Participation of Polish scientific institutions in the Wendelstein 7-X project

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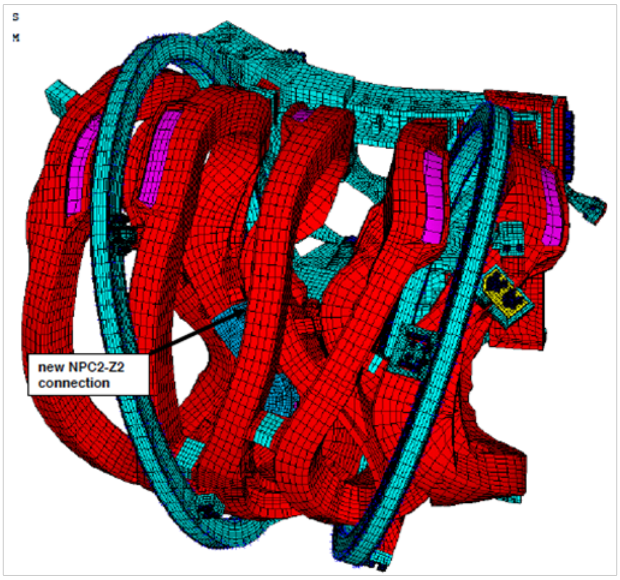
The Wendelstein 7-X stellarator is now being assembled at the Max Planck Institute for Plasma Physics (IPP), Greifswald, Germany. Polish involvement in the Wendelstein 7-X stellarator programme is quite large and covers many areas, started from cooperation on device assembly and development of the NBI system, structural and mechanical calculations through development of several diagnostics, like X-ray pulse height analysis PHA, C/O monitor system, neutron and microwave diagnostics, and modeling studies related to neutron MCNP calculations and 3D edge plasma simulations.

The magnetic system of the Wendelstein 7-X consists of 20 planar and 50 non-planar superconducting coils toroidally arranged in five identical modules made of half-modules set with 2-fold rotational symmetry. Due to the complex geometry, the complex load pattern, and the nonlinear interaction between the components, the accurate analysis of the magnetic system of W7-X is only possible by numerical means.

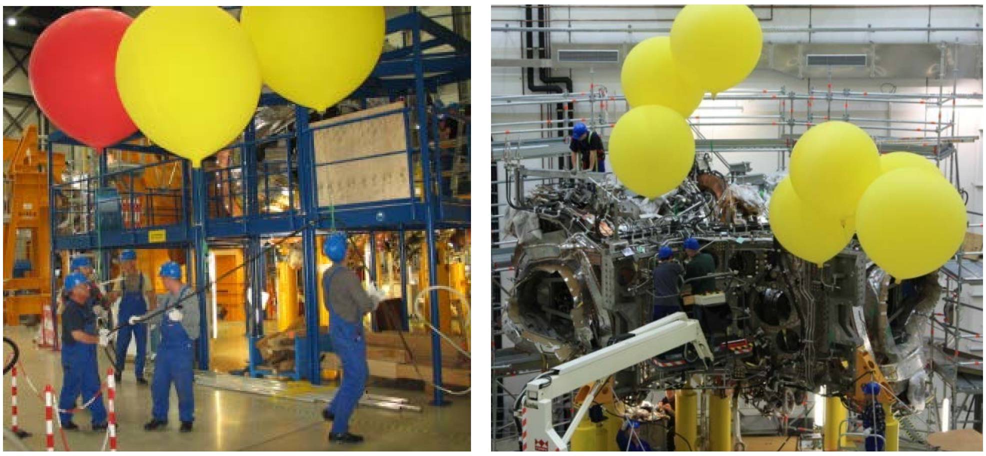
IPPLM Association has carried out the structural – mechanical analyses of this system since 2004. Among others, finite element parametric models of critical system elements have been developed at Warsaw University of Technology (WUT) in cooperation with the team of Structural Integrity at Max-Plank-Institute für Plasmaphysik (IPP) in Greifswald. Those models, built using ANSYS code, enabled semi-automatic numerical analyses of the connections and provided a better understanding of the structural behaviour of the joints, as well as enabled to study influences of tolerances, and to follow complex manufacture and assembly processes subjected to non-conformities after some manual modifications. Further details on these activities can be found in [1 - 3].



A general view of the W7-X half-module FEM model.

The Agreement on Cooperation between the Max-Planck-Institut fur Plasmaphysik in Garching and the Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences in Krakow, Poland, (IFJ PAN) was signed off in 2007. According to the agreement IFJ PAN was responsible for the assembly of the bus bar system powering 70 superconducting coils on five modules of the W7-X stellarator. The bus bars are made of the NbTi superconductors in an aluminium jacket. The bus bar system is very complex and its final reliability and performance is strongly dependent on both the quality and accuracy of the assembly process.

To complete the system it was also necessary to connect the bus bars between neighboring modules at so called Module Separation Planes (MSP). There are eight joints to be made at three MSPs and ten joints at two MSPs. The Bus Bar Assembly (BBA) team consisted of 10 to 20 technicians from IFJ PAN and IPP Greifswald headed by Responsible Officers from IFJ PAN. IFJ PAN completed the task in 2012. The bus bar systems had been assembled on all five modules of W7-X and connected together. During assembly of the bus bar system, mechanical and electrical connection of the bus bar ends and/or the coil current leads was the most crucial operation as well as electrical insulation of the joints. The IFJ PAN team made 184 joints in total. All of them passed successfully quality tests. The total effort made by IFJ PAN over six years of the collaboration amounted to more than 160 FTEs (Full Time Equivalent). More than 50 engineers and technicians were involved and trained in the assembly process of the bus bars. The results of the work performed have been presented and described in 14 reports [4 - 17].



Trial and final installation of the bus bars on a single module

Five modules on the W7-X ring

German Chancellor A. Merkel (left) and Polish Ministry of Science and Higher Education J. Szwed (right) discussing with IFJ PAN employees.

The collaboration between National Center for Nuclear Research, Otwock/Swierk, Poland (NCBJ) and IPP started in March 2011, when a first official kick-off meeting took place in Garching. It has been agreed, that Polish contribution into Neutral Beam Injector system will consists of: 1) Support structures for NBI boxes as well as hydraulic system for positioning and displacement of boxes, 2) Two gates valves separating the NBI boxes from the stellarator torus, 3) Cooling system ensuring the heat dissipation from ion sources, rf-generators and plasma grids and 4) Two reflection magnets. The total value of NCBJ project equals to about 5 MEUR.

The current status of the project is the following:

1. Support structures. Design of support structures has been completed in CATIA, the project passed static checks. Static calculations have been certified by TUV NORD company. The contracts for manufacturing have been signed with TEPRO (steel construction) and Parker-Hannifin (hydraulic system) companies. Support structures have been manufactured and hydraulic systems installed, the first acceptance tests are scheduled for April 10 in TEPRO, Koszalin, Poland. Later on the support structures will be dismounted and transported to IPP Greifswald where final acceptance tests will be performed. The formal delivery is expected for early May 2013.

2. Gate valves. One new and one refurbished gate valve were delivered to NCBJ in 2012. Both valves were equipped with an additional blocking device, a safety system preventing the valve of being shut or open accidentally. The contract for "design and build" for the heating systems has been signed with Prevac company, Rogow, Poland. Each heating system is composed of four independent heating sectors, each of them containing two heating loops (one spare), temperature sensors, thermal protectors and controlled power supply. The distribution of temperature has been checked by using finite elements simulations. Most of elements needed for construction are already in Prevac, power supplies are tested. The delivery of gate valves and of the heating system is scheduled on July 2013.

3. Cooling system. Several major modifications of the cooling system have been imposed by the IPP side, mainly the significant reduction in water flow. The initial project has been redesigned accordingly. The contract for cooling system manufacturing has been signed with Inss-Pol company, Wroclaw, Poland. The installation started in March 2013, final delivery is expected in May 2013.

4. Magnets. The first, refurbished magnet should be ready in April 2013. The second, new one, in September 2013. Both magnets will be manufactured by Tesla company, Storrington, UK and will be modified with respect to the original project; new copper liners, insulation feedthroughs and several minor elements were redesigned. Final delivery of magnets to IPP Greifswald is expected in October 2013.

Concluding, despite of several substantial modifications imposed by modifications of the W7-X project the complete delivery of Polish in-kind contribution is expected to be completed in 2013.

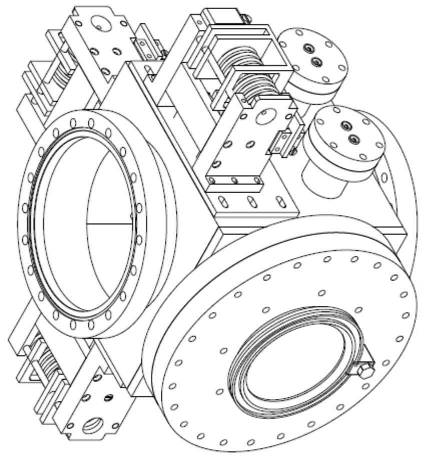
Support structures for the NBI boxes.

The Institute of Plasma Physics and Laser Microfusion in Warsaw, Poland, (IPPLM) builds of two soft X-ray diagnostics, namely PHA and MFS systems. The project is realized in the frame of cooperation agreement between IPP Greifswald and IPPLM and is a part of the contract of Association between EURATOM and IPPLM, performed within the framework of the European Fusion Development Agreement.

A pulse height analysis (PHA) system which is planned to obtain the shape of X-ray spectrum by measurement of the energy carried by individual quanta (the height of a pulse measured is proportional to this energy) is now in manufacture phase. The intensity of radiation must be low enough to assure that the condition at which the electrical signals from the individual quanta do not overlap (no “pile-up” effect) in the electronics following the detector. The second diagnostic is a multi-foil temperature analysis system (MFS) which is a method destined to obtain the shape of the X-ray spectrum from the data recorded with the use of different semiconductor detectors. In this method the spectrum is determined by measurements of the total X-ray emission (as the effect of an interaction of many quanta) in some different ranges of energy, which are determined by the type and thickness of filters and the thickness of detectors. The MFS method is characterised by the lower spectral resolution in comparison with the PHA system.

For designing these two diagnostic systems a numerical code for evaluation of X-ray emission from stellarator plasma, named RayX has been developed. The code simulates the composition of ionization stages for some important elements (C, Fe, O) and the intensity of free-free, free-bound and bound-bound radiation. Basing on the assumption about the configuration of the detection system and the amount of impurities, the code predicts the response of the 1-D imaging system for a given plasma density and temperature spatial profiles. The results of simulations for predicted plasma scenarios, different diagnostic geometry, different kinds of detectors and thickness of applied filters were used in designing the diagnostic systems.

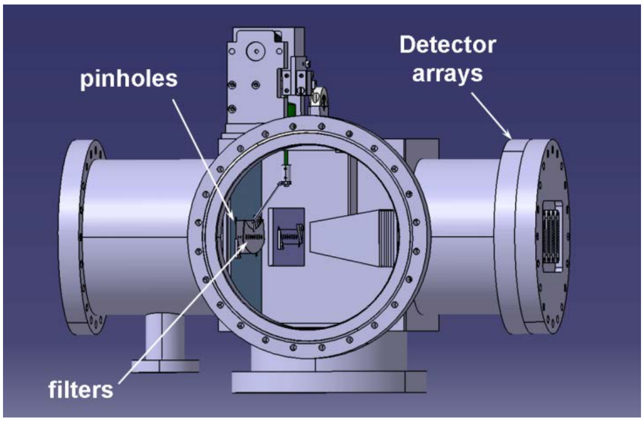
The proposed X-ray pulse height analysis system is intended to provide the spectral energy distribution with an energy resolution of about 200 eV along a central line of sight. The low energy detector response can be adjusted by interchangeable energy filters (Beryllium transmission foils). This will allow to enhance the sensitivity for particular impurity species and for the investigation of superthermal tails in the spectra. The system will consist of a set of 3 SDD (Silicon Drift Detectors) detectors operated with different filters in order to obtain a good sensitivity in a wide energy range. The combination of spectral data obtained along a single line of sight with broadband radial X-ray intensity profiles will provide a sufficiently good characterization of the impurity radiation in the plasma core. The measurements yield impurity survey spectra in the X-ray region above 0.5 keV (up to 20 keV typically) allowing to identify the line radiation from all relevant impurities and to determine their concentration in the hot plasma core. The slope of the hydrogen and low-Z continuum radiation is used to determine the central electron temperature. The intensity of the continuum radiation along with additional spectroscopic data allows to assess Z_{eff} values in the plasma center. In addition, the presence of suprathermal electrons can be detected in the high energy region of the continuum spectrum.

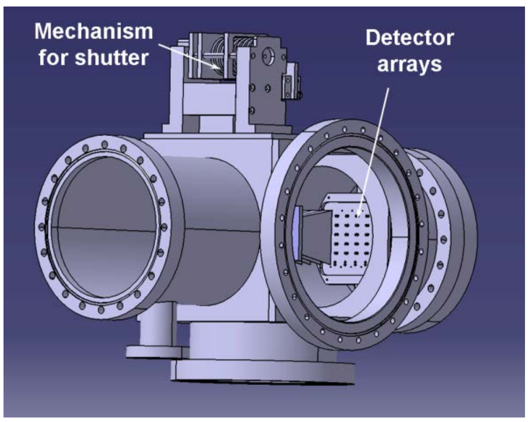


Vacuum chaber of PHA soft X-ray diagnostic designed and buit at the IPPLM, Warsaw for W7-X stellarator.

The MFS system will be realized on port AEN20 as a part of the so-called flexible SX camera system on the AEM10-AEN10-AEO10 port combination.

This diagnostics will consist of 8 detector arrays (for 5 detectors each) using different 8 filter-foils, current amplifiers and a memorising system. Basing on the simulations it was established that the distance from plasma center to pinhole should be 2.5 m and the distance from pinholes to detectors 0.20 - 0.25 m. Additionally, there will be possibility to change this distance adequately to the plasma conditions. Taking into account the influence of magnetic field on diagnostic components, the turbo molecular pump has been placed at 6 m from the plasma center. It is expected to run both diagnostics in 2014.

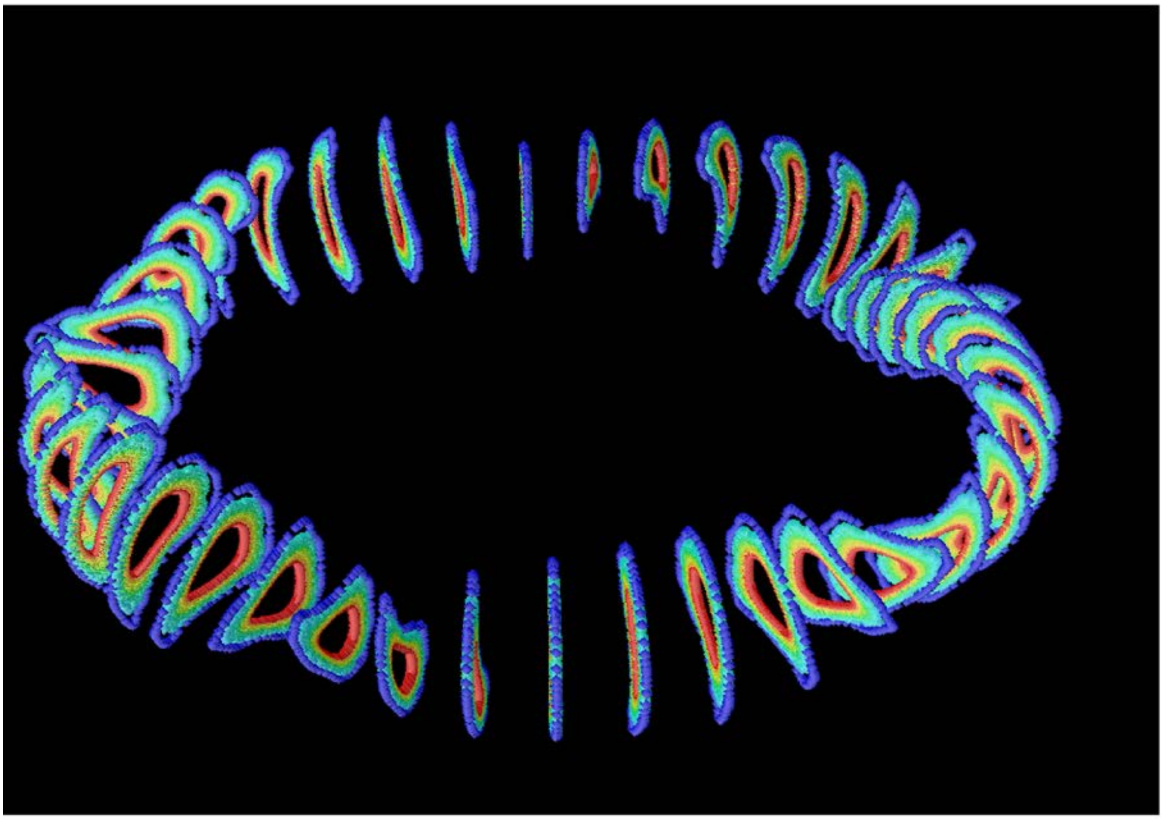




Design of the MFS soft X-ray diagnostic system for W7-X done by the IPPLM, Warsaw.

The collaboration between IPPLM and IPP on edge plasma modeling started already in 2003 with the aim to contribute to development of the 3D fluid code (FINDIF) for simulations of plasma parameters in the boundary region of the stellerator W7-X device. The numerical model was based on the concept of local magnetic coordinates allowing a correct discretization with mimimized numerical errors. The finite difference discretization method was used which allows the numerical simulation of energy transport in complex 3D edge geometries (in particular for W7-X) using a custom-tailored unstructured grid in local magnetic coordinates. This grid is generated by field-line tracing to guarantee an exact discretization of the dominant parallel transport. Along the magnetic field lines the standard Patankar concept was used to discretize the convection-diffusion equation, whereas in order to solve a quasi-isotropic problem in a plane

(toroidal cut), the finite volume method was modified to obtain its finite difference representation with the radial fluxes on plasma cross-sections being interpolated using a constrained Delaunay triangulation. FINDIF calculations have been performed for W7-X geometry as well as for the 3D TEXTOR-DED configuration [18-23].
It is planned to continue common works on edge plasma modeling in future and to use the FINDIF code to interpret experimental results from W7-X.



Calculated 3D electron temperature solution in a W7-X configuration

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