Analysis of magnetic fluctuations on the CASTOR tokamak

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1 Introduction

Link between the transport processes and magnetic turbulence in tokamaks is not yet clearly understood. One of the reasons is that the relevant magnetic data directly measured in the central region of plasma are not available. The major difficulty is that the magnetic coils can not be inserted into a high parameter plasma of large fusion devices. However, in small size devices the plasma core is accessible by the magnetic coils and the plasma parameters are believed to be similar to those at the plasma edge in larger tokamaks.

Some aspects of the magnetic turbulence are investigated on the CASTOR tokamak ($R = 0.4m, a = 0.085m, B_T = 0.5 \div 1.1T, I_p = 5 \div 20kA, \tau_d \leq 50ms$) using the array of eight absolutely calibrated coils spaced in the radial direction. The total active length of the array represents $\sim 60\%$ of the plasma minor radius. In short discharges (t $\leq$ 10 ms) with a reduced plasma current ($I_p \leq 7$ kA), the whole array can be inserted into the plasma column without any damage and plasma is not perturbed significantly.

2 Experimental arrangement

For measuring radial profile of magnetic fluctuations in Castor tokamak, the array of eight magnetic coils was constructed. All these coils are 4 mm long and 4.4 mm in diameter and are radially spaced from each other. Each coil has 196 turns: 33 turns in each of the first five layers and 31 turns in the sixth layer. An insulated copper wire 0.1 mm in diameter is used for windings. The coils are fixed on ceramic skeleton shown in Fig. 1.

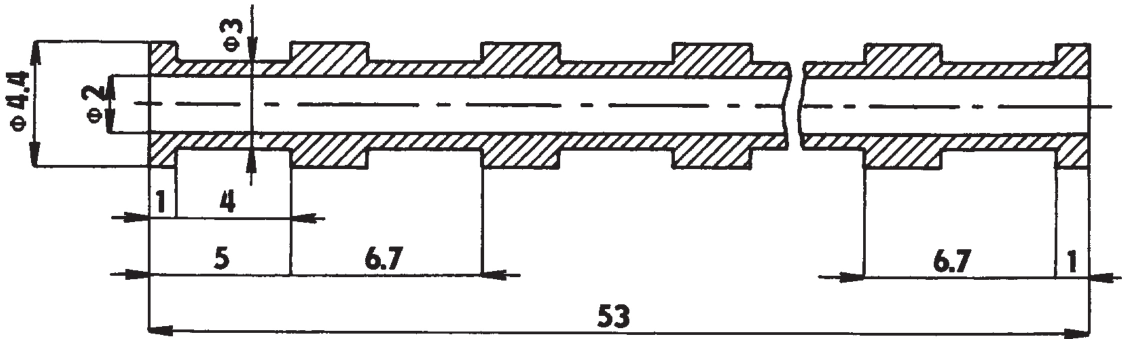

Figure 1: Skeleton of the magnetic probes array.

The whole array is encased in a protective stainless steel tube of 0.2 mm wall thickness, slotted by 0.8 mm to improve frequency response of the probes.

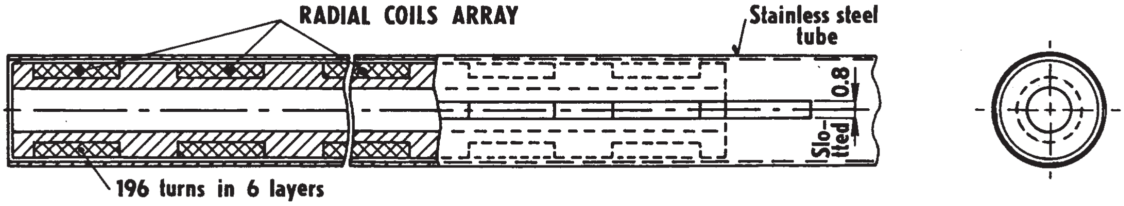

Figure 2: Cross-section of the coils arranged in the stainless steel tube.

It is possible to change radial position of probes array in the tokamak chamber. Therefore, we are able to insert probes deeper in plasma or pull them out even outside the limiter, if necessary. It enabled us to accommodate the position of the probes to chosen plasma parameters for each shot. The array inserted deepest in the plasma allowed us to measure the level of magnetic turbulence from r/a=1 to r/a=0.45 in a single shot. The position of probes in the tokamak is schematically shown in the Fig. 3.

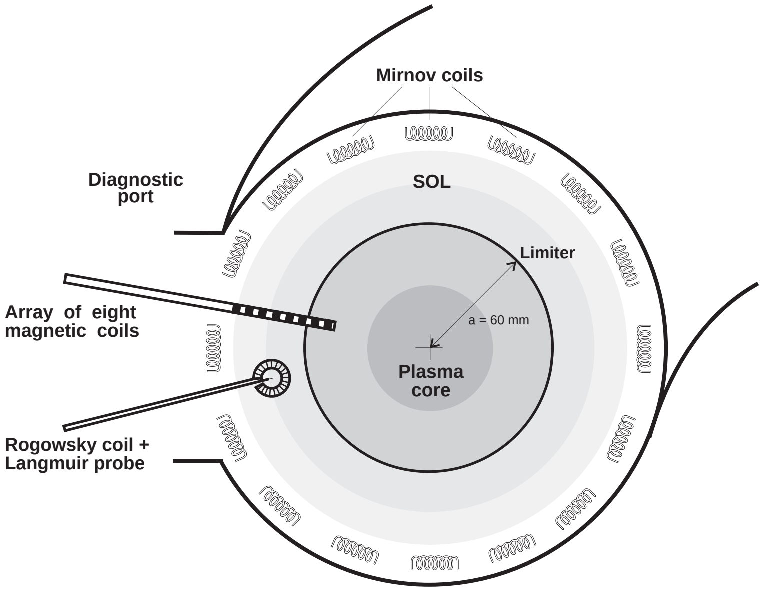

Figure 3: Position of the probes within the tokamak chamber.

Signals from individual coils are pre-integrated by passive RC integrator circuits to remove high frequency component ($>$ 300kHz). It can be done because previous experiments showed that the dominant part of the fluctuating power is bellow $\sim$ 100 kHz. Then, the signals are sampled by A/D converter and saved by PC oriented acquisition system.

Majority of shots were performed in the low $B_T \approx 0.5T$ regime to obtain plasma with the lowest possible safety factor q(a) at low plasma current. It is assumed that the highest level of magnetic turbulence is present around the q=1 and q=2 magnetic surfaces. The following formula for safety factor q(a) is valid for CASTOR tokamak :

$$q(a) = \frac{aB_T}{RB_\theta} = 90.3\frac{B_T}{I_p} \qquad\qquad [m,T,m,T,T,kA].$$

With above mentioned plasma parameters we were able to obtain $q(a) \approx 4$.

3 Results

All results presented in this section are based on measurements of B$_r$ (radial component of magnetic field) with the eight coils array inserted into plasma. The evolution of basic plasma parameters during a typical shot which is further analysed in more details is shown in Fig. 4.

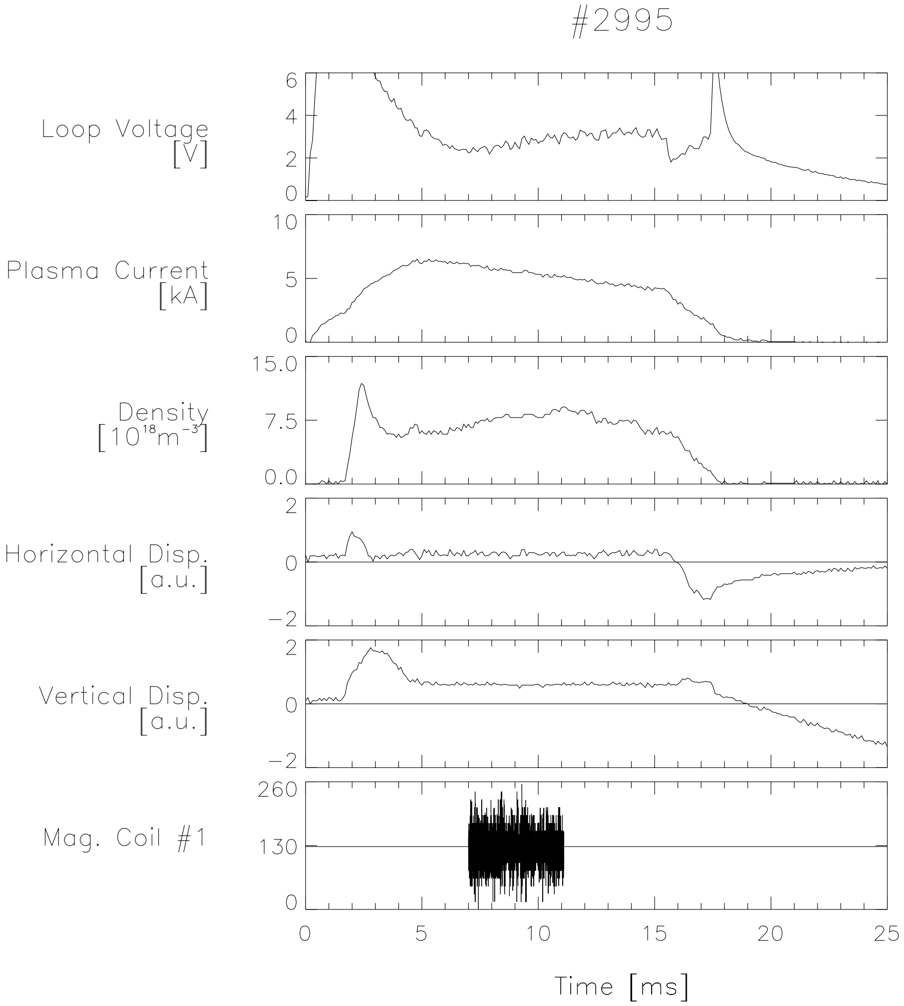

Figure 4: Evolution of the basic plasma parameters and the signal from the first coil, registered during the period 4 ms, for the shot 2995.

The signals of coils were sampled from 7 ms to 11 ms with sampling rate 1μs. All basic plasma parameters are quasistationary during this time interval : the loop voltage is 2.5 V, the line averaged plasma density $7.5\times10^{18}m^{-3}$, the plasma current 6 kA and the toroidal magnetic field 0.5 T. The safety factor at the limiter position q(a) was 7.5. The most inner coil was placed 38 mm from the center of the plasma column that means at r/a=0.45 (a=85 mm).

Shifts and drifts of the signals from the coils were removed by estimation of zero level through the linear regression. Moreover, the low frequency components of the signals ($<$ 10 kHz) were numerically removed by filtering in frequency domain.

The level of the magnetic turbulence is characterized by the root-mean-square (RMS) value of the B_r fluctuations which is further denoted as $\tilde{B}_r$. The radial profile of $\tilde{B}_r$ for the shot with q(a)=7.5 is shown in Fig. 5.

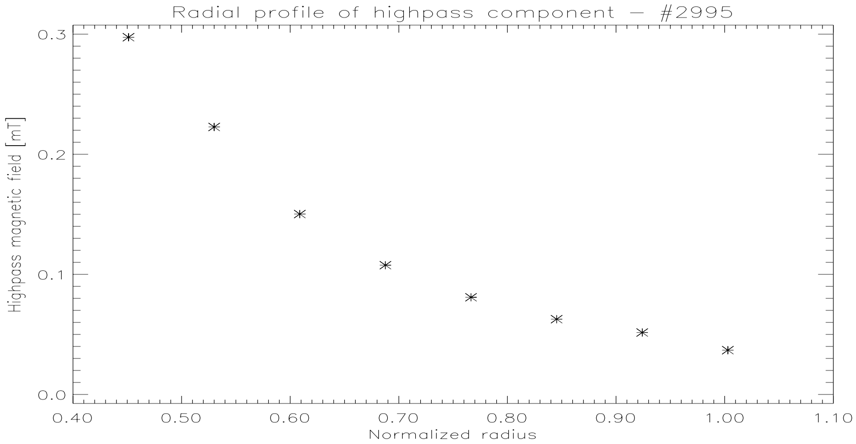

Figure 5: Radial profile of $\tilde{B}_r$ fluctuations, B_T=0.5 T, I_p=6 kA, q(a)=7.5.

It is seen that the maximum amplitude of the fluctuations 0.3 mT ($\tilde{B}_r/B_T \sim 6.10^{-4}$) is measured at r/a=0.45. Than, the amplitude is monotonously decreasing down to 0.04 mT ($\tilde{B}_r/B_T \sim 8.10^{-5}$) at r/a=1 corresponding to the limiter position.

Further, the dependence of the level of magnetic turbulence on the safety factor q(a) was examined. The Fig. 6 shows the radial profile of $\tilde{B}_r$ for two different values of q(a) - 4 and 4.5. Each value of q(a) was obtained for the two different combinations of I_p and B_T.

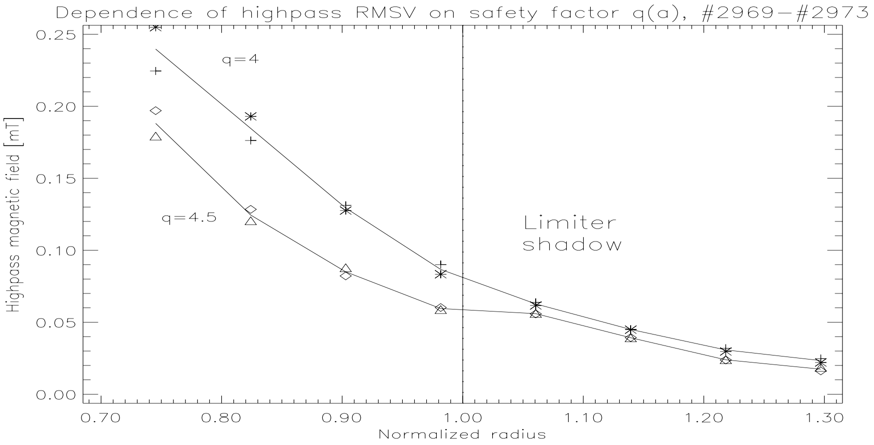

Figure 6: Radial profile of $\tilde{B}_r$ fluctuations at the two values of q(a).
The four shots are analyzed:
$I_p/B_T = 9kA/0.4T$ ($\star$) and $11kA/0.5T$ ($+$) $\rightarrow q(a) = 4$
$I_p/B_T = 12kA/0.6T$ ($\triangle$) and $14kA/0.7T$ ($\diamond$) $\rightarrow q(a) = 4.5$.

It is evident that within the last closed surface (limiter radius), the level of $\tilde{B}_r$ is controlled by the safety factor.

It is also found that $\tilde{B}_r$ decreases with increasing q(a) as confirmed for q(a) = 3.5 ÷ 12.

The temporal and radial evolution of B$_r$ fluctuations are depicted in the Fig. 7 in which only frequencies above 10 kHz are considered.

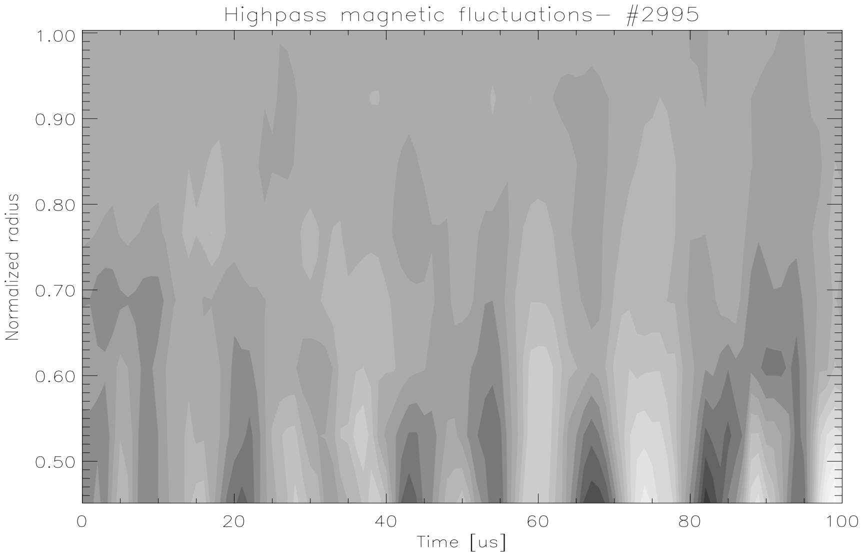

Figure 7: 2D plot of the B$_r$ signals (> 10 kHz).

This figure shows the radially elongated magnetic structures with a lifetime $\sim 10\mu s$. These structures are clearer and more regular near the center of the plasma column. The spectral analysis showed that the highpass fluctuations have a broadband character. However, for frequencies higher than 100 kHz the exponential decrease of power with exponent ∼-3 was observed.

The correlation analysis was performed to determine the average radial dimensions of B$_r$ magnetic structures seen in Fig. 7. The correlation coefficients with the reference probes 1, 5 and 8 were computed to obtain mean level of correlation related to these probes.

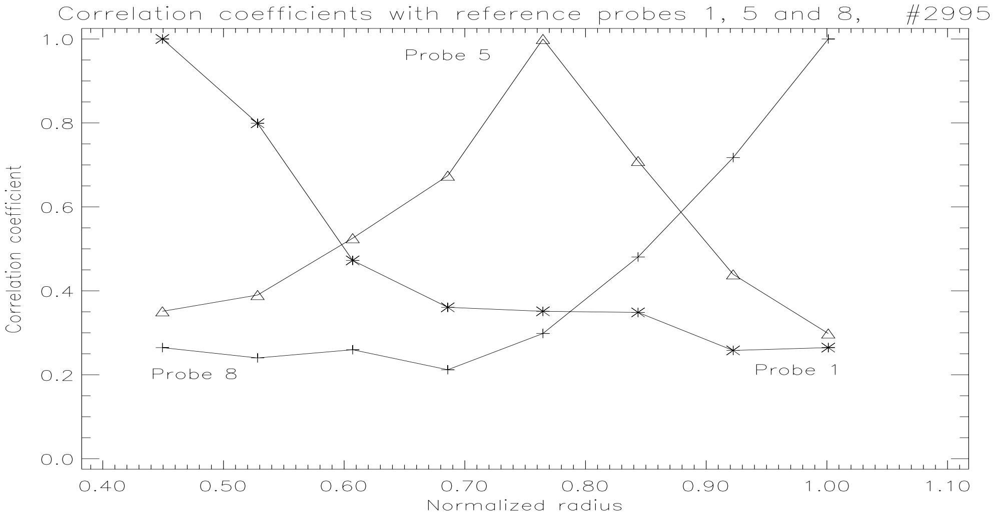

Figure 8: Correlation coefficients with reference probes 1,5 and 8.

The radial dependence of correlation coefficient related to all coils shows the same behaviour. The correlation of signals is significantly high for the three nearest coils and falls down to approx 0.2 for the coils which are the most radially separated from the reference one.

The correlation length λ, usually used to characterize the dimensions of fluctuation, is defined as the radial distance where the correlation coefficient falls to 1/e of its initial value. It is seen from the Fig. 8 that the radial correlation length is approximately the same in the central region as well as near the plasma edge and equals ~ 2 cm. It implies that the radial dimensions of magnetic fluctuations in the central region and at the plasma edge are approximately the same.

4 Conclusions

- The array of the eight magnetic coils was constructed and absolutely calibrated. Resulting calibration curve is nearly constant for the whole range of calibration frequencies (5 - 300 kHz).
- The measurements with probes inserted into tokamak plasma up to r/a=0.45 were performed.
- The measured data were numerically integrated to obtain the time evolutions and the radial profiles of the radial magnetic field in absolute unites. Further, the spectral and correlation analysis was applied on the measured data.
- The high frequency component of the signal ($>$ 10kHz) decreases monotonously from $B_r/B_T = 6.10^{-4}$ at the r/a=0.45 down to $B_r/B_T = 8.10^{-5}$ at the limiter position.
- The significantly long temporal radial structures were observed. The correlation analysis showed that the radial dimension of these structures is around 2 cm. The radial propagation of these structures was not observed.

Within the knowledge of the authors, the similar measurements of the magnetic fluctuations were performed only on Tokapole tokamak [1], which is slightly smaller device than Castor. Nevertheless, its construction and plasma parameters are comparable with the Castor ones. The level of magnetic turbulence is approx. one order in magnitude higher in Castor. The radial profiles have the same character. The dependence of the magnitude of magnetic fluctuations on safety factor was also verified. Similarly, the exponential decrease in power spectral density after 100 kHz was also observed.

5 Future plans

All the data processing was performed upon mostly one shot, therefore the more systematic measurements have to be made to derive more general conclusions. The poloidally and toroidally spaced coils will be used to obtain spatial distribution of magnetic structures in the respective directions.

References

[1] D.E. Graessle, S.C. Prager, R.N. Dexter: Q dependence of magnetic turbulence in a tokamak, Phys. Fluids B3(9), 1991

[2] V. Dhyani: Magnetic fluctuations in CASTOR tokamak, PhD thesis, VOT UFP Praha, 1995