18PB-067

Development of Linear MHD Code based on Vector Potential and its Application to LHD

ベクトルポテンシャルに基づいた線形MHDコードの開発と大型ヘリカル装置への適用

Kenta Kitayama, Wataru Takado, Yutaka Matsumoto, Ryosuke Ueda, Kiyomasa Watanabe and Masafumi Itagaki
北山健太[1), 髙堂渉[1), 松本裕[1), 上田亮介[2), 渡邊清政[2), 板垣正文[1)

1) School of Engineering, Hokkaido University
Kita 13, Nishi 8, Kita-ku, Sapporo 0608628, Japan
北海道大学大学院工学院 〒060-8628 札幌市北区北13条西8丁目
2) National Institute for Fusion Science
322-6 Oroshi-cho, Toki, Gifu 509-5292, Japan
核融合科学研究所〒509-5292 岐阜県土岐市下石町322-6

We develop a new linear MHD code satisfying the solenoidal condition for the magnetic field by use of the vector potential in the MHD equations. The developed code is applied to the typical LHD plasma and the instability analysis is done. The obtained results by the developed code are compared with the results by the existing code.

1. Introduction

In the LHD experiments, kinds of fluctuations caused by the MHD instabilities are observed in the peripheral region [1]. A lot of simulation studies based on the real coordinates have been done in order to clarify the influence of these instabilities on the plasma confinement [2-3]. In many these theoretical research, however, the solenoidal condition for the magnetic field (div$\boldsymbol{B}$ = 0) is not considered, where $\boldsymbol{B}$ is the magnetic field. If the solenoidal condition is not satisfied, the artificial velocity is produced. Therefore, it is important to satisfy the solenoidal condition in the MHD simulation.

However, it is difficult to consider the solenoidal condition since this is not explicitly appeared in the MHD equations. In the present study, we develop a new linear MHD code satisfying the solenoidal condition by use of the vector potential in the MHD equations. The developed code is applied to the typical LHD plasma. In addition, the obtained results by the developed code are compared with the results by the existing code.

2. Outline of Developed Code

In the developed code, we calculate the time evolution of the magnetic field by use of the vector potential as,

$$\frac{\partial \boldsymbol{A}}{\partial t} = -\eta\left(\boldsymbol{J}-\boldsymbol{J}_{\mathrm{eq}}\right)+\boldsymbol{V}\times\boldsymbol{B}_{\mathrm{eq}}, \tag{1}$$

$$\boldsymbol{B} = \nabla\times\boldsymbol{A}, \tag{2}$$

where $\boldsymbol{A}$ is the vector potential, η the resistivity, $\boldsymbol{J}$ the current density and $\boldsymbol{V}$ the velocity, respectively. The suffix “eq” represents the equilibrium quantity. By use of eqs. (1) and (2), the perturbed magnetic field is automatically satisfied the solenoidal condition to an accuracy of the numerical computation.

The pseudo-plasma model is adopted in the developed code. In this model, it is assumed that the plasma with the low temperature and high resistivity exists in the region between the plasma and the vacuum vessel wall. Thus, the calculation of the whole simulation region can be done based on the same MHD equations.

The linearized MHD equations are discretized in the rotating helical coordinates [4] by the 4th order finite difference method. The time evolution is calculated by the 4th order Runge-Kutta method.

3. Application of Developed Code to LHD Plasma

3.1 *Equilibrium Magnetic Field satisfying the solenoidal condition*

We apply the developed code to the LHD plasma with the central beta is 2.4% calculated by the HINT code [5]. This equilibrium magnetic field is not satisfied the solenoidal condition. Therefore, the equilibrium magnetic field is recomputed by the aid of the projection method to satisfy the solenoidal condition. The used equilibrium pressure profile is shown in Fig. 1.

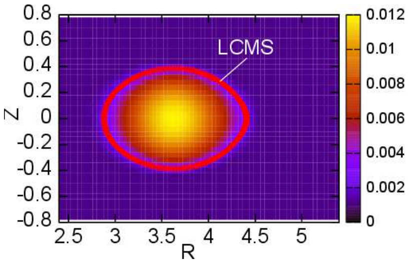

Fig. 1. The used equilibrium pressure profile on the horizontally elongated poloidal plane.

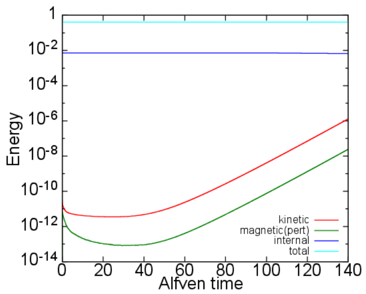

Fig. 2. Time evolution of the kinetic and magnetic energies.

3.2 *Initial and Boundary Conditions*

As the initial perturbation, the velocity is randomly added. The resistivity is initially given by the equilibrium pressure as,

$$\eta = \eta_{\text{in}} + (\eta_{\text{out}} - \eta_{\text{in}}) \frac{P^{-\frac{3}{2}} - P_{\max}^{-\frac{3}{2}}}{P_{\min}^{-\frac{3}{2}} - P_{\max}^{-\frac{3}{2}}} \quad (3)$$

and is assumed to be constant in time. Here, P denotes the equilibrium pressure. Suffix “max” and “min” represent the maximum and minimum value on the poloidal plane. η_{in} is the resistivity on the magnetic axis and η_{out} the resistivity in the pseudo-plasma region, respectively. In the present study, $\eta_{\text{in}} = 10^{-6}$ and $\eta_{\text{out}} = 10^{-2}$ are assumed.

On the boundary, the perfect conducting wall and no-slip condition are adopted.

3.3 *Instability in Real Coordinates*

The obtained time evolution of the kinetic and magnetic energies is shown in Fig. 2. The profiles of the perturbed pressure and kinetic energy on the horizontally elongated poloidal plane are shown in Fig. 3. The growth of the MHD instability can be seen from these figures.

3.4 *Mode Analysis of Instability*

Based on the equilibrium pressure and the magnetic field, the Boozer coordinates [6] is constructed by VMEC code [7]. The mode analysis has been done by use of this Boozer coordinates.

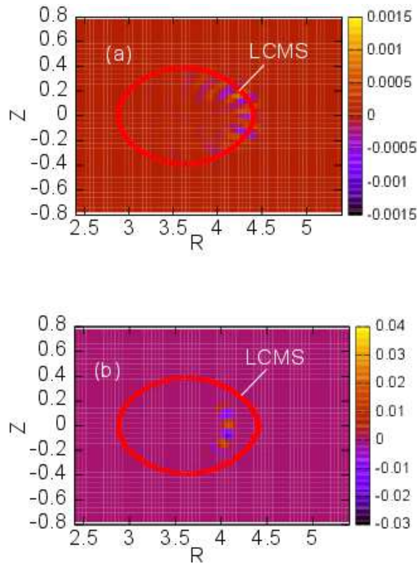

Fig. 3. The profiles of the (a) perturbed pressure and (b) kinetic energy on the horizontally elongated poloidal plane.

4. Summary

The linear MHD code based on the vector potential has been developed in order to satisfy the solenoidal condition for the magnetic field. The developed code has been applied to the LHD plasma and the instability analysis has been done.

We will discuss the detail of the developed code and the difference between our code and the existing codes in the conference.

Acknowledgments

The authors would like to thank Prof. S. Oikawa (Hokkaido Univ.) for fruitful discussions. A part of the numerical calculations in this paper is carried out in Plasma Simulator and LHD Numerical Analyses system.

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