Development of a system SIEMNED for integrated modeling of processes in tokamak installations

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Abstract. The paper describes a new system of integrated modelling SIEMNED (Software and Information Environment for Modelling and Numerical support of Experiments on complex Devices) designed for numerical support of experiments on tokamak installations. Also discussed are the results of its application to the modelling of discharge scenarios at the T-15 MD installation, which is currently being prepared for the physical launch.

1. Introduction

In recent years, a new approach to mathematical modeling of both technical devices and processes occurring in physical media has become widespread in the world. The essence of this approach is to develop a virtual analogue of a technical device (or an analog of physical or humanitarian process). By combining the available numerical codes into a unified software environment (integrated modeling system), it is possible to achieve an impressive increase in efficiency leading to several times (or even orders of magnitude) reduction in both design time and cost. This tendency is fully manifested in the work on controlled thermonuclear fusion during the design, construction and preparation for the physical start-up of new generation tokamak installations.

2. Introduction to SIEMNED

It is expected that such an integrated modelling system would accompany the entire life cycle of Tokamak installations, including design, physical start-up, and experiments. SIEMNED (Software and Information Environment for Modelling and Numerical support of Experiments on complex Devices) is such a system designed primarily for Tokamak installations with an aim to eventually broaden the spectrum of applicable devices.

SIEMNED development is based on “Virtual Tokamak” system [1-4] but is much broader in scope. As “Virtual Tokamak” SIEMNED is a web-based system with client interface designed for modern browsers and a server infrastructure that does actual calculations.

As seen in figure 1 SIEMNED consists of a client browser interface and backend server part which is responsible for actual calculations, data storage and exchange between modules. The system on the server is responsible for translating user interactions in the browser into commands for computational codes and for data exchange between codes, database and users – reading data from database or storing data computational or user data.
In comparison to “Virtual Tokamak” SIEMNED provides more flexible and streamlined approach to introduction of the new computational codes and includes internal data storage solution that is generalized and applicable for both input and output data of computational codes. Storage solution is based on database with generic tables with special dictionary tables that allow to accommodate different naming and measurement unit requirements from different codes.

3. SIEMNED – codes integration process
Tokamak installations continue to actively develop, their numerical simulations should have a similar ability to change, and SIEMNED is designed with that in mind.

To facilitate introduction and update of the codes into the system SIEMNED requires that computational codes be compiled as command line applications. In most cases it is done by simply excluding GUI part of the codes and combining all control commands into a single function that reads input and executes corresponding function. SIEMNED system automatically creates browser interfaces for computational codes from configuration JSON files. The configuration file is a schematic description of visual interface and actions associated with control elements. The actions are automatically translated to server and passed to code so authors of the code only need to describe the interface. This way code’s authors can easily update both computational part of the code by updating the command line application as well as changing client interface for the code via configuration json file.

This approach allows to minimize involvement of coding during the process of introduction of new computational codes.

After the code is loaded onto server the administration of the server only need to register it as available for the users.
4. SIEMNED – data exchange technology
In many cases time-proven computational codes are very specialized and created by different teams with very different ideas and technologies in mind. That leads to most codes having a very specific input and output formats that require additional data conversion for them to be used in other computational codes. Furthermore, creation of a single unified format is very difficult because of different requirements, naming, measurement units and specific limitations that every code has. This creates a requirement for a unified software environment to accommodate individual needs and requirements of every computational code that is include into it.

In SIEMNED this requirement is satisfied by introducing a database and internal format for data storage. While appearing counterproductive at a first glance it actually simplifies and nearly automates data exchange between the codes. This is achieved by introducing additional dictionary tables into the database. They are used to map naming and measurement units of computational codes to those used internally in database. It allows to automatically prepare the data for computational code during the querying of database and all that is left to do is to correctly parse the data into the file. And since all data transfer between codes is done via database it eliminates the need to create any code-to-code data pipes and specific data conversions for them.

File creation is unfortunately something that needs to be at least somewhat unique in most cases. Files can be grouped by data presentation format that is used in them and built or parsed with adjustments for specific computational code in question (e.g. computational code may require some type of marker in the file that designates it as usable for this code). But the amount of effort required for that is negligible in comparison to writing a separate code for creation of input files for every new computational code introduced into system.

5. Currently included codes
The following codes (modules) are already included into SIEMNED:

- **TOKAMEQ (TOKAMak EQuilibrium)** - calculation of MHD plasma equilibrium in a tokamak [2], based on the algorithm of the numerical Grad-Shafranov equation.
- **TOKSCEN (TOKAMak SCENario)** - calculation of plasma evolution in a tokamak [1,4]. It is based on an algorithm for the numerical solution of the equations of plasma evolution in a tokamak together with the Kirchhoff equations for the conductive elements of the installation structure (coils of an external magnetic field, passive and active feedback loops, etc.). The code has undergone significant modernization, which made it possible to reduce the calculation time of the discharge scenario by an order of magnitude, to 10-15 seconds on a modern personal computer, which makes it possible to use it in an interactive mode.
- **TOKSTAB (TOKAMak STABility)** - calculation of the vertical stability of plasma, including the finite conductivity of passive conducting structural elements. Embedded as a separate block in TOKSCEN code.
- TokScen Plasmaless code is a separate module and modified block for calculating induced magnetic fields and currents inside the vacuum chamber and on the structural elements of the installation. The reason for this separation is the need to create conditions before the start of the discharge that allow breakdown, which is extremely difficult to do without a detailed calculation of the magnetic fields and currents induced in the structural elements of the installation. The code is based on the numerical solution of the system of Kirchhoff equations for the coils of the poloidal field and the structural elements of the installation.

With described codes it is possible to demonstrate the process of using SIEMNED as unified software environment with the calculation of one of scenarios of the formation of a configuration with two X-points on the T-15 MD installation [5].

6. Application of the system to testing of the T-15 MD installation
T-15 MD [5] installation is completed and is currently being prepared for physical start-up. One of the stages of this work is the testing of the magnetic sensor system, without the correct operation of which
it is impossible to control the plasma during the discharge. The testing process consists of a series of tests where specific currents are passed through the poloidal magnetic field coils (PF coils), and the measurements of induced currents on the structural elements of the installation are taken. The same experiments were conducted numerically using the code TokScen Plasmaless. Good agreement of the measurements from experiments and calculations was achieved for T-15MD installation which shows that model of installation’s magnetic system is adequate and can be used for setting up the plasma cord control system. Some examples of results of performed calculations [8] are given in Figure 2. The difference in calculation with the experiment is insignificant and can be explained by errors in measuring the position of the sensors, or by the features of winding the coils.

7. Search for discharges with reduced plasma volume
Main basic scenarios for the T-15 MD installation are already calculated [9]. However due to energy constraints the first series of experiments will investigate modes with reduced plasma currents. Interesting configurations with low plasma current were calculated using the TOKAMEQ code [10], but the question of how to achieve them remained unanswered. Solution was found after the upgrade of TOKSCEN code, a new version of which allows to quickly calculate a large number of variants.

An example of calculation of one of these scenarios is shown in Figure 3. It sequentially shows the discharge times $t = 0.06 \, \text{s}$, $t = 0.37 \, \text{s}$, $t = 0.65 \, \text{s}$, $t = 0.91 \, \text{s}$. The plasma current at the time of separatrix formation is near 0.6 MA, which is significantly less than the base plasma current 1.8 MA. Calculations of plasma vertical stability using the TOKSTAB code showed that the given scenario is realistic and can be achieved in practice.
8. Conclusions
The described SIEMNED software environment combines the basic set of codes and systems for storing and exchanging data and expedites the process of designing of tokamak installations and allows to numerically accompany experiments in an interactive mode. Although this system is aimed at tokamak installations, the principles of data storage and exchange inherent in it can be applied to the creation of other virtual analogs of complex technical devices.
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