

PFC/JA-82-13

THE LOW BETA PULSED TOKAMAK AS A
MODULAR COMMERCIAL REACTOR WITH VERY LONG PULSES

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July 1982

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Abstract

We describe a tokamak design concept which could provide solutions to some of the possible problems of using a pulsed tokamak as a commercial power reactor, namely effects of pulsed operation, complexity and maintainability. The design concept is a device which provides very long pulses (several hours - 1 day) with the voltsecond capability of the ohmic heating transformer. It operates at low beta with a near circular plasma and a simple equilibrium field system. The superconducting toroidal field coils are individually removable and the tokamak is completely modularized. Illustrative parameters are a major radius of 15 m, an aspect ratio of 6, magnetic field on axis of 7.2 T, an average toroidal beta of 0.017, and a pulse length of 14 hours.

Introduction

Concerns about the use of tokamaks as commercial power reactors include effects of pulsed operation, complexity and maintainability. In this paper we consider a design concept which could provide solutions to these problems while at the same time using relatively conservative assumptions about physics performance. The concept is a tokamak which is completely modularized and could provide very long pulses (several hours - 1 day) with the voltsecond capability of the ohmic heating transformer.

Design Features

Capability to provide very long pulses is obtained by using a large major radius design. The volt-second capability of the ohmic heating transformer increases rapidly with major radius and a pulse length on the order of several hours - one day should be possible in a tokamak with a major radius which is about twice that of present commercial power reactor designs. Operation with very long pulses will greatly reduce thermal fatigue of the first wall and allow for more gradual plasma startup and shutdown.

A potential problem with a large major radius design is that very large values of reactor thermal power are produced at wall loadings which are high enough for acceptably low cost/kW. The thermal power level can be reduced by use of a moderately high aspect ratio and a near circular plasma in order to minimize first wall area.

The use of a relatively large aspect ratio facilitates the use of a toroidal field (TF) magnet design in which the superconducting TF coils are individually removable and the entire tokamak system is modularized. This concept has been used in a recent design study of a tokamak reactor with helical coils.¹ Each TF coil would be in a separate dewar and one or two TF coils could be removed while the other TF coils remain in place and are kept at liquid helium temperature. An important feature of this concept is the separation of the TF coils in the throat of the tokamak; this separation is facilitated by a relatively high aspect ratio design. Contact between the low temperature region of the magnet and the casing, which is at room temperature, is made through struts of G-10 insulation which has an acceptably low heat leak.

In order to facilitate maintenance the tokamak would be modularized into pieces which contain one or two TF coils plus blanket and shield and first wall. If it is necessary to place EF coils inside the TF coils, they would be joined by pressure contacts so as to facilitate removal of the modules. Removal of a module would be accomplished by a relatively small number of operations.

Although the allowed value of toroidal beta is predicted to go as $\beta \simeq 1/A$ where A is the aspect ratio, the ratio of the magnetic field at the plasma axis to the magnetic field at the toroidal field (TF) coil increases with increasing A . As a result the ratio of plasma pressure to the magnetic field pressure at the inside edge of the TF coil decreases rather slowly with increased aspect ratio.

The use of a near circular plasma in the design significantly simplifies the equilibrium field (EF) magnet design. It may not be necessary to locate EF coils inside the TF coils. The reduction in plasma elongation also facilitates the use of more circular shaped TF coils with reduced size and reduced requirements on external EF coils.

A pump divertor is used for impurity control in order to maintain the simplicity of the design.

Illustrative Design Parameters

An engineering scoping study of the concept has not been performed. However, a set of rough illustrative parameters can be obtained by extrapolation from the HFCTR power reactor design² and from recent design work on high field tokamaks with DD-DT fuel mixtures and reduced tritium breeding requirements. These illustrative parameters are given in Table 1.

The illustrative design should provide a pulse length of 14 hours. The 15 m major radius provides sufficient space for an OH drive capability of 2800 voltseconds. The field in the OH transformer is swung from +9T to -9T. The time between burn pulses might be minimized by driving the transformer, the EF coils and the plasma current in opposite directions during each successive pulse. In this way the time between pulses would be limited by the startup and shutdown time of the plasma rather than by the time to recock the OH transformer.

With a modest value of average toroidal beta, 0.017, the magnetic field of 7.2 T on axis provides a total wall loading of $2.3 \text{ MW}/\text{m}^2$. 4300 MW of thermal power is produced.

According to the INTOR scaling law of the electron energy confinement time the value of $n\tau_e$ in the plasma is more than sufficient to obtain ignition. The margin of ignition (MI) where $MI = (n\tau_e)_{INTOR}/(N\tau_e)_{IGNITION}$ is 3.5.

The stored energy in the TF magnet in the illustrative design, which is D shaped, is 150 GJ. A significant reduction in the stored energy should be possible by use of a circular TF coil.

Summary

Significant improvements in the engineering features of a pulsed tokamak power reactor might be obtained with the concept described here. In addition, the physics requirement for increased beta from plasma elongation is removed. A range of variations about the illustrative design are possible and should be studied to determine the potential usefulness of the concept. Engineering studies of the magnet system and modularization concept should be performed and the use of a divertor as an alternative to a pump limiter should be assessed.

References

1. R.E. Potok *et al.*, "Physical and Engineering Constraints for Tokamak Reactors with Helical Coils," MIT Plasma Fusion Center Report, RR-82-10, (1982).
2. D.R. Cohn *et al.*, "High Field Compact Tokamak Reactor (HFCTR)" MIT Plasma Fusion Center Report PFC/RR-79-2(1979); J. Schultz, F.S. Malick, D.R. Cohn and J.E.C. Williams, "Advantages of High Force Density Magnets and Total Modularization," MIT Plasma Fusion Center Report PFC/RR-80-3(1979).

Table 1

Illustrative Parameters

Major radius:	15 m
Minor radius:	2.5 m
Plasma elongation:	1.2
Aspect ratio:	6
Magnetic field on axis:	7.2T
Magnetic field at the TF coil:	9.9T
Toroidal beta:	0.017
MI [= $(n\tau_E)_{INTOR}/(n\tau_E)_{IGN}$]:	3.5
Plasma current: (for q = 3)	7.2 MA
Average electron temperature: (parabolic profile)	15
Pulse length:	14 hours
Total wall loading:	2.3 MW/m ²
thermal power: (21 MeV/fusion reaction)	4300 MW
Number of TF magnet coils:	20
TF magnet stored energy:	150 GJ
Tensile stress in TF magnet structure:	200 MPA
Tensile stress in OH transformer structure:	225 MPA
Voltsecond capability of OH transformer:	2800 voltsec