impeding the required equilibrium fields for a D-shaped plasma. Current studies at ORNL on high beta D-shaped plasmas[2] and the poloidal field systems for high beta plasmas in the iron core ISX device[3] have provided substantial improvements in understanding the iron core effects on the plasma. Operations of high beta fusion plasmas in an iron core tokamak reactor are now considered doable.

Recently, TNS[4] and DEMO[5] studies and the ohmic heating study by Los Alamos Scientific Laboratory[6] have shown that air core tokamaks in the 1000 Megawatt (electric) range require poloidal field power supplies with a capital cost between $100 and $200 million (20-30% of the total cost of the fusion system concept being studied). ORNL has conducted some preliminary studies of the use of an iron core and the results have been particularly encouraging. To better understand these results, it is necessary to first list and discuss the generally recognized key concerns about the air core approach. (Table 1)

TABLE 1
The Key Concerns About Air Core Systems

1. High power needs of PFS (P>1 GW)
2. High energy needs of PFS (E>1 GJ)
3. Energy storage components required
4. Needed economic high power switches - not available without costly development
5. Certain OH coil maintenance nearly impossible
6. Probable requirement for superconducting OH coils

Discussion of Key Concerns

1. The requirement to handle the high electrical power in an air core PFS is major cost ($100-200 million) driver. The cost of the major PFS electrical components such as switches and rectifiers is a nearly linear function of the peak power handled. These elements comprise over eighty (80) percent of the total PFS electrical equipment capital cost. The energy storage equipment necessary to buffer the utility grid system from sudden energy demands beyond its capacity would account for about twenty (20) percent.

2.-3 The air core design concepts under consideration for TNS and DEMO machines require energy pulses during the initiation and startup phase of each burn cycle that exceed the capability of any U.S. utility. This 1-1.3 GJ peak energy demand dictates a buffer or isolation from the grid by use of some energy storage device such as a motor-generator-flywheel or a homopolar generator. Either would account for about twenty (20) percent of the PFS total cost. Each would require development to meet the long life pulsing demands. It is estimated that the homopolar generator would require tens of millions of dollars to develop, an order of magnitude larger than that required to assure the same pulse life for the motor-generator-flywheel equipment.

4. At the peak power levels that these machines demand, only solid state switches could be used without significant development - and the numbers of solid state devices that must be ganged to make switches of these ratings dangerously stretches the available component experiences. New, economic switching systems must be developed for these powers.

5.-6 An air core machine requires the distribution of the OH coils around the plasma for optimum flux linking. An iron core device will permit coil locations that substantially ease the assembly and maintenance difficulties because the return legs of iron assure the proper flux paths. Some OH coils in air core designs must be placed under, and to the inside of the plasma, and are practically impossible to maintain. It will be seen that significant advantages appear to accrue from the use of an iron core. (Table 2)

TABLE 2
Potential Advantages of an Iron Core

1. Maintainability - Ease of remote handling
2. Less Cost - By order of magnitude
3. No Energy Storage Machine
4. Little Need for Superconducting PF Coils
5. Less Electrical Development by Order of Magnitude
6. Siting Flexibility in Availability of Commercial Power. (Can hook directly to most U.S. grids)

A quantitative comparison of the iron core vs air core concepts was carried out on a preliminary basis by using a representative tokamak reactor design with the following self-consistent reference parameters. (Table 3)

The following sections will discuss in more detail the impact of using an iron core in a tokamak reactor. In the area of plasma engineering, poloidal field and MHD equilibrium considerations with an unsaturated iron core will be discussed. The question of proper poloidal field coils to maintain D-shaped plasmas of relatively high $\bar{\beta}$ (7%) with a saturated iron core is also discussed in Section 2, where it is considered feasible. Estimates of the required iron core size, volt seconds, magnetic flux and its influence on force loading on the superconducting toroidal field coils are shown in Section 3. Conceptual designs of the mechanical structure of an iron core device are presented in Section 4. Favorable impacts on the OH power supply cost and complexity are indicated in Section 5 followed by a brief conclusion in Section 6.

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