Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Development of Vector Following Mesh Generator (VEGA); Improvement to Adapting General Magnetic Flux Configuration

J. G. Lee, Y.J. Kim, J. W. Park, M. G. Yoo, D. H. Na and Yong-Su Na*
Department of Nuclear Engineering, Seoul National University, Seoul, Korea

**Corresponding author: ysna@snu.ac.kr*

1. Introduction

High-mode (H-mode) scenario, which shows remarkably improved confinement of plasma comparing the low-mode (L-mode) [1], is regarded as a reference operation for International Thermonuclear Experimental Reactor (ITER) and other fusion experiments [2]. The plasma equilibrium can evolve significantly because of the L- to H-mode transition or occurring Edge-Localized Mode (ELM) on H-mode plasma pedestal region [3]. These evolved plasma equilibrium can make recognizable influences in plasma transport simulation results. For the above reasons, a field based adaptive mesh generator, VEctor-following Grid generator for Adaptive mesh (VEGA), was developed to cover the evolving magnetic field configuration [4].

The mesh created from VEGA covers the core-edge pedestal-SOL (Scrape-Off Layer) region. This mesh is aligned with the magnetic flux through vector following method, and is able to be distributed non-uniformly in space. From the listed properties and through combining plasma transport solver, VEGA has potential of turning into a time-varying mesh generator.

Nonetheless some limitations have been found. First, it limits the magnetic field configuration in tokamak plasma in 4 cases. However, since it is hard to sustain symmetry of magnetic field profile, another case should be included, disconnected double null (DDN) case. Next, because VEGA was coded in MATLAB, it performs relatively slowly and can be very cumbersome to operate with other Linux system based plasma simulation solvers.

Therefore, in this article, VEGA is modified to adjust itself more generally to the evolution of magnetic field, and to improve in availability and speed through code in C++ language.

2. Introduction of VEGA

In this section, the specifications of mesh and some of methodology used in VEGA are introduced.

2.1 Check Mesh Specifications

VEGA is designed for creating grids for 2-D plasma transport code in coupled core-edge pedestal-SOL region. Most of plasma solvers use Finite Volume Method (FVM) for the computational discretization domain. Therefore, resulting structural grid should include points that are as much as curvilinear and orthogonal in a control volume as shown in fig. 1.

The input is magnetic flux, ψ, data for each r, z uniform grid. First work in the generator is looking at this data script to define O point, the magnetic local maximum/minimum made by plasma current and X point, saddle point due to installation of divertor. Hence, the magnetic field configuration should be verified automatically in the mesh generator. In VEGA, bilinear interpolation method is used to search for null point through B = 0,

$$\begin{aligned} B_x^{00} + B_x^{10}x + B_x^{01}y + B_x^{11}xy &= \frac{\partial\psi}{\partial x} = 0 \\ B_y^{00} + B_y^{10}x + B_y^{01}y + B_y^{11}xy &= \frac{\partial\psi}{\partial y} = 0 \end{aligned} \qquad (1)$$

where $B_{x,y}^{ij}(i, j = 0,1)$ is the coefficient of bilinear interpolation. Then classification of the magnetic geometry is defined by the number of the verified the null point to X and O point. The possible magnetic field shapes are Lower/Upper Single Null (LSN/USN) and Connected Double Null (CDN) [5].

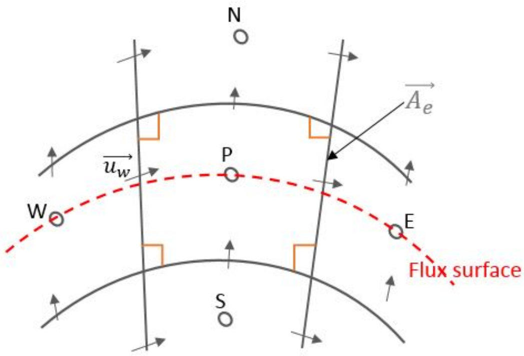

Fig. 1. Schematic cartoon for a control volume of FVM

2.2 Generate Mesh

In tokamak geometry, the poloidal magnetic field is represented by the equation of equilibrium magnetic flux as follow.

$$\vec{B}_{pol} = \frac{1}{2\pi}\nabla\varphi\times\nabla\psi \qquad (2)$$

Where $\vec{B}_{pol}$ is the poloidal magnetic field, φ and ψ are the magnetic flux function to the toroidal and poloidal direction, respectively. It implies that the magnetic flux lines can easily be obtained from the contour lines of ψ. Thus, in order to draw the magnetic flux contour lines, vector following method is used.

From a given point (e.g. X point), the direction vector is calculated by Runge-Kutta 4th order scheme. Then the point of equivalent value of ψ by linear interpolation from the input grid data is found. The separatrix line, which divides the core and SOL region, can be determined by this sequence.

The whole domain is covered by applying normal vector trace scheme, which is similar method to a vector following method. From the separatrix points, rotate the direction vector to normal, and search for certain poloidal magnetic flux value, until it contacts the boundary value.

2.3 Non-uniform Grid

For the object of plasma simulation, grid space should be distributed manually as user desires. VEGA has a stretching function as below, to make mesh as uniform or non-uniform.

$$s_i = \sum_{1}^{i-1}\left[\frac{2}{\exp(\phi)+\exp(-\phi)}\right]^E \Big/ \sum_{1}^{i-1}\left[\frac{2}{\exp(\phi)+\exp(-\phi)}\right]^E \quad (3)$$

Where,

$$\phi = \left[\frac{i-1}{N} - D\right] \times S \quad (4)$$

E (= 1, 0, -1) is the exponential parameter, S (>0) is the scale parameter, D called the deviation parameter and N is the number of certain grid line. The user can adjust the distribution of grid points as fig. 2

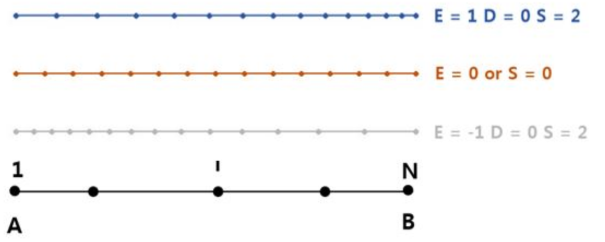

Fig. 2. Example of point distribution for each E, D, S case

2.4 Improvements

VEGA was developed for aiming mesh generator for time-varying 2-D plasma transport code. Therefore, the computational time and the flexibility of magnetic field configuration case are very important. Because VEGA was coded in MATLAB with divided configuration cases using several if sentences, it was slow (~5s) and limited in varying functions. Especially, it is hard to yield same value in both X points in double null case. Disconnected double null geometry should be more general during a magnetic field configuration evolution [5]. However, due to the difficulty from the listed reasons, DDN was suitable for VEGA.

To overcome the limitations from the above, VEGA has been coded in C++ and implanted with improved classification algorithm. It becomes faster (~330ms) and gives more general mesh, according to evolution magnetic field include DDN geometry.

3. Test Result

(Paragraph justified, not centered) In order to verify the modified code with the input equilibrium data produced by a free boundary MHD equilibrium code, Tokamak Equilibrium Solver (TES) [6]. The target poloidal magnetic fluxes are CDN and DDN cases of the Korea Superconducting Tokamak Advanced Research (KSTAR) plasma. The grid distribution parameters are shown in Table I below.

Domain	Core	SOL	Private
Node number	19 x 80	10 x 60	10 x 20
Preference	uniform	Non-uniform	Non-uniform
E, D, S	0, 0, 0	1, 0, 3	1, 0, 3

Table I: Reference grid distribution parameters for KSTAR connected double null (CDN) configuration

The grid points are located as the parameters from Table I. in Fig. 3, VEGA shows its capability to build mesh for DDN geometry.

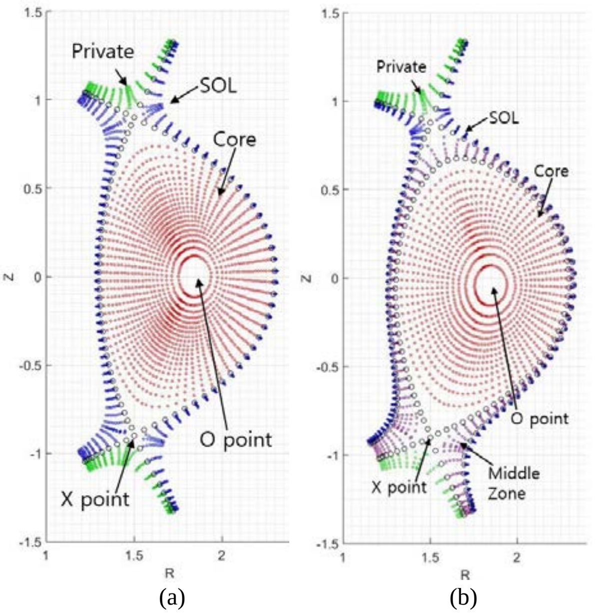

Fig. 3. Test grid applied for KSTAR (a) CDN case, (b) DDN case

4. Conclusions

As expecting improvements of plasma transport simulation in time-varying magnetic field, VEGA was developed for mesh generator. It weaves mesh keeping alignment to poloidal magnetic flux surface and orthogonality, by using vector following method and normal vector trace method. VEGA is modified to C++ language from MATLAB, to be able to embrace more broad and general magnetic configuration.

There are still several variables to couple VEGA with the 2-D plasma transport solver which is able to simulate the H-mode operation scenario (e.g. C2[7]), such as data re-allocating and defining data flow between each time step, in order to improve the quality of the study.

REFERENCES

[1] F. Wagner et al., “Regime of Improved Confinement and High Beta in Neutral-Beam-Heated Divertor Discharges of the ASDEX Tokamak”, Phys. Rev. Lett., 49, 1408 (1982)
[2] ITER Physics Expert Group on Confinement and Transport, ITER Physics Expert Group on Confinement Modelling and Database, and ITER Physics Basis Editors, “ITER Physics Basis”, Nucl. Fusion, 39, 2175 (1999)
[3] X. Bonnin et al.,"The Two-Mesh Grid Refinement Method for the B2 Code," Contrib. Plasma Phys. 42, (2002) 2-4, 175 (2002).
[4] Y.J. Kim et al., “Development of vector following mesh generator for analysis of two dimensional tokamak plasma transport” [Comput. Phys. Comm. 186 (2015) 31–38]
[5] R. Marchand and M. Dumberry, "CARRE: a quasi-orthogonal mesh generator for 2D edge plasma modeling," Com. Phys. Com., 96, 232-246 (1996).
[6] Y.M. Jeon, "Design of optimal position and shape controller based on perturbed equilibrium response model for tokamak plasmas," Ph.D. Dissertation, Seoul National University (2006).
[7] J.M. Park, "Integrated Simulation of Tokamak H=mode Operation by a Two-Dimensional Plasma Transport Code in Coupled Core-Edge Pedestal-SOL Region," Ph.D. Dissertation, Seoul National University (2005).