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HL-2A Plasma Imaging

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1 Introduction

HL-2A device, the first non-circular cross-section tokamak with diverter in P.R.China, has been constructed and put into operation in 2002 and realized diverter configuration discharge. The main components were transferred from ASDEX device, IPP, Germany.

Apart from boundary transport and SOL study, the HL-2A major subject is to investigate the improvement of confinement with high parameters, and lots of front physics and relevant engineering techniques by means of its special closed diverter in China (1).

Plasma imaging (so called as "visible TV "or "TTV (tangential TV) ") (3) (4) is extremely useful to overview the edge and diverter structure; the plasma boundary may be identified in principle (2) (5). In order to satisfy the demands of the engineering adjustment and near real-time monitor of the device operation, plasma-imaging diagnostic has been developed.

2 Plasma-imaging system

The imaging system consists of (1) color video camera and CCD camera with H_α(CIII) filter, taking an identical tangential view (2) observation window & turn mirror (3) viewing & collection optics (4) video capture card and (5) PC (Fig.1). Along line-of-sight, whole cross-section of the torus can be observed, including diverter regions, movable & fixed limiter. The color camera SCC-731P (South Korea) with super low luminance (0.004Lux), pixel number 768(H) ×576(V), FPS 25, the CCD camera SensiCam (Germany) with exposure time setting, the capture card MVPCI-V3A, capable of real- time picture display.

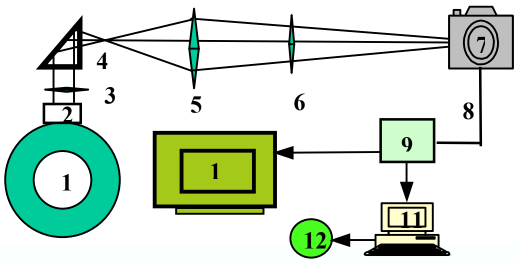


Fig. 1 Schematic of the plasma imaging system **1.HL-2A plasma 2. Observation window 3. f_2 550mm(Wide angle lens) 4. Turn mirror 5. f_2 =550mm(Large aperture lens) 6.Motorized zoom CCTV lens 7. Color video camera & CCD camera 8. Video cable 9. Video capture card 10. Large screen display 11. Personnel computer12. Permanent CD**

The observation window (k9 glass), diameter 100mm, thickness 10mm is put at the mid-plane of the torus. It protrudes from the vacuum vessel wall 25 cm outside, 32.7^0 with respect to the toroidal direction of the torus so as to prevent the so-called " first mirror" from pollution during temperature baking, discharge cleaning, etc.

Outside the window two lenses constitute a typical optic path of telescope. The distance Δ between them satisfies the following relationship: $\Delta = f_1 + f_2$. The first one f_1= 38.4mm,**Φ** = 25mm with wide angle facing the entire torus, while the second one f_2 =550mm, **Φ** = 100mm. Coupling to the camera is collection lens group and a motorized zoom CCTV lens (Japan) to adjust optic parameters and picture quality. The whole field of view, 1.6 m high, 1.2 m wide can be collected onto 0.8 × 0.8 cm^2 CCD photosensitive surface of the camera.

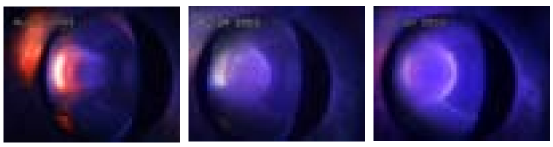
Along the outward direction of the radiation, some objects, such as B_T assembly, support plates, etc. block the light path, so put a total-reflection mirror to turn 90^0 directions.

The color TV camera is sensitive to strong electric and magnetic fields, the local magnetic field has been measured high up to 7300 gauss when toroidal magnetic field Bt is 1.12T, and decreased rapidly far from the torus (For example, several tens gausses 2m away.). It is necessary to mount the camera farther than 2 m from the torus body.

For further shield the electromagnetic interference, the camera is wrapped by three types of shield layers, namely, 10 or more layers of high magnetic permeability alloy + iron pieces, galvanized iron skin box, and brass skin box, etc. Through the video cable more than 30 m long, plasma imagines are thus acquired, stored, and displayed frame-by-frame on the large screen in the control hall. The imaging system works very well and stably.

3 Observation results

The system was firstly applied to adjustment and operation of first plasma discharge. In a word, HL-2A first plasma contained more radiation compositions.



(1) Shot 1452 (2) Shot 1023 (3) Shot 992

Fig.2 Tangential view of limiter

In 2003, both limiter and diverter discharges were carried out. Ohmic-heated hydrogen plasma discharge parameters: current Ip 100~168 KA, Bt 1.4 T (maximum), duration t_p of 300~750 ms, within plateau time 100~180 ms, electron density n_e 0.8~1.7 × 10^{13}/ cm^2.

Of all discharges the unfiltered photos were acquired, normally 10 or more frames per shot, at most to 25 or more. When the movable limiter was moved inward 3cm and there was no control of plasma horizontal displacement, limiter became convergent point of the plasma radiation and the surface of bombardment by electrons and ions (Fig. 2 (1)).

Color photo also showed impurity sputtering from the vacuum vessel wall (Fig. 2 (2)), plasma disruption, etc. Fig. 2(3) is an example of limiter discharges under fine control of equilibrium and displacement, where Ip 100 KA, t_p 420 ms, among them plateau time 180 ms. Plasma shape was circular and didn't touch with the wall of the vacuum vessel. There appeared hardly any visible light in the core region.

The HL-2A torus can be operated in double null, upper single null (USN) and lower single null (LSN) configurations with the same main plasma condition to study diverter operation and various improved confinements regimes. Due to insulated resistance problem of the USN coil on the upper diverter, only the LSN configuration discharge was carried out.

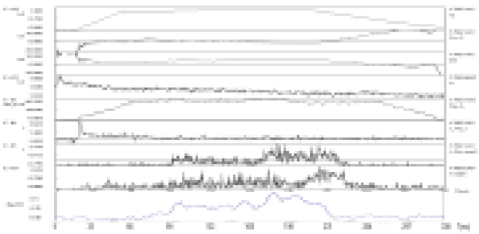


Fig.3 A representative discharge that shows the diverter configuration, (Shot 1766)

By comparing the CCD photos with $H_\alpha$filter (exp. time 0.5~1ms) and CIII filter (exp. time 5~10ms) during diverter configuration period, H_α emission intensity was 5~10 times stronger than that of CIII impurity emission.

When plasma disruption occurred, the corresponding photos indicated strong CIII emission. The plasma visible emission during the diverter configuration was apparently weaker than that during the limiter one in the same discharge.

Shot. 1766 was representative discharge of LSN diverter configuration. The time evolution of plasma parameters displays in Fig.3. In this shot, Ip was 130 KA, maintained 330 ms, of which, the diverter configuration was 145ms, n_e 0.8 × 10^{13}/ cm^2. The variations of H_α emission both limiter and diverter regions (I- $H_{\alpha\text{-S}}$, I-Div-Imp2, Fig.3) were quite different. The later appeared only the diverter configuration formation. Te, n_e and, H_α emission at the target plate of the LSN diverter were measured by Langmuir probe, 8 mm microwave and visible emission detector array respectively. The measurement curves were shown in the last three ones from the bottom in Fig.3 and also in accordance with the following Fig.4.

Table 1 Simulation result with filament-current method

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shot1766   T(ms)=   198.4000
Ip(kA)= 130.7745
number of filament nf = 1
Xr(m)=     1.548000  Xz(m)=    -0.456000
xmax(m)=     1.99410  xmaxz(m)=     0.00000
xmin(m)=     1.25676  xminz(m)=     0.01200
Rp(m)=    1.6254  Zp(m)=  -0.0385
ap(m)=    0.3687  k=    1.1326
q=   4.3343
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X point position : X_r,X_z Plasma position: Z_p,R_p,a_p
k: elongation ratio, q: safety factor at plasma boundary

The flux surface perimeters of the diverter structure were rendered from equilibrium reconstruction procedure [(6)]. Table 1 expressed plasma parameter calculation at 198ms, corresponding to photo No.7 in Fig.4.

Combination photo shows video imagines and simulation curves, Shot. 1766. For picture No.3~8 in Fig.4, relevant exposure time is 40~72ms, 72~119ms, 119~150ms, 50~179ms, 197~244ms, 244~275 ms in Fig.3 respectively.

Along the main plasma emission region downward, brought out obvious radiation lines (All in Fig.4). The main beam separated and entered into two sides of the protect plates, down to the groove inside.

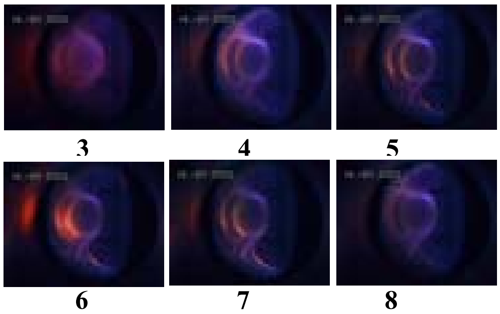

Fig.4 Color Photo & simulation curve,

In Fig.4, the simulation line (red) implied the plasma boundary and x point location (intersection); this curve was in a plane perpendicular to the line of sight through its center.

When the diverter configuration was formed, plasma shape became longer, while the position of x point is basically unchangeable and shifted inward. Fig.4 showed quite clearly that the imagines were in good agreement with the above simulation curve (LCFS).

4 Summary and discussion

HL-2A tokamak realized (1) diverter configuration discharge and (2) TTV plasma imaging. Telescopic optic-path makes it possible to monitor the entire scenario of the torus. The imaging system can distinguish both limiter and diverter discharges process, and plasma configuration and position of the strike lines on the target plates can be also determined, so far as to other phenomenon, etc [8].

The improvement includes adoption of high-speed CCD camera (FPS 100~1000) and related capture card, protection of observation window from pollution, etc. The authors would like to thank the HL-2A operation, control & diagnostic groups for help.

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