Introduction

Framework

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The author has taken advantage of the infrastructure and high level scientific environment of the tokamak TORE SUPRA of the *Département de Recherches sur la Fusion Contrôlée* (DRFC) at the *Commissariat à l'Énergie Atomique* (CEA) of Cadarache (France).

Numerical calculations have been performed using the computer services of the DRFC (as for example, the multiprocessor EV6-500 workstation), as well as the vectorial computer Fujitsu VPP5000 (9,6 GFLOPS) and the parallel computer Compaq SC232 (made up of 232 processors EV6.7) of the CEA at the *Direction de l'informatique* of Grenoble.

Objectives and plan of the thesis

The main objectives of the present thesis are as follows:

- Derivation of an improved model for the calculation of synchrotron radiation losses for realistic conditions of toroidal plasma geometry, using an accurate method for the calculation of the self-absorption, and for arbitrary shapes of density and temperature profiles; evaluation of the consequences of this new formulation.

- Use of this model in the plasma thermal equilibrium in order to analyse the performance of next step tokamaks and of a commercial reactor, and to isolate the key issues which limit the performance.

- Optimization of a next step tokamak at a given plasma performance in inductive mode of operation, meeting the physical and technological requirements.

In Chapter 1, the energy use growth through the XXI century is discussed, and the thermonuclear fusion is presented. To achieve performance required for a commercial fusion reactor, magnetic confinement approaches, namely the tokamak concept, are described.

The understanding and modelling of heat and radiation transport in tokamak plasmas is essential in order to progress in the development of thermonuclear fusion. In Chapter 2, we describe the tokamak plasma model proposed to analyse the global thermal equilibrium using a realistic geometry, composition, and arbitrary profiles for density and temperature. The synchrotron loss term in the plasma thermal equilibrium is usually estimated with expressions derived from a plasma description using simplifying assumptions on the geometry, radiation absorption, and density and temperature profiles. The use of these approximate expressions can be explained both by the small magnitude of the synchrotron radiation losses in present tokamaks and by the complexity of the exact calculation.

In Chapter 3, we propose a general formulation for the calculation of synchrotron radiation losses without wall reflections. In particular, this formulation is able to describe plasmas with arbitrary aspect ratios and with temperature profiles obtained in internal transport barrier regimes, which cannot be described accurately with the present expressions. The results are compared with those of previous studies and the validity of a previously proposed method for the calculation of the plasma self-absorption is discussed. Considering the quantitative importance of the effects of toroidicity and temperature profile on synchrotron radiation losses, which are not included in present approximate expressions, a new fit for the fast calculation of the synchrotron radiation loss is proposed.

In Chapter 4, using this improved model in the thermal balance, the plasma performance of the next step tokamak ITER-FEAT are analysed in detail in the inductive and non-inductive mode of operation. Sensitivity studies for this device enable us to isolate the key issues which limit the performance.

In the frame of a multi-step strategy towards a commercial reactor, a superconducting European next step tokamak has been optimized in Chapter 5. Considering both the plasma physics and the magnetic system technology, the smallest machine meeting the physical and technological requirements is determined.

In Chapter 6, we evaluate the plasma performance of a proposed commercial fusion reactor in non-inductive (continuous) operation, and we compare them with the reactor objectives, in terms of electrical power into the network and global power plant efficiency. A parametric study on the current drive efficiency is carried out and the key issues limiting the performance are isolated. In such a reactor, the magnitude of synchrotron losses and the effect of wall reflections are analysed in detail. Finally, the optimal plasma confinement for a reactor is discussed.

Unless otherwise indicated, all units are SI in the present thesis except for the temperature, which is always expressed in keV. This means that $k = 1.6022 \times 10^{-16}$ J/keV could be taken for the Boltzmann constant.