Observations of 3D magnetic perturbation effects induced by LHWs on the EAST first wall

S. Shu [1, 2, *], Y. Liang [2], S. Xu [2], M. Chen [3], C. Liu [1], Z. Yang [4], K. Gan [3], F. Wang [5], Z.Huang [6], J. Luo [5], J. Zhang [1], and the EAST Team

[1] *School of Instrument Science and Opto-electronics Engineering, Hefei University of Technology, Hefei, 230009, China.*

[2] *Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung – Plasmaphysik, Partner of the Trilateral Euregio Cluster (TEC), 52425, Jülich, Germany*

[3] *Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, 230031, China*

[4] *Tongling University, Tongling, 244000, China*

[5] *College of Sciences, Donghua University, Shanghai,201620,*

[6] *China School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China*

Abstract

To investigate further the three-dimensional (3D) effects induced by the lower hybrid wave (LHW) on the interaction between the plasma and the first wall on the Experimental Advanced Superconducting Tokamak (EAST), an infra-red (IR)/visible integrated endoscope diagnostic system has been developed to measure the surface temperature on important inner components like lower divertors and LHW protection guide limiter, etc. Using the surface temperature obtained by an IR camera, the heat flux distribution on the divertor and the LHW guard limiter was calculated by resolving heat transfer equations. Five helical current filaments (HCFs) were modelled with two cases using the field-line tracing method in the scrape-off layer (SOL) for modelling of LHW-induced 3D magnetic field topology change in this paper. Through the theoretical calculation of the 3D magnetic field induced by LHW and the heat flux analysis using the infrared camera system, the splitting of the strike line on the lower target plate is verified, and two cases with different HCFs are analyzed and discussed. The profiles of the penetration depth of the field line with different HCFs currents compared with experimental heat flux on the LHW guard limiter are also presented and discussed.

1. Motivation and experimental set-up

Previous experimental results from the Experimental Advanced Superconducting Tokamak (EAST) have shown that the lower hybrid current drive (LHCD) can induce a three-dimensional (3D) magnetic topology change at the plasma edge, thus affect significantly the heat flux distribution [1, 2]. In this paper, the effects of the lower hybrid wave (LHW) on the heat flux distribution in the lower outer divertor and the LHW guard limiter were discussed. The IR/visible integrated endoscope diagnostic system was developed, and then the heat flux can be calculated by resolving heat transfer equations [3, 4].

As shown in Fig. 1(lefit), the infra-red (IR) diagnostic system applied to this work, which consists of an IR camera and an endoscope system, is installed in port K. The endoscope, which has a wide field of view (47° × 58°), can simultaneously obtain images of ports N, O, and P. Toroidal angle (phi) at the center of the N port is assured zero with anticlockwise direction for the following modelling use. Fig. 1(right) shows an image obtained from the IR diagnostic system. The high speed IR camera is used in this system (a FLIR SC700BB camera used before 2017 campaign, and a Telops TS-IR-MCT used from 2017 to now).

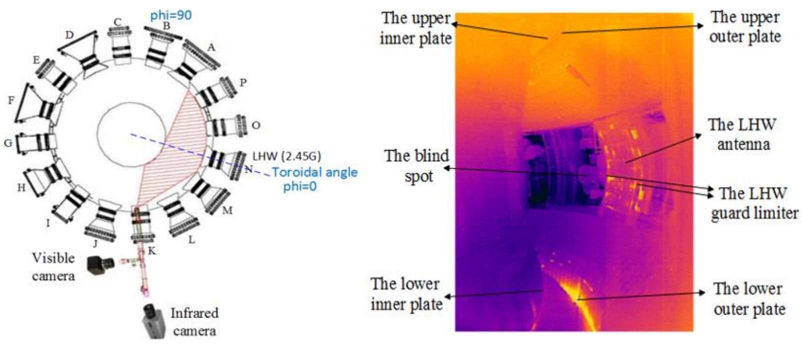

Fig. 1: left: Sketch of port positions (Top view of the IR diagnostic system on EAST with the toroidal positions of 2.45GHz-LHW), right: an IR image obtained from the IR diagnostic system.

2. Modelling of magnetic topology induced by LHW

Modelled scrape-off layer (SOL) field lines, starting in front of the LHW antenna, show agreement in position and pitch-angle with the experimentally observed radiation belts [1, 5]. EAST shot # 55537@3740ms are simulated (with the 2.45G LHW). The main discharge parameters are shown in Fig. 2. Using field line tracing, five helical current filaments (HCFs) were modelled with two cases (always in the low field side or maybe in the high field side). As shown in Fig. 3, There are two cases are discussed in the paper. It is also shown that the dominant toroidal mode number of LHW-induced perturbation field is n=1 due to the geometric effect of the LHW antenna [5].

3. Effects of LHW-induced filaments on the lower outer target

The LHW-induced 3D magnetic topology change at the plasma edge affect significantly the edge plasma transport and divertor heat flux distribution. Splitting of the original strike line, which characterized as the appearance of multiple peaks in the heat flux distribution profile along with the divertor target, has been observed during the application of LHW. By using DFLUX, the heat flux was calculated, as shown in Fig. 4.

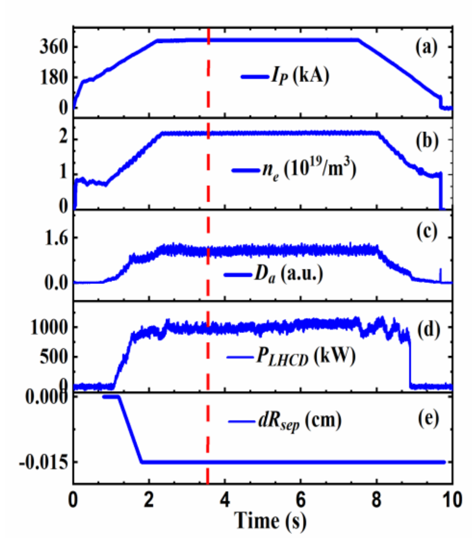

Fig. 2 Time evolution of the EAST discharge #55537 (red dash line is the simulation time)

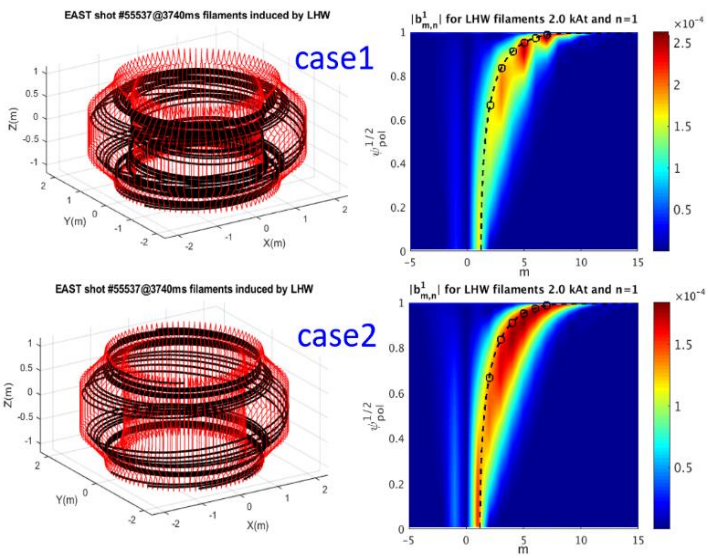

Fig. 3 Two cases field line tracing results (left: EAST wall (red line), helical current filaments (black line)), right: the Fourier spectrums of the radial component of the n=1 harmonics)

The penetration depth of the field line on the lower outer divertor plate at two cases with different HCFs current are compared. It is shown in Fig. 5. Through the compared results with the different cases of the heat flux on the lower outer divertor between simulations and experiments measured by an IR camera, an HCFs current ~ 2.0 kA at case2 shows a good agreement.

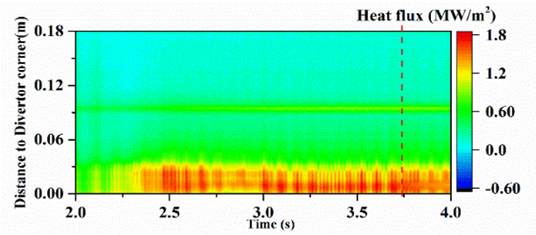

Fig.4 Heat flux on the lower divertor target plate (2.0-4.0s) using IR system (The red dash line is the simulation time.)

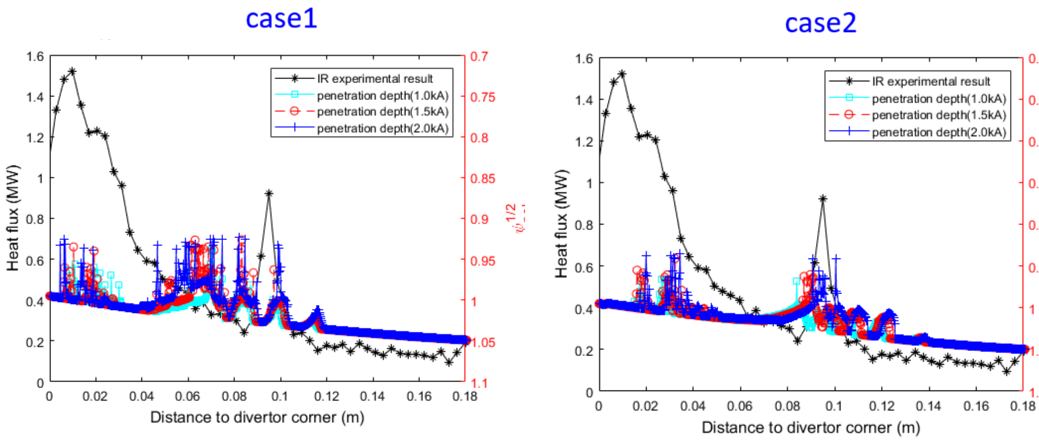

Fig. 5 The profiles of field line penetration depth with different HCFs current compared with experimental heat flux (letf: case1,right: case2)

4. Effects of LHW-induced filaments on the LHW guard limiter

LHW guard limiters are important PFCs to protect the LHW antenna and others. When LHW heating or non-inductive current drive experiment, the large heat flow on the guard limiters of the LHW antenna have been widely observed in several tokamaks [6]. The strong plasma-wall interaction could bring in impurity species to deteriorate the plasma confinement.

According to the structure of the LHW guard limiter, using the surface temperature obtained by IR camera, the heat flux on the LHW guard limiter is calculated by the finite difference method. Some results are shown in Fig. 6.

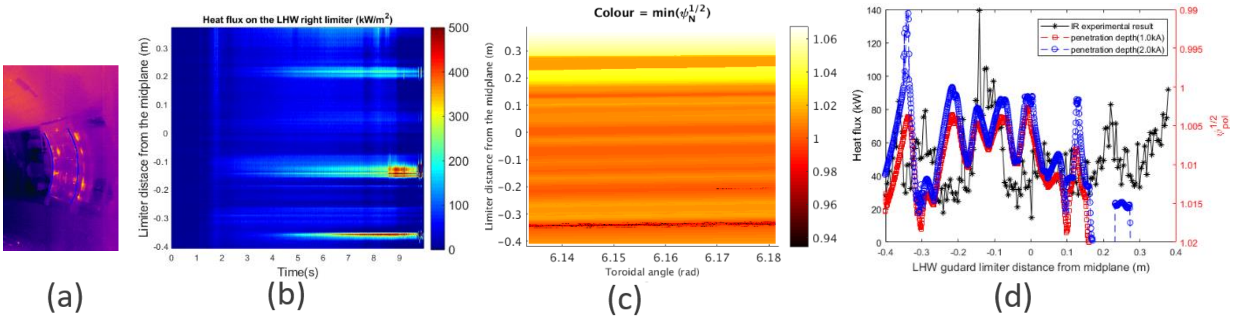

Fig. 6 (a) Location of the LHW guard limiters(blue curve) in EAST and an image captured by the IR camera; (b) Heat flux on the right LHW limiter; (c) The profiles of the penetration depth of the field line (d) The profiles of the penetration depth of the field line with different HCFs currents compared with experimental heat flux mearsured by an IR camera.

The main reason of the inconsistency between the experimental measurements and the simulations may lie in the two aspects: one is from the method used for the experimental results deducing process, and the other may be relevant to the simulation model and simulation locations of the HCFs current, etc. A further study will go on with a suitable model, such as the field diffusion model.

5. Summary and discussion

Five helical current filaments (HCFs) were modelled with two cases using the field-line tracing method in the scrape-off layer (SOL) for modelling of LHW-induced 3D magnetic field topology change with two cases in this paper. The topological structure is calculated in the vacuum paradigm. Furthermore, non-axisymmetric perturbation fields are covered by the vacuum assumption. Through the theoretical calculation of the 3D magnetic field induced by LHW and the heat flux analysis using the infrared camera system in the EAST, the splitting of the strike line on the lower target plate is verified. The result on the LHW guard limiter needs to be further studied. Much further work is still needed in the future, including both the experimental work (different discharge conditions, such as plasma configuration, safety factor, and plasma density, etc.) and simulation work (such as the field diffusion model, etc.).

6. References

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