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A STUDY OF HELICAL MODULATION IN THE DOUBLET III PLASMA COLUMN

(Doublet-III Experimental Report, 4)

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Helical modulation of the m=1 mode was observed in soft X-ray emissions from circular plasma in Doublet III. It is shown that the emission profile exhibits the peak displaced from the unperturbed axis in the central region.

Keywords : Doublet III tokamak, Oscillations, Soft X-ray,
Helical modulation

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Doublet Ⅲプラズマ柱のヘリカル振動の研究

（ダブレットⅢ実験報告・4）

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モードm＝1のヘリカル不安定振動がダブレットプラズマからの軟X線放出に観測された。軟X線の放出分布の解析から，中心部で軸からずれた振動成分があることがわかった。

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1. INTRODUCTION

Recent experimental observations of the soft X-ray emissions from the Doublet III plasma have shown that MHD activity contributes to the reduction of impurities.(1),(2) Soft X-ray signals for the discharges with $q_a < 3$ evolve in sequence beginning with a central emission increase, onset of strong oscillatory modulation and decay into sawtooth oscillation. However, until now, the properties of oscillatory modulation, such as the radial size of the perturbed region, the poloidal mode number and the width of the related island, have not been clarified. The objective of this memo is to investigate these properties.

2. CHORD-AVERAGED SOFT X-RAY EMISSION

Doublet III has a major radius of 143 cm and a horizontal half-width of 45 cm. The vacuum chamber and limiter are Inconel.(3) The time behavior of a typical discharge with a plasma current of 550 kA and a toroidal magnetic field of 20 kG is shown in Fig. 1. The line-averaged density and electron temperature were measured by a vertical CO_2 laser and a biharmonics electron cyclotron emission, respectively. Soft X-ray emissions were detected by a vertically collimated PIN-diode array. Each channel's view of the plasma is through a common slit at an angle interval of 4 degrees placed 203 cm from the symmetric axis at the radius and at a height of 88 cm from the median midplane. This slit limits the viewing angle to ~1°. The channel label in Fig. 1 refer to the rounded vertical height in centimeters of the chord at the major radius of 143 cm. The soft X-ray detectors used are sensitive to emissions in the energy range of greater than 1.4 keV. The plasma shown in Fig. 1 has a circular cross-section shape. The onset of strong oscillatory modulations is observed at the mid-point of the soft X-ray signal. The plasma cross-section shape can be derived from MHD analysis using a set of magnetic probe signals located outside the vacuum vessel.

Figure 2 shows an expanded view of these traces. This figure indicates that the upper and lower signals are clearly out of phase. Figure 3 gives the chord-averaged intensity profile at 441.0 ms and 441.8 ms where the intensity of the channel 88 signal provides the maximum and minimum (range) of the oscillatory modulations. Oscillations in the soft X-ray signal can be interpreted as the rotation of the helically modulated plasma column at the same velocity.(4) The chord-averaged intensity profile shows that the emission structure is composed of a constricted and shifted central emission and an unperturbed residual part. Since the safety factor at the limiter position is 2.6, it is clear that the poloidal mode number is m = 1, when comparing the obtained phase difference and intensity profile with MHD theory.

3. ANALYSIS OF POLOIDAL STRUCTURE

In general, the inversion of chord-averaged data to a cross-sectional profile is not unique. We may assume that a helically modulated plasma column with a single mode does rotate. In addition, we may neglect the fine structure of a size smaller than the distance between the chords along which the soft X-ray emission is integrated. To obtain a cross-sectional profile of the emission, we used the following trial profile and compared the numerically calculated line integral with the raw data. The trial emission profile e shown in Fig. 4 has a small number of adjustable parameters;

$$\varepsilon \propto \left\{ 1 - \left(\frac{\tilde{r}}{a_s - \Delta} \right)^2 \right\}^{\lambda} \cdot H\,(a_s - \Delta - \tilde{r})$$

$$+ \mu \left\{ H(a_s - r) + \exp \left(\frac{a_s{}^2 - r^2}{a_b{}^2} \right) \cdot H\,(r - a_s) \right\}$$

where the function H(x) is a step function defined as H(x) = 1 for positive x and 0 for negative xc. The radii r and $\tilde{r}$ are given by

$$r^2 = (R - R_o)^2 + (Z - Z_o)^2$$

$$\tilde{r}^2 = (R - R_o - \Delta\cos\theta^*)^2 + (Z - Z_o - \Delta\sin\theta^*)^2 \quad .$$

Here, R_0 and Z_0 are the major radius and the height from the median plane of the plasma column before the onset of oscillatory modulations, Δ is the displacement of the perturbed central emission peak, θ^* is the poloidal azimuthal angle of rotation. The parameters of a_s and a_b indicate the radial size of the helically perturbed region and the characteristic length of the emission decay outside the core, respectively. The first term of the emission profile means the constricted and shifted central emission. The second term expresses non-shifted support. A plausible profile, ,which approximates the raw data, is obtained under the parameters of a_s = 14 cm, a_b = 17 cm, Δ = 5 cm, λ = 2 and μ = 0.0475. The comparison of the fitted line integral with the raw data is given in Fig. 5, where the solid line and dots indicate the fitted integral and raw data, respectively. The difference between the measured and fitted points at channel 75 and 80 arises from the approximation of uniform emissions within the m = 1 island which apparently has a small peaked emission. From this fitting, it appears that the width of the m = 1 island is ~10 cm and that the central region with 14 cm is perturbed. The radial size of the perturbed region is thought to indicate the dimensions of the q = 1 layer. Figure 6 shows the q-profile derived from the electron temperature distribution assuming uniform effective charge. The effective charge obtained in this model results in Z_{eff} = 2.3. Figure 6 indicates that the radius of the q = 1 layer is 21 cm. The strong decay of soft X-ray emissions after the onset of the m = 1 mode as shown in Fig. 1 however, reveals a peaked Z_{eff} profile rather than a uniform one. Taking this fact into account, the true radius of q = -1 is expected to be smaller than 21 cm, which is consistent with the observed size of the perturbed region.

4. CONCLUSION

The results of brief investigations of modulated soft X-ray emissions are summarized as follows:

(1) Helical perturbations observed in the discharge with $q_a < 3$ is the m = 1 mode.

(2) The width of the m = 1 island expands to 10 cm during a discharge.

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Figure Captions

Fig. 1 Time evolution of loop voltage V_L, plasma current I_p, chord-averaged density $\bar{n}_e$, central electron temperature $T_e(0)$, and chord-averaged soft X-ray emissions during a discharge at the toroidal magnetic field of 20 kG.

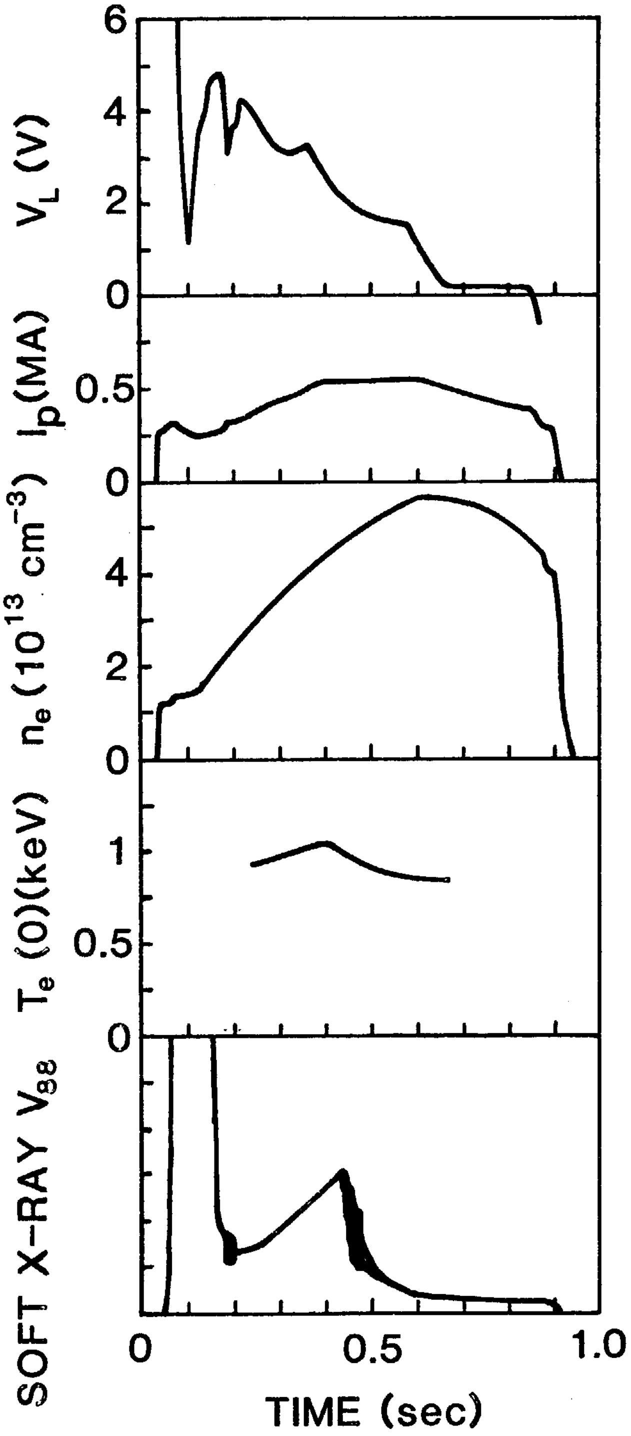
Fig. 2 Traces of soft X-ray signals detected by a vertically collimated PIN-diode array. Channel label refers to the rounded vertical height of the chord in cm.

Fig. 3 Chord-averaged intensity profile of soft X-ray emissions at 441 ms (dots) and 441.8 ms (circles).

Fig. 4 Trial emission profile composed of an unperturbed section and a shifted helical column.

Fig. 5 Comparison of fitted line integral profile (solid line) with measured profile (dots). Emission density profile used for fitting is provided in text.

Fig. 6 Profile of safety factor q derived from the electron temperature profile assuming a uniform effective charge.



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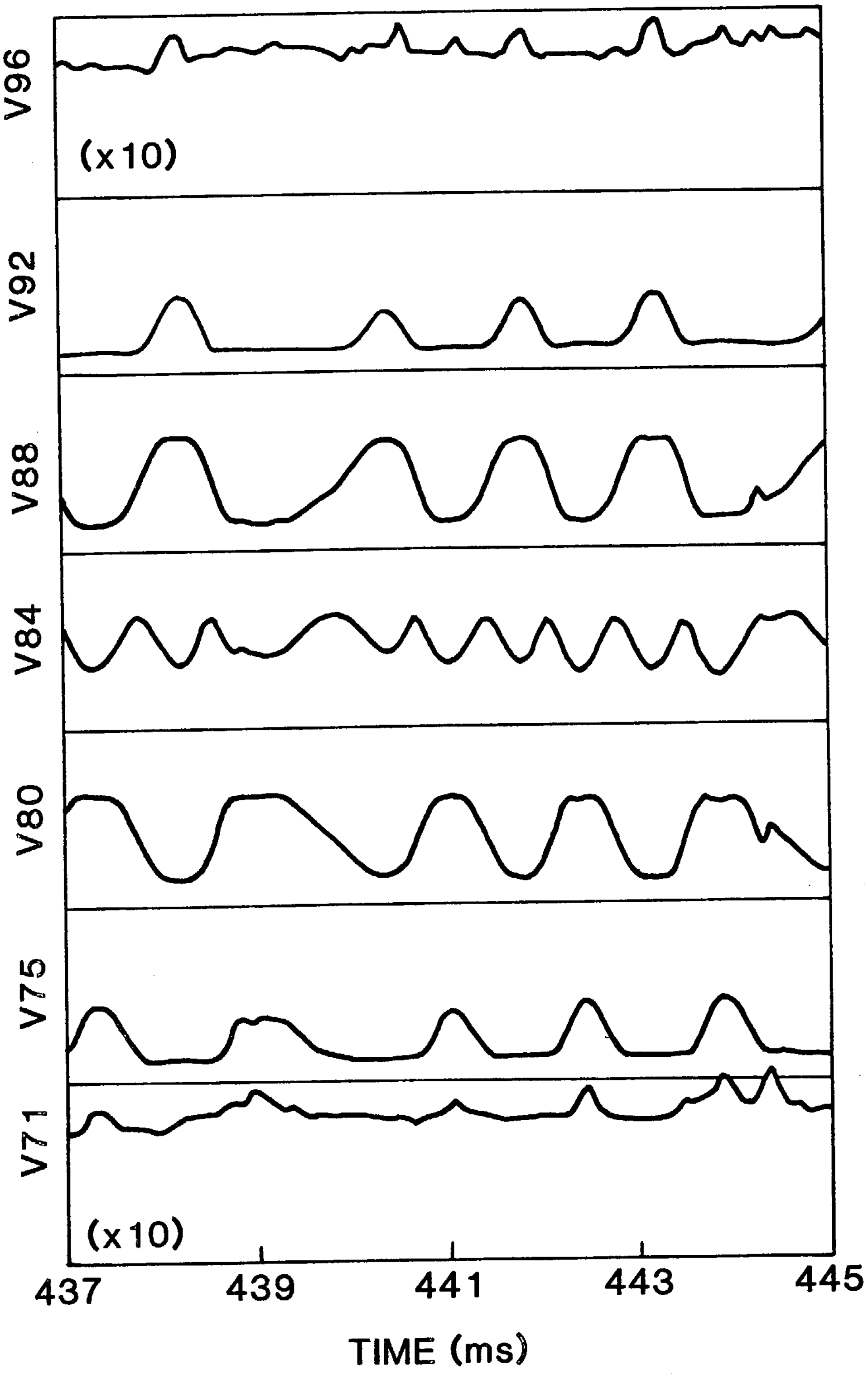

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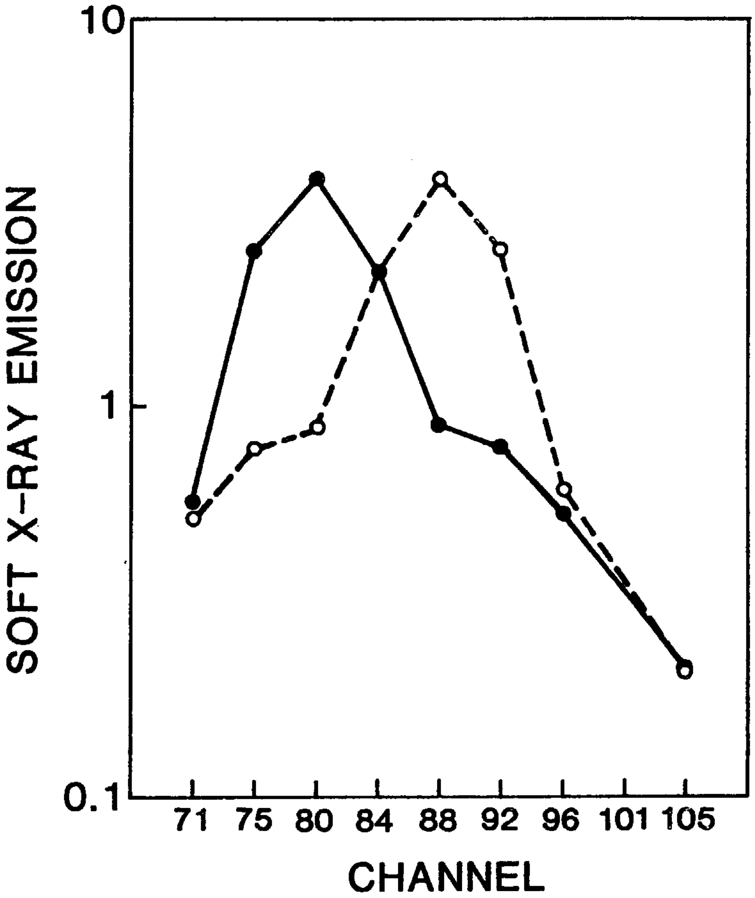

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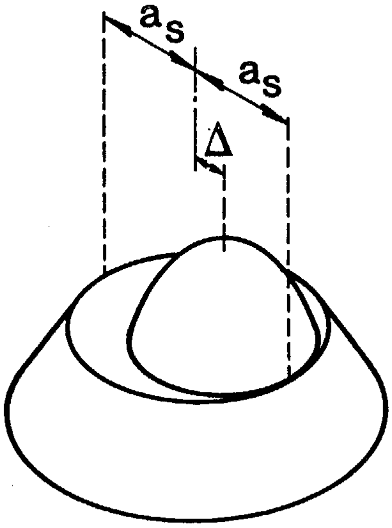

Fig. 4

Trial emission profile composed of an unperturbed section and a shifted helical column.

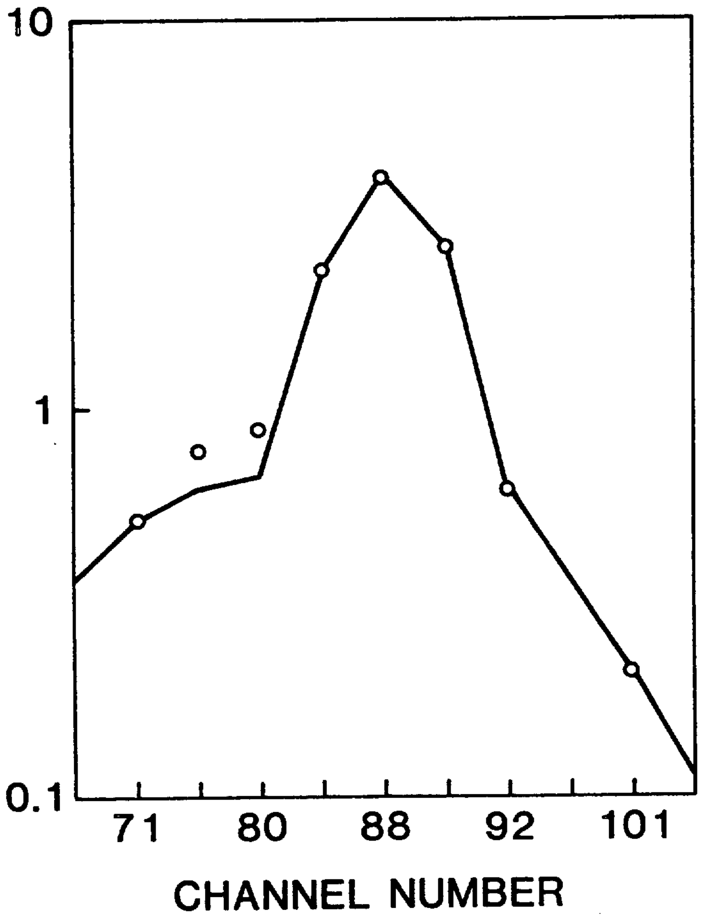

Fig. 5

Comparison of fitted line integral profile (solid line) with measured profile (dots). Emission density profile used for fitting is provided in text.

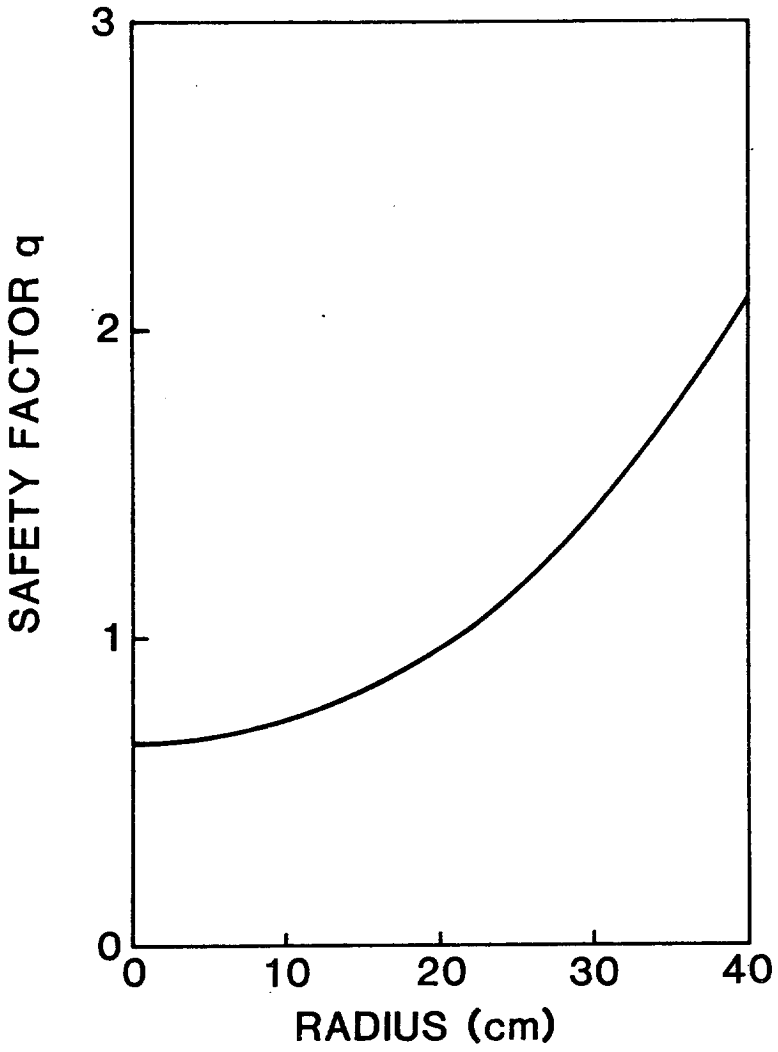

Fig. 6

Profile of safety factor q derived from the electron temperature profile assuming a uniform effective charge.