

STELLARATOR THEORY STUDIES AND OPTIMIZATION UNDER EUROfusion

F. Castejón and WPS2 EUROfusion contributors

Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain

E-mail: francisco.castejon@ciemat.es

The WPS2 EUROfusion work package entitled “Stellarator Optimization: Theory, Development, Modelling and Engineering” and is targeted to the development of tools for designing new optimised configurations and to support W7-X exploitation. We present here the main research lines and recent achievements under the work package S2, including those to support W7-X project.

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INTRODUCTION

The EUROfusion roadmap establishes several Missions to be accomplished by the EUROfusion consortium in order to achieve commercial fusion. Mission number 8 is devoted to bring stellarators to maturity and the work is divided into two workpackages, WPS1 and WPS2. The first one is devoted to the scientific exploitation of W7-X, extracting the necessary physics knowledge. The WPS2 is entitled “Stellarator Optimization: Theory, Development, Modelling and Engineering” and is targeted to the development of tools for designing new optimised configurations and to support W7-X exploitation. We present here a summary of the results that have been achieved under WPS2 up to date and, more importantly, the work plan for 2017 and next years. This exposition is though to describe the possibilities of collaborating with WPS2 programme.

1. WPS2 OBJECTIVES

The S2 is work package, together with the S1 one, is devoted to “contribute to bring the stellarator to maturity”. We recognise that stellarators are one generation in delay with respect to tokamaks because of the intrinsic difficulties that the design and simulation of these devices pose. Stellarators are free from the main tokamak caveats, so they are considered as a solid alternative to tokamak concept for a fusion reactor. Stellarators can work in steady state and are free from ELMs and disruptions. Disruptions imply an intrinsic nuclear security problem and ELMs cause an intolerable heat and particle flux on the walls. The efforts to get steady state operation are based on current drive methods, which are not able to guarantee steady state for the moment.

On the other hand, stellarators need to improve their confinement and their complicated design, i. e., to achieve maturity. The main stream of stellarator research is to research the on the helias, or W7-X-like configurations. With this target in mind, we have defined the objectives of this work package as three-folded. On the one hand we plan to give support to W7-X Exploitation, producing the necessary simulations and theoretical tools to help to the exploitation of this device. This implies also to extract the physical results from the operation of W7-X and

other stellarators like TJ-II and LHD in order to introduce them in the optimization loop.

The second target is the optimisation of the W7-X-like (Helias) concept in view of a future reactor. Here we will introduce the new developments and findings, including turbulence, topology and fast ion confinement. The consideration of new physics for optimization sometime requires the development of proxies that allow fast calculations to be introduced in an optimization loop.

The third target is the inclusion of engineering in the optimization process: Coil design and room for the Breeding Blankets. The final chosen magnetic configuration will be a balance between good confinement and simplicity in the building of the device. Engineering activities will be reinforce in the next future, since the physics is more and more known.

2. NEXT WORK LINES AND RECENT ACHIEVEMENTS IN WP2

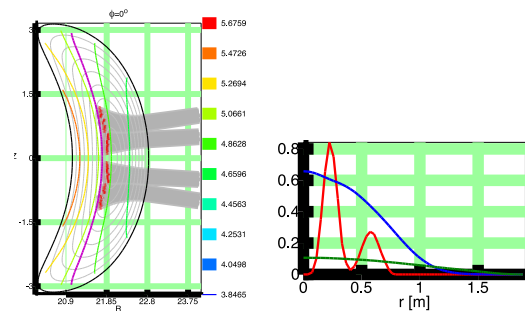


Fig. 1. Left: ray tracing calculations for X₂ in W7-X. Right: Power deposition profile together with the input density and temperature profiles

One of the activities in support of W7-X operation, which implies the development of theoretical tools for design and exploitation of future stellarator reactors is ECRH and ECCD studies. During the former year, the ray tracing code TRAVIS, developed at IPP-Greifswald has been used to identify the best ECRH regimes in W7-X as well as to estimate the driven current. In particular X₂ and O₂ heating scenarios have been identified, developed and the calculations were the input for testing of these scenarios during the first experimental phase in W7-X. The test was successful and shows that these scenarios are feasible to be used routinely in this device. In the next future, a model for OXB heating in overdense plasmas (including the

description of non-planar regions of O-X conversion) will be built. This module will be introduced in the TRAVIS code in order to simulate this heating method. Fig. 1 shows the ray tracing for X₂ scenario in W7-X.

Regarding ECCD, during next year we plan to introduce finite collisionality in the current drive calculations which have been performed in the high energy limit up to now. The neoclassical code NEO is modified to include finite collisionality and non-local effects and this new development is also included in TRAVIS, so first estimates of finite collisionality current drive will be available.

Fast ion dynamics and confinement has been also studied in optimized Helias-like configurations with reduced bootstrap current. A new configuration suitable for a reactor has been created (HYDRA-21) with the conditions of reducing bootstrap current and to improve fast ion confinement. The first target is necessary in order to keep almost frozen the value of the rotational transform in the edge, in order that the island divertor concept can work properly. The fast ion confinement is not usually well achieved in stellarator configurations, so we have to try to improve this. New methods for calculating fast ion orbits is under development. The influence of the number of field periods is also studied.

The study of ICRH-generated fast ions and their confinement is performed using SCENIC, a suit of codes that includes equilibrium calculation, full wave propagation and absorption, and fast ion orbits. Hit points on the vacuum vessel are also calculated. SCENIC has been developed under WPS2, including anisotropic equilibrium calculations, a full wave code and a MC code that estimates fast ion orbits in a complex 3D system, which allow us to calculate the fast ion distribution function. The full wave code has allowed to explore the ICRH regimes suitable for W7X. Fig. 2 shows the escape of fast ions created by ICRH in W7-X as a function of toroidal angle.

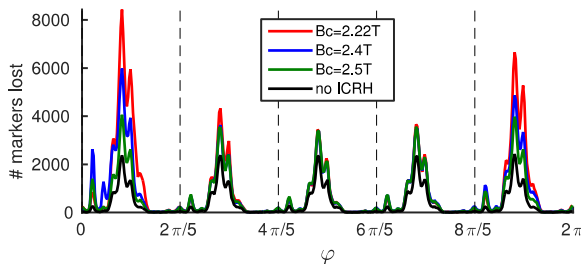


Fig. 2. Number of lost fast ions created by ICRH as a function of toroidal angle in W7-X estimated with SCENIC

Basic transport theory based on Hamiltonian techniques is used to characterise the properties of configurations regarding the confinement quality. Quasi-Symmetric configurations were studied to develop the tools starting by the simplest case. The effects of the deviation from Omnigenity are now considered, being a basic tool to explore how much the configuration characteristics can be deviated. These findings have been implemented in numerical tools for fast NC calculations, which allows one to compute neoclassical transport in low collisionality regimes for optimized stellarators, which might be useful as a

component of an optimization code. Analytical computation of the effect of high-helicity deviations in the sqrt(nu) regime and in the superbanana-plateau one is also considered.

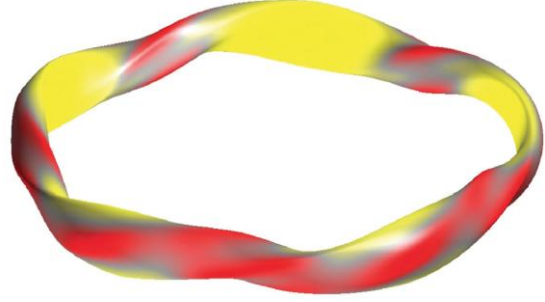


Fig. 3. W7-X like configuration optimised to reduce ITG transport

Turbulent optimization will be relevant in NC-optimised stellarators, where turbulent transport will not be negligible. ITG optimization of Helias configurations have been carried (Fig. 3) then we have investigated the possibility of optimizing configurations taking into account both the ITG and TEM transport channels combined. On top of that, fast semianalytical calculations for optimization are developed in order to estimate the zonal flow properties to explore the influence of the ZF on the saturation of the turbulence. The ZF oscillation frequency will be calculated and compared to GK simulations. Linear and non-linear GK simulations have been performed in stellarator configurations, where asymmetries in the potential will be identified. Semianalytical study of electrostatic potential perturbations, non-constant on the flux surfaces, with an assessment on their impact on impurity transport. Several configurations will be studied, including Helias-like one. Fig. 4 shows the results of the ZF residual estimates using these semianalytical calculations, compared with GK estimations.

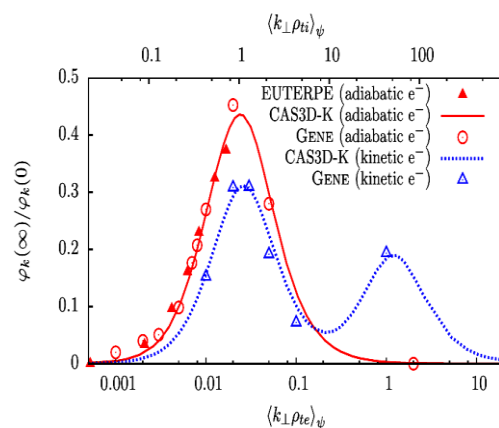


Fig. 4. Comparison of quasi-analytical (CAS3D-K) estimates of the ZF residual with GK calculations with the global EUTERPE and the tube-flux GENE codes, showing a good agreement with both kinetic and adiabatic electrons

The influence of magnetic topology and equilibrium on confinement is also studied. It has been found a decoupling of the NC transport of the rotational transform value, despite the positive confinement

scalings with iota, and the weak influence, if any, of magnetic well on confinement.

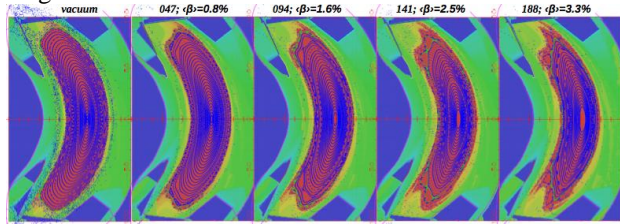


Fig. 5. EXTENDER calculations of the plasma edge and SOL topology in W7-X device for different plasma pressure values. Beta is varied from 0 to 3.3 %

On top of that, the symmetry-breaking caused by magnetic islands is considered as a possible generator of ZF by neoclassical effects.

Another important topic considered under WPS2 is the development of tools to simulate the plasma edge properly, especially considering the importance of the divertor design and performance. The island based divertor concept will be tested in W7-X in full performance plasmas. The EXTENDER code has been developed to describe the magnetic topology of plasma edge and from the LCFS to the device walls. Fig. 5 shows the results of EXTENDER calculations in W7-X for several values of plasma pressure: beta is varied from 0 to 3.3 %. On top of EXTENDER, the multi fluid edge transport code FINDIF is being developed to perform fast calculations in W7-X and next step stellarator reactors.

One of the important topics of this WP is to deal with engineering aspects, trying to take them into account in the optimization process. The idea is to find a balance between good confinement stellarators and a relatively simple coil and TBM sets. The NESCOIL code is being used to extract the conceptual design of the coils that create a given magnetic configuration. Fig. 6 shows a set of the coils that create a possible reactor configuration that presents good confinement of fast particles and low value of bootstrap current.

Further engineering activities include the development and exploitation of the 0D system code PROCESS devoted to the estimate of the performance of the device and the neutronic estimates that will be a useful input for Test Blanket Module activities.

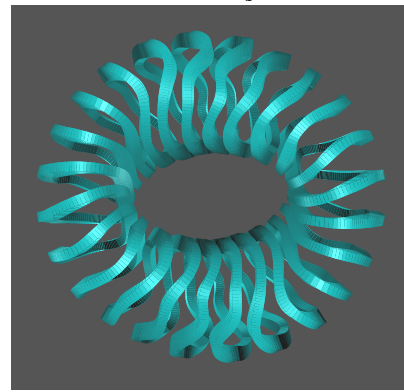


Fig. 6. Conceptual design of the non planar coils that create the configuration HYDRA-21, which presents good fast ion confinement and a reduced value of bootstrap current

CONCLUSIONS

The WPS2 includes the necessary activities to give support to W7-X exploitation and to develop the tools and new criteria to optimise stellarator configurations in order to produce a future stellarator reactor. We deal with calculations of ECRH, ECCD, ICRH and fast ion generation. New tools for basic transport theory to evaluate the quality of configurations are developed. Equilibrium relaxation and magnetic topology and turbulence are considered for the first time in the optimization loop. Basic optimization including good fast particle confinement and reduced value of bootstrap current has continued, including the study against the number of periods. Engineering activities are also considered in the optimization loop.

No references are shown in this report, given the extensive number of published papers and reports and the difficulty of choosing some of them.

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ТЕОРЕТИЧЕСКИЕ ИССЛЕДОВАНИЯ И ОПТИМИЗАЦИЯ СТЕЛЛАТОРОВ В РАМКАХ EUROfusion

F. Castejón and WPS2 EUROfusion contributors

Рабочий пакет WPS2 EUROfusion «Оптимизация стеллараторов: теория, новые разработки, моделирование и инженерия» направлен на развитие методов расчёта новых оптимальных конфигураций для поддержания эксплуатации установки W7-X. Приводятся основные направления и результаты недавних достижений в рамках пакета S2, включая и те, что направлены на поддержку проекта W7-X.

ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ТА ОПТИМІЗАЦІЯ СТЕЛАТОРІВ У РАМКАХ EUROfusion

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Рабочий пакет WPS2 EUROfusion «Оптимізація стеллараторів: теорія, нові розробки, моделювання та інженерія» спрямований на розвиток методів розрахунку нових оптимальних конфігурацій для підтримки експлуатації установки W7-X. Наводяться основні напрямки і результати недавніх досягнень у рамках пакету S2, включаючи і ті, що спрямовані на підтримку проекту W7-X.