AUTOMATED MESH PRODUCTION FOR LIMITER WENDELSTEIN-7X CONFIGURATION

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A tool for automated mesh production for 3D multifluid plasma transport code Findif is presented. Mesh points for the code lie on magnetic field lines, which, in general, form a complicated tangle. Open field lines that end on solid parts of the machine are the source of difficulties. These lines are usually short and thousands of them are needed. A tool that helps to pick lines for the mesh that is described in this paper is based on calculation the distances of lines already admitted to the mesh and candidate ones. The results of the code run for the limiter configuration (OP-1.1 experimental phase) of the Wendelstein-7X device are shown here. Reasonably even coverage of space by points is achieved.

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INTRODUCTION

Simulations of plasma in magnetic confinement fusion devices need to address the issue of very strong anisotropy of heat and particle transport in the directions parallel and perpendicular to the magnetic field ***B*** lines. The common approach is to use a so called field-align mesh, so as to minimise numerical cross-field diffusion. The 3-dimensional multifluid code Findif runs on such field-align meshes. They used to be prepared manually which, with rising vessel and ***B*** field complication, was getting increasingly tedious and time-consuming. It prevented considering many magnetic configurations or wide application to different devices.

The main purpose the 3-dimensional multifluid code Findif is designed for are transport simulations of scrape-off layer (SOL) of fusion devices. Indeed, it is SOL, where due to sufficient collisionality, fluid simulations of the plasma are valid. The code calculates gradients using finite difference scheme. The parallel transport is assumed to be classical, governed by Braginskii equations, while the perpendicular one is taken to be anomalous, parametrised by anomalous diffusion coefficient. All of the equations are discretised in field-aligned local coordinate systems. The mesh is irregular; a "free point method" is used for derivative calculation. The code has been used in dynamic ergodic divertor simulations in the TEXTOR tokamak [1] and initial calculations for the Wendelstein-7X stellarator [2].

The level of complication of possible magnetic field configurations can be appreciated from Fig. 1, where a sample magnetic field for future Wendelstein runs is pictured (closed lines only).

The Findif mesh consists of points that result from crossing of a set of fixed-toroidal-angle half-planes by chosen field lines. In our calculations pictured on Figs. 2-4 we choose to have 40 such half-planes ("cuts" or "Poincaré plots" as they are called in the literature); so, we have cuts every 0.05 π toroidally. Additionally, there is a small group of points where (open) lines hit solid structures. Those points only sometimes not lie on the cuts.

The distances between nearest mesh points on the same cut are normally much smaller then between the cuts, which reflects the anisotropy of transport coefficients. Strong transport along the field lines smoothes out the profiles and flattens the gradients. Weak perpendicular ("on a cut") transport allows steep gradients (of temperature, density…) to develop. We need a dense mesh to be able to resolve the gradients.

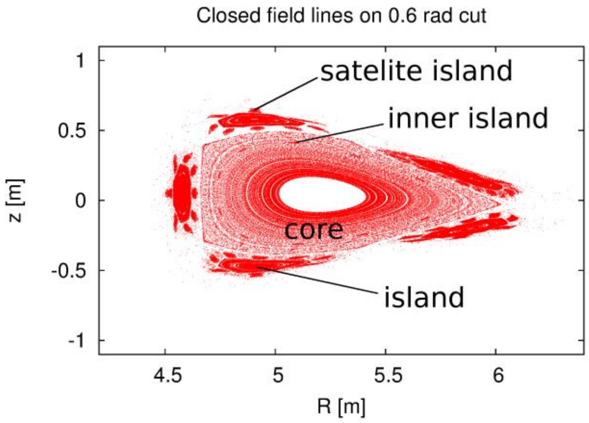

Fig. 1. Closed field lines as points on a fixed-toroidal-angle cut (each time a line crosses the cut a point appears). The positions are parametrised by radial R and vertical z cylindrical coordinates

It is feasible, but time-consuming to produce proper meshes by hand, as it used to be done earlier. All-manual approach takes disagreeably much time, however, if good spacial resolution is required, or complicated cases of underlying ***B*** fields are considered.

1. THE PROCEDURE OF COMPUTER-ASSISTED MESH GENERATION

There are distinct regions of ordered, nested magnetic surfaces like the core and islands (see Fig. 1). That area can be covered by points generated by few lines crossing a cut. The lines can well be hand-picked (so it has been done by us). The rest of the area is where the lines are open (connect first wall elements) or ergodic (closed but do not lie on nested magnetic surfaces).

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Open and ergodic field lines need to be picked in such a way that a few conditions are attempted to be met: 1) no lines (short or long) are favoured, 2) solid structures are sufficiently covered, 3) points are locally equidistant.

Ad 1. Lines of different length should feature in the mesh as often as they appear in the real device, due to different contributions to the total transport they can make.

Ad 2. Solid structures are where the energy streaming with plasma is eventually deposited. Also impurities, sputtered or otherwise released, enter plasma just at the plasma – first wall interface. There must be many enough points to allow plausible estimation of mentioned phenomena. Only those patches where $\boldsymbol{B}$ field lines are parallel to the solid structures can be sparsely covered, because heat loads and there are expected to be much smaller. Indeed, most of the transport is parallel to the field lines.

Ad 3.Points should be (locally) as equidistant as possible, to improve the accuracy of gradients and Hessian computations. Mimicking the practical realisation of magnetic surface average calculations in [3], where that average is approximated by appropriate $\boldsymbol{B}$ field line average with a weighting factor $1/B$, we assume that ideal distance between closes neighbours should be proportional to the local value of $1/B$.

Our open-line-picking procedure consists of several steps:

1) $\boldsymbol{B}$ field lines tracing partially starts from random locations in the torus but also specifically from the first wall elements. The lines are traced until they close on themselves (come close enough to the starting point) or hit some solid structure.

2) A minimal number of lines starting from the first wall elements are admitted to the mesh – they provide a minimal coverage of the structures.

3) More lines are picked in an iterative procedure. Each candidate line distance l_i from the lines already chosen is evaluated. Currently used procedure: for each cut the line i produces points if it crosses this cut. Calculate the $1/B$ weighted distances of those point(s) to the points produces by the lines already chosen. Take the shortest distance on the cut. Take the shortest of all cuts, call it l_i.

For some $x>1$, $a\geq 0$ (fixed during calculations) a line j is an acceptable candidate if $1/l_j < a + x * 1/(\min_i l_i)$. Then one of the acceptable candidates is picked at random (the likelihood of being picked is proportional to the length of the line concerned).

4) The procedure in 3) is repeated, until the expected number of points in the mesh is reached.

It is always a potential danger that long or short lines might be disadvantaged. Long – because they can pass unacceptably close to already-admitted lines in one of many points, short – have less chances in random-pick step. This point deserves attention and possibly some adjustments of code parameters during future mesh generations.

2. THE OP-1.1 MESH PRODUCED

The algorithm presented above was coded and the resulting program was run for an instance of a OP-1.1 W-7X magnetic configuration. The limiters installed for the OP-1.1 phase are thrust deep into what would otherwise be a large core plasma region. Many magnetic field lines that would otherwise be closed, where opened by the limiter surface. It is to be expected that the vast majority of the heat flux should be deposited on the limiter. We therefore added an “artificial wall” to limit the simulation space. The volume directly connected to the limiter by the field lines is the part of the SOL where most of the heat flow should occur. A thin, outermost part of the region core was also included. The mesh is plotted in the Fig. 2.

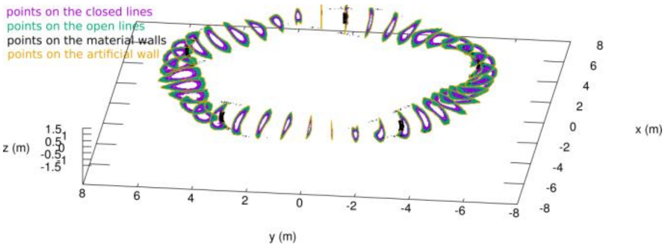

Fig. 2. Overview of the mesh as a whole. Points that lie on closed and open field lines are violet and green respectively. Open lines' end points (they lie on the first wall elements) are marked with black colour. Artificial wall points are dark yellow

The region where ergodic field lines could be found is skipped. That volume is too far away to be relevant for our simulations of OP-1.1 phase. Ergodic lines will have to be included in the simulations of later experimental phases on W-7X when deep-thrust limiters are removed.

The picture of one, selected cut shows the point distribution in more details. Fig. 3 features two open lines crossing selected cut, on the background of four aforementioned point types.

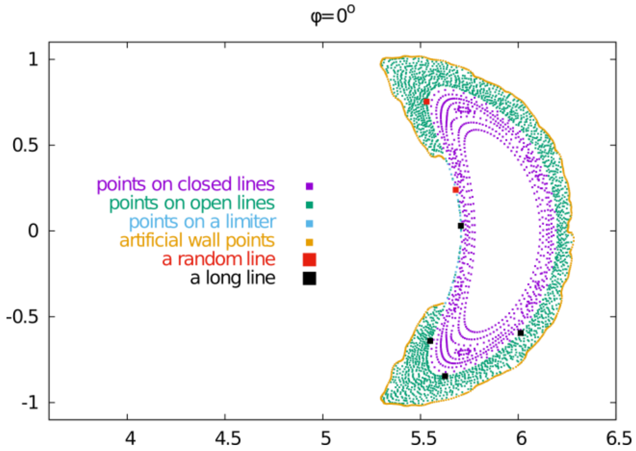

Fig. 3. Mesh points on one cut. One relatively short and one long open field lines are highlighted with respectively red and black big squares. Closed field lines with 5/6 inner island chain are violet, open lines – green, blue are points in the immediate vicinity of the limiter and are dark yellow points belong to the artificial wall. The positions given in R-z cylindrical coordinates

The points are relatively evenly spaced evenly spaced except for the outermost part, where less accuracy is demanded due to expected lower fluxes.

The coverage of one of the limiters is shown in Fig. 4. The row of points in the central part comes from the line admitted at the beginning. This region is otherwise not covered (very few lines cross the limiter there). Elsewhere the coverage is good. It should be emphasised that just by demanding that the lines are sufficiently far away from each other, we can quite quickly produce reasonable-looking mesh on a regular PC. And in fact most of the time is consumed by the field line tracing procedure.

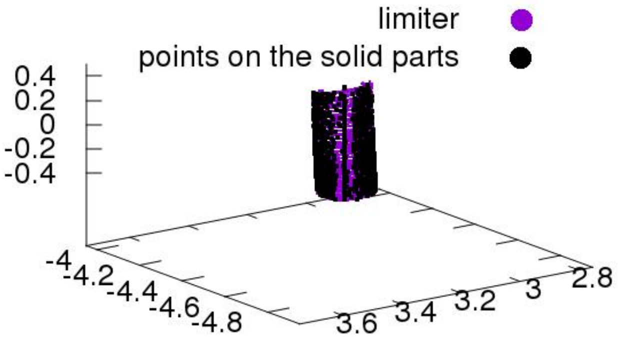

Fig. 4. Limiter (violet) coverage by mesh points (black) that lie directly at its surface

CONCLUSIONS

A fast, semi-automatic method of mesh production for the 3D plasma code Findif was presented. Computer power is used to sort the seemingly disordered tangle of open field lines and limit the simulation space by fitting artificial wall. Some human assistance is needed to assure basic coverage of first wall structures, in places where field lines are nearly parallel to the limiter surface.

The tool presented is ready to be applied also to more complicated field configurations.

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АВТОМАТИЗИРОВАННОЕ ПРОИЗВОДСТВО СЕТКИ ДЛЯ КОНФИГУРАЦИИ ЛИМИТЕРА WENDELSTEIN-7X

Г. Пелка, В. Степневский, Р. Загорский и команда W-7X

Представлен трёхмерный код Findif для переноса многожидкостной модели плазмы как инструмент автоматизированного производства сетки. Сетка точек для кода лежит на магнитных силовых линиях, которые, вообще говоря, образуют сложную конфигурацию. Открытые силовые линии, которые ограничены твёрдыми частями механизма, являются источником сложностей. Эти линии, как правило, короткие, и нужны тысячи из них. Инструмент, который помогает подобрать линии для сетки, описан в этой статье и основан на вычислении расстояния линий уже допущенных к сетке и кандидатов из них. Представлены результаты прогона кода для конфигурации лимитера (OP-1.1 экспериментальная фаза) стелларатора Wendelstein-7X.

АВТОМАТИЗОВАНЕ ВИРОБНИЦТВО СІТКИ ДЛЯ КОНФІГУРАЦІЇ ЛІМІТЕРА WENDELSTEIN-7X

Г. Пелка, В. Степневський, Р. Загорський і команда W-7X

Представлено тривимірний код Findif для перенесення багаторідинної моделі плазми як інструмент автоматизованого виробництва сітки. Сітка точок для коду лежить на магнітних силових лініях, які, взагалі кажучи, утворюють складну конфігурацію. Відкриті силові лінії, що обмежені твердими частинами механізма, є джерелом труднощів. Ці лінії, як правило, короткі, і потрібні тисячі з них. Інструмент, який допомагає підібрати лінії для сітки, описаний в цій статті і заснований на обчисленні відстані ліній вже допущених до сітки і кандидатів з них. Представлено результати прогону коду для конфігурації лимитера (OP-1.1 експериментальна фаза) стеларатора Wendelstein-7X**.**