Preliminary Design of MHD Equilibrium Configuration for a new scheme of HL-2M*

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1. Introduction

The mission of HL-2M project is to develop an advanced tokamak to establish a scientific and technological basis for an attractive fusion reactor. To support this project mission, a new scheme of HL-2M device is designed to be a non-circular cross-section tokamak with high elongation and triangularity. The major parameters of the HL-2M tokamak are summarized in Table 1.

The plasma current up to 2.5 MA with toroidal field at 2.2 T, while the plasma major radius is 1.78 meters and minor radius is 0.68 meter. The goal of design require the maximum elongation up to 2 and the triangularity greater than 0.5. In addition, the OH coils of HL-2M must have ability to provide the volt-seconds more than 14Vs, which can maintain 5 seconds flattop of discharge, and the full discharge process will more than 10 seconds.

Table 1.HL-2M main parameters

$Ip\ (MA)$	2.5
$R(m)$	1.78
$a(m)$	0.65
R/a	2.74
κ_{LCFS}	2
δ_{LCFS}	≥ 0.5
$B_T\ (T)$	2.2
Volt-second	14
Flat top (s)	>5
configuration	LSN,DN, limiter

The layout of the poloidal coils system for the new scheme of HL-2M has been shown in figure 1. All of the coils are located between TF coils and vacuum vessel. These coils include 8 groups up and down symmetrical PF coils which used to configuration the plasma, and 5 groups OH coils, which also up and down symmetrical and used to provide the volt-seconds for the plasma discharges. These PF coils have been required to restraint Lower Single Null divertor (LSN), Double Null divertor (DN) and elongated limiter configurations only by change the currents.

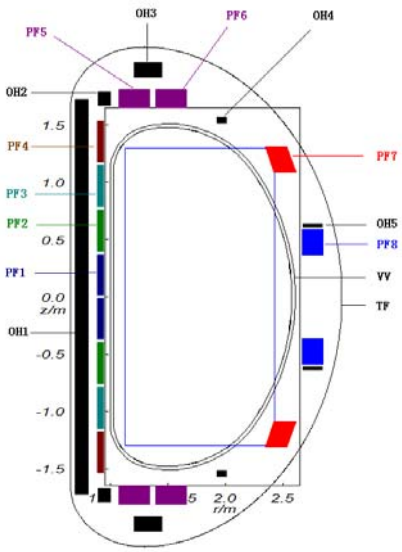

Figure1. Poloidal field coils system of HL-2M

These configurations have flexible shape, such as have different elongation and different triangularity. Table 2 gives the R and Z co-ordinates, ampere-turns, maximum current, width

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and height of the PF coils. Need to pay attention to: the PF7 coils have a tilt angle to the horizon about 70 degree. In this paper, EFIT is used as the major code to design basic configurations for the new scheme of HL-2M. In addition, the volt-seconds consumption of the first plasma discharge for HL-2M has been analyzed by TSC. This work also confirmed these configurations designed by EFIT.

Table 2.HL-2M poloidal coils parameter (R=1.78m,a=0.65m)

	R (mm)	Z (mm)	W (mm)	H (mm)	Tilt angle (°)	Ncoil (Nr×Nz)	Imax (kA)
PF1	910	194	51	358	0	58(3×20)[a]	6
PF2	910	581	51	358	0	58(3×20)[a]	6
PF3	910	968	51	358	0	58(3×20)[a]	6
PF4	910	1355	51	358	0	58(3×20)[a]	6
PF5	1212	1730	267	159	0	58(10×6)[a]	19
PF6	1531	1730	267	159	0	58(10×6)[a]	19
PF7	2500	1200	187	214	70	55(7×8)[a]	21
PF8	2760	480	186	214	0	55(7×8)[a]	19

Note: “a”, the differences of circle number between the effective power supply and the engineering layout

2. Overview of EFIT and TSC

The equilibrium fitting code (EFIT) has been developed to perform magnetic and optionally kinetic magnetic analysis on tokamak device operation [1-3]. The basic equation of the EFIT code is the Grad-Shafranov equilibrium equation[4]， it can be written as:

$$\Delta^*\psi \equiv \frac{\partial}{\partial \mathrm{R}}\frac{1}{R}\frac{\partial}{\partial R}\psi + \frac{\partial^2\psi}{\partial Z^2} = -\mu_0 R J_\varphi(R,\psi) \quad (1), \qquad J_t(R,\psi) = R[P'(\psi) + \mu_0 FF'(\psi)/(4\pi^2 R^2)] \quad (2)$$

where ψ is poloidal magnetic flux, R and Z are radial and axial co-ordinates in a cylindrical co-ordinate system, respectively, while J_t is the current density in the azimuthally direction. In order to calculate an equilibrium configuration, the plasma pressure $P'(\psi)$ and diamagnetic function $FF'(\psi)$ depending on poloidal magnetic flux have to be provided. In addition, appropriate boundary conditions are also required. In this work, the two free functions $P'(\psi)$ and $FF'(\psi)$ Eq. (2) are modeled with polynomials as following:

$$P'(\psi) = \sum_{n=0}^{np} \alpha_n {\psi_N}^n, \; FF'(\psi) = \sum_{n=0}^{nF} \gamma_n {\psi_N}^n$$

where $\psi_N = (\psi - \psi_a)/(\psi_b - \psi_a)$ is the normalized poloidal flux, ψ_a is the poloidal flux at the

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magnetic axis, ψ_b is that at plasma boundary.

EFIT can be run in either the fitting mode or the equilibrium mode. In the equilibrium mode, it acts as an equilibrium solver and the equilibrium can be computed either with a fixed specified boundary or with a free boundary when the shaping coil currents or the fluxes at a set of flux loops are given. In this work, an input file for the free boundary calculation is generated at the completion of a fixed boundary run.

Tokamak Simulation Code (TSC) [5], developed by Princeton Physics Laboratory, is widely used for design of new axisymmetric toroidal experiments. It models the evolution of free-boundary axisymmetric toroidal plasma on resistive and energy confinement time scales. It has been used to detailed analyzed the volt-seconds consumption of the plasma discharges for many famous tokamak [6-7].

3 Basic HL-2M equilibrium configurations design with EFIT

According to the new scheme of HL-2M, the basic equilibrium configurations which contain the LSN, DN and elongated limiter configuration have been designed by the EFIT.

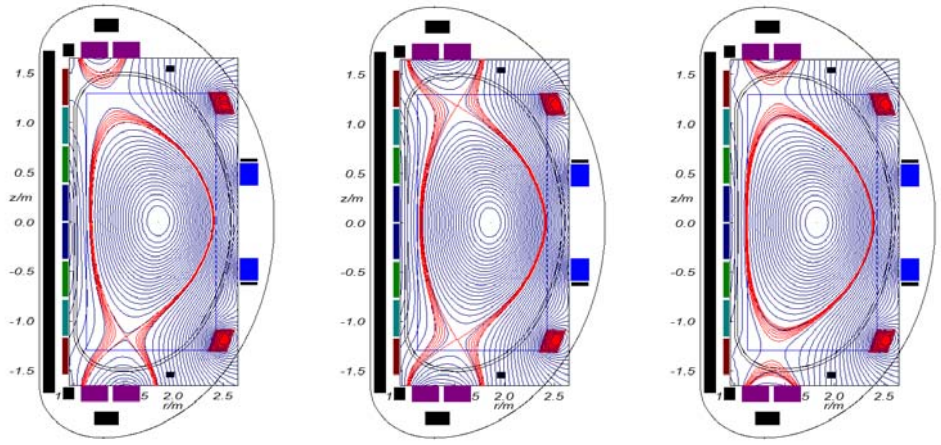

Figure 2 Basic equilibrium configuration of HL-2M, LSN (left) DN (middle), limiter (right)

The lower single null divertor (LSN) configuration as shown in left picture of figure 2, which is the conventional operation of HL-2M. The elongation and the triangularity of the Double Null divertor (DN) configuration as shown in middle part of figure 2 are up to 1.95 and 0.46. The new scheme of HL-2M not only can produce LSN and DN configuration, also can produce an elongated limiter configuration. As shown in right part of figure 2, the elongation and triangularity are 1.7 and 0.4 respectively. In addition, the poloidal beta and the

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plasma current for these basic equilibrium configuration are 0.6 and 2MA, respectively.

4 Volt-seconds analysis with TSC

In order to analyze the volt-seconds consumption during the plasma discharge of HL-2M, a series of equilibrium configurations designed by EFIT which provide to TSC as the initial equilibrium, and then do the simulation for volt-seconds consumption analysis. Figure 3 show the time evolution of volt-seconds consumption from TSC. The upper part of this figure show the actual volt-second (about 13.44 Vs), which is the need to maintain the discharge evolution in TSC, and the lower part is the volt-seconds provide by ohmic coils (about 13.5 Vs). In brief, the actual volt-seconds consumption is closed to the volt-seconds provide by ohmic coils. Pay attention the current of OH coils fall from 80kA to -110kA in this figure, the discharge pulse about 8sec with the plasma current are 2MA, while the current of OH coils fall from 110kA to -110kA, maybe can maintain the discharge pulse about 10 sec.

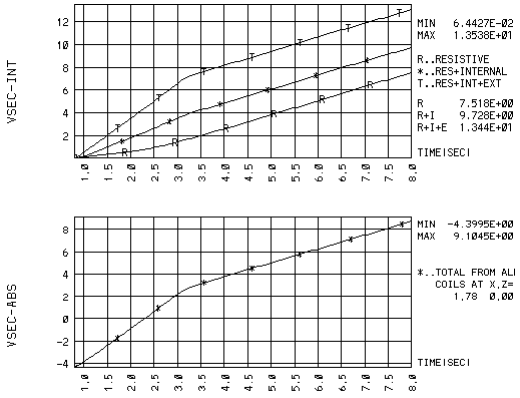

Figure 3 The time evolution of volt-seconds consumption

5 Summary

The main parameters and the layout of the poloidal coils system for the new scheme of HL-2M have been introduced briefly. The preliminary design of the basic equilibrium configurations for a new scheme of HL-2M have been finished by EFIT. These basic equilibrium configurations contains LSN, DN and limiter, all of these meet the goal which listed in table 1. In addition, the volt-seconds consumption has been estimated by TSC. The OH coils can provide more than 14 volt-seconds, which can maintain 5 seconds flattop of discharge, while the plasma current may up to 2.5MA.

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