Fusion Engineering and Design xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Edge transport and fluctuation induced turbulence characteristics in early SST-1 plasma

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HIGHLIGHTS

- Anomalous particle transport during the high MHD activity at SST-1.
- Electrostatic turbulence is modulated by MHD activity at SST-1 tokamak.
- Edge floating potential fluctuations shows poloidal long-range cross correlation.

ARTICLE INFO

Article history:
Received 9 July 2016
Received in revised form 8 November 2016
Accepted 28 December 2016
Available online xxx

Keywords:
Tokamak plasma
MHD
Plasma confinement
Particle transport
Plasma diagnostics

ABSTRACT

Plasma edge transport characteristics are known to be heavily influenced by the edge fluctuation induced turbulences. These characteristics play a critical role towards the confinement of plasma column in a Tokamak. The edge magnetic fluctuations and its subsequent effect on electrostatic fluctuations have been experimentally investigated for the first time at the edge of the SST-1 plasma column. This paper reports the correlations that exist and is experimentally been observed between the edge densities and floating potential fluctuations with the magnetic fluctuations. The edge density and floating potential fluctuations have been measured with the help of poloidally separated Langmuir probes, whereas the magnetic fluctuations have been measured with poloidally spaced Mirnov coils. Increase in magnetic fluctuations associated with enhanced MHD activities has been found to increase the floating potential and ion saturation current. These observations indicate electrostatic turbulence getting influenced with the MHD activities and reveal the edge anomalous particle transport during SST-1 tokamak discharge. Large-scale coherent structures have been observed in the floating potential fluctuations, indicating long-distance cross correlation in the poloidal directions. From bispectral analysis, a strong nonlinear coupling among the floating potential fluctuations is observed in the low-frequency range about 0–15 kHz.

1. Introduction

In general, the plasma turbulence refers to the microscopic random fluctuations in particle density, temperature, potential and magnetic field. These fluctuations are generally driven by radial gradients that exist in the plasma density and temperature [1]. Plasma turbulence and transport properties, especially at the edge region are known to influence the overall plasma confinement characteristics in a tokamak. Turbulence, in fact is one of the primary reason attributed towards the anomalous particle and energy transport in a tokamak [1–4]. The magnetic and electrostatic fluctuations that lead to magnetic and electrostatic turbulence at the tokamak edge are known to drive the plasma turbulences [5,6]. These magnetic fluctuations further reduce the plasma performances. They limit relevant parameters like poloidal beta due to the change of plasma profiles [7]. The magnetic transport due to magnetic fluctuations is not large enough as compared to electrostatic transport in tokamak plasma. The edge plasma transport is primarily driven by electrostatic fluctuations [7].

Several efforts have been put towards understanding the plasma transport and turbulence behaviour in the last decades in tokamak plasmas. Presence of large-scale magneto-hydrodynamic (MHD) instabilities and small-scale turbulence are generally present at a sufficient to result in the anomalous particle transport in tokamak devices [8]. In presence of strong toroidal magnetic field, the time-varying radial electric field drives the E x B drift flows in poloidal direction. Such plasma flow is termed as zonal flow (ZF). In the

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http://dx.doi.org/10.1016/j.fusengdes.2016.12.041

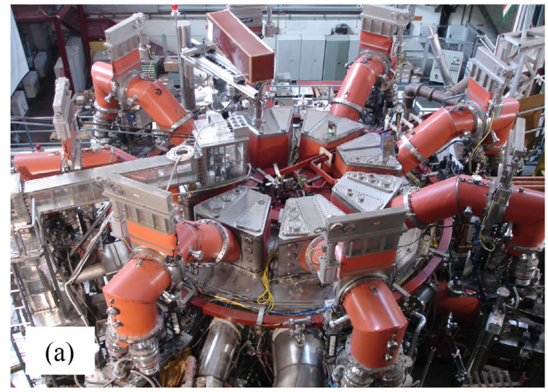
context of the tokamak configuration, the ZFs are radially localized potential perturbations which are toroidally and poloidally symmetric. Such plasma flows are generated due to the radial turbulent transport of poloidal momentum, i.e. the Reynolds stress [9]. In toroidal confined tokamak plasmas, two types of ZFs have been observed, i.e. a low-frequency zonal flow (LFZF) with nearly zero frequency and a geodesic acoustic mode (GAM) with higher frequency [9]. The plasma turbulence is expected to be in a self-organized state mediated by zonal flows [10].

The MHD phenomenon is another important topic for fusion community. MHD instabilities are considered as dangerous phenomena as they lead to destruction of magnetic surfaces and termination of plasma discharge. The MHD influences the sheared radial electric field within the plasma column. Depending on the strength of the MHD behaviour, the magnetic oscillations (MHD activity) change the plasma density, electron temperature and plasma potentials which in turn influence the electrostatic fluctuations [3]. The anomalous transports, together with MHD instabilities control the plasma confinement and overall plasma performance. It is observed and reported by different researcher that the radial electric field suppress the MHD activity which in turn improves the plasma confinement in tokamak [11–13].

The correlation between the magnetic oscillations and electrostatic turbulence is not significant [1] in many tokamak devices. However, the correlation between the magnetic oscillations and the electrostatic turbulence turns to be relevant in new high-confinement regimes achieved in tokamaks [14–16]. The studies on reversed field pinch (RFP) show that the electrostatic fluctuations are influenced by the magnetic fluctuations [5,6]. B. J. Ding et al. [7] have reported the edge density and potential fluctuations having high correlation with magnetic fluctuations; and the resulting mode spectra being similar to those of magnetic field fluctuations. These strongly indicate that, the electrostatic fluctuations are primarily caused by electromagnetic turbulence.

In recent years, particular attention has been paid to the coherent structures in plasma turbulences. In fusion and non-fusion plasmas, the transport processes mostly contains the short range correlations, rather than long-range correlations. Recently, several authors [17–20] have reported the observations of long-range correlation and self-similarity in plasma edge fluctuations in the so called "mesoscale" range. These are larger than turbulence decorrelation time and plasma confinement time in many tokamak devices [17–20]. It has also been reported by many authors that the presence of the long-range correlation and self-similarity can be easily understood if the self-organized criticality (SOC) dynamics play a dominant role in the plasma transport processes [17–22]. Different statistical analysis techniques have been extended to identify the existence of long range correlations and self-similarity in plasma fluctuation [23]. G. S. Xu et al. [10] observed the poloidal long-distance correlations and have reported about 40% coherence at the poloidal distance (31.4 mm) that is nearly three times of the turbulence decorrelation length at HT-7 tokamak. Despite of the huge efforts on these aspects in the last decades, many features of plasma transports are still to be understood. Thus, more careful investigations are still necessary for better controlling of plasma confinement in tokamaks.

Recently, the edge density and potential fluctuations and their correlation with magnetic fluctuations have been studied at Steadystate Superconducting Tokamak-1 (SST-1) tokamak. SST-1 is a medium sized tokamak having large aspect ratio with a major radius of 1.1 m and a plasma minor radius of 0.2 m with elongation of 1.7–1.9 and triangularity of 0.5–0.7 [24]. The recent experimental observations show a high correlation of edge density and potential fluctuations with that of the magnetic fluctuations. The cross correlation and coherence between the electrostatic fluctuations measured at different poloidal locations have been carried out under this investigation. These events have also been studied with synchronized MHD activities as observed experimentally in SST-1 early plasmas.



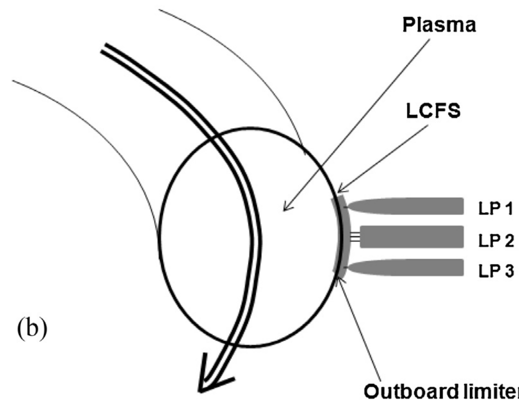


Fig. 1. (Colour online) (a) Top view of SST-1 tokamak and (b) schematic of Langmuir probe arrangement.

The remaining sections of this paper have been organized as follows. In Section 2, the experimental set-up, methodology and the diagnostic tools are described in detail. Section 3 summarizes the results and their physical interpretations. Finally, the present work has been concluded in Section 4.

2. Experimental assembly and methodology

The present studies have been carried out in SST-1 tokamak over a large number of repeatable shots under identical plasma conditions. However, under this investigation two representative plasma shots (shot no 7799 and 7873) have been discussed. The top view of SST-1 tokamak and schematic of Langmuir probe arrangement is shown in Fig. 1(a) and (b).

The SST-1 tokamak is operated in limiter configuration with a central field of 1.5 T. Graphite tiles have a density of 1.82 g/cm^3 and a porosity of about 9.00% is used as limiter materials. Sixteen (16) toroidal field (TF) superconducting coils are used to produce the required toroidal field. A pair of vertical field coils placed symmetric to Z = 0 plane is used to provide the necessary equilibrium field to the plasma column formed [23].

In SST-1, the plasma is initiated with the help of ECH pre-ionization, employing a 42 GHz Gyrotron in fundamental mode followed by the Ohmic transformer [25]. At present, plasma currents are produced in excess of 100 KA extending in durations up to ~500 m s in a repeatable fashion. The plasma is confined within the two poloidal limiters. In the present report, two identical plasma shots (shot no 7799 and 7873) in terms of plasma duration and current have been chosen to study the edge parameters and its correlation with MHD. The plasma current reaches a maximum value