

Experimental Studies of Edge Turbulence, Convective Transport and SOL Flow in the Spherical Tokamak QUEST

サントヌ, バナジー

<https://doi.org/10.15017/1398411>

出版情報：九州大学, 2013, 博士（学術）, 課程博士
バージョン：
権利関係：全文ファイル公表済



氏名・(本籍・国籍)	バナジー サンタヌ Banerjee Santanu (インド)
学位の種類	博士(学術)
学位記番号	総理工博甲第879号
学位授与の日付	平成25年9月24日
学位授与の要件	学位規則第4条第1項該当 総合理工学府 先端エネルギー理工学専攻
学位論文題目	Experimental Studies of Edge Turbulence, Convective Transport and SOL Flow in the Spherical Tokamak QUEST (球状トカマクQUESTにおける周辺乱流、対流輸送およびSOL流れに関する実験研究)
論文調査委員	(主査) 教授 関子秀樹 (副査) 教授 田中雅慶 教授 内野喜一郎

論文内容の要旨

Issues related to edge turbulence and transport in tokamaks are quite indispensable, as they dictate the dynamical plasma behavior both in the plasma core and the edge. Edge turbulence may have a dramatic impact on the fusion reactor operation by causing rapid release of energy and particles which may produce significant local damages on the first wall. On the other hand, when controlled effectively, edge turbulence could also play a beneficial role in removing exhaust particles that, if accumulated, would lead to fuel dilution, quenching the fusion reactivity. Edge turbulence is typically characterized by very high relative fluctuation levels, leading to strong nonlinear effects and to the formation of macroscopic field-aligned structures, often referred to as ‘blobs’ (or filaments).

Another important phenomenon is the plasma flow along the magnetic field lines in the scrape off layer (SOL). It is believed to play a vital role in the regulation of instabilities, turbulent transport and L-H transition. Plasma flow can attain velocities approaching a significant fraction of the local sound speed. A number of mechanisms are known to generate parallel flows in the SOL: ionization imbalances, Pfirsch–Schlüter flows, poloidal transport asymmetries (e.g. ballooning-like transport), and toroidal rotation. However, experimental evidence of RF-induced poloidal flow is less readily available. Analytical models and numerical simulations have been proposed to reconstruct observed flows with, nevertheless, limited success rate due to the complexity of flow pattern.

A two-fold objective is set for this thesis. First, the characteristics of the edge and SOL turbulence and transport are studied in both slab annular plasma featuring open field lines and Ohmic plasma with well defined last closed flux surface. Statistical features of the edge fluctuations and physical mechanisms controlling the generation and propagation of blobs are considered imperative for the core confinement efficiency and heat and particle transport to the material wall. These issues are envisaged crucial for the future fusion devices like ITER and beyond. Fluctuations and blob trajectories can be traced comprehensively in 2D with tangential fast imaging across a wide region in the SOL. Hence it can provide significant improvements over the single point probe measurements.

The second aspect addressed in this thesis is the characterization of the SOL flow and the associated mechanisms. This is aimed at gaining knowledge of the flow pattern in the SOL and its impact on the turbulent transport. Flow generation mechanisms and the physical parameters that can control the

flow are important as they can provide the necessary knob to regulate the particle exhaust and turbulence driven transport at the edge. Tangential fast imaging diagnostic along with the conventional Langmuir and Mach probes in the SOL can provide a wealth of information regarding the poloidal flow components. This thesis is therefore organized as follows:

In Chapter 2, brief description of the spherical tokamak QUEST is outlined. The fast visible imaging systems that are used in this study are described. Details of the reciprocating probe system are also given.

Chapter 3 deals in the edge turbulence and convective intermittent transport in slab plasma. Two types of slab plasma with different ECR heating are studied.

- In the first part, statistical aspects of the convective transport with respect to the variation in magnetic field pitch are dwelled upon. Progressive enhancement of fluctuations and consequent blob generation and propagation are observed with the increase in B_z at a constant B_t . Amplitude and waiting time of the blobs attains a maximum for highest B_z/B_t ($=7.8\%$). 2D statistical analysis of the images enables us to identify blob formation location precisely at the steep density gradient region. Accelerated radial propagation was observed for large sized blobs.
- In the second part the effect of mirror ratio on turbulence is studied with the change in poloidal field curvature. Fluctuation characteristics are quite different for the poloidal field coil pairs PF17, 26 and 35 with high, moderate and low magnetic shears respectively. Coherent peak appears for deep PF well (PF35) beyond $B_z \sim 13$ mT. It was not apparent for either of PF17 and 26.

In chapter 4, plasma turbulence characteristics in the edge and SOL of Ohmic plasma are summarized. Intermittency, dominated by blobs, is observed in the SOL. A simple parabolic relation exists between skewness and kurtosis, and the probability density function (*PDF*) significantly deviates from Gaussian beyond the density gradient region towards the far SOL. A model has been proposed to characterize the *PDFs* in the density gradient and far SOL regions.

In chapter 5, observation of ECW induced SOL flow is reported. Definite flow structures with long range radial and poloidal correlation and a distinct mode at 781 Hz are observed. Cross correlation of intensity shows poloidal spin-up and radial out-flow. Also, a novel technique based on particle image velocimetry using orthogonal dynamic programming is developed to further analyze the flow velocity of the coherent mode. Increase in H_α and ion saturation current suggests strong cross-field transport. This may be driving the SOL parallel flow under the unique scenario of ECW induced inboard poloidal null configuration in QUEST

In conclusion, this study has provided deeper insights in the generation mechanisms and propagation dynamics of the coherent convective structures (blobs). The effect of field pitch and curvature may provide better controls on the intermittent transport at the edge. Further, characterization of the SOL flow induced by ECW, which is one of the most common auxiliary heating and current drive systems in fusion devices, may provide better regulation of instabilities and help in achieving improved confinement.

論文審査の結果の要旨

本論文は、プラズマ発光の高速カメラ映像をもとに、周辺プラズマの間歇性揺動の高次モーメント解析を行い、プラズマ塊の発生・伝播と統計確率分布の空間構造の相関を明らかにし、さらに強度パターンの追跡からプラズマ流れの二次元空間構造を調べる手法を開発している。これらの成果は、核融合学及びプラズマ物理学に寄与するところが大きい。よって博士（学術）の学位論文に値するものと認められる。