Observation of Helical Structure with a Fast Camera in a Low-Aspect Ratio RFP "RELAX"

T. Onchi, N.Nishino[1)], R.Ikezoe, A.Sanpei, H.Himura, S.Masamune

Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan
[1)] Hiroshima University , Kagamiyama HigashiHiroshima 739-8527, Japan

onchi5t@nuclear.dj.kit.ac.jp

A fast camera has provided the appearance of a clear simple helical structure in the visible light emission region for the first time in the RFP configuration. The observed structure is consistent with magnetic field structures deduced from magnetic measurements with the help of equilibrium reconstruction. The observed simple structure may be an indication of the simple MHD mode dynamics of low-aspect ratio RFP configuration.

Keywords: Reversed Field Pinch, Low-Aspect ratio, Fast Camera, Helical structure

1. Introduction

The reversed field pinch (RFP) is one of the toroidal magnetic confinement systems for compact, high-beta plasmas for nuclear fusion reactor. The RFP configuration is formed and sustained as a result of nonlinear MHD phenomena such as MHD relaxation and RFP dynamo. Recent progress in the RFP research has revealed the importance of resistive tearing modes in improving the RFP confinement. One of the solutions to the confinement problems is the (quasi-) single helicity ((Q)SH) RFP state[1], in which a large helical magnetic island dominates over a significant area of a plasma minor cross section.

A low-aspect ratio (A) RFP configuration is expected to have an advantage of simpler magnetic mode dynamics because mode rational surfaces are less densely spaced, which may allow us to expect easier access to the QSH RFP state than in conventional medium-A RFP. Furthermore, it has also been pointed out that the QSH configuration might be self-sustained by the laminar dynamo mechanism, which does not accompany magnetic chaos. With the aim to explore the possibility of active control of transition to the QSH state, an RFP machine RELAX (REversed field pinch of Low Aspect ratio eXperiment)[2] has been constructed which has the aspect ratio of 2 (R/a=0.51m/0.25m).

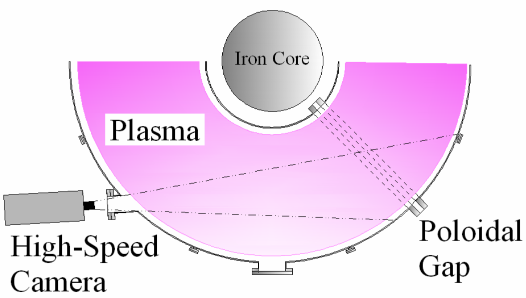


Fig.1 Experimental setup of the installation of a fast camera in RELAX from a tangential port.

Recently it has become possible to use a fast camera for the study on plasma instability and turbulent structures in many magnetic confinement devices[3-5]. We have installed a fast camera in RELAX for the first time in the RFP configuration to study the plasma dynamics. Time evolution of the visible light image of the RFP plasma has been observed over ~60% of the minor cross sectional area through a tangential port in RELAX.

2. Experimental arrangement and characteristics of RELAX RFP plasmas

Figure 1 shows the experimental setup in the present fast camera experiment. The fast camera is set to observe the RELAX plasma through a tangential port. The camera takes 80,000 images per second at the maximum rate with pixel size of 96×80. Typical discharge regime of RELAX RFP plasmas are as follows: plasma current Ip from 40 to 70 kA, discharge resistance Vl/Ip estimated at the current maximum decreasing with Ip from 4 mΩ to 1.5 mΩ, and Since discharge duration of the RELAX plasma is about 2 ms, we have observed time evolution of the tangential image of the visible light emission from the start to the end of low-aspect ratio RFP plasmas.

Figure 2 shows typical waveforms of a round-topped RELAX discharge. The plasma current grows to 60 kA in about 0.5 ms, with formation of RFP configuration at

author's e-mail: onchi5t@nuclear.dj.kit.ac.jp

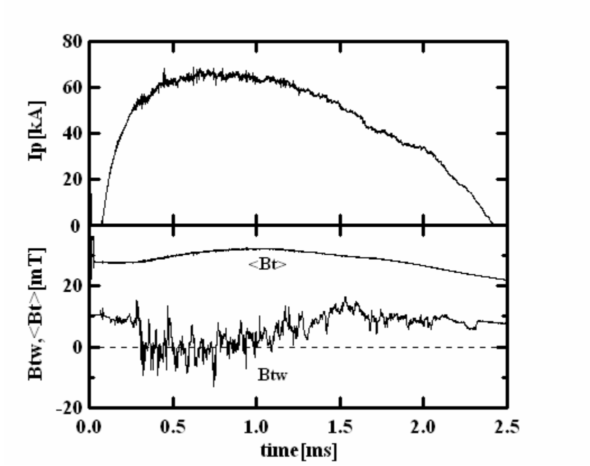
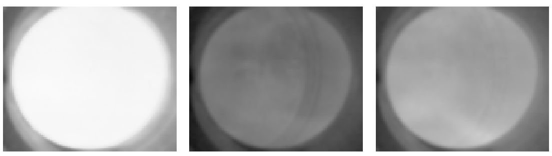


Fig.2 The typical discharge waveforms round-topped RFP discharge in RELAX. Ip is the plasma current, edge toroidal magnetic field Btw and average of torodal magnetic field <Bt>.

0.3ms into the discharge. The plasma current maintains the value higher than 60 kA for 1 ms, followed by a gradual decay after the loss of field reversal at 1.2ms. Thus, in round-topped discharges, the RFP configuration can be sustained for 1 ms followed by the so-called Ultra-Low Q (ULQ) configuration with decaying current. The total duration of this round-topped RFP discharge is about 2 ms. A single-chord soft-X ray diagnostics with absorbing method using two polyethylene filters has provided line-averaged electron temperature higher than 50eV, exceeding the radiation barrier for a hydrogen plasma at least in the core region.



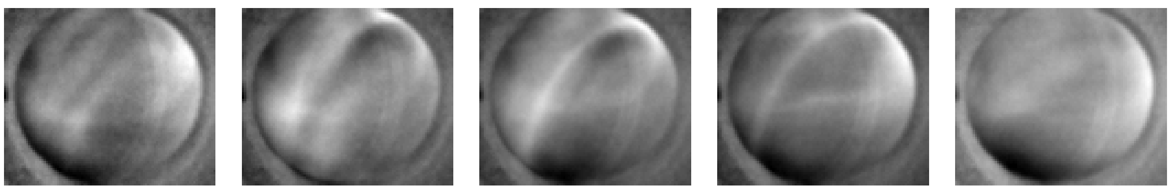
(a)t=100μs (b)t=500μs (c)t=1ms

Fig.3 Some typical fast camera images in "RELAX" plasma, corresponding to shot of Fig.2.

3. Observation of helical structures in the visible light image

First, we will describe typical evolution of the fast camera images in this type of round-topped discharges. As shown in Fig.3(a), strong visible light emission due to Hα line radiation is observed over the minor cross section in the early phase of a discharge, 0.1ms into the discharge in the case of Fig.3(a). This strong Hα emission is the indication of ionization phase of a discharge. As the plasma current Ip grows, the RFP configuration is set up at 0.3 ms, and sustained for about 1 ms with Ip of 50-60 kA. The visible light emission decreases as the current rises, as shown in Fig.3(b) at 0.5ms into the discharge. During the RFP sustainment phase, intensity of the emission is too weak to identify any characteristic structures. In the round-topped discharge, it happens at 1-1.2 ms into the discharge that the toroidal field reversal is lost with a smooth transition of the magnetic field configuration from RFP to non-reversed low-q discharge, so called ultra-low q (ULQ) regime. The emission increases again at the incidence of transition, as shown in Fig.3(c) 1.0 ms into the discharge. The increased emission is probably an indication of enhanced influx of hydrogen particles at the configuration transition phase. In round-topped RFP discharges, we can identify the characteristic structure in the visible light emission most evidently in the ULQ discharge regime, and the observed structure in the emission shows good correlation with magnetic fluctuation behavior. .

Figure 4 shows time evolution of the emission images for 50μs before and after the appearance of simple helix structure in the emission image. The time evolution shows that transition from three or two helices structure in Fig.4(a) and (b) to a simple single helix structure at 1.4125 ms in Fig.4(c), followed by a gradual fading away of the helices. It has been shown that the simple helix structure agrees well with simulated helix tube on the m=1/n=4 mode rational surface which was reconstructed using the modified MSTFIT code. This is simple helical structure in the emission image may indicate that the density and temperature of electrons have the similar structure, because it is unlikely that residual neutral particles distribute with such kind of helical structure.



(a)t=1.38750ms (b) t=1.4000ms (c) t=1.4125ms (d) t=1.4250ms (e) t=1.4375ms

Fig.4. Time evolution of the fast camera images during 50 μs before and after the transition to simple helical structure at (c). These data correspond to the same shot as in Fig.2.

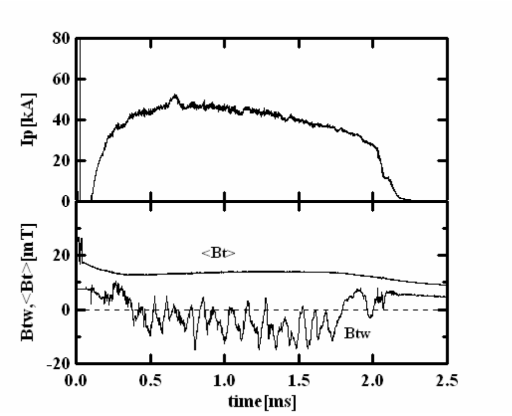
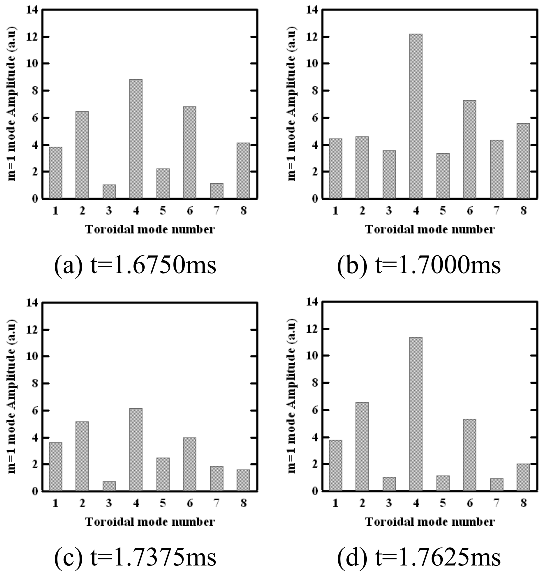


Fig.5 The waveforms of Ip, Btw and <Bt> in “RELAX” RFP plasma, which are different from Fig.2.

This helical structure in the emission image has some correlation with magnetic fluctuations as discussed in [6].

Next, we will describe typical evolution of the fast camera images in flat-topped RFP discharges with plasma current of 40-50 kA, as shown in Fig.5. In this type of discharges, the RFP configuration is sustained for 1.5-2.0 ms, almost to the end of discharge. Typical evolution of visible light images throughout a discharge is similar to that in round-topped discharge. The main difference is that we can identify characteristic helical structures in the fast camera images in the RFP sustainment phase. The magnetic mode behavior shows that m=1/n=4 mode grows after ~1.4ms, becoming dominant mode towards the end of discharge.

Figure 6 shows time evolution of the fast camera images from 1.650ms to 1.775ms. The set of pictures indicates that there are some helical structures observable in the images throughout the period of 0.1 ms. The helical structures are, however, not so simple as in the case shown in Fig.4. Figure 7 shows the toroidal mode spectrum of m=1 modes ,



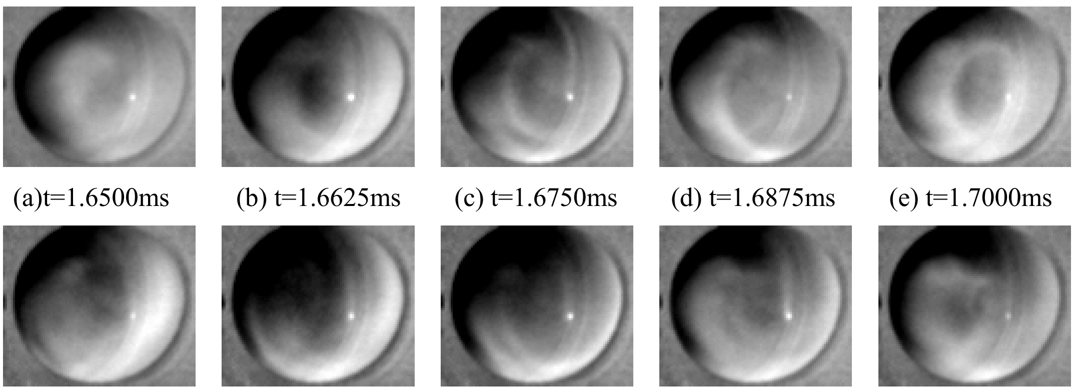
(a) t=1.6750ms (b) t=1.7000ms

(c) t=1.7375ms (d) t=1.7625ms

Fig.7 Comparison of some toroidal mode spectrum. (a),(b),(c) and (d) are correspond to Fig.7(c),(e),(h) and (j).

indicating that m=1/n=4 mode is dominant throughout the duration of 0.1 ms, with some secondary resonant modes. Comparing these two figures, we can identify that the number of dominant helicities in the fast camera pictures agrees with the number of dominant and secondary modes throughout this period of 0.1 ms. Equilibrium reconstruction in order to deduce the q profile to identify the radial locations of mode rational surfaces both the dominant and secondary modes has been in progress to compare the observed helical structures with magnetic field structures inside the plasma.

We can also identify toroidal rotation of the helical structures in the opposite direction to the toroidal plasma current. Detailed comparison of the toroidal rotation of the



(a)t=1.6500ms (b) t=1.6625ms (c) t=1.6750ms (d) t=1.6875ms (e) t=1.7000ms

(f) t=1.7125ms (g) t=1.7250ms (h) t=1.7375ms (i) t=1.7500ms (j) t=1.7625ms

Fig.6 Time evolution of the fast camera images, corresponding to the same shot as in Fig.6. Time zone is 1.650~1.775ms.

m=1 modes are also in progress.

4. Conclusion

There have been observed several types of helical structures in the fast camera images in low-A RFP plasmas in RELAX. This is the first observation of helical structures in the visible light images in the RFP plasma. Such structures are an indication of the similar structure of both the density and temperature of electrons because it is not likely that the residual or enhanced neutral particles have such kind of structure. The remaining issue is the reason for the formation of such kind of helical structures in the visible light emission. It may be closely related to the magnetic island issues in low-A RFP configurations, so we need to implement the soft-X ray imaging diagnostics.

References

[1] D. F. Escande *et al*, Phys. Rev. Lett. **85**, 1662 (2000).
[2] S. Masamune et al., Trans. Fusion Science and Technology, **51**, 197 (2007).
[3] N. Nishino et al., J. Plasma Fusion Res. **78**, 1278 (2002).
[4] N. Nishino et al., J. Plasma Fusion Res. **80**, 175 (2004).
[5] N. Nishino et al., Plasma Fusion Res. **1**, 035 (2006).
[6] T.Onchi et al., submitted to PFR.