Comparison of the results of numerical simulation of magnetic fields in the T-15MD installation with the experiment using the upgraded Plasmaless computational code

A.S. Zhilkin[1], D.Yu. Sychugov[1], A.D. Sadykov[2], A.V. Melnikov[3], V.F. Andreev[3], A.V. Sushkov[3]

[1] *Moscow State University, Moscow, Russia*

[2] *Institute of Atomic Energy of NNC RK, Kurchatov, Kazakhstan*

[3] *National Research Center "Kurchatov Institute", Moscow, Russia*

Abstract. The paper describes the upgraded version of the PLASMALESS computational code and presents the results of its application to the calculations of magnetic fields in tokamak installations. This code is a part of new version of unified software environment based on approach described in our previous paper [1]. PLASMALESS code is a part of a TOKSCEN computational block [2] and is designed to calculate magnetic fields and eddy currents in tokamak installations. PLASMALESS code is based on the numerical solution of a system of Kirchhoff electrical equations in a two-dimensional model. Comparisons of experimentally measured and calculated magnetic fields in the Tokamak T-15MD [3-5] installation were made using the upgraded PLASMALESS code and results are discussed. The results of the work will be used to calibrate the system of magnetic probes.

1. The concept and set of modules for a unified software and information environment.

At present, Russia is carrying out commissioning work on the T-15MD tokamak [3], which makes it urgent to create a unified software and information environment that would allow supporting experiments on this installation. The currently existing numerical codes for modelling processes in plasma were mostly by different separate scientific groups at different times. Therefore, a unified system is needed that would make it possible to create a full-fledged virtual analogue of an object. This problem goes beyond the field of Nuclear Fusion.

The authors of this work were engaged in the development of such a system for tokamak installations [1]. The functional part of the first version of the unified environment consisted of module TOKAMEQ for calculating the plasma equilibrium in tokamak installations [6], the evolution and vertical stability of the plasma TOKSCEN [2], as well as the RPB code for modeling the magnetic diagnostics system [4]. To assist in carrying out three-dimensional calculations, a code for generating three-dimensional meshes MESH has been introduced into environment [7]. Previously, modules of an environment were used in collective works [5, 8].

The current version of the system [1] consists of information and reference (plasma-fusion.ru) and functional (nfusion.cs.msu.ru) parts. The functional part of the system is implemented according to the "client-server" principle. The server part of the system is responsible for providing access to data and allocating computing resources, for launching modules and interacting with them, as well as data transfer between the client and the server. The client part implements the user interface, including graphs, tables and figures, and provides interactive capabilities for interaction with it. The system provides simultaneous access to computational resources to multiple users.

2. Description of the new module PLASMALESS. To support in carrying out commissioning work new module PLASMALESS was added to unified software environment. This code is designed for modelling of induced magnetic fields and currents inside the vacuum chamber and on the structural elements of the installation. Eddy currents in the passive elements are determined by numerical solving of circuit equations:

$$\mathbf{L}\frac{d\mathbf{I}}{dt}+\mathbf{RI}=-\frac{\partial\boldsymbol{\psi}}{\partial t}$$

Here **L** is the inductance, **I** is the vector of eddy currents in passive elements, **R** is the resistivity matrix, **Ψ** is the vector of sum flux from plasma and outer active coils.

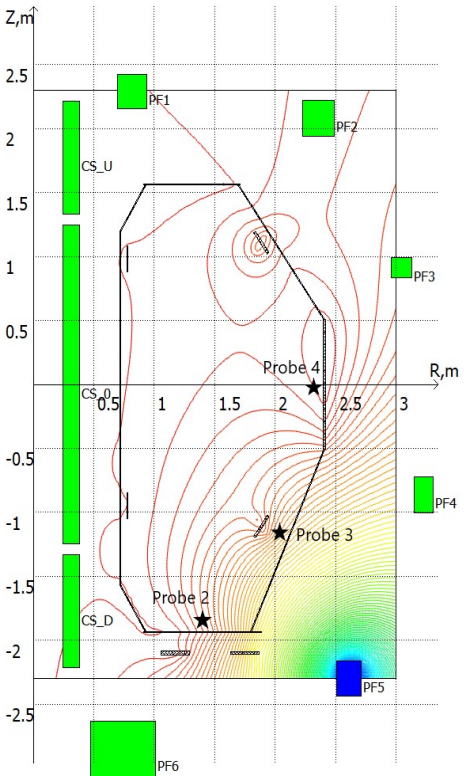

Figure 1 –Approximate locations of test probes 2, 3 and 4 in Tokamak T15-MD

For use in a unified environment PLASMALESS was updated with new input system as well as auxiliary tool for comparison of modelling results with experimental data.

3. Results of mathematical modelling and comparison to experiments. Several experiments were carried out, in which the current was run through only one of the coils, and measurements were obtained from the probes that were suitable for calibrating the parameters of the virtual analogue of the installation.

Using PLASMALESS code we conducted corresponding numerical experiments and compared the results. When comparing measurements from experiments and calculations, good agreement of the results was achieved for all probes, except for the probe located near the branch. Even at a glance at the

experimental measurements, it becomes clear that magnetic fields are induced there from branch pipes or some unaccounted-for elements of the final design. Comparison with computational ones, which show good agreement in all other seven probes in all experiments shows how strong and localized influence the branch pipes or some other structural elements have in this zone.

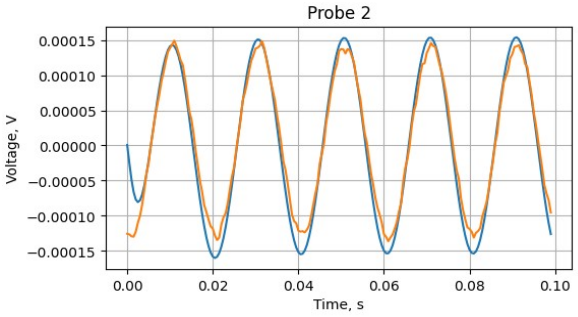

Figure 2 - Comparison of experimental (orange) and computational data for probe 2

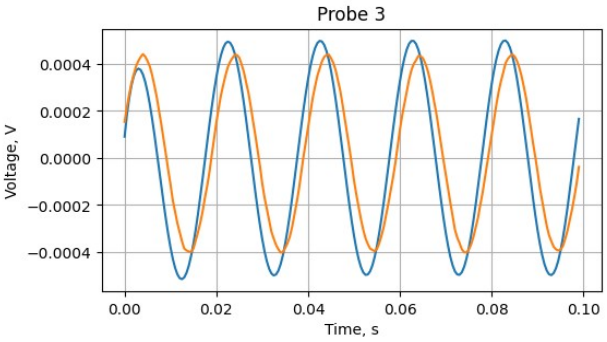

Figure 3 - Comparison of experimental (orange) and computational data for probe 3

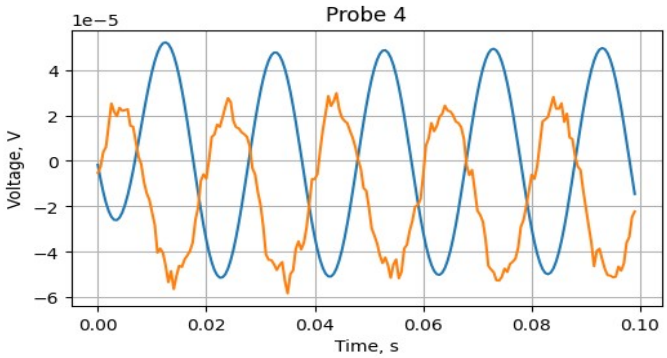

Figure 4 -Comparison of experimental (orange) and computational data for probe 4

4. Conclusions. Introduction of the PLASMALESS into unified software environment allows to expand the area of application for environment. This module allows for calculation of magnetic field configurations favorable for breakdown and of methods to reach them.

The good agreement of experimental data and computational results indicate that it is possible to create a completely adequate model for magnetic system of Tokamak T-15MD installation, which will be used in the future for setting up the plasma cord control system.

Acknowledgements. This work is supported by Moscow Center of Fundamental and Applied Mathematics and RFBR grant № 20-07-00391.

Literature

1. Aleksandr Zhilkin, Dmitry Sychugov, Lev Vysotsky, Ihor Zotov, Sergey Soloviev, Anuar Sadykov. New open computational resource for plasma processes modeling. Journal of

Physics: Conference Series, v. 1730 (2021), p. 012048, doi:10.1088/1742-6596/1730/1/012048.

2. A.D. Sadykov, D.Yu. Sychugov, G.V. Shapovalov, B.Zh. Chektybaev, M.K. Skakov and N.A. Gasilov. The numerical code TOKSCEN for modelling plasma evolution in tokamaks. Nuclear Fusion, v. 55, Number 4, 55 043017, doi:10.1088/0029-5515/55/4/043017.

3. Melnikov A.V., Sushkov A.V., Belov A.M., Dnestrovskij Yu N., Eliseev L.G., Ivanov D.P., Kirneva N.A., Korobov K.V., Krupin V.A., Lysenko S.E., Mukhovatov V.S., Mustafin N.A., Perfilov S.V., Razumova K.A., Roy I.N., Savrukhin P.V., Strelkov V.S., Shestakov E.A., Tilinin and V L Vdovin G.N. Physical Program and Diagnostics of the T-15 Upgrade Tokamak: Brief Overview // Fusion Engineering and Design, Issue 96, 2015.

4. Zotov I.V., Belov A.G., Sychugov D.Yu., Lukash V.E., Khayrutdinov R.R. Simulation of electromagnetic diagnostics system of the tokamak T-15M. – In 41 st EPS conference on Plasma Physics, Berlin, Germany, 23-27 June 2014, Europhysics Conference Abstracts (ECA) series, v.38F, P4.045, European Physical Society, Switzerland, ISBN 2-914771-90-8.

5. Sychugov D.Yu, Zotov I.V., Kasyanova N.V., Melnikov A.V., Sushkov A.V., Sadykov A.D., Shapovalov G.V.Analysis of discharge scenarios in the T-15 tokamak – Journal of Physics: Conference Series, Institute of Physics (United Kingdom), 2017, v. 907, p.012011.

6. Gorbun, M.S., Mel'nikov, A.V., Sychugov, D.Y., Sadukov, A.D. Discharges with Reduced-Volume Plasma Filament in T-15 Upgrade Tokamak. Computational Mathematics and Modeling, v. 31, 421–430 (2020). doi:10.1007/s10598-021-09503-4.

7. Zhilkin A.S., Sychugov D.Yu. A New Algorithm for Generating Tetrahedral Grids. Moscow University Computational Mathematics and Cybernetics, Allerton Press Inc. (United States), 2018, v. 42, n. 2, pp. 63-68.

8. G.M. Voss, S. Davis, A. Dnestrovskij, A. Kirk, P.J. Knight, M. Loughlin, M.H. O'Brien, D. Sychugov, A. Tabasso, H.R. Wilson. Conceptual design of a component test facility based on the spherical tokamak. Fusion Engineering and Design, v. 83, 2008, pp. 1648-1653.