Abstract

The tokamak configuration is widely accepted successful plasma confinement system for a fusion reactor. For the past four decades, large aspect ratio tokamaks have been built and studied extensively due to their inherent advantages. They are likely to satisfy the ignition condition which is needed for an economically viable fusion reactor. However, the cost of such reactor is expected to be quite high. To compete with other power generation techniques, it is essential to improve the tokamak concept to build a less expensive reactor. The reduction of aspect ratio is found to have a lot of potential to reduce the cost and improve the performance. Several compact toroidal (CT) systems have been studied in the past. Out of those, Field Reversed Configuration (FRC), Spheromak and Spherical Tokamak (ST) are found to be interesting. Each one of them has few merits and demerits towards the fusion reactor. As the tokamak concept is well proven, one would like to improve the ST configuration for a reactor. The main disadvantage in ST arises due to its compactness that reduces the inner bore area. This makes the TF inner leg to be unshielded and exposed to high neutron flux and heat flux. So in a reactor, the inner leg of TF coil has to be replaced frequently. It is essential to solve this issue and improve ST with the help of other CT configurations. The resultant hybrid configuration may be a combination of two or more CT equilibria.

In this thesis work, as a first step, an analytical study is attempted to establish a link between various hybrid configurations with ST. For this study, an analytical solution of Grad-Shafranov (GS) equation in the low-aspect ratio regime for specific choice of pressure and toroidal field profiles is considered. This study has shown the existence of various hybrid equilibria like Spherical Tokamak surrounded by Spheromak Shell (STSS), Field Reversed Configuration surrounded by Spherical Tokamak (FRCST), "hole" - like equilibria and their relationship with ST. This study has shown that one can change STSS to hole-like equilibrium via STSS with little external toroidal field, FRCST and ST just by increasing the β (ratio of plasma pressure to magnetic pressure) of the system. The further improvement of hybrid equilibria like STSS and FRCST needs an arbitrary choice of pressure and toroidal flux profile which requires to solve GS equation numerically. A Hybrid Toroidal Equilibrium (HTEQ) code is developed and validated with standard tokamak equilibrium codes. This is used for optimizing the hybrid equilibria. A pilot plant with STSS configuration is

constructed using this code. The dependence of plasma parameters on the profile is studied in detail. This code is also used to construct a typical FRCST configuration with plasma current of 3 MA. In this equilibrium, a poloidal current layer exists just outside the FRC region to nullify the external toroidal field.

At very high β, it is shown theoretically that one can have a magnetic hole [poloidal and toroidal field vanishes] region in the belly of tokamak. This study is carried out for a large aspect ratio tokamak with a circular boundary. In the hole-like equilibrium, there are two regions; a core region where flux surfaces are nearly vertical and a boundary layer region near the wall. Even though the existence of such a configuration is identified with the simple analytical study, a two region calculation is needed to construct them properly. A two region calculation with inverse of safety factor as the expansion parameter is carried out for arbitrary aspect ratio tokamaks with shaped plasma boundary. The core solution with and without "hole" region is obtained. The aspect ratio dependence of critical β (needed to form a hole - like equilibrium) is studied. This configuration is compared with its tokamak counterpart and found that producing such a configuration is little easier in ST than in the conventional tokamak.

The internal transport phenomena in any configuration decides the confinement time which is crucial for the design of reactor. In the past, various advanced configurations have been achieved where the transport is reduced for input power more than a certain critical power. In these configurations, a transport barrier is formed at the edge. Recently, one such configuration [enhanced reverse shear (ERS)] is achieved by altering the q profile. Here the transport barrier is formed at the radial location where the safety factor is minimum (near the core). In a recent experimental study of this configuration, a poloidal flow shear reversal is observed just before the transition. It is seen that this reversal is only responsible to trigger the transition and not to sustain it. The study of this aspect can improve the operating regime of each optimized configuration and may be useful for the next generation fusion reactor. For this study, a reduced enhanced reverse shear (RERS) model is developed. This model evolves the flow-fluctuation equilibrium in transport time scale along with the evolution of density gradient. The zero-D of this model reproduced qualitatively the temporal behaviour of poloidal flow dynamics during ERS transition as seen in the experiment. This model is further extended to include the spatial behaviour of the poloidal flow and this predicted the formation of a shear layer at the radial location where the the safety factor is minimum (as seen in experiment). These models also predicted the transition to ERS without the precursor for values above the critical value of the damping to generation ratio.