Observation of Striation in Collapsing Plasma

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A high-luminosity striation, which rotates within a flux surface of the plasma boundary having helical structure, has been observed in the LHD plasmas by means of a fast camera. The striation appears when the plasma is shrinking due to excessive gas fueling despite the existence of neutral beam heating.

Keywords: LHD, striation, radiation collapse, fast camera

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In order to explore the operational space of the high-density regime, massive gas puffing and/or pellet injection have been performed in the Large Helical Device (LHD). Under these experimental conditions, high density plasmas collapse when excessive gas fueling is applied. Through the use of a fast camera, we have revealed a rotating high-luminosity striation in such collapsing plasma. This paper is the first to describe the three-dimensional structure of that striation. The fast camera is outfitted with bifurcated imaging fiber optics, and it can make observation from two different locations simultaneously. Since the fast camera optics system has been calibrated [1], the image can be related to a three-dimensional spatial point. Figure 1 (a) shows a vertical cross-section of the LHD plasma and the observation points of the fast camera. The fast camera views the plasma at a viewing angle of 15 degrees without an optical filter. The time resolution of the fast camera is 20 kHz. The last closed flux surface (LCFS) which is observed from field of view 1 (FOV-1) and FOV-2 is shown in Fig. 1 (b). Blue, red, green, and black lines indicate near-side field lines, far-side field lines, the magnetic axis, and a horizontally elongated poloidal cross-section, respectively. Typical striation images are shown in Fig. 1 (c). The fields of view are cut by inner wall of viewing ports; therefore, the interior image of the circle is valid. The striation appears under the condition that the boundary plasma density exceeds $1 \times 10^{20}\,\mathrm{m}^{-3}$ and the high temperature plasma boundary shrinks into the LCFS due to excessive gas puffing despite the existence of neutral beam heating. The position of the striation oscillates at a frequency of around 200 Hz. A similar phenomenon has been observed by absolute extreme ultraviolet photodiode (AXUVD) fan arrays [2].

Assuming that the striation spreads along the magnetic field line, magnetic field line trace calculations have been performed by using the position and apparent tilt angle of the striation on the image as a fitting parameter. The striation images, which are viewed from the FOV-2, are shown in Fig. 2. These images employ pseudo-color-mapping in order to emphasize the low intensity emission. The calculated magnetic flux surface, which appears to correspond to the striation since one of the field lines coincides with the striation (indicated by the thick-line in Fig. 2), is superimposed onto the striation images. We use the far-side magnetic field line to fit here because the tilt angle of this field line is more sensitive than the near-side one from a geometrical consideration and can be easily dis-

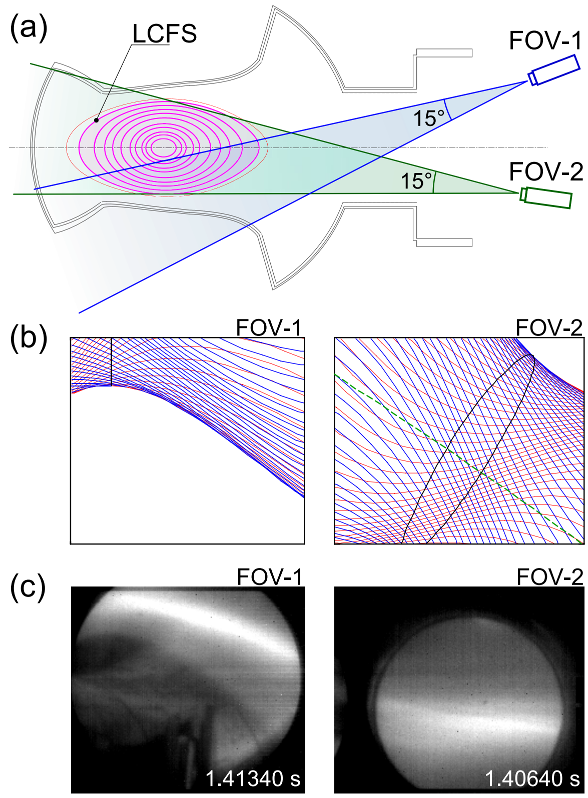

Fig. 1 (a) Horizontally elongated poloidal cross-section of LHD and fields of view of the fast camera. (b) Magnetic field lines on the LCFS which are projected to the fast camera imaging plane. (c) Typical images of the striation.

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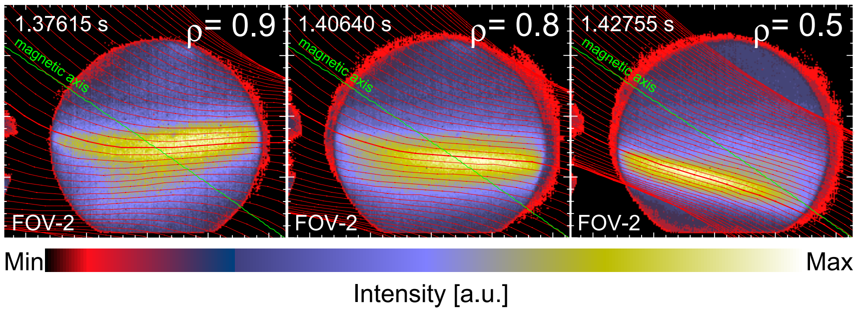

Fig. 2 Superimposed far-side magnetic field lines onto the pseudo-colored striation images.

tinguished. These results indicate that the striation has a helical structure along the field line, and the location of the striation can be identified by comparing the images with the calculated field lines. The aforementioned comparison over the life of the striation indicates that the striation rotates helically while containing a $-\boldsymbol{r}\times\boldsymbol{B}$ component, where $\boldsymbol{r}$ and $\boldsymbol{B}$ denote the minor radius vector and the magnetic field, respectively. The striation width occasionally broadens out, but its typical half-breadth is estimated to be about 5 cm when the striation crosses the image center of FOV-2. The striation thickness is estimated to be less than 5 cm based on the apparent width on the FOV-1 image when the striation is located at the edge. The striations expand beyond the both viewing fields and its end is not observed, suggesting that the striation expands to the torus. On the other hand, the striation maximum length must be shorter than the circumference of the torus because multiple striations cannot be observed in spite of the irrational surface. The electron density of the striation is roughly estimated at 5×10^{20} m^{-3} based on the line-averaged electron density of an edge chord of the far infrared laser interferometer.

Because the plasma is in the process of collapsing, the plasma boundary shrinks with time as shown by the open circles in Fig. 3. The rotating radius of the striation, which is estimated by the aforementioned method, is located somewhat outside of the 30 eV boundary and continuously shrinks with the plasma, as shown by the black squares. These results suggest that the striation rotates on the high temperature plasma boundary and that the rotation radius shrinks continuously regardless of the rational surface. Although the striation has a structure similar to the snake-mode which is observed on the $q = 1$ rational surface in tokamak plasma [3], these two phenomena should be distinguished in terms of their relationships with the rational surface.

The onset of the striation is unexpected and its mechanism is difficult to explain at this time. The striation must be caused by high edge density and existence of the neutral beam heating during collapse, and is a low-temperature, high-density plasmoid that spreads along the field lines because it emanates visible light intensively. There is no clue to the formation mechanism of such a high-density striation. As a cause of the rotation of the striation, following possibilities are assumable from our observations. One possibility is the existence of locally rotating particle sources. Another is the existence of driving forces acting on the striation. In the first case, since it is difficult to suppose a rotating localized neutral particle source in a vacuum, the source may be expelled from within the high temperature plasma boundary. In the latter case, since a negative radial electric field is predicted by neoclassical transport theory in the high density regime [4], $\boldsymbol{E_r}\times\boldsymbol{B}$ drift has the potential to drive the striation on a flux surface. From our observations, the drift velocity of the striation in poloidal cross section is estimated to be around 600 m/s. This velocity corresponds to the $\boldsymbol{E_r}\times\boldsymbol{B}$ drift velocity at around 1 kV/m and this value is a typically presumable $\boldsymbol{E_r}$ in the LHD. It is speculated that neutral beam heating plays a role in maintaining the negative radial electric field.

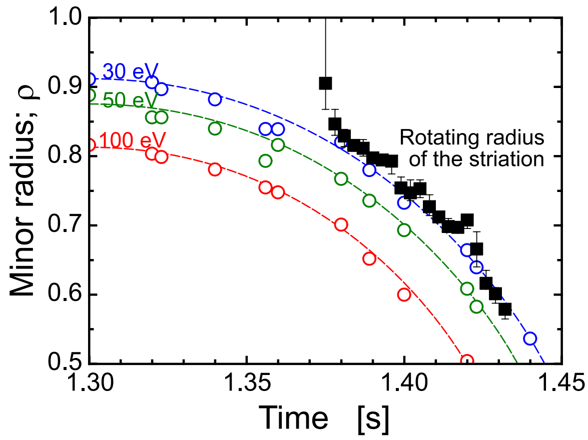

Fig. 3 Temporal change of the rotating radius of the striation and minor radius where the electron temperature is 30 eV, 50 eV and 100 eV.

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