Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Equilibrium analysis using finite element method of ohmic plasmas in VEST

Jeongwon Lee, YoungHwa An, JeongHun Yang, Young-Gi Kim, Jong-Yoon Park, Min-Gu Yoo, Kyoung-Jae Chung, Y.S. Hwang and Yong-Su Na*
Department of Nuclear Engineering, Seoul National University, Seoul, Korea
**Corresponding author: ysna@snu.ac.kr*

1. Introduction

As one of the nuclear fusion reactor concept, the spherical torus has its own advantages of compactness, cost effectiveness, and high plasma performance compared with the conventional tokamak. For researching the basic physics and engineering issues of the spherical torus, Versatile Experiment Spherical Torus (VEST) is constructed [1] and ohmic start-up is successfully achieved of plasma current up to 70 kA with aid of an electron cyclotron heating (ECH) pre-ionization system.

To investigate the equilibrium properties such as the plasma position, shape and plasma current distribution of the initial plasma, a finite element method [2, 3] is selected due to its simplicity to apply in the initial phase. These results can give plasma information not only the plasma position and shape, but also the plasma internal inductance.

In this paper, one of the typical VEST ohmic plasmas is selected and analyzed by the finite element method to find plasma equilibrium properties. Details of the analysis and validation with other diagnostics results will be presented.

2. Numerical Modeling

2.1 Finite element method

As one of the plasma equilibrium analysis method, finite element method has been used for fast identification of plasma equilibrium properties. It is similar with a filament method, but there is no singularity problem and the plasma current distribution can be considered. In the finite element method, the plasma current distribution is assumed by some finite elements and the current of the each element is determined by minimizing the error cost function, *J*.

$$J = \sum_{i=1}^{M} \frac{(y_i - y_{ci})^2}{y_i} + \alpha \sum_{j=1}^{N} \frac{N_j\left(I_j - I_{j0}\right)^2}{\sigma_j}. \quad (1)$$

Cost function *J* consists of two terms. The first term corresponds to the normalized error of each magnetic sensor signal, which represents how much the fitted result is similar to the real plasma. The second part prevents diverging of the element currents. This term is required for gathering more physically meaningful results, not just mathematically optimized fitting which comes from the diagnostics data with a measurement error.

2.2 Eddy current modeling

Eddy current modeling is required to carry out an accurate plasma equilibrium reconstruction. As VEST vacuum vessel has thick part to support a machine structure, large amount of the eddy current, which is up to 2 times larger than the total plasma current, is induced during the plasma discharge. Therefore, the magnetic field configuration is seriously affected by the eddy current.

To find the eddy current distribution on the vacuum vessel, each vessel segment is considered as a toroidally continuous ring and RL circuit approximation is applied. Time evolution of the eddy current at the each vessel segment is calculated by an eigenmode expansion method [4]. To assess the accuracy of this calculation, calculated magnetic signal which comes from the eddy current simulation is compared with the real magnetic measurement.

3. Experimental Set-up

3.1. Magnetic diagnostic system

Magnetic diagnostics are prepared for the equilibrium reconstruction, which measures a plasma current, a poloidal magnetic flux and a poloidal magnetic field [5]. The total plasma current is measured by a Rogowski coil installed inside of the vacuum vessel, and poloidal magnetic flux is measured by flux loops at 9 points. Also, there are 49 magnetic pick-up coils to measure the poloidal magnetic field outside of the plasma. Additionally, to find the plasma current density profile at the midplane and enhance the accuracy of 2-dimentonal current distribution, the internal magnetic probe array [6] is also used.

3.2 Segmented limiter current monitoring system

A segmented limiter current monitoring system is developed to directly find the plasma limiting point. The outboard limiter is polodally discretized and isolated from the vacuum vessel. These limiter segments are connected to a machine ground and the flowing current between the limiter and the ground has been measured. This result is compared with the finite element reconstruction result.

3. Result and discussion

In VEST, the ohmic plasma is successfully achieved with the plasma current up to 70 kA and pulse duration of 15 ms. Not only the magnetics data already described in chapter 2, but also the electron density and temperature at the SOL regime and the H_α signal are measured to analyze the plasma. Details of the VEST ohmic plasma parameters are depicted in Fig. 1.

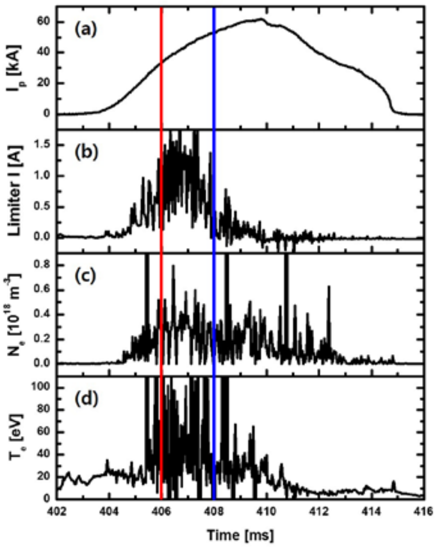

Fig. 1. Plasma parameters of the reference ohmic plasma, shot #9580. (a) Plasma current, (b) limiter current monitor, (c) electron density and (d) temperature at the SOL region (R = 0.78 m)

As shown in Fig. 1, the plasma current is initiated at 403 ms and maximized at 409 ms. The limiter current shows that the plasma is outboard limited during the current ramp-up phase. During the discharge, the electron temperature and the density in SOL are few tens of *eV* and order of 10^{17} m^{-3}, respectively.

The plasma equilibrium reconstruction has been conducted using the finite element method. Fig. 2 shows the plasma shape reconstruction result at 406 ms and 408 ms. The result shows that the plasma is outboard limited at the initial phase of the current ramp-up but changes to the inboard limited. This result is validated with the limiter current shown in Fig 1 (b). The current flowing through the outboard limiter decreases as the plasma moves to the inboard limiter.

4. Conclusions

Equilibrium analysis to the VEST typical ohmic scenario is conducted and the equilibrium properties of the plasma are taken. The plasma is assumed as finite elements and the plasma equilibrium properties such as the plasma position, shape and current distribution is identified. The result shows that the plasma moves to the inboard side during the current ramp-up phase which is validated with the limiter current measurement.

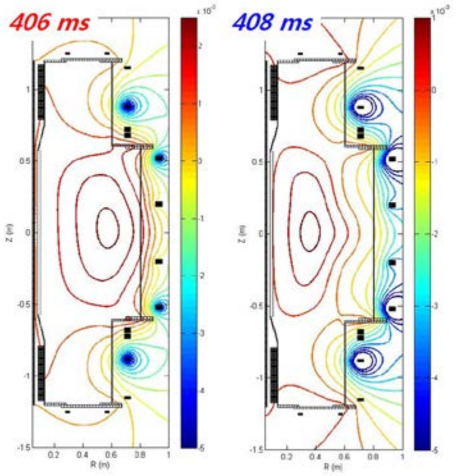

Fig. 2. Finite element reconstruction result of the reference ohmic scenario at 407 ms and 409 ms. Limiting point changes from the outer wall to the inboard limiter.

REFERENCES

[1] K.J. Chung, Y.H. An, B.K Jung, H.Y. Lee, C. Sung, Y.S. Na, T.S. Hahm and Y.S. Hwang, Design features and commissioning of the Versatile Experiment Spherical Torus (VEST) at Seoul National University, Plasm. Sci. and Techn., Vol.15, 244, 2013

[2] F. Hofmann and G. Tonetti, Fast Identification of Plasma Boundary and X-points in Elongated Tokamaks, Nuclear Fusion, Vol.28, p.519, 1988

[3] Y.S. Hwang, C.B. Forest, D.S. Darrow, G. Greene and M. Ono, Reconstruction of current density distribution in the CDX-U tokamak, Rev. Sci. Instrum. Vol63, p4747, 1992

[4] J.A. Leuer and J.C. Wesley, ITER plasma start-up modeling, Fusion Engineering, Vol.2, p.629, 1993

[5] J. Lee, K.J. Chung, Y.H. An, J.-H. Yang, Y.-G Kim, B.-K. Jung, Y.S. Hwang, T.S. Hahm and Y.-S. Na, Design and commissioning of magnetic diagnostics in VEST, Fusion Engineering and Design, Vol.88, p1327, 2013

[6] J. Yang, J.W. Lee, B.K. Jung, K.J. Chung and Y.S. Hwang, Development of internal magnetic probe for current density profile measurement in Versatile Experiment Spherical Torus, Rev. Sci. Instrum. Vol.85, 11D809, 2014