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Commissioning and first operation of the pulse-height analysis diagnostic on Wendelstein 7-X stellarator

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The Wendelstein 7-X (W7-X) stellarator started its operation at the end of 2015. The first operational phase (OP1.1) has been conducted with helium and hydrogen as working gas. The initial experimental programs have been devoted to commissioning, tests and optimization of diagnostic systems.

This paper reports on the commissioning of the 3-channel Pulse Height Analysis (PHA) diagnostic, which has been installed at W7-X in the middle of 2015. The system measures X-ray radiation from the plasma core in the energy range of 0.25 - 20 keV in order to estimate the electron temperature of the plasma (from the Bremsstrahlung radiation) and impurity content. The PHA diagnostic is designed for making measurements on long-lasting plasmas (up to 30 min.) in future operation phases of W7-X.

During the first experimental campaign, the PHA system was successfully put into operation and tested. The 1st PHA channel has been optimised, however the 2nd and 3rd still need more time for proper adjustment. Registered spectra were characterized by satisfactory counting rates, which allowed to observe well separated spectral lines, thereby allowing impurity identification. More additional tests before OP1.2 and during the restart of W7-X should help to find ideal combination of diagnostic settings.

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1. Introduction

On 10 December 2015, Wendelstein 7-X, a large-scale optimized stellarator with a superconducting coil system [1,2] located in Greifswald, Germany, started its operation. The first experimental campaign (called OP1.1) was conducted in condition of using five inertially cooled inboard limiters made of graphite [1,2]. Moreover, hydrogen and helium have been used as working gases. During the first phase of operation, it was possible to achieve the following plasma parameterrs values were achieved: electron temperature $T_e \leq 10$ keV, ion temperature $T_i \leq 2$ keV and electron densities ne ≤ $5x10^{-19}$ m^{-3} for discharge duration of up to 6-seconds [3,4]. Most of the installed diagnostics have been designed for quasi-steady state operation with discharges up to 30 minutes duration, heated by up to 10 MW of electron cyclotron resonance heating (ECRH) [3,4].

The Pulse Height Analysis (PHA) system [5,6,7], has been included in the initial set of core impurity diagnostics. Other such diagnostics include an X-ray Imaging Crystal Spectrometer (XICS) [8], a High Resolution X-ray Imaging Spectrometer (HR-XIS) and High Efficiency XUV Overview Spectrometer (HEXOS) [9,10]. The principal task of the PHA system is to investigate the soft X-ray emission from the W7-X plasma in a board energy range starting from 250 eV up to 20 keV. The measurements of X-ray spectra provide information about the electron temperature (estimated from the slope of the Bremsstrahlung radiation), identification of impurity types and high ionization stages, plus the spectrum of the highest energy X-rays produced by a supra-thermal electron tail (usually above 10 keV) [11] that is typically present in ECRH plasmas.

2. The Pulse Height Analysis (PHA) system dedicated to W7-X

The Pulse Height Analysis system for the W7-X was designed in collaboration between the Max-Planck-Institut für Plasmaphysik (IPP), Greifswald, Germany and the Institute of Plasma Physics and Laser Microfusion (IPPLM), Warsaw, Poland. The diagnostic was designed and built in accordance with all W7-X requirements related to permitted materials, restrictions from the disturbance to the magnetic field (the PHA chamber is located about 5 meters from the gate valve where the magnetic field induction is smaller than 5 mT) and taking into account limitations in access to the torus hall. Therefore, the mechanical components were manufactured from materials with low Cobalt content (to avoid activation by D-D neutrons in future experimental campaigns) and low magnetic permeability, as well as, with low sensitivity to high ECRH power fluxes up to 50 kW/m2 [10]. A computer-aided design drawing of the PHA system is shown in Fig.1. The main components are: detector flange, beam line with turbo-molecular vacuum pump, gate valve and PHA vacuum chamber, which contains pinholes and beryllium filters.

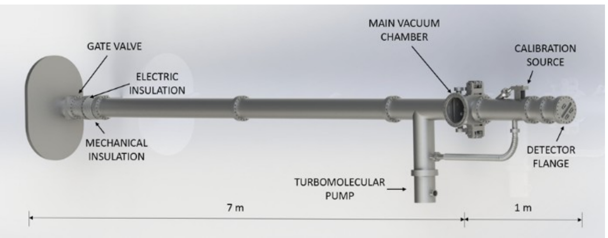

Fig. 1. The mechanical design of the Pulse Height Analysis system for the W7-X.

The described soft X-ray diagnostic is connected to the AEK50 port of the W7-X chamber. This port is positioned in the half-module number 50 (HM50) (see Fig.2.) which is located in the neighbourhood of the ECRH system (also in HM50).

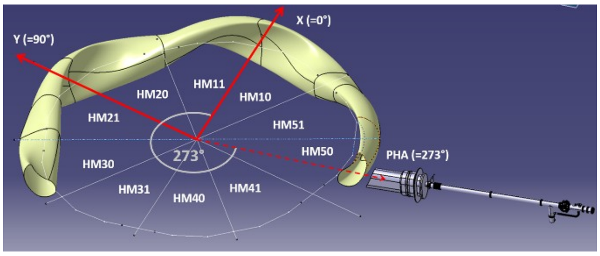

Fig. 2. The position of the PHA system with respect to the W7-X plasma.

The PHA diagnostic consists of 3 energy channels. The first and second channel are equipped with Silicon Drift Detectors (SDD) from PNDetector and are fitted with 8 μm Be windows to cover the energy range from 0.9 to 20 keV, while the third channel is equipped with a SDD detector covered by a thin polymer window that transmits photons above 250 eV. In order to block visible light, the polymer window has an additional 30 nm aluminium layer. The detector lines-of-sight, which partly overlap each other, are set to observe the plasma centre. Line-of-sight simulations based on (VMEC) flux surface data from J Magnetic Configuration (the standard W7-X configuration during OP1.1), show that each detector should view the plasma centre with diameter of 3.5 cm for a pinhole size equal to 1.2 mm.

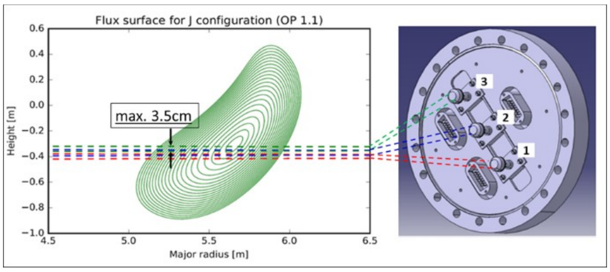

Fig. 3. Lines of sight from three SDD detectors for the following geometry of the PHA system: distance plasma-pinhole = 7m, distance pinhole-detector = 1m, pinhole size 1.2 mm.

In addition to the above, each energy channel (detector) is equipped with a set of changeable Beryllium foils with different thicknesses plus individual control of pinholes size (piezo-slits) [5]. The application of such a solution enables precise control of the photon fluxes that reach the detectors. This intensity is an important parameter due to the measurement principle of the detectors and has a significant impact on the collected spectrum and energy resolution. Moreover, the construction of piezo-slits enables rapid changes of the width of pinholes, during a plasma discharge, if needed. The time required for this operation is about 50 ms.

An especially important part of the PHA system, from the optimization point of view, is the high-speed digital pulse processor (DPP, XIA, Mercury-4 [12]), which is an interface between the detector and the personal computer (PC) unit. This system can operate with a maximum of 4 detectors simultaneously and undertakes the data acquisition. The setting parameters of acquisition can be selected for each PHA channel individually. When the acquisition time is equal 100 ms, data transfer below 200 kB/sec is required while possible data transfer (guaranteed by the manufacturer) speeds across the USB 2.0 interface exceed 16 MB/sec. The DPP offers remote control access to some relevant spectrometer settings e.g., preamplifier gain, peaking time or trigger threshold. Additionally, there are preamplifier settings , important for the signal to noise ratio and needs to be individually adjusted to the sensitivity of each detector used in the three PHA channels. All of these parameters have a direct impact on recorded signals.

The temporal resolution of the PHA system was set to 100 ms integration time. The choice of this value was a compromise between the quality of collected spectra and the temporal resolution of diagnostics, as well as the characteristics of discharges and duration of particular ECRH steps along a discharge. An improvement of the spectra quality can be achieved by summing over several recorded spectra.

2. Commissioning and first test of the PHA system

The PHA system was commissioned and tested during the OP1.1 and delivered first spectra in the soft X-ray range from W7-X helium and hydrogen plasmas. In order to obtain a good spectrum of well separated spectral lines and low noise level a sufficient number of counts is required. The operational diagram of the signal processing stages (Fig.4.) presents particular steps in the shaping of spectrum.

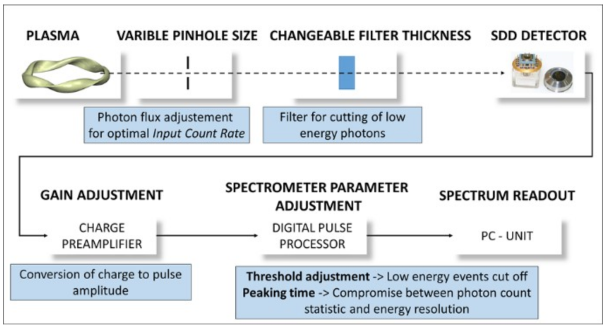

Fig. 4. Operational diagram of transmission stages.

At the beginning of the spectra registration process, the photon flux from the W7-X plasma is adjusted by applying variable pinhole sizes (p_d). To get an optimal counting statistic, the PHA system should be operated close to or lower than the input count rate at which a maximum output count rate occurs (the achievable throughput has a maximum limited by the digital pulse processor (DPP) electronics) (Fig.5.)

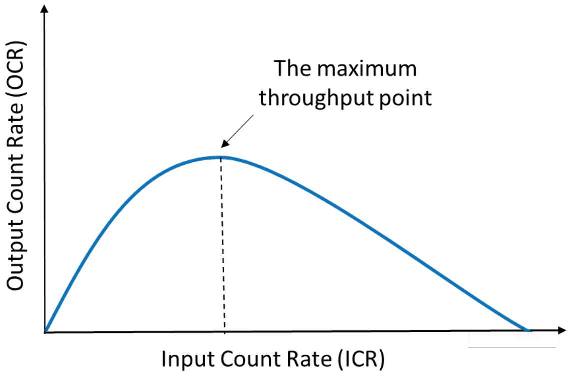

Fig. 5. Schematic diagram showing the Input Count Rate (ICR) varies with Output Count Rate (OCR) for the digital pulse processor.

When the Input Count Rate (ICR) is set on the sloping part of the curve above the maximum throughput point (by increasing p_d), the output count rate decreases at increasing Input Count Rate. In this case, a significant pile-up takes place and the dead time drastically increases. Both phenomena have a negative impact on counting statistic due to loss of counts. Such a situation was observed during tests of the PHA system at W7-X at the beginning of experimental campaign. Therefore, it was necessary to reduce the ICR by reducing the pd. The X-ray photons which reach the SDD detectors are converted to electrical charges. The charges generated in a detector active region are converted to pulse amplitudes by a charge preamplifier [13]. In the next step, the signal is processed by the DPP where the pile-up effect is created. The signal to noise ratio can be optimised by careful setting of the preamplifier and DPP.

During the commissioning of the PHA system, specific attention was given to the adjustment of DPP parameters that have a direct impact on recorded signals. These are especially the peaking time and the trigger thresholds.

The peaking time parameter tp defines the maximal time required for a shaped pulse to go from the baseline to the pulse maximum.

The fast trigger threshold Ett parameter is responsible for setting the low-energy limit for the fast filter (component responsible for pileup inspection). It is used to define the low energy cut-off. In some cases, when the value of Ett is too low, a zero-energy noise peak was generated. For this reason, this parameter plays an important role in optimisation of the diagnostic.

The tp time parameter has a major impact on the energy resolution, but also influences the output count rate. Thus, the optimization of this parameter leads to a compromise between the count rate per bin and energy resolution.

In practice, when the tp is set too large, sometimes a spectrum could not be observed due to the low output count rate. On the other hand, setting the tp too small, the energy resolution of the spectrum was significantly deteriorated.

Figure 6 presents collected spectra for two different tp, thereby showing the difference in energy resolution.

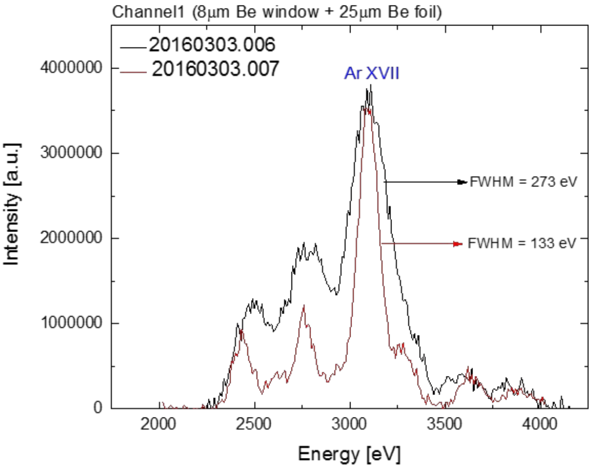

Fig. 6. Examples of spectra collected in channel 1 for $t_p = 1$ µs (red) and $t_p = 0.3$ µs (black). Other diagnostic settings are as follows: $E_{tt} = 1000$ eV, $p_d = 300$ µm.

All these parameters (E_{tt}, t_p) can be changed via the user interface software, which allows one to monitor and manage (remotely from the control room) the 3-channel PHA system. Additionally, the software ensures adjustments of the slits widths, which can be changed independently for the vertical and horizontal pair, thereby defining the p_d.

The optimisation of the PHA settings was mainly achieved by changing the p_d and DPP parameters. The most significant changes in the recorded spectra were observed when reducing p_d from 1200 µm to 300 µm (minimizing the pileup effect), as well as, when reducing t_p value from 20 µs to 1 µs. After many tests, the 1st energy channel of the PHA system was optimised. The most optimized settings for the experimental conditions during the OP1.1 were as follows: $t_p = 1$ µs, $E_{tt} = 1000$ eV, $p_d = 300\text{x}300$ µm.

The optimization process for the 2nd and 3rd PHA channels had not been completed during OP1.1. However, the t_p set at 1 µs for the 2nd channel also provided spectra with good counting statistics (up to a thousand counts per bin and per second). Figure 7 presents a comparison of spectra before and after the optimisation process of the PHA system. Identified spectral lines are labelled by the originating impurities and their ionization stages.

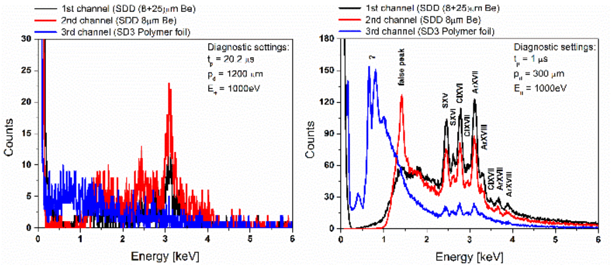

Fig. 7. Example of collected PHA spectra before (left) and after (right) optimisation. The number of counts are normalized to 250 ms. The discharges times were equal to 4s (right figure) and 250ms (left figure).

After optimisation, the number of spectral counts increased by two orders of magnitude and a spectrum with well-separated spectral lines was obtained (Full-Width at Half-Maximum = 130 eV at $t_p = 1$ µs). This enabled identification of several impurities, and their ionization stages, present in the plasma core. Note: the observed false peak in the 2nd PHA channel (at ~1.4 keV) in Fig.8. is considered to be noise, which moves over to higher energy for smaller t_p (e.g. at 1 µs) due to the effect of counting logic inside the DPP digital filter

Nevertheless, in order to find the best combination of t_p, Ett and p_d, additional tests (the optimum under the same experimental conditions) are needed. This will help to optimize the second (8 µm Be window) and third (thin Polymer window) PHA channels for future campaigns.

4. Conclusions and perspectives

During the first operation phase of W7-X (OP1.1), the Pulse Height Analysis system was successfully put into operation. Preliminary measurements taken with the PHA system confirm the readiness of the X-ray diagnostic to deliver information related to the identification of impurities and electron temperature estimation. During OP1.1, an optimization of the PHA system was conducted. As a result of this process, the determination of a set of optimal DPP parameters was possible. The recorded spectra from hydrogen-plasma experiments were sufficient to perform an analysis of the intrinsic impurities (especially from 1st PHA channel).

Before the next experimental campaign it is planned to test the PHA system in laboratory hall using an X-ray source with an intense photon flux. Final optimization will be done during the restart of the W7-X when it will be possible to commission the diagnostic in a longer

Acknowledgements

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References

[1] R.Koenig et al., The Set of Diagnostics for the First Operation Campaign of the Wendelstein 7-X Stellarator, J. Instrum. 10 (2015) P10002.

[2] H.–S.Bosch et al., Technical challenges in the construction of the steady-state stellarator Wendelstein 7-X, Nucl. Fusion, 53 (2013) 126001

[3] T. Klinger et al., Performance and properties of the first plasmas of Wendelstein 7-X, Plasma Phys. Contr. F. (2016) (accepted) 101221.R1

[4] M.Krychowiak et al., Overview of diagnostic performance and results for the first operation phase in Wendelstein 7-X, HTPD conference, 2016.

[5] M.Kubkowska et al., Laboratory tests of the Pulse Height Analysis system for Wendelstein 7-X, J. Instrum., 10 (2015) P10016.

[6] S.Jablonski et al., J. Instrum. 10 (2015) P10021.

[7] A.Weller et al., Concepts of X-ray diagnostics for Wendelstein 7-X, Rev. Sci. Instrum., 75, 10 (2004)

[8] N.A. Pablant et al., Measurement of core plasma temperature and rotation on W7-X made available by the x-ray imaging crystal spectrometer (XICS),in 41st EPS Conf. On Plasma Phys., 38F (2014).

[9] W.Biel et al., Designe of a high-efficiency extreme ultraviolet overview spectrometer system for plasma impurity studies on the stellarator experiment Wendelstein 7-X, Sci. Instrum. 75, 3268 (2004).

[10] H. Thomsen et al., Startup impurity diagnostics in Wendelstein 7-X stellarator in the first operational phase, J. Instrum. 10 (2015) P10015.

[11] S. Von Goeler et al., Thermal X-ray spectra and impurities in the ST Tokamak, Nucl. Fusion 15 (1975)

[12] Digital X Ray Processor User's Manual. Models Mercury and Mercury-4 with Prospect Software version 1.0.x, XIA Company, 2010

[13] PulsedReset Preamplifier Rev. X2