Retrieval of information of perturbed displacement of MHD instabilities from the tangentially viewing imaging data

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Introduction

High-beta operation is required to realized the fusion reactor. In Heliotron devices, such as the Large Helical Device (LHD), the rotational transform is provided by the external coil system and not by the plasma current. Therefore, the pressure driven modes are mostly concerned in high-beta plasmas. In LHD, he plasma confinement is better in so-called inward shifted configurations, where the stability for the pressure driven mode is not favorable. That means, LHD plasma is always operated with MHD unstable conditions. Therefore, the non-linear evolution of the MHD modes should be investigated in order to evaluate the danger of the MHD instabilities. The spatial structure of the MHD modes, especially, the radial displacement of the Eigen function is one of the key parameters to predict the non-linear evolution of pressure driven mode. It is believed that the radial displacement of the interchange mode is an even function across the rational surface; no magnetic island is made. However, from the recent studies, the interchange mode with magnetic island is also expected in the non–linear phase. The phase of the radial displacement is measured by the phase of the fluctuations across the rational surface. Local measurements, e.g., ECE measurement [1] is usually used. However in most of the high-beta operational conditions, ECE is not available. In this paper, the possibility to estimate the radial displacement from the line-integrated measurements, especially by two dimensional imaging measurement [3] is investigated.

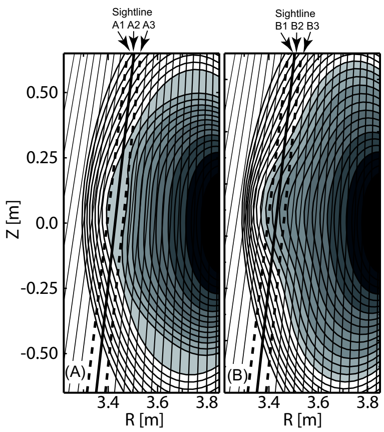

Figure 1: Concept of the island detection with line–integraged measurements.

Radial displacement and the phase information with line-integrated measurement

Line-integrated soft X–ray measurements perpendicular to the magnetic field is a standard diagnostics. The phase estimate with line–integrated diagnostics is introduced in this section[2].

Schematic drawing of the flux surfaces with MHD activities are shown in Fig. 1. When the island is formed (Fig. 1(A)), the signals measured by the sight lines A1 and A3 (across the rational surface) has opposite phase. When the perturbations are non–island type (Fig. 1(B)), the signals from B1 and B2 are in–phase. Fig. 2 shows the estimate of the phase profile assuming these two types of the deformation. The radial displacement ξ_r is assumed to be a function of averaged minor radius ρ,

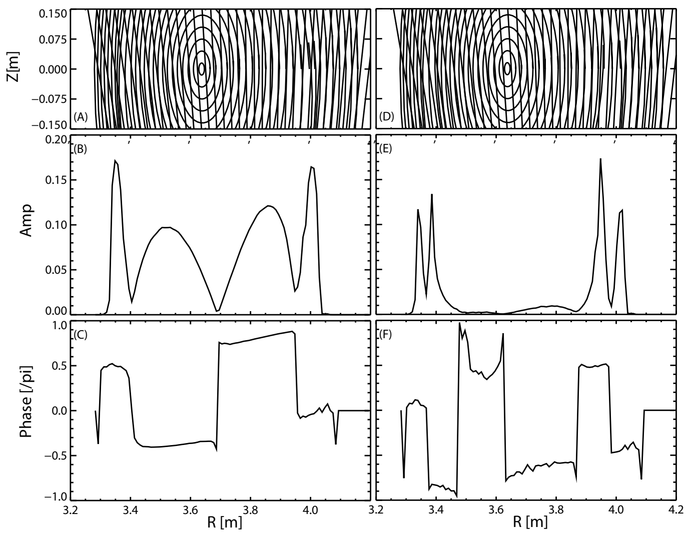

Figure 2: The simulated profile of the amplitude and the relative phase from the rotation of the deformation of the MHD instabilities. Fig.l 2(A), (B) and (C) are for non-island case, and Fig. 2(D), (E) and (F) are for island case. The poloidal mode number $m = 3$, $\rho_r \sim 0.6$ and $w \sim 0.1$ are used.

$$\xi_r = A_0 \exp(-\left(\frac{\rho - \rho_r}{w}\right)^2) \times f(\rho - \rho_r). \tag{1}$$

Here, A_0, ρ_r and w are the amplitude, the location of the rational surface and the width of the perturbation, respectively. $f(r) = 1$ for non-island type and $f(r) = 1(\rho \geq \rho_r), -1(\rho < \rho_r)$ for island type. When the emission profile and the shape of the flux surfaces (estimated from VMEC-based equilibrium) with deformation of MHD activities are assumed, the line integrated profile can be obtained. Then the deformation structure is rotated numerically in the simulation and fluctuating component is separated. The fluctuation amplitude (Fig. 2(B) and (E)) and relative phase (Fig. 2(C) and (F)) is obtained by this way. There are peaks of the amplitude corresponds to the location of the rational surface. There are also pseudo peaks $R = 3.5, 3.8$m at inner region with non-island case. The phase within the peak at the location of the rational surface ($3.3 < R < 3.4m$ and $3.95 < R < 4.05m$) is quite distinctive. The phase is constant in non-island case and is changing 180 degrees at $\rho \sim 3.35$ and ~ 3.97 in island case. Therefore, if the coverage of the sightlines is enough for the deformation structure, and if there is a gradient in the emission profile around the rational surface, the parity of the radial displacement can be determined. However, number of the SX channels is not as large as this simulation (20 sight lines in LHD). The detectable island size is thus about $0.1 < a >$, where $< a >$ is the averaged minor radius. In the next section similar procedure for the two dimensional measurements, whose sightlines are much dense (typically 256x256 sightlines) are investigated.

Numerical method to estimate the two dimensional image

Tangentially viewing diagnostics[3] has been developed from several advantages on the LHD[2]. Especially, the fairly high spatial resolution is the most attractive point. However, LHD device is a helical device and the shape of the magnetic surface is quite complex (Fig. 3(A)). It is not straightforward to estimate the 2D image when the plasma is observe tangentially.

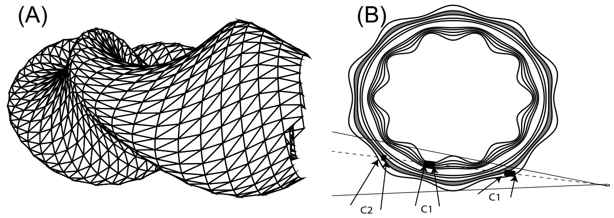

Figure 3: Shape of the flux surface of the LHD(A) and interssection of the sight lines(B).

Here, 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 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. Then, the method described in the previous section can be performed three dimensionally. The deformed structure is rotated numerically and the fluctuation component is separated based on the singular value decomposition (SVD) [4, 5]. The results are shown in Fig. 4(C) and (D). Since the mode is rotating, two orthogonal components appear by SVD analysis. Even the two dimensional measurement, the phase reversal is observed, which is shown in the area bounded by the white dashed-line in (C3) and (C4). Experimentally observed modes which are m=2 pre-cursor oscillations before the sawthooth-like events [6] are shown in (A3) and (A4). The spatial structure is similar with the synthetic image assuming no magnetic island ((D3) and (D4)). It is quite likely the MHD modes are not accompanied by the magnetic island in the precursor phase. This method is also applied to the post-cursor oscillation (m=3) described in the reference[6]. However, the gradient of the emission in the core region is small. The difference of the mode pattern with and without magnetic island is not large. Though the experimental observation is similar to that with island, the certainty of the analysis is not as high as the m=2 pre-cursor case.

In summary, from the phase information of the line-integrated diagnostics, the radial displacement of the MHD activities is retrieved by the comparison of the synthetic image and the exponential image. This method is applied with the experimental data of LHD. The merit and drawbacks of this method will be compared with another method based of the magnetic field line tracing[7].

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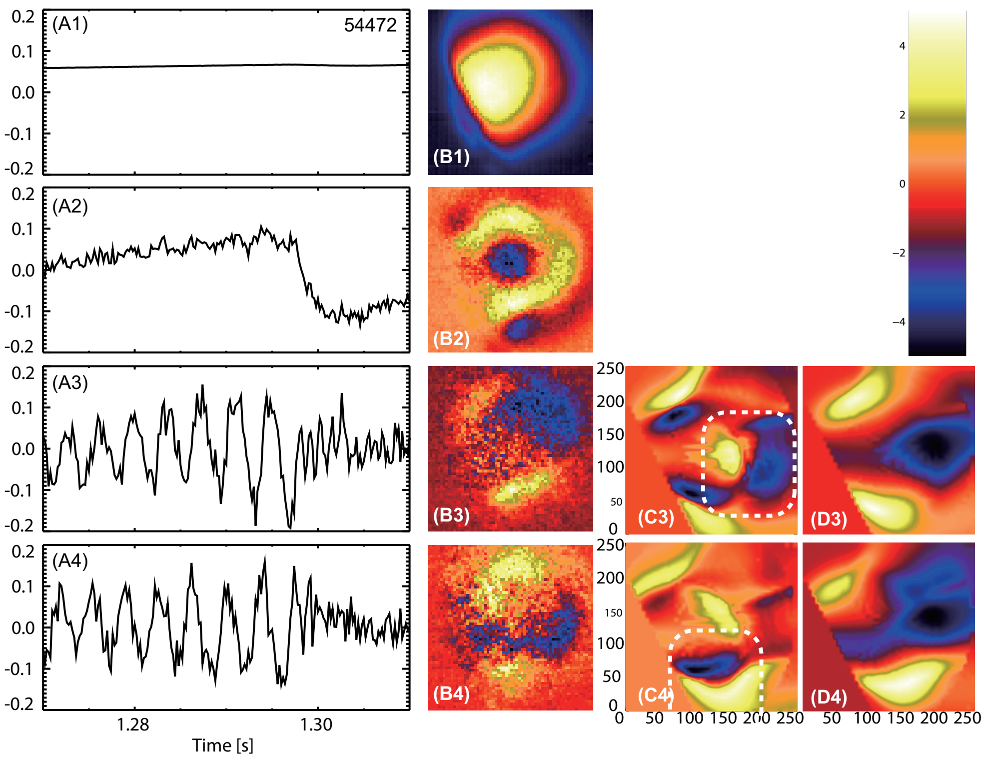

Figure 4: SV decomposed components of time(A) and space(B) are shown. The synthetic image with magnetic island(C) and without island(D) are also shownn.

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