Abstract

The most promising results in the field of nuclear fusion have been achieved in a device called tokamak. Presently tokamaks are in operation at several laboratories throughout the world. Although there are generalized guidelines of tokamak operations, every tokamak device responds to specific discharge conditions. For example, the evolution of plasma current (and current density profile) depends on the applied toroidal electric field (loop voltage) and the vessel time constant. Instabilities (e.g. double tearing modes) driven by current gradient may be present during the current rise phase depending on the rate of current rise. Similarly, plasma equilibrium is affected by the eddy currents and the stray magnetic field. The scenario for the plasma current termination is also not uniform in various tokamaks. It depends on the actual discharge condition and instabilities which determine the fate of the discharge. It is therefore, necessary that systematic studies be carried out in each tokamak to understand its performance better. The magnetohydrodynamic (MHD) instabilities are the most important instabilities which determine the growth, sustenance and the termination of tokamak discharge.

We have introduced the magnetic confinement of toroidal plasma column and discussed the concept of tokamak device. We have given a brief description of the first Indian tokamak ADITYA in which we have carried out the research work presented in this thesis. In view of our next generation steady state tokamak, SST-1, we have carried out relevant analysis techniques to interpret the experimental results of ADITYA tokamak.

We have described the magnetic diagnostics consist of magnetic probes and pick up coils installed in ADITYA tokamak. These diagnostics were selected to carry out systematic study of plasma equilibrium and MHD instability in ADITYA tokamak. A set of magnetic probes for the estimation of plasma equilibrium position and a poloidal array of magnetic pickup coils for studying the mode structures of MHD instability were properly calibrated in the laboratory prior to installation inside the vacuum vessel. We have described the relevant calibration procedures.

The techniques for the tokamak equilibrium reconstruction have been discussed. We have been routinely using the conventional Shafranov's equilibrium calculation for determining the plasma equilibrium positions. This technique is good enough for the circular plasma but cannot be used for a shaped plasma like our next tokamak SST-1. With a view to extend the equilibrium reconstruction technique for a non-circular plasma of SST-1, we have used one of the most advanced technique called function parametrization (FP) technique on ADITYA. The results obtained by FP were compared with the conventional Shafranov's equilibrium calculation as well as the MHD simulation code. The simulation code was also used to estimate the magnetic flux surfaces and helped us in understanding of the plasma discharge characteristics. We had got opportunity to benchmark the FP technique in the Swiss tokamak TCV which generates variety of plasma shapes. This experience has been useful in view of our next tokamak SST-1 which would also have non-circular plasmas.

As pointed out earlier, the MHD instabilities play dominant role in determining the sustenance of the discharge. We have, therefore, presented an introduction to MHD instability and analytical techniques used to determine the poloidal mode structure. We have used singular value decomposition (SVD) for this purpose. We had an opportunity to apply this technique to TCV tokamak data and test its validity against their results

(obtained using bi-orthogonal decomposition technique). Several ADITYA discharges were analyzed using SVD technique to determine the mode structure of low frequency MHD oscillations. We have observed that the poloidal structure of the MHD oscillations depends on the phase of discharge. The current rise phase was typically dominated by m=5 and m=4 structures. During the current flattop phase, m=3 and m=2 modes were present. The safety factor q, at the limiter radius was typically between 2.5 and 3.5 in all the experiments. We have also observed significant increase in MHD activity during the current termination phase. Correlation of soft X-ray, μ-wave interferometer and Mirnov signals were also present during this phase. This observation shows the role of m=2 mode in triggering and growth of instability and coupling with m=1 mode. The nonlinear coupling among low mode instabilities has been studied using bi-coherence spectrum. We have seen that significant level of squared bi-coherence between low frequency modes determine the disruption of the discharge. During the flattop phase the bi-coherence spectrum is poor and such discharges sustain for a long time.

The MHD instability in a tokamak is a subject of continuing interest. We have studied such instability in the Ohmically heated ADITYA tokamak. Many of these characteristics may change when additional heating with ion and electron cyclotron resonance heating (ICRH and ECRH) are applied. In addition, the attempts to improve energy confinement by applying gas puffing and impurity injection alter the MHD activity. We hope to carry out such studies in future.