Numerical grid matching for Coupling SOLPS-ITER and NEO

Sungpil Yum, Kyu Been Kwon and Eisung Yoon*
Department of Nuclear Engineering, UNIST, Ulsan
**Corresponding author: esyoon@unist.ac.kr*

1. Introduction

High temperature is one of the key components to achieve a high fusion reaction rate in the core plasma of nuclear fusion reactors. The insulation quality of the magnetically confined plasma is measured by τ_E, which can be affected by the bremsstrahlung radiation. In that regard, impurities in the core plasma must be removed to avoid contamination since the bremsstrahlung radiation is proportional to the square of the atomic number of plasma ions ($Z_i = 1$ for hydrogen plasmas).

The divertor concept plays a fundamental role in the design of modern tokamaks. It facilitates power exhaust, helps control impurities in the main plasma, and removes He ash, which is a byproduct of the fusion reaction. Its importance cannot be overstated in achieving successful and efficient fusion reactions [1]. Designing sophisticated shapes of the divertor is essential for operating the Tokamak device, as it is known that a significant heat load burdens the relatively small divertor target surface due to the bombardment of particles passing along the flux surface in the Scrape-Off-Layer (SOL) [2].

The SOLPS-ITER code [3] has been widely utilized for designing the divertor and simulating plasma in the SOL regions. However, the input parameters for SOLPS-ITER are retrieved from experimental data of the plasma states in the core region, with certain approximations, such as the total electron/ion heat flux density and total particle flux density. By implementing simulation results from core plasma simulations, such as NEO, as input parameters for SOLPS-ITER instead of approximations, it is anticipated that SOLPS-ITER's calculations result will be more realistic.

In this study, a preliminary investigation was conducted to lay the groundwork for coupling SOLPS-ITER as a simulation code for Edge-SOL plasma and NEO as a simulation code for core plasma. In particular, the numerical grids of both simulations were matched iteratively to fit the mesh for integrated codes.

2. Methods and Results

In this section, we explain how the numerical meshes for SOLPS-ITER and NEO are created and matched to fit together.

2.1 Numerical mesh of SOLPS-ITER

SOLPS-ITER is a packaged integrated code that couples the plasma fluid simulation code, B2.5, and the neutral partial simulation code, Eirene. The different meshes used by each code require SOLPS-ITER to generate two types of meshes using the *Carre* and *Triang* modules. The meshes are aligned with the magnetic field lines, necessitating the use of flux surface contour lines based on magnetic equilibrium as guidance. The resulting meshes on the 2D poloidal cross-section of tokamak geometry are visually depicted in Fig. 1.

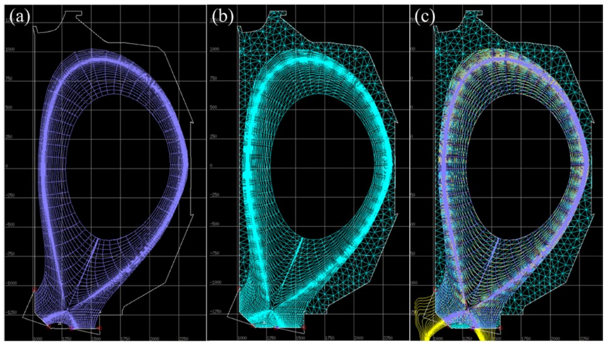

Fig. 1. SOLPS-ITER's numerical mesh from a sample magnetic equilibrium data, (a) square mesh for B2.5, (b) triangle mesh for Eirene, and (c) overwrapping square and triangle meshes with flux surface line(yellow solid lines) as guidance.
**Drawn by GUI of DivGeo module*

The yellow lines beneath the green and blue meshes represent the flux surface contour lines, which serve as a guide for mesh generation. As shown, the meshes for the SOL and core regions are square for B2.5, while those outside the SOL region are composed of triangle meshes only. A noteworthy aspect is that the square and triangle meshes in the SOL and core regions share the same vertex points, as neutral and ionized particles are assumed to coexist in those regions. Meanwhile, SOLPS-ITER assumes that neutral particles solely exist outside the SOL region.

2.2 Numerical mesh of NEO

NEO [4] is a plasma simulation code that solves the neoclassical transport equation in the core plasma region. Similar to SOLPS-ITER, NEO also utilizes a numerical mesh generated along the flux surface line. As a result, SOLPS-ITER's innermost meshes and NEO's outermost meshes can share a common flux surface for their meshes.

Once the numerical meshes of NEO are generated from the magnetic equilibrium data, the mesh information is expressed in the form of plasma shape parameters, as outlined below [5].

$$R(r,\theta) = R_0(r) + r\cos\theta_R,$$
$$Z(r,\theta) = Z_0(r) + \kappa(r) r \sin\theta,$$

where the harmonic angle θ_R is

$$\theta_R = \theta + c_0(r) + \sum_{n=1}^{3}[c_n(r)\cos n\theta + s_n(r)\sin n\theta].$$

The equation presented above involves shape parameters as anti-symmetric moments denoted by c_n, symmetric moments denoted by s_n, and elongation by κ. R_0, r, and Z_0 are major radius, minor radius, and elevation, respectively. When characterizing the shape of a plasma, the harmonic angle θ_R is used to combine parameters and express the plasma shape in terms of closed contours on a 2D plane defined by the $R(r,\theta)$ and $Z(r,\theta)$ coordinates. These coordinates represent the major radius and height, respectively. This approach offers a rigorous and precise method for describing the shape of a plasma. The resulting meshes of NEO for the 2D poloidal cross section of tokamak geometry are illustrated below.

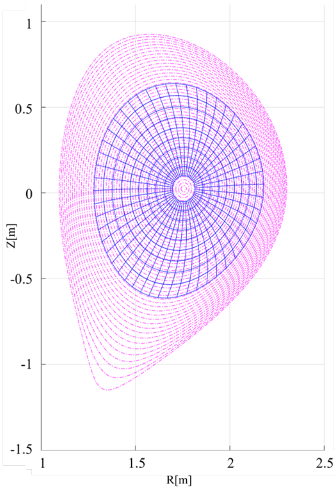

Fig. 2. A NEO's numerical mesh using sample magnetic equilibrium data. The magenta dashed lines represent the flux surfaces, and the blue solid lines represent the meshes.

2.3 Mesh matching technics

The numerical meshes of SOLPS-ITER and NEO are generated based on the same flux surface derived from magnetic equilibrium data. This enables the meshes to be utilized for interpolating plasma parameters between the codes on the meshes. Both codes can share the same flux surface for their vertex points, which enables them to generate meshes that are compatible with each other. A schematic representation of the workflow for mesh generation between the two codes is presented below:

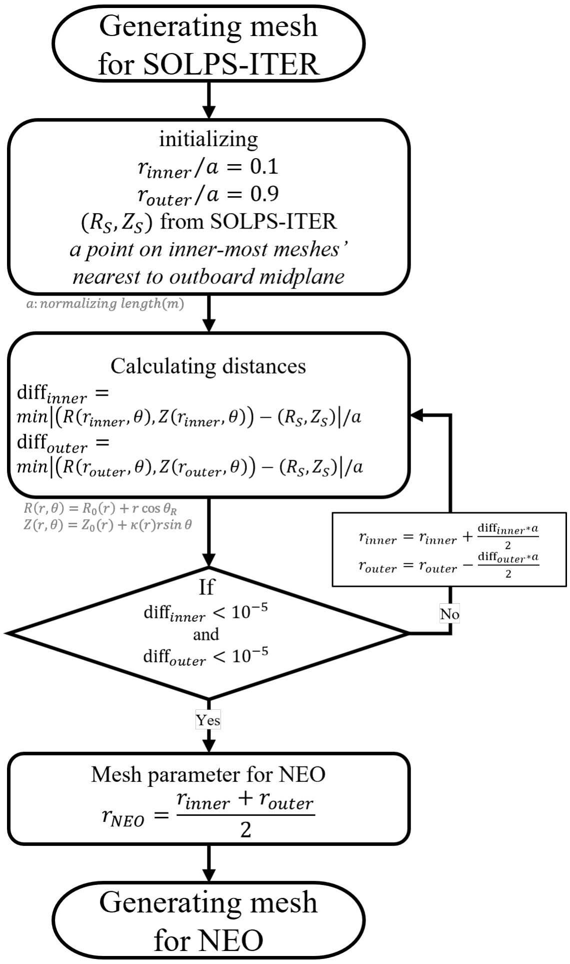

Fig. 3. Workflow of computing r_{NEO}

In the case of SOLPS-ITER, manual modification of mesh parameters such as the number of poloidal and radial grid points, and the location of the innermost flux surface is required when generating numerical meshes. After establishing these mesh parameters in SOLPS-ITER, NEO uses the minor radius of the innermost flux surface as an input to generate its own meshes. The computation of the minor radius on the outboard midplane for NEO is shown in the following steps:

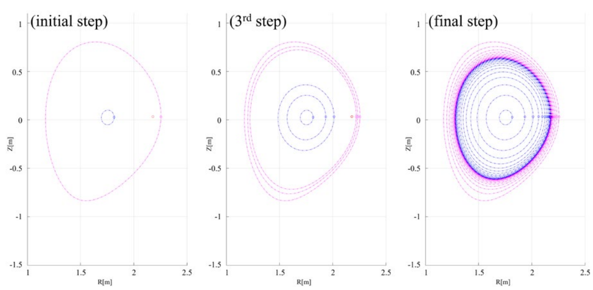

Fig. 4. Processes of the method to find r_{NEO}. The red circle is target point retrieved from SOLPS-ITER, and the blue, magenta circles are r_{inner}, r_{outer} respectively.

2.4 Result of simulation with modified meshes

The methodology described in section 2.3 was implemented using a sample magnetic equilibrium file(geqdsk) for both SOLPS-ITER and NEO. The resulting meshes are presented in Fig. 5 where the minor radius for generating the NEO mesh was computed through the method described above with a numerical tolerance of 10^{-5}.

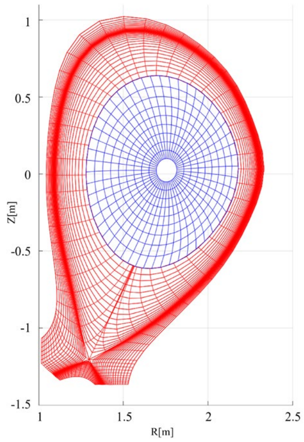

Fig. 5. Numerical mesh matching between SOLPS-ITER (red solid line) and NEO (blue solid line).

3. Conclusions

This study aimed to investigate the mesh compatibility between SOLPS-ITER and NEO, and to demonstrate matching the numerical meshes of both codes as a preliminary step towards code coupling. By computing minor radius on outboard midplane, data transfer between codes can be performed on the meshes along the same flux surface. Further work will explore the plasma parameters that can couple SOLPS-ITER and NEO codes.

Acknowledgements

This work was supported by the National Research Foundation of Korea(NRF) funded by the Korea government. (Ministry of Science and ICT) (RS-2022-00155991)

REFERENCES

[1] D. Düchs et al, On the impurity problem in quasi steady-state toroidal plasma experiments and fusion reactors, Journal of Nuclear Materials, Vol. 53, pp. 102-106, 1974.
[2] P. Norajitra, Divertor Development for a Future Fusion Power Plant, KIT Scientific Publishing, pp. 10-14, 2011.
[3] S. Wiesen et al, The new SOLPS-ITER code package, Journal of Nuclear Materials, Vol. 463, pp. 480-484, 2015.
[4] E.A. Belli and J. Candy, Full linearized Fokker–Planck collisions in neoclassical transport simulations, Plasma Physics and Controlled Fusion, Vol. 54, No. 1, 2011.
[5] J. Candy and E.A. Belli, GYRO Technical Guide, General Atomics Technical Report, 2010.