MHD instabilities studied by imaging diagnostics in the Large Helical Device

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1. Purpose of study

From the first finding of the sawtooth activities in the ST tokamak [1], measurement of the spatial structure of the MHD activities is key method to understand the MHD phenomena. Using the frame work of the A3 collaboration activities, our group has proposed several tangentially viewing two dimensional (2D) camera systems targeting for MHD study to groups in China and Korea. By introducing the effective analysis method for tangentially viewing 2D camera measurement, the merit and the weak point of the 2D measurement will be presented.

2. Merit of the tangential viewing

The soft x-ray emission from the fusion plasma has been used to estimate the shape of the magnetic surface, assuming that the electron temperature, the electron density and the impurity density is constant on a magnetic surface. From the tomographic reconstruction using several 1D SX detector arrays, the shape of the flux surface can be estimated [2]. Then the modification by the MHD activities is examined. However, the reconstruction process is a kind of differential operation which enhances noises; only large scale structure, e.g. poloidal mode number $m = 1, 2, \cdots$ can be derived with 1D array system. In order to overcome this weak point, tangentially viewing camera system was proposed [3]. Since the most of the MHD activities has very small wave number along the magnetic field lines. MHD mode can be better visualized from the tangential direction where it is close to the direction of the magnetic field lines. Based on this proposal several types of tangentially viewing 2D camera system have been developed [4, 5]. However, the data analysis for the tangentially viewing image is not straightforward.

3. Expansion with orthogonal function

If images at a poloidal cross section can be obtained, Fourier expansion in the poloidal direction can be good tool to study the instabilities. Since the instabilities are analyzed or numerically simulated in the wave number space, comparison with wave number or mode number is the best way to be compared. However, the mode structure is strongly deformed when the structure is observed tangentially (see, Fig. 1).

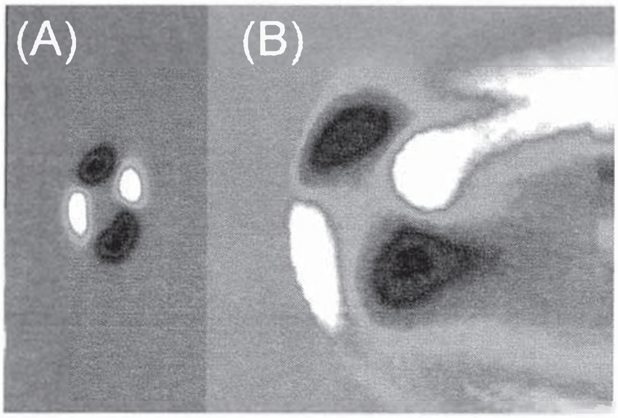

Fig. 1: Example of the mode structure at a poloidal section with poloidal/toroidal mode number m/n = 2/1 (A) and its tangential image (B).DIII-D equilibrium is used.

In order to get effective function for expansion instead of the Fourier series, so-called singular value decomposition (SVD) method [4, 6-8] is found to be quite useful. This kind of method has been used since 1960's with different names in different scientific fields, such as empirical orthogonal functions (EOF) in the meteorology, proper orthogonal decomposition (POD) in fluid mechanics. By SVD, a matrix A(MxN) made up of N time series of M (pixel number) frames (A = ($\mathbf{a}_1$, $\mathbf{a}_2$, $\mathbf{a}_3$, ····, $\mathbf{a}_n$)) is decomposed into three matrices, U(MxN), V(NxN) and a diagonal matrix W(NxN); A = UWV^t. The columns of U and V are spatial and temporal eigenvectors and are called Topos and Chronos, respectively. Each image in the moving picture $\mathbf{a}_i$ can be expressed as,

$$a_i = w_1 \times v_{i1} \times u_1 + w_2 \times v_{i2} \times u_2 + \cdots + w_m \times v_{im} \times u_m \quad . \quad (1)$$

That means each picture can be express as the summation of the the spatial eigen function Topos times its time evolution Chronos. An example take from the LHD experiments are shown in Fig. 2 [9]. Singular value decomposed components of both time (A) and space (B) from the time evolution of the tangential image are shown. Four larger components A1-A4 and B1-B4 are selected. B1 shows stationary image of the LHD plasma viewed from a tangential port, which can be understood by the fact that this component does not vary in time, as seen from A1. Images of other components are the relative change from the static image of B1 using the color bar shown at the top of the figure. Component 2 shows change of the emission profile at a collapse event happened at 1.288s. Decrease of emission at the center of the plasma and increase in the outer region can be seen in B2. Before this collapse phenomenon, development of an MHD instability having poloidal / toroidal mode number m/n = 2/1 can be seen. Two oscillating component (E3 and E4) with different phase are observed just before the minor collapse event caused by an MHD instability at ~1.3

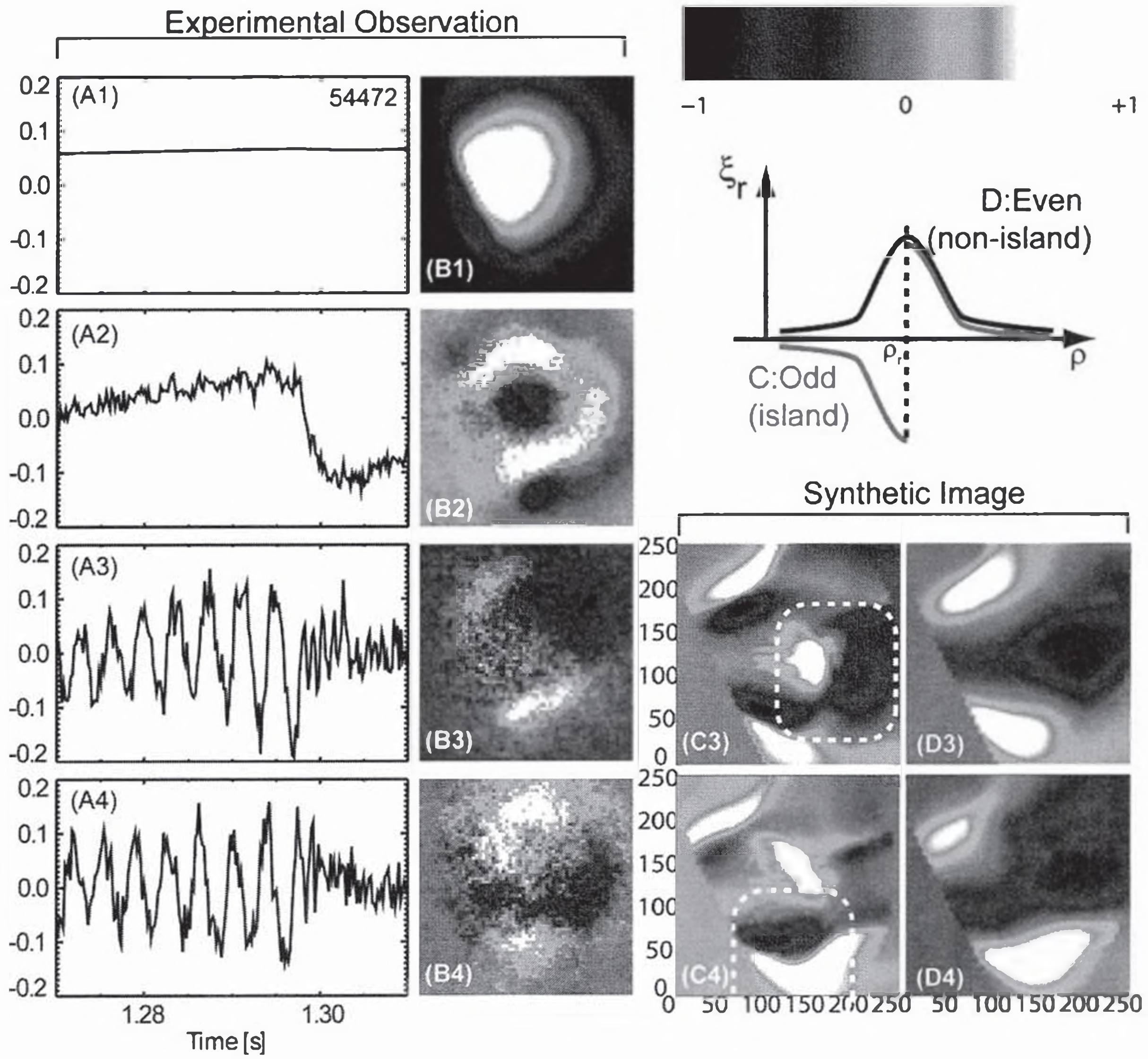

Fig. 2: Singular value decomposed components of both time (A) and space (B) from the time evolution of the tangential image obtained in LHD experiment are shown. Synthetic image assuming island type (C) and no-island type (C) are show also for the comparison.

It is clear that orthogonal spatial pattern, so-called Topos (B) are automatically determined from the experimental data and they work as the basis function for expansion. Each Topos represents different phenomena, e.g., rotation of the mode (B3, B4) and collapse events (B2)

4. How to understand the meaning of the Topos

Then, in order to compare the theory of the simulation, synthetic image should be made in order to compare with obtained Tops. The method to make synthetic image of the fluctuating component based on the MHD instability mode is described here. When we assume the MHD instabilities, the radial displacement ξ_r at the mode rational surface (averaged minor radius $\rho=\rho_r$) can be assumed to be

$$\xi_r = A_0 \exp(-\left(\frac{\rho-\rho_r}{w}\right)^2) \times f(\rho-\rho_r). \qquad (2)$$

Here, A_0 and w are the amplitude and the width of the perturbation, respectively. $f(\rho) = 1$ for non-island type and $f(\rho) = 1$ $(\rho \geq \rho_r)$, -1 $(\rho < \rho_r)$ for island type (see schematic graph shown in Fig. 2). The flux surfaces are approximated by the small triangles as shown in Fig. 3(A). From this approximation the calculation of the crossing point of the sight line with the flux surfaces become quite simple. The contribution to a pixel from the emission in a layer between the two flux surfaces can be obtained (Fig. 3(B)). Thereby the relation of the radial emission profile and the 2D image is expressed by the matrix form. The deformed structure by the radial displacement (made by eq. 2) is then rotated numerically and the fluctuation component is separated based on the singular value decomposition again.

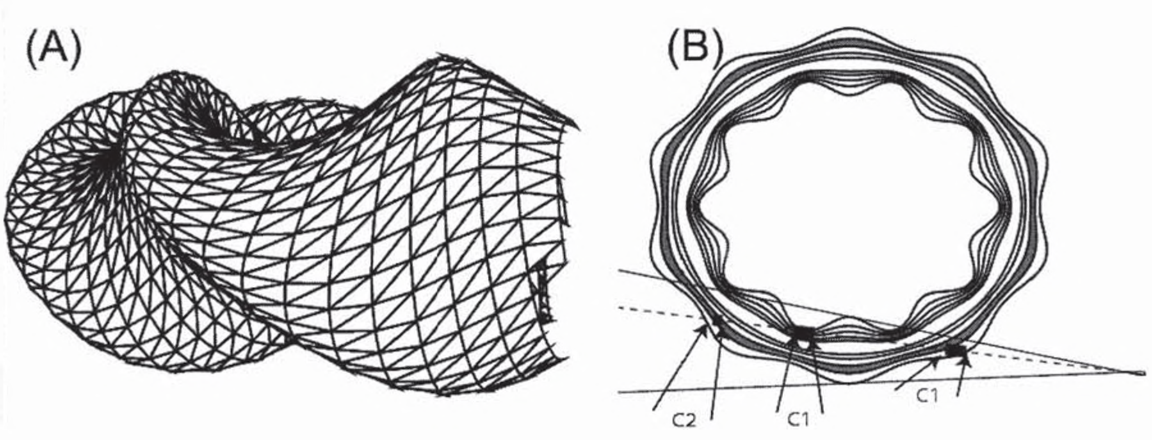

Fig. 3 Shape of the flux surface of the LHD (A) and intersection of the sight lines with the flux surface (B).

The two components are shown in the Fig. 2(C3, C4) and Fig. 2(D3, D4). From the comparison of the synthetic image with experimental ones, one can choose the reasonable model of the MHD instabilities. In this example, there is no small structure showing the phase change (like in the dashed box of C3 and C4) in the experimental image. Experimental image is rather similar to D3 and D4. Therefore, it is concluded that the radial displacement is determined to an even function (non-island type) in this type of LHD plasma even though the amplitude is large enough to make collapse events.

5. Summary

Tangentially viewing imaging diagnostics is a powerful tool since it is quite intuitive to understand the complicated phenomena. Direct decomposition using SV is the most effective way. Even though it is line integrated measurement, comparison of the MHD modeling can be performed. In LHD, the radial displacement at the rational surface is found to be of non-island type. The minimum size, where we can distinguish radial displacement is about 5% of the plasma minor radius. This type measurement will work better in the Tokamak devices, where the shape of the plasma is much simpler.

Acknowledgements

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