Development of vector following mesh generator for analysis of two-dimensional tokamak plasma transport

Younghun Kim a, Min-Gu Yoo a, S.H. Kim b, Yong-Su Na a,∗

a Department of Nuclear Engineering, Seoul National University, Seoul, Republic of Korea
b ITER Organization, Route de Vinon sur Verdon, 13067 St Paul lez Durance, France

ABSTRACT

A field-based new adaptive mesh generator, VEGA (VEctor-following Grid generator for Adaptive mesh), is developed for 2-D core–edge coupled tokamak plasma transport simulations. VEGA can generate time-varying and spatially non-uniform grids by using a stretching function. It provides two operation modes for generating non-uniform radial distributions. One is so-called ion mode where the grid is automatically generated by considering the ion temperature gradient which plays an important role in the ion and the momentum transport mechanism of a tokamak plasma. The other is so-called high-gradient mode where the grid is produced by considering the locality of plasma profiles which appears particularly in transport barriers. VEGA is benchmarked with a conventional code for a reference double null (DN) KSTAR divertor configuration. Three factors are newly introduced in this work to evaluate the quality of a grid. It is found that VEGA is particularly suitable for delicate integrated simulations of the plasma edge and the scrape off layer (SOL) due to its high cell orthogonality and low radial flux deviation. Quality of non-uniform grids generated by the two operation modes of VEGA, the ion mode and the high-gradient mode is examined. A more refined grid is found near the edge region characterized with steeper gradients whereas coarser one in the core region. Such fine grids at the edge region can result in highly reduced radial flux deviation, which is indeed important for analysis of edge–SOL physics with time-varying simulations.

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1. Introduction

A time-varying adaptive grid is required for multi-dimensional and time-dependent transport modeling of tokamak plasmas where the plasma equilibrium evolves in time in response to plasma transport [1] and also to currents flowing in the surrounding conducting structures [2]. In addition, a spatially inhomogeneous adaptive grid is needed for integrated transport modeling dealing with different spatial scales. In this context, various two-dimensional mesh generators [3–5] have been developed. They generate a logically rectangular curvilinear quadrilateral field-aligned grid for modeling. Once an orthogonal mesh is constructed, edge–SOL simulations are conducted onto a static grid to analyze the divertor and edge physics such as divertor heat load, detachment process, Edge Localized Modes (ELMs), Multifaceted Asymmetric Radiation From the Edge (MARFE) [6], and so on. For the adaptive grid generation, some mesh generators have been developed using two mesh refinement [1,7]. This method provides finer grids in regions of sharp gradients so to handle those regions more delicately. The structured fine mesh is converted into the unstructured mesh in this process.

However, most of the mesh generators available in present days focus only on the edge–scrape off layer (SOL) region due to difficulties in integrating the core and the edge region in terms of the topology and time scales. Moreover, they could face problems when dealing with situations where the plasma equilibrium evolves in time since the static mesh is generated only once and fixed during the rest of simulations [8]. The plasma equilibrium is rapidly varying especially in the edge region according to the change of plasma kinetic profiles associated with the confinement mode transition, neutral fueling, impurity seeding, auxiliary heating, and so on. Therefore, the mesh generator needs to be capable of dealing with a real plasma configuration by considering its time evolution for reliable two-dimensional modeling. For the above reasons, a new mesh generator named as VEGA (VEctor-following Grid generator for Adaptive mesh) is developed in...
this work which is capable of generating spatially non-uniform adaptive grids suitable for 2-D core–edge coupled time-dependent transport simulations.

The paper is organized as follows: Section 2 describes the numerical approach employed in VEGA. In Section 3, three grid quality factors are newly introduced and quality of the mesh generated by VEGA is evaluated by them. VEGA is benchmarked with other conventional code, CARRE. Non-uniform mesh generation by VEGA is addressed in Section 4. Finally, a summary and some concluding remarks are presented in Section 5.

2. Specifications of the numerical approach

Requirements of the mesh and the numerical approach employed in this work, such as the vector following method and non-uniform grid generation, are described in this section.

2.1. Mesh requirements

The code is developed to satisfy the following requirements necessary for solving the 2-D core–edge coupled plasma transport in a tokamak plasma.

- The developed mesh should provide a calculation domain for Finite Volume Method (FVM) discretization which can deal with the anisotropy of transport characteristics in a tokamak plasma.
- The grid should be aligned with the magnetic field and each grid should have curvilinear orthogonality in between, i.e. every grid point must be aligned with each local flux surface and each cell must be as rectangular as possible to be locally quasi-orthogonal.
- A non-uniform mesh generation suitable for addressing various plasma phenomena without requiring too much additional computational resources should be possible.
- Various magnetic configurations widely used in modern tokamaks should be tractable: Lower Single Null (LSN), Upper Single Null (USN) and (connected) Double Null (DN).

2.2. Vector following method

We adopt the structured mesh with an algebraic grid generation method. The algebraic method is preferable for generating adaptive grids due to its low computational effort [9]. The vector following method is used for the entire algebraic grid generation sequence in this code. The vector following method determines grid points with an interpolation method using direction vectors of the poloidal magnetic field since there are no exact transformation equations available in typical plasma configurations [10]. This method has advantages of producing the mesh more efficiently with accuracy and with applicability to arbitrary plasma configurations. In addition, the size of direction vectors is adjusted to allow weaker sensitivity in grid resolution than that of other grid-based interpolation methods [3,4].

The relation between the equilibrium magnetic flux surface and the poloidal magnetic field is represented as follows:

$$\vec{B}_{pol} = \frac{1}{2\pi} \nabla \psi \times \nabla \phi$$  \hspace{1cm} (1)

where \(\vec{B}_{pol}\) is the poloidal magnetic field, and \(\phi\) and \(\psi\) are the magnetic flux function to the toroidal and poloidal directions, respectively. This implies that magnetic flux surfaces can be simply obtained from contour lines of the poloidal magnetic flux function \(\psi\) and magnetic field lines having the same poloidal magnetic field lie on the same magnetic surface. Thus, an equal \(\psi\) surface and a gradient of \(\psi\) can be determined simply by following \(\vec{B}_{pol}\) and the normal direction to \(\vec{B}_{pol}\), respectively. The expressions of the poloidal magnetic field component are related to the derivative of \(\psi\) with respect to \(R\) and \(Z\):

$$B_R = -\frac{1}{R} \frac{\partial \psi}{\partial Z}, \quad B_Z = \frac{1}{R} \frac{\partial \psi}{\partial R}$$ \hspace{1cm} (2)

where \(B_R\) and \(B_Z\) are the poloidal magnetic field components to the radial (\(R\)) and vertical (\(Z\)) directions, respectively. In VEGA, the direction vector in a given poloidal magnetic field map is calculated by using the Runge–Kutta method which has 4th order accuracy of a grid size. This sequence is repeated until a grid point meets a boundary such as the divertor structure or the initial point after circulating on a constant \(\psi\) surface. However, this method cannot be applied to all regions. In particular, in regions near the divertor plate or the X-point, it leads to a tangled mesh which can produce significant errors in calculating the transport equations. To resolve this problem, two constraints are additionally given as below.

1. If a grid point gets too close to a divertor plate (lower than \(\epsilon\)), a direction vector is forced not to be normal (dashed circle in Fig. 1(a)) to the previous position but to be parallel to the divertor plate (red solid circle in Fig. 1(a)).

2. If any two neighboring points place too close to each other (dashed circles in Fig. 1(b)), their positions are adjusted to have better poloidal separation (red solid circles in Fig. 1(b)). The direction vector is newly calculated to be normal to the next magnetic surface (blue dashed line in Fig. 1(b)). This constraint is commonly used nearby the X-point where the radius of the curvature is large.

The vector following sequence used in this work is shown in Fig. 2.
2.3. Non-uniform grid generation for time-dependent tokamak discharge simulations

A plasma boundary is first defined to identify the plasma configuration by the vector following method. After this, the grid distribution is conducted for the various simulation purposes. VEGA is designed to be capable of generating the mesh automatically at each time step for time-dependent tokamak discharge simulations by avoiding manual setting of the code at each time step. Moreover, it can generate spatially non-uniform adaptive grids suitable for sophisticated 2-D core–edge coupled transport simulations. Stretching functions are employed in VEGA to deal with this non-uniform grid distribution [11]. Especially the radial distribution in the core–edge region is treated in two ways. One is so-called ion mode where the grid is automatically generated by considering the ion temperature gradient which plays an important role in the ion and the momentum transport mechanism of a tokamak plasma. The other is so-called high-gradient mode where the grid is produced by considering the locality of plasma profiles which appears particularly in transport barriers. Details of the stretching function and the two non-uniform distribution modes are described below.

Stretching function

The stretching functions use several deviation parameters, $E$, $D$, and $S$, to distribute computational nodes along the magnetic surface (including the separatrix) as well as the plasma radius.

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

where $s_i$ is the relative location with $i$ the label of one point. $N$ is the total number of points along the separatrix line or the magnetic flux surface and $E (\equiv (-1, 0, 1)$ is the deviation parameter which determines the characteristic of the distribution: contraction to a point, repulsion from a point, or uniformity. The deviation parameter ($D$) provides the relative location of this point. $S (> 0)$ is the parameter to control the degree of stretching. After setting the distribution parameters, grid spacing of the poloidal and the radial direction is determined individually.

Ion mode

The length scale of the ion and the momentum transport [12–14] is mainly correlated with the ion temperature gradient. As it varies from the core to the edge of the plasma, it is useful to distribute grids in the radial direction taking the ion temperature gradient into account. Therefore, if an ion temperature profile is given from a transport solver, the radial grid can be reallocated automatically to have similar gradient length scale for the given temperature variation. The example is shown in Fig. 3. In this context, we named this type of the non-uniform grid generation as ion mode. The grid size in the real space ($R, Z$ coordinate) can be correlated with the ion temperature as follows:

$$\Delta r \sim \frac{\Delta T_{ref}}{VT} \Delta T_{ref} = \frac{\Delta T_{tot}}{N}$$ (5)

where $\Delta T_{tot}$ is the difference in the ion temperature between at a certain flux surface in the core region and at the separatrix. $VT$ is the ion temperature gradient and $N$ is the node number. $\Delta r$ is the grid spacing that varies according to $VT$, more refined grid at a large ion temperature gradient region and coarser one at a small gradient region.

High-gradient mode

The plasma transport sometimes results in highly localized phenomena. For example, the temperature and the density profiles have steep gradients at the edge region of H-mode plasmas, so-called the edge pedestal, whose characteristics largely determine global confinement of the plasma. In this case, domain decomposition is useful for more specific analysis of the steep gradient regions. The core grid distribution can be divided into two domains at a separating position ($\rho_s$) of the normalized magnetic flux coordinate ($0 < \rho < 1$) where $s$ implies separation. Grid points in the separated domains can be generated independently using the stretching function. For example, if $\rho_s = 0.95$ is selected as the pedestal top position in an H-mode plasma, the core region ($\rho_s < 0.95$) can have sparser grid distribution; on the contrary the pedestal region can have finer distribution so to address detailed edge physics. This type of non-uniform distribution is named as high-gradient mode. This mode of VEGA can automatically generate the non-uniform mesh each time step of transport simulations if the location of the domain separation point is either given or evaluated using a physics-based model.

3. 2-D core–edge mesh generation using VEGA

An initial equilibrium data provided by a free boundary magnetohydrodynamics (MHD) equilibrium code, Tokamak Equilibrium Solver (TES) [15] is used to investigate the performance of the developed code. TES calculates the 2-D distribution of the poloidal
magnetic flux, $\psi(R,Z)$ by solving the Grad–Shafranov equation. Various target equilibria can be selected such as an LSN, a USN, and a DN configuration but a DN KSTAR configuration is only used in this work. The real divertor geometry is also taken into account to determine the boundary of the separatrix and the SOL region. Non-uniform grids are generated for the initial distribution by considering the fact that the gradient of plasma variables becomes larger approaching boundary regions such as the divertor plate, the separatrix, and the X-point. The reference mesh for the DN configuration is shown in Fig. 4 where the number in each region indicates each domain of the plasma as defined in Table 1. This distribution is called as uniform mode for comparison of other grid distribution methods. The grid distribution parameters of the stretching function determining the non-uniformity are also presented for both poloidal ($X$) and radial ($\Psi$) directions of each domain in the table.

### Table 1
Reference grid distribution parameters of the stretching function at each region of the KSTAR Double Null (DN) configuration.

<table>
<thead>
<tr>
<th>Region</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Outer SOL</td>
<td>Upper private</td>
<td>Inner SOL</td>
<td>Lower private</td>
<td>Core</td>
</tr>
<tr>
<td>Node Number $(X, \Psi)$</td>
<td>$79 \times 10$</td>
<td>$29 \times 10$</td>
<td>$59 \times 10$</td>
<td>$29 \times 10$</td>
<td>$81 \times 20$</td>
</tr>
<tr>
<td>$E(X, \Psi)$</td>
<td>$1, -1$</td>
<td>$1, -1$</td>
<td>$1, -1$</td>
<td>$0, -1$</td>
<td>$0, 0$</td>
</tr>
<tr>
<td>$D(X, \Psi)$</td>
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<td>$0, 0$</td>
<td>$0, 0$</td>
<td>$0, 0$</td>
<td>$0, 0$</td>
</tr>
<tr>
<td>$S(X, \Psi)$</td>
<td>$3, 2$</td>
<td>$3, 2$</td>
<td>$3, 2$</td>
<td>$3, 2$</td>
<td>$0, 0$</td>
</tr>
</tbody>
</table>

### 3.1. Grid quality factors

For evaluation of a created mesh, several mesh grid factors are newly introduced in this work for the FVM method. The FVM equations have to follow the flux conservation theorem [16]; however, the generated mesh can slightly violate it in each calculation domain. If a deviation from an ideal mesh shape is high, one cannot guarantee numerical accuracy and stability in simulations. Fig. 5 shows the schematic diagram of a control volume of FVM and its deviations. In the FVM method, the radial transport is assumed to be onto an ideal rectangular shape (red dot points in Fig. 5). But the real control volume of the mesh does not fully satisfy the orthogonal relations so that the plasma parameters such as the plasma density and the temperature are calculated at the wrong position (black open circles in Fig. 5). To evaluate the amount of the deviations in quantitative ways, three grid quality factors are newly introduced as below.

#### Standard deviation of average flux surface

This factor is derived from the concept of field alignment. Fig. 5 presents an example of field misalignment where the cell centers, W, P, and E are not aligned with the flux surface indicated by the horizontal dashed line. To test if the grid points are located on the same flux surface, the poloidal flux value ($\psi$) in each cell center can be scanned poloidally following the cells aligned along the same flux label. After the poloidal scan, an average value of $\psi$ and a standard deviation of $\psi$ from the average are obtained.

#### Cell orthogonality

Local quasi-orthogonality secures geometrical quality of a grid which is closely related to the rectangular shape. Thus, the cell orthogonality can be examined by the degree of deviation from a rectangular shape defined as follows:

$$
\sigma_{\text{orthogonality}} = \sqrt{(90 - \alpha)^2 + (90 - \beta)^2 + (90 - \gamma)^2 + (90 - \delta)^2}.
$$

In general, an algebraic mesh does not ensure mesh smoothness and uniformity, which implies that if the cell orthogonality factor in Eq. (6) is highly peaked at some points, numerical instabilities are possible to arise there.

#### Radial flux deviation

In the FVM method, all radial fluxes at each cell are assumed to be normal to the local flux surface. However, this can be locally violated in a grid. An example of possible radial flux deviations where the bottom and the top surface of each cell are not parallel to the flux surfaces is also shown in Fig. 5. To minimize this deviation, the radial flux vector at every cell must point the center of the next cell. In this sense, a measure of the radial flux deviation can be defined as follows:

$$
\text{Radial flux deviation} = d / A_n.
$$

Fig. 4. The reference mesh of a KSTAR DN configuration. The number in each region indicates each domain of the plasma as defined in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 5. Schematic diagram of a control volume of FVM and its deviation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
3.2. Benchmarking with the CARRE code

A well-known 2-D mesh generating code mainly used for edge-divertor plasma simulations, CARRE [3], is chosen to benchmark the developed code. The reference equilibrium is chosen to be the reference KSTAR DN configuration. The node number and the grid distribution are set to be the same for both codes in the entire calculation domains as described in Table 1. Here, VEGA is operated in the uniform mode for direct comparisons with CARRE. First, averaged values of the grid quality factors are evaluated for both codes in the overall region to evaluate the global mesh performance. Second, the radial flux deviation factor at the separatrix is compared as a measure of the local grid quality because the characteristic of the edge plasma physics and the SOL physics can be separated at the separatrix.

Comparison of the global mesh quality

Fig. 6 shows the total averaged value of the each quality factors defined in Section 3.1 for both codes. Qualitative similarities appear in every region for all the quality factors. In particular, the standard deviation of \( \psi \) is nearly the same between the codes as presented in Fig. 6(c). However, a difference is observed in the private regions (region 2, 4) as shown in Fig. 5(a) and (b) where VEGA exhibits relatively higher mesh qualities compared with CARRE.

The quality factors of cell orthogonality and radial flux deviation are checked in the private regions (region 2, 4) where they exhibit large differences along the radial and the poloidal directions, respectively to investigate the origin of the difference between the two codes in more detail. In the radial direction, the largest differences appear near the boundary surfaces (see Fig. 7(a)); the separatrix and the last flux surface at the private region. As CARRE is designed to adjust flux surfaces near the separatrix to be similar with the separatrix line, this different treatment of field line shapes between the separatrix and the boundary layer could result in lower cell orthogonality and higher radial flux deviations than VEGA. In the poloidal direction in Fig. 7(b), a peak is observed at the X-point in both codes. The peak at the X-point is a global tendency since generating a constructed mesh is not guaranteed to have a perfect orthogonal shape due to the X-point constraint to prevent an entangled mesh. This drastic radial curvature variation near the X-point mainly results in breaking of orthogonality. This large deviation is expected to affect the divertor simulation results significantly such as the divertor heat load and the detachment process [17] since SOL–private regions exhibit large gradients in the ion temperature, the neutral density, and so on. Another peak is observed only in CARRE near the outer divertor plate. As shown, the largest difference occurs in the vicinity of the boundary layer. Especially, peaks in the radial flux deviation and the cell orthogonality appear near the X-point, which could play a source of numerical errors in transport simulations.

Comparison of the grid quality at the separatrix

As for comparison of local grid qualities at the separatrix, the boundary which separates the edge plasma physics and the SOL physics where the atomic physics comes into play is selected for comparison of the two codes. Fig. 8(a) shows the radial flux deviation along the poloidal direction where the largest difference appears at the outer divertor plate between the two codes. This is related with differences in the constraint condition. The radial flux deviation at the core separatrix is also more improved when using VEGA. In general, edge–SOL–private regions are not homogeneous along the poloidal direction; hence the radial flux conservation is more important to distinct the parallel and the perpendicular
Fig. 8. Radial flux deviations at each separatrix lines along the poloidal direction: (a) divertor separatrix and (b) core separatrix from VEGA (red) and CARRE (blue) code. The red ‘X’ indicated on abscissa refers the X-point. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 9. The prescribed radial ion temperature profile for non-uniform distribution of ion mode.

transport. In this context, VEGA would provide a more precise domain for simulations of various boundary phenomena such as ELMs, MARFE, and inward pinch of neutral particles [18].

4. Performance of radially non-uniform grid generation with VEGA

The mesh distribution at the core can be varied depending on the operation mode of VEGA as mentioned in Section 2.3; uniform distribution (uniform mode), automatic non-uniform distribution at each time step according to the ion temperature gradient (ion mode), and manual non-uniform distribution by specifying a high gradient region (high-gradient mode). In this section, non-uniform meshes generated by the ion mode and the high-gradient mode are evaluated with the quality factors and compared with the uniform distribution with the same number of the radial node. Here, the high-gradient mode is designed to have refined grids at the edge and coarse ones at the core so to allow more sophisticated analysis of the edge region.

In ion mode, the radial distribution of the mesh can be updated with the transport time scale based on the ion temperature profile obtained from the plasma transport solver. The ion temperature profile, $T_i(r)$, is prescribed as below to examine the quality of the mesh generated with the ion mode.

$$T_i(R) = -\alpha R^\beta + \gamma, \quad R_n = \frac{R - R_b}{R_a - R_b}$$  \hspace{1cm} (8)

where $R_b$ and $R_a$ are the radial position of the magnetic axis and of the separatrix at the outer mid plane, respectively which can be determined during the process of field null seeking. $\alpha$, $\beta$, and $\gamma$ are shape parameters which are set to be $\alpha = 2900$, $\beta = 3$, and $\gamma = 3000$ in this work. The prescribed ion temperature profile is shown in Fig. 9.

**High-gradient mode**

In high-gradient mode, regions requiring high resolution of the grid are specified. In this work, the separating point is selected as $\rho_s = 0.95$, the pedestal top in an H-mode plasma, so that more fine grids are assigned to the region around and outer the separating point and coarser ones to the rest using the stretching function. Consequently, the grid quality factors are expected to be more improved at the edge region but degenerated at the core region, a trade-off as fixing the total grid number. The grid distribution information is described in Table 2.

**Comparison with the reference uniform distribution**

Fig. 10 presents the core grid distributions produced by the uniform mode, the ion mode, and the high-gradient mode of VEGA. First, an average of radial flux deviations is compared at the core region. The total average radial flux deviations in the core region look similar but they are globally reduced at the separatrix in both non-uniform distributions. Especially the high-gradient mode shows about 11 times much smaller values than that of the uniform mode as shown in Fig. 11(a). Second, the radial flux deviations are compared by a poloidal scan at the core separatrix. As shown in Fig. 11(b), a peak point of the radial flux deviation at the X-points are highly relaxed in the non-uniform distribution due to the low grid spacing near the separatrix. The high-gradient mode stands out in reducing the X-point peaking that comes from the separating point of $\rho_s = 0.95$. Therefore, radial transport in the high gradient mode could be highly improved by grid refinement, which ensures that the boundary physics could be solved more accurately. The peaking point in the ion mode is also reduced where the ion temperature is sharply varying (see Fig. 9). Since the ion temperature gradient near the separatrix line is much greater than the core region, the step size of the ion radial transport becomes smaller as approaching the separatrix. Thus, according to the correlation of the ion and the momentum transport with the ion temperature gradient, the grid size is adapted for appropriate spatial scales in transport simulations.

<table>
<thead>
<tr>
<th>Table 2 Grid distribution of high-gradient mode.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Main core</td>
</tr>
<tr>
<td>Edge</td>
</tr>
</tbody>
</table>
5. Conclusions

A field aligned quasi-orthogonal structured mesh generator, VEGA (VEctor-following Grid generator for Adaptive mesh), is developed using a vector following method based on a poloidal magnetic field line. VEGA is designed to deal with automatic generation of a mesh at each time step for time-dependent simulations by avoiding manual setting of the code at each time step. Therefore, it is able to reallocate the grid distribution according to evolution of the plasma equilibrium in time. Moreover, it can generate radially non-uniform adaptive grids suitable for sophisticated 2-D core–edge coupled transport simulations using a stretching function. The non-uniform radial distribution is treated in two ways in VEGA. One is so-called ion mode where the grid is automatically generated by considering the ion temperature gradient which plays an important role in the ion and the momentum transport mechanism of a tokamak plasma. The other is so-called high-gradient mode where the grid produced by considering the locality of plasma profiles which appears particularly in transport barriers.

VEGA is benchmarked with CARRE for a reference double null (DN) KSTAR divertor configuration. To evaluate quality of the generated mesh suitable for the FVM method in quantitative ways, three grid quality factors are newly introduced. They examine how well the generated grid satisfies the flux conservation criteria, the field alignment, the cell orthogonality, and minimization of the radial flux deviation. The comparison between VEGA and CARRE exhibits that the field alignment is nearly the same; on the other hand, the cell orthogonality and the radial flux deviation are found to be more improved at the private regions when VEGA is used. This difference mainly comes from near the divertor region. Especially, the radial flux deviation crossing the separatrix lines is much relieved in VEGA than CARRE.

Quality of non-uniform grids generated by the two operation modes of VEGA, the ion mode and the high-gradient mode is evaluated for the KSTAR DN configuration. They are compared with the reference uniform distribution. The non-uniform grid distributions from the two modes show more refined grids near the edge region whereas coarser one in the core region. In particular, the highest refined grid is generated in the high-gradient mode at the edge region due to the local steep gradient there. Both the cell orthogonality and the radial flux deviation are turned out to be improved since the non-orthogonality and the radial flux deviation at the X-point are highly reduced. The radial flux deviation at the core separatrix lines which play an important role as a boundary is also largely reduced, which is desirable for analysis of the edge–SOL transport.

Note that the vector following mesh generator developed in this work have several things still to be improved. Plasma configurations are yet restricted for only divertor configurations. This code will be further developed to handle the limiter configuration in the future. Coupling VEGA with a time-dependent transport solver will also be a subject of future research. The C2 code [8] which solves 2-D radial transport at entire core–edge–SOL regions is a potential candidate for the work. This newly developed mesh generator, VEGA, is envisaged to contribute to enhance understanding of outstanding core–edge–SOL coupled phenomena in
magnetic fusion plasmas such as L- to H-mode transition, ELMs, MARFE, etc.

References