CONTROL OF THE EDGE PLASMA MODES BY HOT LIMITER BIASING IN THE IR-T1 TOKAMAK

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Tokamak plasma modes were analyzed using the Fast Fourier Transform (FFT) in presence of hot limiter biasing system in the IR-T1 Tokamak. Fourier analysis is reliable technique for mode detection in tokamaks. For this purpose we used a poloidal array of Mirnov coils and hot limiter biasing system. After Fourier analysis of Mirnov coils data in presence of hot biased limiter, Power Spectral Density (PSD) diagram was plotted. PSD describes how the power of a signal is distributed with frequency. In this contribution we also determined edge safety factor and safety factor from Fourier based derived mode numbers q = m/n. We obtained the maximum MHD activity using power spectrum at the frequency 33 kHz. Also the edge safety factor was determined less than 3, and the values of obtained safety factor from the mode numbers are between $2 \le q \le 5$. Results show that hot limiter biasing can be used for increasing the plasma safety factor.

PACS**:** 52.55.Fa

INTRODUCTION

Investigation of behavior and structure of MHD is important in tokamaks and interesting issue in plasma physics. Besides there can be found much information such as, plasma cross section, MHD activity, mode numbers, magnetic islands and plasma instability. Different diagnostics are used for plasma edge studies. One of the commonly used diagnostics are Mirnov coils [1]. These coils are very simple design and researcher can utilize them easily. They can have many applications in tokamak and also record the magnetic fluctuations. Analysis of Mirnov coils fluctuations using the Fast Fourier transformation (FFT) is one of the effective methods to investigate the mode of tokamak plasma [2, 5]. In this paper, we used the poloidal array of 12 external Mirnov coils which are located poloidally by 30 degrees. We determined plasma mode numbers based on FFT. After Fourier analysis of Mirnov coils data, we plotted the power spectrum density. We also determined the edge safety factor and safety factor derived from Fourier based mode numbers q = m/n for IR-T1 tokamak.

The safety factor, q, is so called because of the role it plays in determination of tokamak plasma stability. In other words, higher values of q lead to greater stability. It also appears as an important factor in transport theory. In an axisymmetric equilibrium such as tokamak plasma each magnetic field line has a value of q. The field line follows a helical path as it goes around the torus on its associated magnetic surface. Knowledge of the q profile in a tokamak is fundamental for the understanding of the MHD properties of plasma. Near the plasma edge, q may be determined with accuracy from magnetic measurements, but this becomes increasingly inaccurate as extrapolations are made towards the plasma centre. Several methods of determining q such as the Faraday rotation method and a ruby laser scattering technique have been developed [3]. In this paper, we presented an investigation of the time evolution of the mode numbers, edge safety factor and maximum MHD activity on IR-T1, which is a small tokamak with large-aspect-ratio and circular cross section (Table).

This paper is organized as follows: in section 2, design, construction and installation of hot limiter biasing system will be presented. In section 3 we presented the FFT for determination of the power spectrum density. In section 4, we presented the results of the mode numbers of plasma using FFT. Section 5 is for edge safety factor determined using plasma current and toroidal magnetic field. The summary and conclusion will be presented in section 6.

Parameters of IR-T1 Tokamak

Parameter	Value
Major radius	45 cm
Minor radius	12.5 cm
Toroidal field	<1.0 T
Plasma current	<40 kA
Discharge duration	<35 ms
Electron density	$(0.7\ldots1.5)\times10^{13}$ cm^{-3}

1. DESIGN, CONSTRUCTION, AND EXPERIMENTAL SET-UP OF THE HOT LIMITER BIASING SYSTEM

IR-T1 is a low beta, large aspect ratio, and circular cross-section tokamak (see Table), which has two stainless steel grounded fully poloidal limiters with radiuses of 12.5 cm. In the experiments described the biased limiter position has been varied between 11.5…12.5 cm, and the bias applied between the limiter and the vessel. This limiter consists of a stainless steel circular head, 2 mm in radial direction (width) and 2 cm in poloidal direction (diameter). It is inserted approximately 1 cm past the fixed poloidal limiter into the plasma through the low field side of the tokamak as it is shown in Fig. 1. Also the electric circuit of limiter biasing system used in IR-T1 is shown in Fig. 2. A capacitor bank biases the limiter positive or negative with respect to the grounded wall. The applied limiter voltage V_{bias} is in the range −400…+400 V, and the bias current I_{bias} is in the range -40…+40 A. The experiments were performed in hydrogen. An edge plasma density and temperature are in the range $(0.7…1.5)\cdot 10^{13}$ cm^{-3} and 20…60 eV respectively, measured using the Langmuir probe, the toroidal magnetic field induction $B_T \approx 0.8$ T, the plasma current $I_p = 25…30$ kA. Also, biasing experiments were performed in regime with ohmic heating, and measurements of the plasma parameters were performed using a single Langmuir probe, Mach probe, triple magnetic probes, poloidal flux loops, and diamagnetic flux loop.

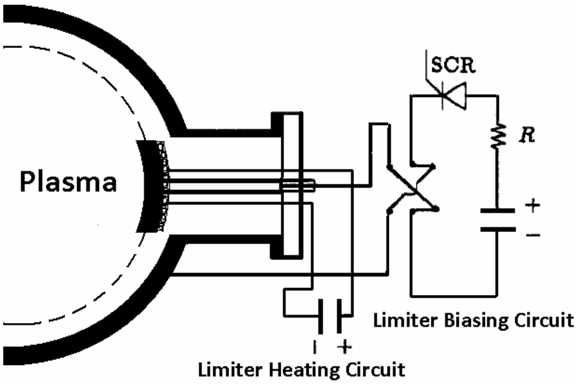

Fig. 1. Schematic drawing of the hot limiter biasing system on the IR-T1

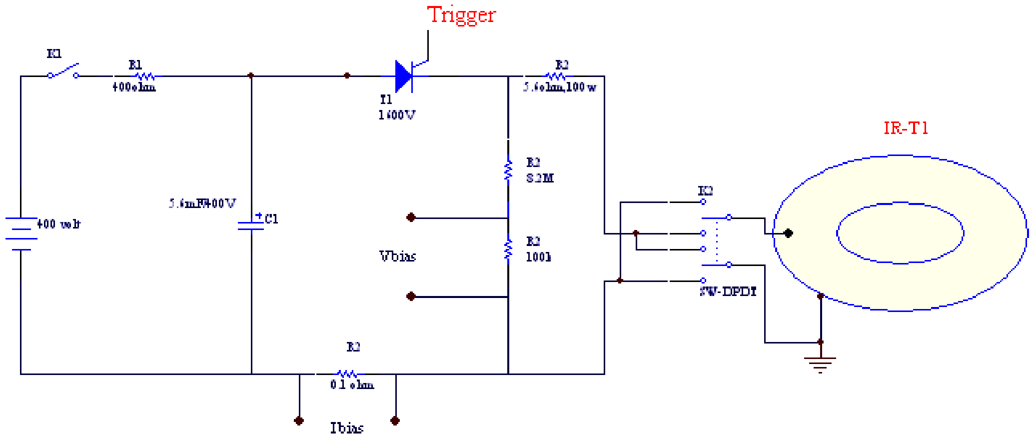

Fig. 2. Electric circuit of the hot limiter biasing system used in the IR-T1

2. FFT BASED DETERMINATION OF POWER SPECTRUM DENSITY

The FFT, representation of functions as a superposition of sinus and cosines, has become ubiquitous for both the analytic and numerical solution of deferential equations and for the analysis and treatment of communication signals [4].

To approximate a function by samples, and to approximate the Fourier integral by the discrete Fourier transform, it requires applying a matrix whose order is the number sample points n. Since multiplying a n × n matrix by a vector costs on the order of n^2 arithmetic operations, the problem gets quickly worse as the number of sample points increases. However, if the samples are uniformly spaced, then the Fourier matrix can be factored into a product of just a few sparse matrices, and the resulting factors can be applied to a vector in a total of order n log n arithmetic operations [4]. Power spectral density function (PSD) shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies variations are weak. The unit of PSD is energy per frequency (width) and we can obtain energy within a specific frequency range by integrating PSD within that frequency range. Computation of PSD is done directly by the method FFT. PSD is a very useful tool to identify oscillatory signals in time series data, and also it describes how the energy or power of a signal is distributed with frequency [6]. If $f(t)$ is a finite-energy (square integrable) signal, the spectral density $F(w)$ of the signal continuous Fourier transform is the square of the magnitude of the continuous of the signal:

$$\Phi(\omega)=\left|\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{+\infty} f(t)e^{-i\omega t}dt\right|^2=\frac{F(\omega)F^*(\omega)}{2\pi}. \quad (1)$$

$F(w)$ is the signal continuous Fourier transform of $f(t)$ and is $F^*(w)$ complex conjugate. If the signal is discrete with values f_n , over an infinite number of elements, we still have an energy spectral density:

$$\Phi(\omega)=\left|\frac{1}{\sqrt{2\pi}}\sum_{-\infty}^{+\infty} f_n e^{-i\omega t}dt\right|^2=\frac{F(\omega)F^*(\omega)}{2\pi}, \quad (2)$$

where t is the discrete-time Fourier transform of f_n. Power can be the actual physical power, or more often, for convenience with abstract signals, can be defined as the squared value of the signal. This instantaneous power is then given by: $p(t) = s(t)^2$ for a signal s(t) [7].

Therefore according to above discussion we obtained the PSD using FFT analysis with Mirnov coils data. For this purpose the MP4 coil was used according to the Fig. 3. PSD result presented in the Fig. 4, as observable, power spectral density diagram has regular trend of frequency diminution, it shows plasma has high mode number with symmetric shape because frequencies are near together. Also according to the appeared peaks, we obtained the maximum MHD activity.

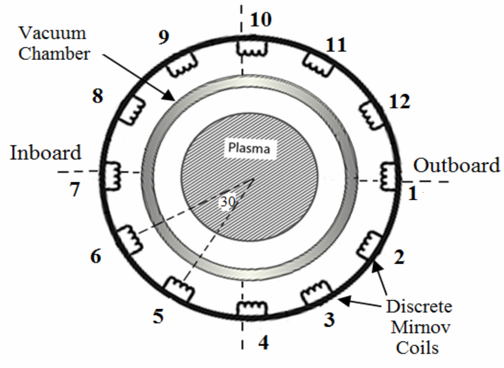

Fig. 3. Position of poloidally array of 12 Mirnov coils

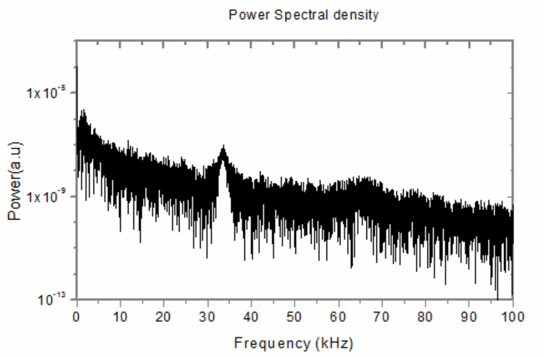

Fig. 4. Power spectrum density of Mirnov oscillation of IR-T1 Tokamak

3. DETERMINATION OF PLASMA MODE NUMBERS

Tokamak plasma can support different modes. Cross section of plasma can have different shapes, which are designated as Roset and have M rose leaves. If the quantity number of M was less than 3, plasma will be stable. Mirnov coils can record current time series caused by poloidal rotation of plasma. The external surface of plasma is not smooth and has noises. We plotted the polar diagram of the magnetic field fluctuations using FFT analysis on the poloidal array of Mirnov coils (see the Fig. 5). In these diagrams we showed cross section of plasma at three time intervals. First time duration is at 19.0…20.0 ms that shows the mode number is (m=3), second interval is at 29.0…30.0 ms that mode number is (m=4) and third interval is at 40.0…41.0 ms that mode number is (m=4). According to above discussion, we also determined the safety factor from mode numbers (q=m/n) at time interval 0…35 ms, that it is discharge duration in IR-T1 tokamak, and in our experiments, toroidal number is (n=1) (Fig. 6).

4. MEASUREMENT OF SAFETY FACTOR PROFILE

The meaning of q dimensionless parameter is the number of toroidal turns it takes a magnetic field line to make a single full poloidal turn. In the case of large aspect-ratio and circular cross-section the radial behavior of q is simply determined by the following equation [8]:

$$q(r) = \frac{rB_f}{R_0 B_q} = \frac{2pr^2 B_f}{m_0 R_0 I}\ , \qquad (3)$$

$$B_q = \frac{m_0 I}{2pr}\ . \qquad (4)$$

Results of these measurements are presented in the Figs. 7, 8. In Fig. 7 we showed (a) Mirnov coil oscillations, (b) toroidal magnetic field, (c) loop voltage and (d) plasma current. Also in Fig. 6 time interval edge safety factor is presented.

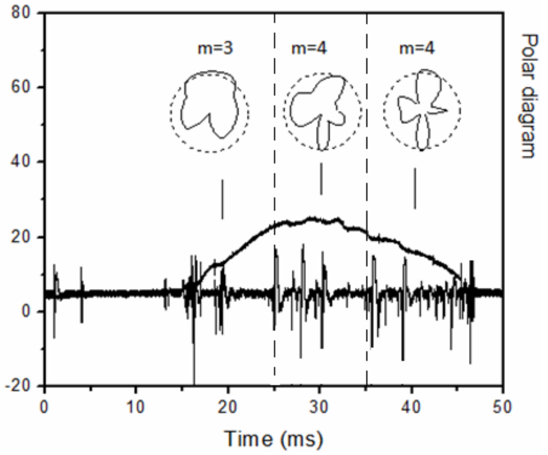

Fig. 5. Polar diagram of the magnetic field fluctuations

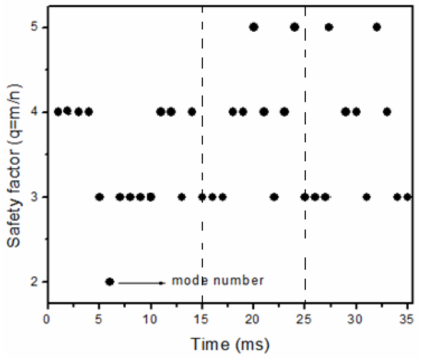

Fig. 6. Safety factor from mode number

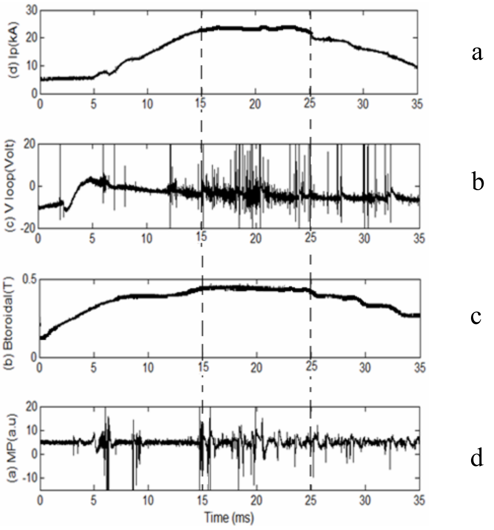

Fig. 7. Mirnov coil oscillations (a); toroidal magnetic field (b); loop voltage (c) and plasma current (d)

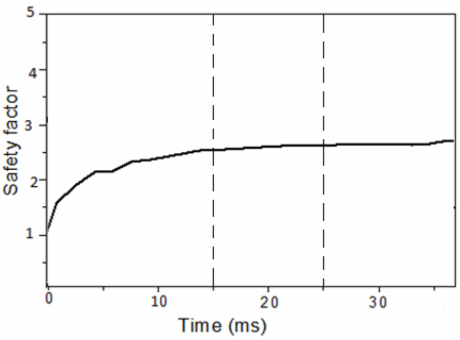

Fig. 8. Time interval of edge safety factor

SUMMERY AND CONCLUSIONS

A tokamak plasma modes were analyzed using the Fast Fourier Transform (FFT) in presence of hot limiter biasing system in the IR-T1 Tokamak. The maximum MHD activity was obtained using power spectrum in the frequency of 33 kHz. We also calculated the mode number with FFT analysis. After Fourier analysis on Mirnov coils data, we determined the edge safety factor and safety factor from Fourier based derived mode numbers q = m/n. The edge safety factor determined smaller than 3 and the value of safety factor from mode numbers observed between 2 ≤ q ≤ 5. Experimental results show that hot limiter biasing can be used for increasing the plasma safety factor. Finally, it is important to stress that the emissive limiter used on IR-T1 proved to be a robust and valuable tool to control the edge radial electric field for both polarities, allowing therefore a detailed investigation of the E×B shear flow role on the control of the edge plasma mode.

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Article received 25.12.12

УПРАВЛЕНИЕ МОДАМИ ПРИСТЕНОЧНОЙ ПЛАЗМЫ ПРИ ПОДАЧЕ НАПРЯЖЕНИЯ НА ЛИМИТЕР В ТОКАМАКЕ IR-T1

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Моды плазмы токамака анализировались с использованием быстрого преобразования Фурье (БПФ) при наличии системы подачи напряжения на горячий лимитер в токамаке IR-T1. Использовалась полоидальная схема расположения катушек Мирнова. С помощью Фурье-анализа данных катушек Мирнова была построена диаграмма спектральной плотности мощности (СПМ), описывающая распределение мощности сигнала с частотой. Были определены величины q на краю плазмы и по данным Фурье-анализа (как отношение мод: q=m/n). Максимум активности МГД оказался на частоте 33 кГц; на краю величина q≤ 3, а найденная из номеров гармоник – 2 ≤ q ≤ 5. Результаты показали, что подача напряжения на лимитер может использоваться для увеличения плазменного коэффициента надежности.

УПРАВЛІННЯ МОДАМИ КРАЙОВОЇ ПЛАЗМИ ЗА ДОПОМОГОЮ ПОДАЧІ НАПРУГИ НА ЛІМІТЕР У ТОКАМАЦІ IR-T1

M. Ghoranneviss, A. Salar Elahi, G. van Oost, R. Arvin, S. Mohammadi

Моди плазми токамака аналізувалися з використанням швидкого перетворення Фур'є (ШПФ) за наявності системи подачі напруги на гарячий лімітер у токамаці IR-T1. Використовувалась полоїдальна схема розміщення котушок Мірнова. За допомогою Фур'є-аналізу даних з котушок Мірнова була побудована діаграма спектральної щільності потужності (СЩП), яка описує розподіл потужності сигналу з частотою. Були визначені величини q на краю плазми і по даним Фур'є-аналізу (як відношення мод: q = m/n). Максимум активності МГД виявився на частоті 33 кГц; на краю величина q ≤ 3, а знайдена з номерів гармонік – 2 ≤ q ≤ 5. Результати показали, що подача напруги на лімітер може використовуватися для збільшення плазмового коефіцієнта надійності.