4 Contribution to the Wendelstein 7-X project

Spectrometry of soft X-ray emission from W7-X stellarator with the use of PHA and MFS diagnostics

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Abstract

Two spectroscopic systems: pulse height analysis (PHA) and multi-foil system are currently under design for Wendelstein 7-X stellarator for long pulse operation. The proposed PHA diagnostic is intended to provide the spectral energy distribution with energy resolution not worse than 180 eV along a central line of sight. The system consisting of 3 single Silicon Drift Detectors (SDDs) operated with different filters will be installed on the horizontal port AEK50 on W7-X. Each detector will record an X-ray spectrum in three different energy ranges from 400 eV to 20 keV. In MFS system the recorded spectrum is determined by measurement of the total X-ray emission (as the effect from interaction of many quanta) in different ranges of energy, which are determined by the type and thickness of the filters and the thickness of the detectors (usually the ranges overlap). The MFS method is characterised by lower, in comparison with the PHA system, spectral resolution.

Introduction

The investigation of the X-ray emission from fusion plasmas has become a standard diagnostic tool used on many different fusion experiments [1]. The measurements of X–ray intensities by using Si–detectors, which are sensitive to the total radiation above a threshold energy determined by thin absorber foils in front of the diodes, yield an excellent spatial and temporal resolution. The determination of the X-ray energy spectrum using PHA systems requires sufficiently long acquisition times resulting in a poor temporal resolution. However, this method is particularly suited for long pulse operation envisaged for W7–X.

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 allowing to identify the line radiation from all relevant impurities (with exception of elements lighter than nitrogen) 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.

Computer simulations of soft X-ray emission from a tokamak plasma played important role in designing of each diagnostic systems. As a tool for checking the performance of the PHA and MFS spectrometry systems and optimizing filters and detectors, a special numerical code, named RayX [2] has been developed. Number of simulations have been done and the results allowed to determined the position of the diagnostics components.

The super conducting stellarator W7-X will run pulse of up to 30 min duration with full heating power. Electron Cyclotron Resonance Heating (ECRH) is the main heating method for steady-state operation of the Wendelstein 7-X stellarator in the reactor relevant plasma parameters. In the first phase of working a heating power of 8-10 MW is planed to use. A wide spectrum of requirements has to be considered during the design and realization of the new X-ray diagnostics. Since ECRH auxiliary heating will be applied in W7-X, different heating scenarios, characterised by widely different electron temperature and density profiles have been taken into account [3].

Pulse height analysis soft X-ray diagnostics for stellarator W7-X

In designing the PHA system on W7-X a special developed numerical code, RayX, was used. The code allowed to investigate the influence of a configuration of the diagnostic systems on the spectra intensity and shape. It also calculates the radiation from plasmas with the use of different pinhole sizes, types of detectors, filters' material and thickness, as well as to simulate emission from different discharges characterised by widely varied electron temperature and density profiles. The results of simulations allowed to develop optimal diagnostic systems and design a mechanical setup.

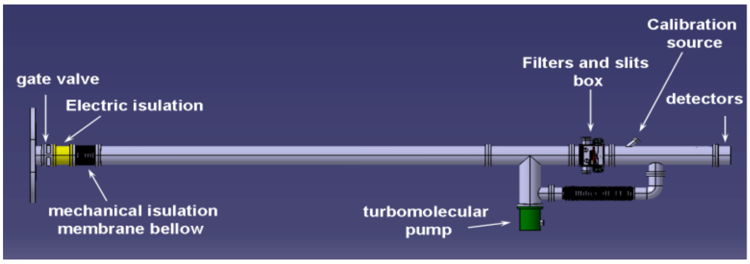

Fig. 1. General design of the PHA diagnostics system for W7-X

The design of PHA system for W7-X is presented in fig.1. In 2011 details of the positioning of individual components have been fixed. At the beginning of the diagnostic port there will be a gate valve, next electric insulation and after a short membrane bellow to reduced vibrations. About 7 m from the plasma center there will be located so-called 'filters and slits box', details of which are shown in fig 2. It contains three sets of movable slits with piezo drives and pinholes, and three interchangeable filter systems.

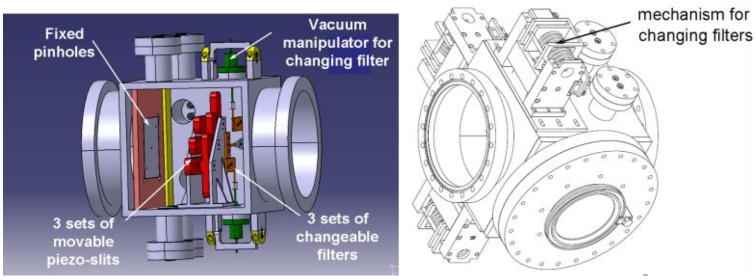

Fig.2. Details of the so-called 'filters and slits box' – vacuum chamber contains three sets of movable slits with piezo drives and pinholes, and three interchangeable filter systems

To collimate and cut off a part of the radiation a plate with three fixed holes has been located in front of the chamber, from the plasma side.
In 2011 prototype of the filter control mechanism by a wobble stick using a small (fast) and large pneumatic cylinder as actuator has been proposed and tested in the laboratory. The wobble stick movement is limited by a brace. This design handles the sucking force of the vacuum on the mechanical feedthrough (bellow). The positioning is a two-stage: fast adjustable is made by a small cylinder and a big cylinder is used for the large (about 20 mm) movement. The precision of the adjustment will be 0.1 mm. A two way pressure valve (supply and exhaust of pressurized air; 3 to 5 bar) controls with a feedback reading the 3 filter positions. There will be also a possibility to have a closed position and if necessary cut the radiation. The details of this mechanism is presented in Fig. 3.

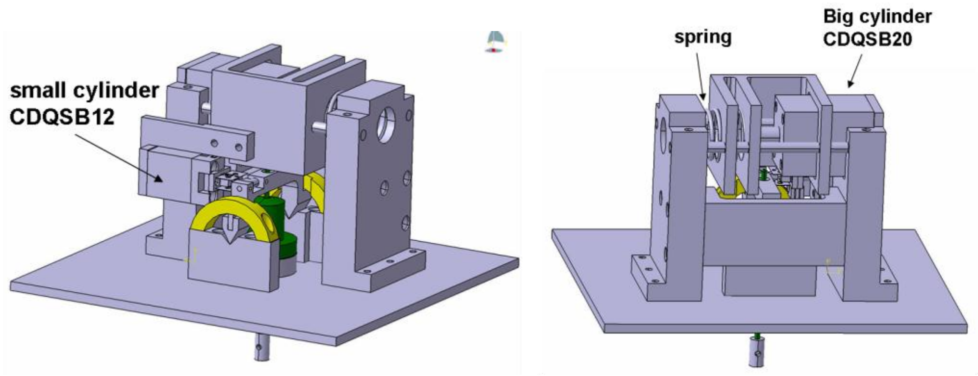

Fig. 3. Details of the mechanism of changing filter with the use of wobble stick (vacuum manipulator)

The PHA system on W7-X will consists of three energy channels. First one will be equipped with SD3 detector containing polymer window and aluminum light protection, to cover energy range between 250eV and 20keV. Second and third channel will be equipped with standard SDD detector with 8µm of Be window, however in the third channel additional thick filter will be used. This will allow to record spectra in the range of 1-20 keV and 7-20keV, respectively. All detectors will be accompanied by an individual control of pinholes size and 3 additional replaceable filters for adjusting the energy range in each system, as it was described above.

In 2011 a DN160CF detectors flange with multipin connectors has been designed and ordered. It is presented in Fig. 4.

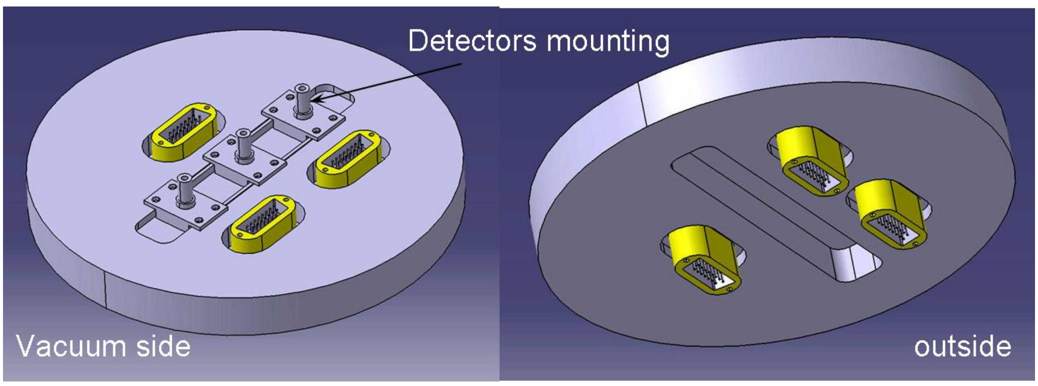

Fig.4. Detectors flange for PHA system on W7-X with special multipin connectors

Multi-foil soft X-ray spectroscopy diagnostics for stellarator W7-X

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 diagnostic will consist of 8 detector arrays (for 5 detectors each) using different 8 filter-foils, current amplifiers and a memorising system. Tests carried out on different types of detectors showed that FLM type detectors with 380 µm of active layer, surface 5×5 mm and 10 pF of capacity, produced by Institute of Electron Technology in Warsaw are the best candidates for this diagnostic. The detectors has been mounted on Alumina with a capacitor and resistor integrated to the board (SMD-technology). As the ranges of sensitivity of individual energy channels overlap, a special mathematical procedure is applied to recover the real X-ray spectrum from the experimental data. An analysis of a dark current and noise of the considered detectors showed that acceptable level of the detected current should be higher than 100 nA. 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. Design of the MFS system with pinholes, filters and detector arrays location is presented in Fig.5.

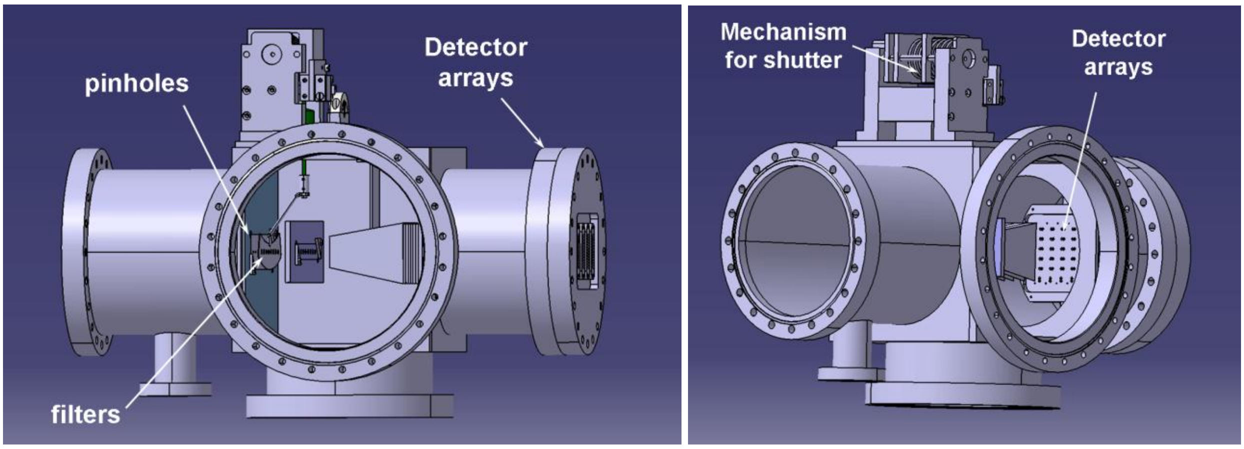

Fig. 5. Design of the MFS diagnostic system for W7-X

In MFS system, a similar as in PHA diagnostic, mechanism with wobble stick will be used but in this case it will play a role of shutter.

Conclusions

In 2011 manufacture drawings with all details of proposed PHA system have been performed. The DN160CF detectors flange with multipin connectors for PHA system has been ordered. For both diagnostics a mechanism with wobble stick, which will be used for changing filters or/and cut the radiation from plasma, has been proposed and tested in laboratory. It is worth noting that all components will be made of specials materials, mainly of the steel SS316LN or 1.4429 quality with low magnetic permeability µr<1.01 and Co-content <2000ppm.

Collaboration

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References

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[2] A. Czarnecka, S. Jabłoński, M. Kubkowska, L. Ryć, A. Weller, J. Wołowski, *Computer simulation of soft X-ray emission from tokamak plasma*, COST MP0601 WG & MC Meetings 14-15 May 2009, Salamanca, SPAIN.
[3] A. Czarnecka, M. Kubkowska, W. Figacz, S. Jabłoński, J. Kaczmarczyk, J. Wołowski, C. Biedermann, R. Burhenn, R. König, A. Weller, Concept of pulse height analysis system (PHA) for Wendelstein 7-X, P1.052, 38th EPS Conference on Plasma Physics (2011).