INVESTIGATION OF FILAMENT DYNAMICS USING HIGH-SPEED VIDEO SHOOTING IN THE GLOBUS-M2 TOKAMAK

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1. MOTIVATION

The study of edge localized modes (ELM) and associated plasma filaments is a crucial goal in the context of limiting the maximum heat fluxes on the first wall components of tokamaks [1]. It can also contribute to understanding the mechanisms of heat and particle transport in the edge plasma. filaments detection is carried out on many tokamaks. The primary diagnostics used for this purpose are Langmuir probes [2] and Doppler backscattering (DBS) [3]. However, these diagnostics have low spatial resolution. Detailed investigations of both a temporal evolution and a spatial structure of filaments can be achieved using fast photography techniques. Studies of filaments using fast camera have been conducted on the MAST tokamak [4]. This has provided information on the number, spatial structure, mode numbers, velocities, and dimensions of filaments, demonstrating the high informativity of this diagnostic technique.

2. DESCRIPTION OF THE DIAGNOSTIC SYSTEM

A new high-speed camera diagnostic system has been developed for the Globus-M2 spherical tokamak. The system includes three high-speed cameras (Phantom Miro M110, Revealer X213, Optronis CR3000X2), a clock generator for synchronizing the cameras, and a set of lenses and filters. The imaging is performed from the equatorial port of the tokamak, covering a wide field of view of the vacuum chamber. This includes both the peripheral regions, as well as the central region of the plasma column. Additionally, a data acquisition, storage, and processing system has been developed. The novel use of multiple cameras allows for simultaneous wide-view plasma imaging and high-speed measurements with a reduced camera resolution of the same plasma region.

3. IMAGE PROCESSING

The characteristic poloidal velocities of filaments in the Globus-M2 tokamak range from 5 to 15 km/s. It takes an exposure time of 1-10 microseconds to capture them reliably. At the same time, the intensity of the filaments does not exceed the background plasma emission. To isolate rapid changes in brightness against the relatively slow-varying glow of the main plasma, methods of "subtracting" the static background from the image are applied. The classical algorithm [6] involves median and Gaussian filtering, calculating the background by simple averaging of several adjacent frames, and subtracting this background from the image. In the proposed method, median and bilateral filtering are used, and background subtraction is performed based on an original algorithm using the formula:

$$F_{\alpha\beta}^{i} = A_{\alpha\beta}^{i} - \left(\frac{1}{N} \sum_{k=i-\frac{N}{2},\, k\neq i}^{i+\frac{N}{2}} A_{\alpha\beta}^{k} - \frac{1}{N(N-1)} \sum_{m=i-\frac{N}{2},\, m\neq i}^{i+\frac{N}{2}} \sum_{k=i-\frac{N}{2},\, k\neq m,i}^{i+\frac{N}{2}} \left(A_{\alpha\beta}^{k} - A_{\alpha\beta}^{m}\right) \right),$$

This approach has allowed for a 2.5-fold reduction in background subtraction errors on synthetic filament images compared to the classical algorithm. This significantly simplifies image interpretation due to fewer distortions and higher contrast.

4. EXPERIMENT RESULTS

To correlate the images with the magnetic configuration, spatial calibration of the images was performed using the CalCam code [7]. This involved mapping visible structural elements of the tokamak chamber in the images to its 3D model. For tracing magnetic field lines based on the calculated magnetic configuration, the PLEQUE code [8] was used. The magnetic configuration was calculated using the FreeGS code [9]. Comparing the filament images with the direction of magnetic field lines lying on the separatrix shows a good agreement. An example of filament image processing is shown in Figure 1.

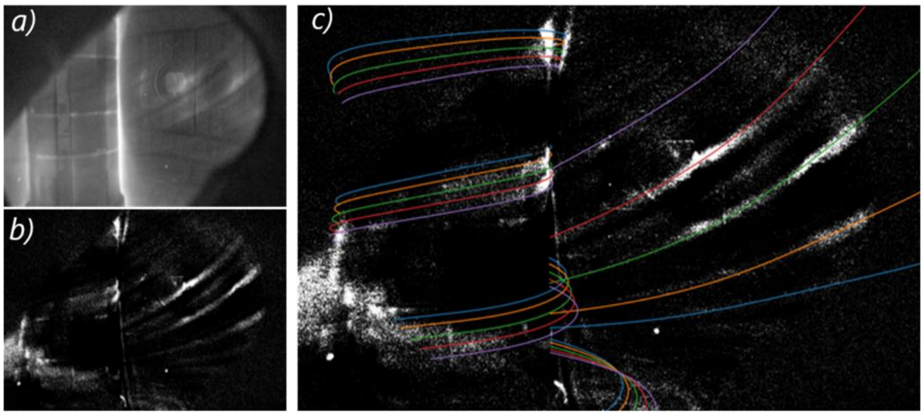

Fig. 1 Example of filament images: a) before processing, b) after background subtraction, c) with superimposed magnetic field lines (exposure time: 2 microseconds).

Wide-view images allow for the determination of the toroidal ELM number, which is approximately 10–15. Imaging with lower camera resolution and higher frame rates enabled the recording of filament dynamics and the determination of their poloidal velocities (~5–15 km/s) and transversal sizes (~2–3 cm). These results correspond well to theoretical predictions and the DBS measurements [10].

5. CONCLUSIONS

A diagnostic system for high-speed plasma imaging and a set of software tools for video processing and correlating data with other diagnostics of the Globus-M2 tokamak have been developed. Measurements of edge plasma using high-speed camera in visible light has been conducted. Filamentary structures elongated in the magnetic field direction were successfully recorded, their parameters were measured, and their localization relative to the separatrix was determined. These results correspond well to theoretical predictions and the DBS measurements.

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REFERENCES

[1] Fundamenski W. et al., ELM-wall interaction on JET and ITER, Journal of Nuclear Materials 363–365 (2007) 319–324

[2] Bencze A. et al., On the statistics of ELM filaments measured by fast low field side wall Langmuir probes on TCV, 34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.31F, P-2.026 (2007)

[3] Ponomarenko A. et al., The investigation of edge-localized modes on the Globus-M2 tokamak using Doppler backscattering, Nucl. Fusion 64 022001 (2024)

[4] Kirk, A. et al., Spatial and Temporal Structure of Edge-Localized Modes, 2004 Phys. Rev. Letters, vol. 92, Issue 24

[5] Timokhin V.M. et al., Spectroscopic Diagnostic of the Peripheral Plasma in the Globus-M2 Tokamak with the Injection of Neutral Helium, JETP Letters, 2022, Vol. 116, No. 5, pp. 300–306

[6] Farley T. et al., Analysis of Scrape-Off Layer Filament Properties Using Visible Camera Data, 3rd IAEA Technical Meeting on Fusion Data Processing, Validation and Analysis (2019)

[7] Silburn S., et al., Calcam Python package, DOI: 10.5281/zenodo.14041548

[8] Kripner L., et al., PLEQUE Python module, https://github.com/kripnerl/pleque

[9] Dudson B., et al., FreeGS Python module, https://github.com/freegs-plasma/freegs

[10] Yashin A.Y. et al., Determination of filament parameters on the spherical tokamak Globus-M2 using Doppler backscattering, Technical Physics Letters, 2023, Vol. 49, No. 7