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Numerical Simulation and Experimental Identification of Divertor Configuration in the HL-2A Tokamak

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Double and single null divertor configurations in HL-2A are simulated by SWEQU equilibrium code. Lower divertor discharges in the first physics campaign have been achieved by two kinds of power supply method of multipole field coils. Magnetic separatrix and minor radius are reconstructed by a current filament code using 18 Mirnov signals.

1. Numerical simulation of divertor configuration

HL-2A is a divertor tokamak constructed at SWIP new site in Chengdu. Its design parameters are R = 1.65m, a = 0.4 m, Bt = 2.8 T, discharge duration 5 s [1]. Figure 1 shows the poloidal cross-section of HL-2A tokamak. Number 1, 2, 3 are multipole coils, 4 is vacuum vessel, 5 is TF coil, 6 is PF coils, 7 is plasma. Shaped coils include 12 pairs of Ohm field carried 30 kA, 8 pairs of vertical field carried 45 kA, 3 pairs of multipole field carried 45 kA, 4 pairs of multipole compensation field carried 45 kA, and 3 pairs of horizontal field carried 4 kA.

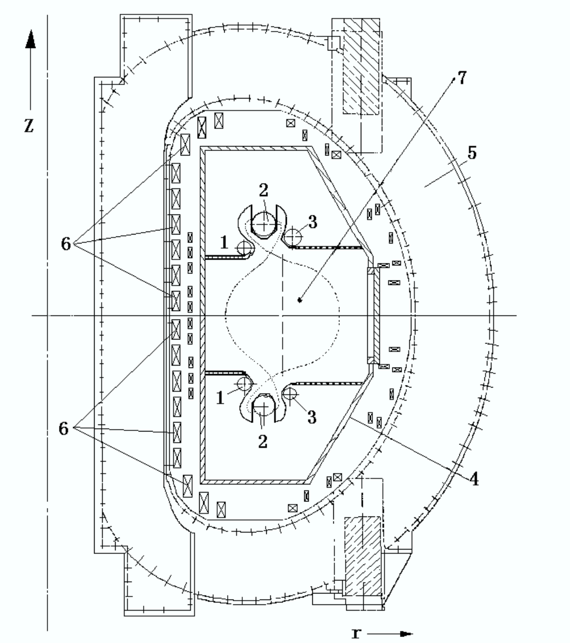

Fig. 1 Cross-section of HL-2A tokamak

No. 1, 2, 3 - multipole coils, 4 - vacuum vessel, 5 - TF coil, 6 - PF coils, 7 - plasma.

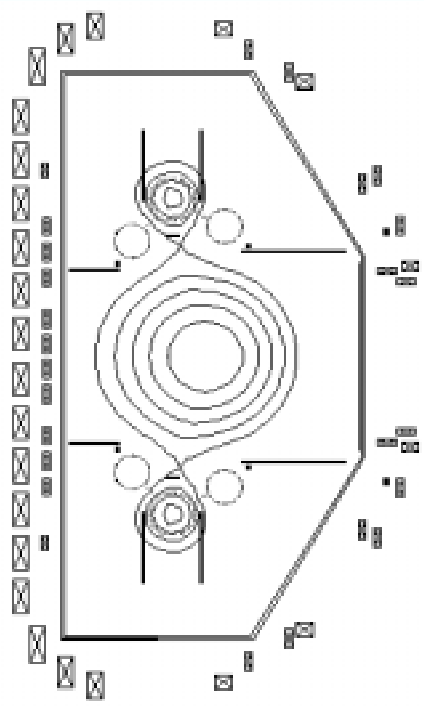

Fig.2 Double null divertor configuration simulated by SWEQU code

Plasma equilibrium in HL-2A is simulated by the code called SWEQU, which solves the Grad - Shafranov equation including two arbitrary functions of pressure and current profiles. We often assume plasma poloidal beta of 0.5 and parabolic pressure and current profiles during our simulations. The discharges of limiter configuration are easily conducted if vertical field current is 7 % of plasma current. Double null divertor configuration can be achieved after vertical field current is optimized. The vertical position of X - points changes 3 cm and horizontal position keeps invariant when multipole currents are scanned in 6-10% of plasma current. The optimization ratio of multipole current with plasma current is 8 %. Figure 2 gives double null divertor configuration with the multipole current ratio of 7.3 %.

Lower divertor discharges are mainly simulated. Two kinds of methods can obtain single null divertor configuration. One method is power supply of three multipole coils (MP1, MP2, MP3) in series, which needs provide horizontal field current very large. The shaped field current ratios to plasma current are roughly 7 % for the vertical field, 8 % for the multipole field, and 4 % for the horizontal field. Plasma current is less than 100 kA because the 4 kA capability limitation of horizontal field coils. A typical lower divertor configuration is shown in Fig.3. The multipole field current is 8 % of plasma current. The other method is that about 12 % current bypass is used for the MP1 and MP3 coils, which are closer core plasma than the MP2. The latter can obtain plasma current much higher than 100 kA because it hardly needs horizontal field current.

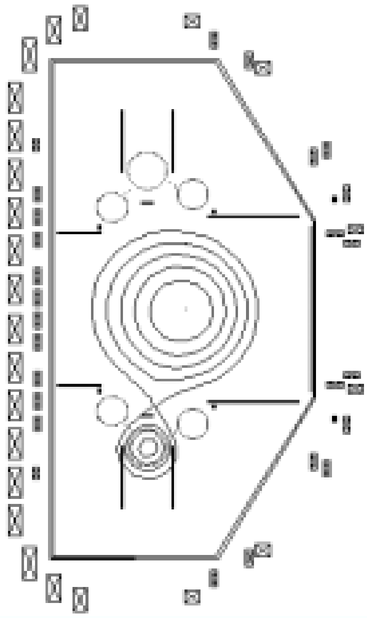

Fig.3 Single null divertor configuration simulated by SWEQU code

2. Main diagnostics of divertor discharges

Three main diagnostics are used to identify divertor discharges in HL-2A. Visible photography mounted on midplane is most direct tool to observe divertor legs. Seven flush probes with triple tips mounted on 4 - neutralizer plates are used to measure the profiles of electron temperature and density along target plates. Magnetic separatrix, X-point position and minor radius are determined by a code using 18 Mirnov signals. The method of multiple current filaments (CF) is used to fit plasma current in the code.

3. Experimental identification of divertor configuration

The Ip = 168 kA and duration 920 ms are obtained with limiter configuration in the first physics campaign. Figure 4 manifests the photography of lower divertor discharge in about 200 ms for shot 1766, which is applied the bypass power supply for multipole field. Divertor configuration is clearly observed. The magnetic separatrix and the position of X-point in the discharge are reconstructed in Fig.5. The divertor plasma succeeds hitting the outer target and inner one. The reconstruction parameters, such as major or minor radius and X-point position, are consistent with the prediction of SWEQU code. The minor radius is 0.384 m and major one is 1.70 m. The horizontal position and vertical one of X-point are X_R = 1.57 m and X_Z = - 0.44 m. The duration of divertor discharge determined by the reconstruction code is the same as measured by probe array on divertor target. Typical minor radius is in 37-40 cm for lower divertor discharges.

Fig.4 Divertor discharge photography at about 200 ms for shot 1766

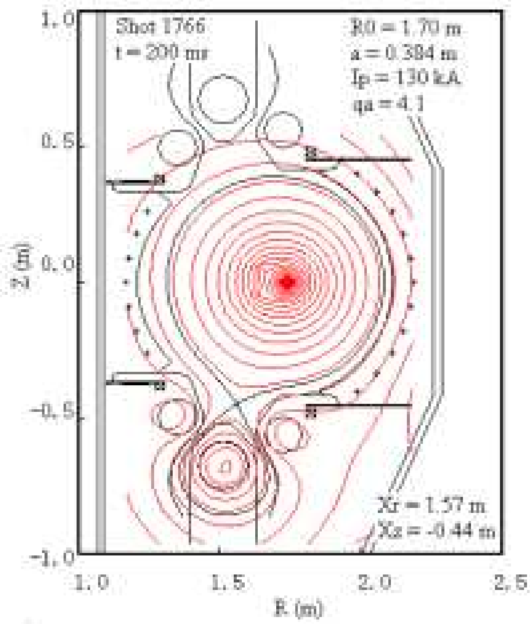

Fig.5 Reconstruction of magnetic surface from 18 Mirnov signals for shot 1766

The temporal evolutions relevant to divertor discharge for shot 1766 are given in Fig.6. The parameters from top are plasma current (a), line-averaged density (b), outer target temperature (c) and density (d), inner target temperature at z = -81cm (e) and z = - 80 cm (f). Divertor plasma is formed between 80 ms and 240 ms. The electron temperature on the outer target is about 80 eV for low-density discharge, while corresponding density is about one fifth of line-averaged density of main plasma. The temperature asymmetry between outer target and inner one is very obvious. These results are corresponding to the prediction of theoretical models.

The current ratios of shaped field coils with bypass power supply for shot 1766 are shown in Fig.7. They are 7.2 % for vertical field, 8.1% for MP1, 9.7 % for the MP2, 0.1 % for horizontal field, respectively. The bypass current of MP1 and MP3 coils is 16 %. The current of horizontal current may be neglected.

A typical discharge with the power supply of multipole field in series is given in Fig.8. The ratios of shaped field current with plasma current are about 7.3% for vertical field, 9.3% for multipole field, 5 % for horizontal field, respectively. Experimental current ratios for two kinds of power supply method are a little higher than theoretical prediction ones.

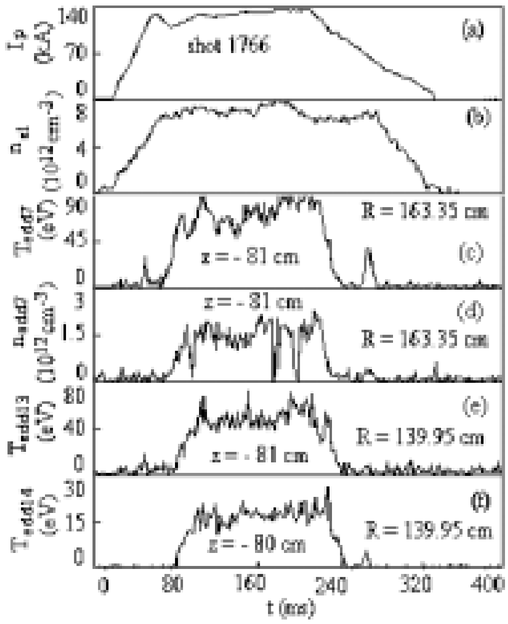

Fig.6 Parameter evolution of divertor discharge for shot 1766

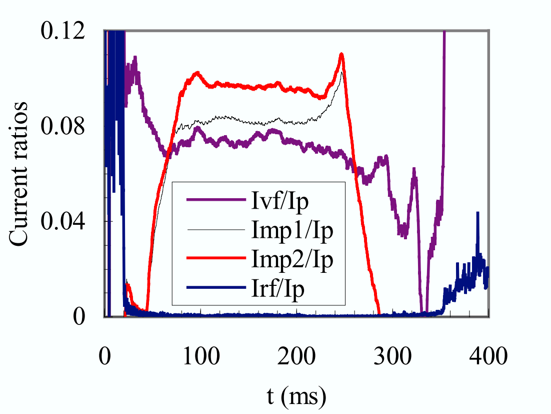

Fig.7 Current ratios of shaped field coils with bypass power supply for shot 1766

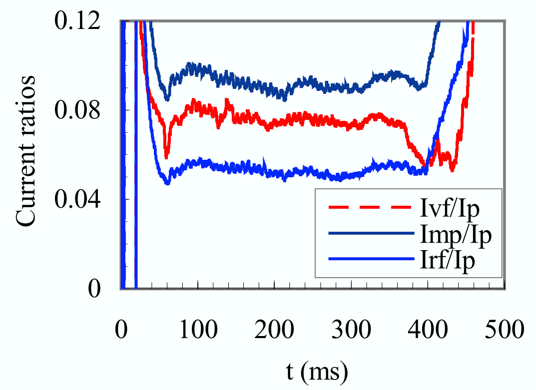

Fig.8 Current ratios of shaped field coils with power supply in series for shot 1573

In conclusion, lower divertor discharges have been identified by visible photography, target probe array and magnetic surface reconstruction. The simulation current ratios of vertical field, multipole and horizontal field to plasma current are consistent with experiment ones. Divertor target density is one fifth of line-averaged density. The temperature asymmetry between outer target and inner one is obvious.

[1] Y. Liu, J. C. Yan, C. P. Zhou, et al. Nuclear Fusion Vol. 44, (2004) 372.