# RECENT RESULTS OF ECRH EXPERIMENTS ON L-2M STELLARATOR

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## Abstract

Results are reported from experimental study of ECH heated plasma in the L-2M stellarator with special emphasis on studying the turbulent processes. It is shown that the total plasma energy at fixed total heating power is strongly dependent on the plasma position. Visible degradation of plasma confinement is observed for the inward shifted magnetic configurations where the stability conditions of ideal interchange MHD modes are violated. However, even in this case the situation can be improved by decreasing the average radius of the plasma boundary with the help of graphite limiter resulting in the increase of the Shafranov shift of magnetic surfaces and deepening of the magnetic well due to the effect of self-stabilization. This in turn causes stabilization of ideal MHD interchange modes and visible increase in plasma energy and volume average value of beta. Statistical properties of turbulence was studied both for the central part of the plasma column and for the plasma edge. It is shown that one of the critical factors determining the coherent structures and turbulent fluxes in the edge plasma is the radial electric field.

## 1. INTRODUCTION

In the last few years a serious effort was made to understand the role of the turbulent processes in plasma confinement. The ATF experiments [1] showed the self-stabilization effect of finite $\beta$ and second stability regime was achieved at relatively low $\bar{\beta}$ values $\bar{\beta} \sim .5\%$ ($\beta$ is the ratio of the plasma pressure to the pressure of the magnetic field, bar denotes the volume average). This was mainly due to the strong self-stabilizing effect in high-shear systems [2]. In CHS experiments [3] the dynamic magnetic field control was used to suppress the outward plasma shift with increasing plasma pressure up to the $\bar{\beta} = 2\%$ value and it was shown that magnetic fluctuations did not increase with the increasing plasma pressure at $\beta$ values exceeded 1%.

The transport of plasma and energy under the influence of fluctuations in the edge plasma has been discussed as one of the processes that can affect global confinement in toroidal devices with different configurations of the magnetic fields [4]. The use of spectral analysis of fluctuation signals in term of wave packets (wavelet analysis) has greatly extended the experimental possibilities [5], making it possible to obtain information about the coherence of frequency wavelet components with high time resolution [6]. Previously, such methods was used to detect coherent poloidal and radial structures and the structure of turbulent flux at the edge plasma of L-2M stellarator [7-9]. Here we present the results of experimental investigation of the turbulent processes in the central part of the plasma coloumn and in the edge plasma and shall attempt to clarify the mechanism of their common influence on the plasma confinement.

## 2. EXPERIMENTAL SET-UP

L-2M is a planar axis classical stellarator with the poloidal multipolarity $l = 2$, the total number of field periods is $N = 14$, the major radius is $R = 1m$, and the minor radius (the average radius of vacuum separatrix) is $r_s = 0.115m$. The vacuum rotational transform can be presented in the form:

$$\mu^* \approx 0.175 + 0.26(r/r_s)^2 + 0.27(r/r_s)^4 \tag{1}$$

where r is the average radius of the magnetic surface. For creating and heating a current-free plasma 75 GHz gyrotron was used ($\lambda = 4mm$) with the power up to $P = 0.4MW$. For the magnetic field $B = 1.34T$, the resonant conditions for ECR at the second harmonic of gyrofrequency ($\omega = 2\omega_{Be}$, X-mode) were fulfilled for $R = 1m$. The heating pulse duration was 10-12ms. Typical for our experiments plasma parameters are $n_e \sim (1-2)10^{19}m^{-3}, T_e(0) \sim 1keV, T_i \sim 0.1 - 0.15$. Vertical magnetic field $B_v$ varies from the value $B_v/B = -0.5\%$ to $B_v/B = 0.5\%$. A graphite limiter was used to decrease plasma-wall interaction. This movable limiter can be introduced from the outside of the torus inward up to 3 cm from the vacuum separatrix. The plasma energy was obtained from the diamagnetic measurements. Knowing the fact that under the relevant experimental conditions the average radius of the plasma boundaries is a weak function of the plasma pressure profile it is quite easy to find $\bar{\beta}$ using the numerical procedure of calculating free-boundary plasma equilibria [10]. Also this procedure gives an opportunity to obtain $T_e(r)$ from SXR diagnostic and to estimate $\beta(r)$ [11]. The X-ray data were supported by ECE data. Modulated ECRH at several frequencies has been used for the estimation the value of electron thermal conductivity and the power deposition profile. The density fluctuations in the central part of the plasma column were investigated with the help of far forward scattering (FFS) [12] of the O-mode appearing due to the splitting of the linearly polarized wave used for ECR heating of plasmas. To investigate the radial structure of fluctuations and turbulent transport at the plasma edge tree movable triple Langmuir probes were used [7].

## 3. EXPERIMENTAL RESULTS.

Let us start with discussing the influence of negative vertical field on the plasma confinement. Let us consider three cases: one will be with $\epsilon = B_v/B_0 = 0$, the second with $\epsilon = -.3\%$ for which the $|\epsilon|$ value slightly exceed the value at which plasma is stable and $\epsilon = -.5\%$ for which stability calculations demonstrate strong violation of stability criteria. For all cases considered Mercier stability criteria was analyzed. To diminish plasma wall interaction graphite limiter was used cutting $\sim 1cm$ of the average radius of vacuum seperatrix. The plasma energy for this cases is presented in Fig.1. Longitudinal magnetic field was varying shifting the zone of heating power absorption. Calculations show that $\epsilon = 0$ case is stable due to the effect of self-stabilization, for case with $\epsilon = -.3\%$ narrow instability zone is located at $(r/r_p) \sim 0.5$. For the case $\epsilon = -.5\%$ broad instability regions were calculated depending on pressure profile. We see from Fig.1 that cases with $\epsilon = -.3\%$ case has practically the same plasma energy as $\epsilon = 0$ case. However, the analysis of SXR signal shows that $T_e$ profile become more flat, that cause the decrease of Shafranov shift and therefore could destabilize interchange modes. However, the flattening the pressure profile in the central part of the plasma column help to achieve the marginally stable state. The further decrease in $\epsilon$ is followed with the strong decrease in the plasma energy. FFS spectra (see Fig.2) in this case demonstrate increase in the spectral density of fluctuations where two spikes are visible (note that $\bar{\beta}$ is significantly less here). However, we have not enough information on plasma parameters to precisely determine the poloidal numbers of dominating modes. To perform an independent check whether the rigid degradation of plasma energy is determined by MHD activity we may use the following trick. The situation can in principle be improved by decreasing the average radius of the plasma boundary with the help of graphite limiter resulting in the increase of the Shafranov shift of magnetic surfaces and deepening of the magnetic well due to the effect of self-stabilization. This in turn may result in stabilization of ideal MHD interchange modes. Is so indeed. The decrease of plasma boundary average radius up to $\sim 9cm$ does not lead to the decrease in plasma energy that could be expected from $\tau \sim a^2$

law for quiescent plasma. This configuration has practically the same FFS spectrum as outward shifted by $\epsilon = .5\%$ configuration with the same minor radius.

The properties of edge plasma was investigated by the use of Langmuir probes. The performed analysis of structure of fluctuations and turbulent transport demonstrated that highly correlated fluctuations are localized predominantly in the outer region of the plasma column that confirms their ballooning nature. The inward shift of configuration cause significant increase in the relative values of fluctuations of density and floating potential (see Fig.3). The value of floating potential also visible changes (see Fig.4).

Also the inward shift cause rigid increase in the value of turbulent flux (see Fig.5 ). Previously, it was shown that one of the leading factors influencing the value of turbulent flux in L-2M stellarator is the radial electric field [9]. Polodial and radial wavelet coherence of plasma fluctuations were analyzed. No visible difference between the cases with- and without vertical field were observed. Remind, however that the distance between probes were fixed and we could claim only that radial width of coherent zone that is responsible for the value of turbulent flux is not less than radial distance between probes (in our case 4mm). In all the cases considered large (ut to 20 cm) coherent poloidal zones were observed.

## 4. DISCUSSION

It is shown that the total plasma energy at fixed total heating power is strongly dependent on the plasma position. Visible degradation of plasma confinement is observed for the inward shifted magnetic configurations where the stability conditions of ideal interchange MHD modes are violated. However, even in this case the situation can be improved by decreasing the average radius of the plasma boundary with the help of graphite limiter resulting in the increase of the Shafranov shift of magnetic surfaces and deepening of the magnetic well due to the effect of self-stabilization. This in turn causes stabilization of ideal MHD interchange modes and visible increase in plasma energy and volume average value of beta.

The structure of fluctuations and turbulent transport at the plasma edge were analyzed. It is shown that inward shift of magnetic surfaces leads also to the significant increase in the turbulent flux at the plasma edge. For L-2M stellarator one of the leading factors influencing the value of turbulent flux is the radial electric field.

Existence of large scale poloidal coherent zones gives circumstantial evidence that toroidal coupling effects survive in the nonlinear phase where turbulent flux increase drastically.

The density fluctuations were investigated with the help of far forward scattering of the O-mode appearing due to the splitting of the linearly polarized wave used for ECR heating of plasmas. This method appeared to be useful and convenient tool for investigating plasma fluctuations in the central part of the plasma column.

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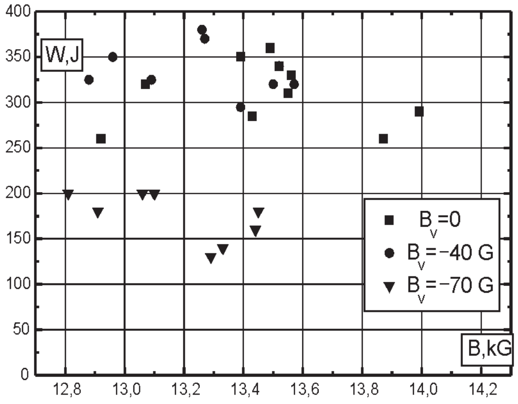


*Fig.1. Plasma energy measured from diamagnetism*

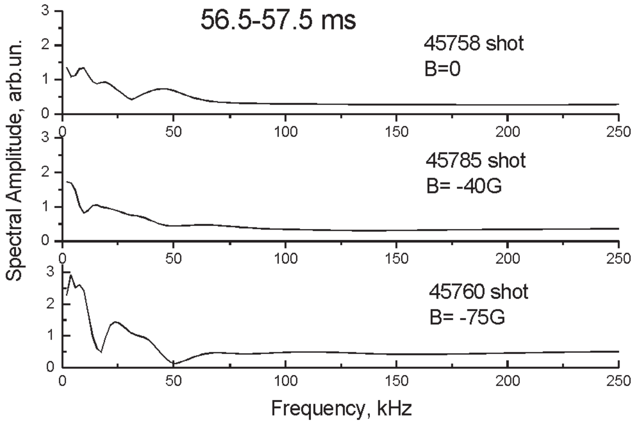


*Fig.2. Wavelet spectra of FFS of heating gyrotron radiation from the central plasma region*

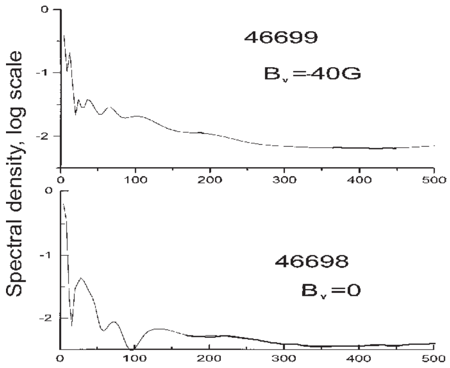


*Fig.3. Wavelet spectra of floating potential at the plasma edge (r / $r_s$ =0.86)*

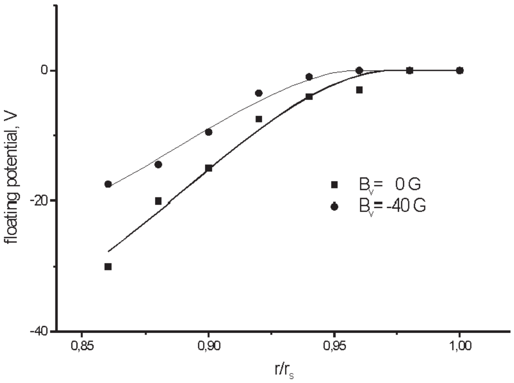
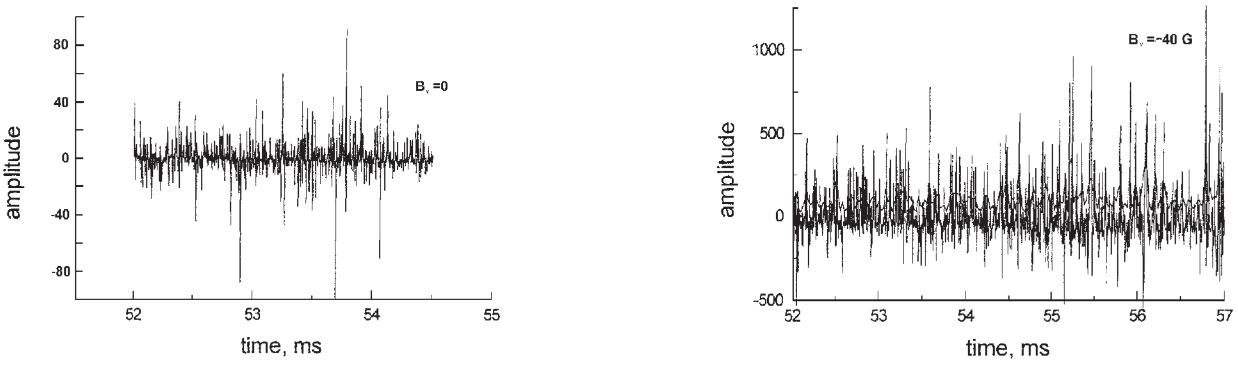


*FIG.4. Floating potential versus normalized average radius ( r / $r_s$ )*



(A)

(B)

*Fig.. 5. Temporal evolution of turbulent flux ( A) - $B_v$ = 0, (B)- $B_v$ = -40G*