XUV diagnostic to monitor H-like emission from B, C, N and O for the W7-X stellarator

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The "C/O Monitor" system for the Wendelstein 7-X (W7-X) is a dedicated spectrometer with high throughput and high time resolution (order of 1 ms) for fast monitoring of content of low-Z impurities in the plasma. The observed spectral lines are fixed to Lyman-α lines of H-like atoms of carbon (3.4 nm), oxygen (1.9 nm), nitrogen (2.5 nm) and boron (4.9 nm). The quality of the wall condition will be monitored by the measurements of oxygen being released from the walls during the experiments. The strong presence of carbon is an indication for enhanced plasma-wall interaction or overload of plasma facing components. The presence of nitrogen (together with oxygen) may indicate a possible leakage in the vacuum system, whereas the intensity of the spectral emission of boron indicates the status of the boron layer evaporated onto the wall in order to reduce the influx of heavier steel ingredients or oxygen. The spectrometer will be fixed in a nearly horizontal position and is divided into two vacuum chambers, each containing two spectral channels assigned to two impurity species. Each channel will consist of a separate dispersive element and detector. The line-of-sight of both sub-spectrometers will cross at the main magnetic axis.
This paper presents the conceptual design of the "C/O Monitor" for W7-X which has already entered the executive stage.

Keywords: EUV/soft X-ray spectroscopy, plasma impurities, stellarator plasma, C/O Monitor, W7-X

1. INTRODUCTION

Measurement of the impurity content in plasma fusion devices is one of the most significant tasks. Beside the high-Z impurities that have large impact on the power balance in the plasma core (due to their strong radiation losses), the low-Z impurities play very significant role during plasma startup, when the temperature is still not high enough and their radiation might prevent the formation of the plasma. Moreover, in the future fusion devices a high concentration of low-Z material can lead to an unfavorable dilution of the plasma 'fuel' and consequently to a degradation of fusion power. Hence, monitoring of intrinsic impurities plays a crucial role in the proper machine operation. Unlike the low ionization states which are observed mainly at the plasma scrape-off layers, Lyman-α transitions emitted by the hydrogen-like atoms originate from the confined plasma region and are good representatives for the actual impurity concentration.

At the W7-X stellarator [1] (which is one of the largest fusion devices of this type, there are several diagnostics dedicated for observation of plasma impurities [2, 3, 4, 5]. One of them, which is foreseen to be installed in 2020 is called "C/O Monitor" system ('C/O Monitor' is a historical name of the system but the diagnostic will measure also B and N). It will be focused on observation of four Lyman-α lines of low-Z impurities, namely: carbon (C VI – 3.4 nm) and oxygen (O VIII – 1.9 nm), as well as nitrogen (N VII – 2.5 nm) and boron (B V – 4.9 nm). Monitoring of those light elements will deliver an important information about the W7-X status which is essential for the long pulse operation.

Oxygen can be observed in the plasma during every discharge. Its presence is associated with machine venting, when the humidity from the air is adsorbed on the surface of the inner wall of the vessel. During the operation, oxygen is slowly released and penetrates into the plasma. Along with the experimental operation time, the oxygen content decreases, hence its measurement indicates general wall condition.

In order to reduce the influence of the impurities on the plasma parameters, the plasma vessel and the plasma facing components (PFC) can be covered by the lower-Z materials by means of the glow discharge. A candidate for this material at W7-X could be, e.g., boron. Due to the local extreme power loads during the discharges, it is necessary to periodically renew the protective layer of the wall and monitor its quality over time.

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In some of the currently working stellarators (and tokamaks), carbon is used as a first wall material. Sudden increase of its Lyman-α radiation could be an indicator of the plasma-wall interaction. Monitoring of radiation intensity of carbon line would indicate the local overload of some plasma facing tiles. Such information would also be a useful tool for the edge localized mode (ELM) plasma instabilities studies, while their occurance may lead to the expulsion of heat and particles, which can be dangerous for the inner wall of the vessel.

Beside the specific experiments, in which the nitrogen is injected into the plasma vessel in order to, e.g., cool down the plasma edge, the observation of its increased level (together with oxygen) might be an indication for a possible malfunction and a leakage in the vacuum system.

To obtain valuable information about indicated elements the diagnostic system needs to have high throughput and high time resolution (1 ms or better). needs to be wavelength/energy resolving spectrometer in order to simultaneously measure the spectral line and the background radiation. This can be achieved by using focusing (Johann) geometry and dispersive elements with possibly high reflectivity and not necessarily high (but sufficient) spectral resolution. It can be possible due to quite isolated spectral line. While the main purpose of the system is fast, simultaneous monitoring of the particular line intensities, the line shapes are not going to be investigated. All the indicated assumptions had to be taken into account during the design process of the new system.

There are similar diagnostic systems dedicated for the low-Z impurities measurements working on the other plasma fusion devices. Some of them are:

- Impurity monitor for W7-AS
- "CO Monitor" for ASDEX-U [6]
- "KS6" for JET [7]

The impurity monitor for W7-AS was constructed as classical Bragg spectrometer (monochromator) with two Soller collimators, in input as well as in output arm. By rotation of the crystal one can set the Bragg angle and select the registered wavelength. In the case of a fixed direction of input beam, if the crystal is set at angle θ with respect to the input beam, the detector must be positioned at angle 2θ (relative input beam direction), where θ is the diffraction angle. The mechanical system of goniometer ensured the appropriate position of the detector (proportional counter). In this case the line intensity and continuum radiation were measured separately i.e. in different pulses with the same discharge parameters. The construction allowed (after venting of the spectrometer) to change the crystal, what enabled measurements in different wavelength ranges (with different spectral lines).

The "C/O Monitor" for ASDEX-U is constructed with two crystals mounted at fixed angle relevant for measurement of Lyman-αline core intensities of hydrogen-like atoms of carbon and oxygen (so it is also monochromator). The detector, in type of multistrip gaseous chamber (MSGC) is divided in two – one half registers the intensity of the line core, the second half is shielded by a metallic plate. The signal registered by the second (shielded) part of the detector is associated with the neutrons and high energy electromagnetic radiation and can be applied for estimation of the continuum radiation (background subtraction).

The JET' spectrometer KS6 is more complex system. It consists of several channels, each equipped with separate, flat dispersive element (crystal or multilayer mirror). The measurement of the XUV/soft X-ray spectrum is realized by changing the incidence angle (scanning wavelength) either by swinging or rotation movements of the crystal during the plasma pulse. The detector is constructed as a very long proportional counter, allowing registering the radiation reflected at different angles, within wide range (approx. 40^0). This solution allows to register spectral range sufficient for measurement of the whole line profile, including its far wings and determining the line intensity. Disadvantage of this device is low time resolution (order of several hundreds of ms) associated with mechanical movement and inertia of the crystal holder.

All above mentioned (already existing on the other machines) constructions are monochromators with flat, crystals as dispersive elements (apart of one channel of the KS6 which is equipped with a multilayer mirror). The main disadvantage of this technical solution is the fact, that for a defined angle (according to the Bragg law) the constructive interference occurs only for a defined wavelength (narrow range). It means one can measure at given angle only the line intensity together with the underlaying continuum radiation. In order to subtract the background radiation, a separate measurement at a spectral position beside the spectral line has to be performed. An advantage of the "C/O Monitor" system for the W7-X stellarator will be its ability for simultaneous measurement of the lines of interest using polychromators with curved dispersive elements. Hence, for the similar investigations on the W7-X, the new "C/O Monitor" system has been developed. In the later sections more detailed information about the system is presented and the principles of each component are described.

2. GENERAL ASSUMPTIONS OF THE "C/O MONITOR" FOR W7-X

The "C/O Monitor" is a high throughput and a high time resolution system with broad acceptance angle. To obtain simultaneous information about the line intensity and the background, a polychromator system is more appropriate than monochromator. Due to that fact, the "C/O Monitor" for W7-X was designed based on the Johann geometry with cylindrically curved dispersive elements [8, 9]. Such crystal diffracts selected wavelength according to the Bragg's law:

$$\lambda n=2d\sin\theta$$

where λ is the reflected wavelength, n is the order of diffraction, d is spacing of the crystal's layers and θ is the angle of reflection. All rays having common intersection points on the entrance side of the Rowland circle are focused on the detector side of the Rowland circle at angles according to their wavelength. The main properties are shown in the schematic figure 1.

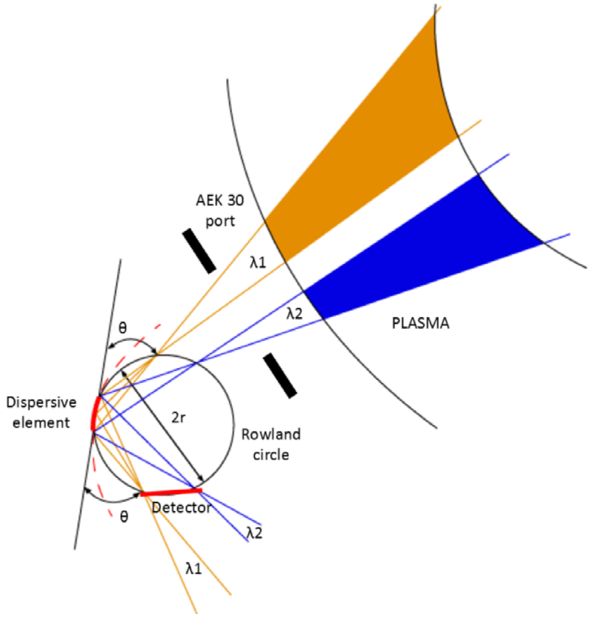

FIG. 1. Johann geometry with Rowland circles radii.

In contradiction to the monochromators, such construction provides energy resolved spectrum that allows to monitor the full spectral range - both central line and its far wings (continuum). Johann geometry determines the position of the detector which is tangential to the Rowland circle (see Fig. 1). Nevertheless, in the case of "C/O Monitor" the detectors are positioned perpendicularly to the reflected beam (which is non-standard solution). This de-focusing infers a certain additional degradation of the spectral resolution, which, however, is sufficient for our purpose, because the lines corresponding to different elements are clearly separated in their spectral ranges and their shapes are not going to be investigated (but intensities only). Their measurement will be performed with high frequency (1 kHz), hence every change of the signal corresponding the measurement of selected impurity would suggest, that the total amount of the particular h-like atom has evolved.

The "C/O Monitor" consists of two spectrometer chambers positioned one over another close to the horizontal position, while one of them (bottom one) is rotated upside down with respect to the upper one. Each chamber consists of two energy channels dedicated for elements which are going to be investigated. One chamber (upper one) is going to measure H-like carbon and oxygen line intensities, while the other two channels in the second chamber will be dedicated for measurement of boron and nitrogen ions. Depending on the incidence angle and the aperture of the incoming light, particular wavelength range is reflected directly onto the detectors active area. To avoid saturation of the system, the intensity of the light will be controlled by piezoelectrical drives with vertically adjusted apertures/shutters. The line-of-sight (LOS) of both sub-spectrometers crosses at the main magnetic axis of the W7-X.

3. REQUIREMENTS FOR THE "C/O MONITOR" DIAGNOSTIC

There are several requirements that must be taken into account in the design process of the diagnostic systems for W7-X. First of all, a very high magnetic field level (reaching up to 2.5 T on the main magnetic axis of the stellarator) should be included in the design process (see Fig. 3).

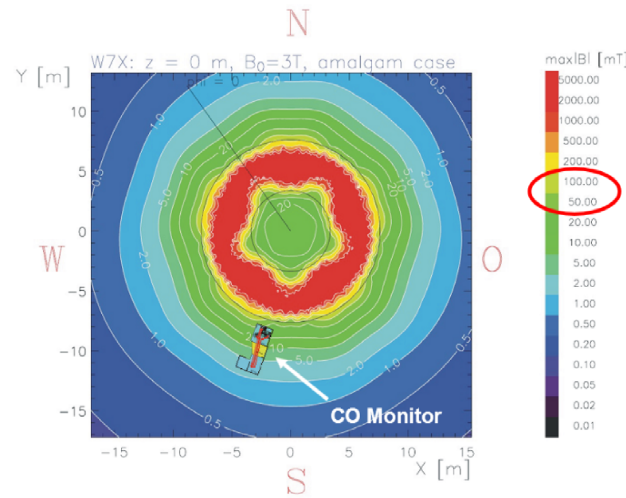

FIG. 2. Magnetic field distribution of W7-X with the indicated position of the "C/O Monitor" system.

The distribution of the magnetic field decreases approximately exponentially with the distance from the main magnetic axis of the plasma. Above 3 m from the plasma center its level is reduced to about 50-100 mT. Operation of the turbomolecular pumps in such strong stationary magnetic field would result with its damage. Moreover, all the electronics as well as the piezoelectrical drives responsible for adjustment of the crystals and shutters positions must be able to work under such conditions and have to be tested in advance.

Therefore, choice of the materials, which the particular components are constructed of, is very essential. Such materials ought to have the lowest possible magnetic permeability in order not to perturb stellarator magnetic field. The possible two types of steels that fulfill this requirement are stainless steels 316LN and 316L.

Absorption of radiation in the observed spectral range in air is very high, therefore the whole spectrometer has to be operated in vacuum and connected to the stellarator's vacuum vessel directly without any window. For the W7-X and related diagnostics, the vacuum level needs to be higher than 10^{-7} mbar. This requires very efficient pumping system that meets serious challenges. Because of the properties of the turbomolecular pumps, such systems should be placed at a distance with sufficiently low magnetic field level (depending on the particular model of a pump). For the safety reasons, the pump dedicated for the “C/O Monitor” should have magnetic bearings instead of regular ones, otherwise there exists a risk that in the case of its failure, the grease lubricating the bearings would be sucked into the plasma diagnostic and then even contaminate the dispersive elements.

During the next plasma operations, several heating systems like Electron Cyclotron Resonance Heating (ECRH), as well as the Ion Cyclotron Resonance Heating (ICRH) and Neutral Beam Injection (NBI) are going to be adapted. In particular, an ECRH heating system heats the plasmas with high-intensity microwave beams (up to 10 MW) in the frequency range of 140 GHz. In many cases the microwaves are not fully absorbed by the plasma. They can be easily reflected by the inner walls of the vessel and penetrate into the diagnostic system, what could cause uncontrolled heating and afterwards even damaging of internal components. As a protection from this kind of hazards, microwave shields against ECRH stray radiation have to be used. Such component is designed as a mesh with 0.7 mm diameter holes and 0.5 mm mesh thickness and is positioned in the entrance bellows flange connecting gate valve with vacuum chambers (see fig. 3). Such protection limits the reaching radiation by about 50%.

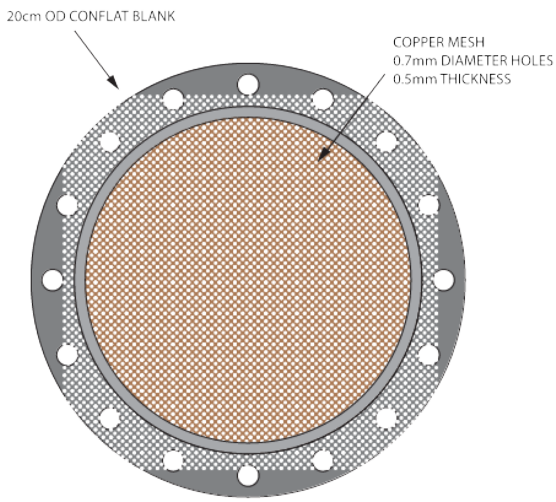

FIG. 3. ECRH shields CAD drawing.

Detectors for the “C/O Monitor” have to fulfill several requirements and withstand the harsh environment of the W7-X. They should characterize with the ability for fast photon measurement with time resolution on the order of 1 ms and the detection sensitivity in the wavelength range of interest. Moreover, an appropriate detection area should correspond to the reflective area of dispersive elements (height). On the other hand, such detection system has to be able to work under high magnetic field level reaching up to 100 mT and be possibly insensitive to the neutron yield and visible light.

4. DETAILS OF THE “C/O MONITOR” DESIGN FOR W7-X

The “C/O Monitor” diagnostic system is a complex device that will be attached horizontally to the AEK30 port of W7-X. The construction consists of 3 main parts – spectrometer part (1), support structure (2) and vacuum line part (3) – see fig. 4. Those are described in the further sections in detail.

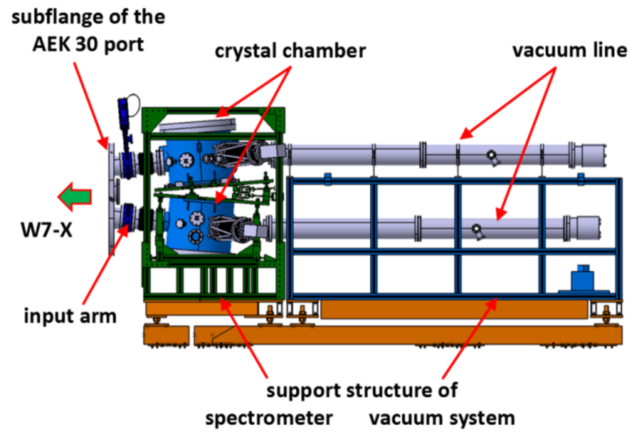

FIG. 4. “C/O Monitor” system attached to the AEK 30 port of W7-X.

4.1. Spectrometer part

The “C/O Monitor” system’s both chambers and all the flanges, screws and bolts will be made of stainless steel 316LN with very low magnetic permeability. The outer vacuum chambers dimensions are 255 mm × 255 mm × 440 mm and the estimated weight is expected to be approximately 200 kg per one chamber. Inside the chambers, the variable apertures adjustment units together with piezoelectrical motors and dispersive elements are positioned (see fig. 5).

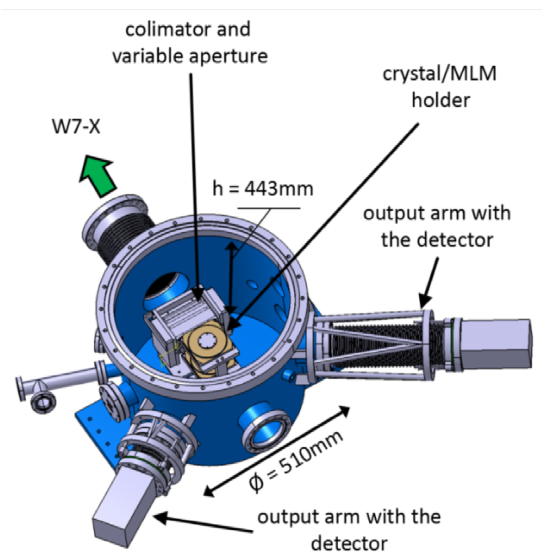

FIG. 5. Sub-spectrometer with internal components.

Both chambers of the spectrometer are connected to the W7-X port via gate valves separating the spectrometers from the plasma vessel. They will be equipped with bellows ensuring their lateral movement in the range of ±7.5 mm. In order to assure its protection from the ECRH stray radiation, the copper micromesh shields will be mounted inside the entrance flange of the vacuum vessel. As an electrical insulation of the "C/O Monitor" from the W7-X machine, the PEEK (polyether ether ketone) sealing will be applied.

The vacuum chambers of the spectrometer are attached to the port in relative angular position equal +4.5° and -4.5° to the horizontal plane. Their mutual setting was dictated by the limited space area reserved for the system. The distance of the centers of the chambers to the plasma main magnetic axis is equal ~3.2 m. Due to the fact that the relative angular position of the crystal chambers is designed to be 9°, the line-of-sight of both sub-spectrometers crosses at the main magnetic axis, and each spectral channel covers the plasma volume of approximately 10 dm^3.

While for the "C/O Monitor" it is essential to obtain the strongest signal corresponding to each of the measured Lyman-α line, it was decided to apply the multilayer mirrors (MLMs) for the observation of C, B and N. Since the oxygen has the shortest wavelength (1.9 nm) and contemporary technology of MLMs production cannot provide good quality mirrors for this wavelength, it was decided to apply the TlAP crystal. Such solution will assure sufficient reflectivity with larger incidence angle for all elements (the reflectivity corresponding to each investigated ion equals: B V = ~25.5%, C VI = ~25.7%, N VII = ~6.3% and O VIII = ~5%). The advantage is relatively high reflectivity adjusted to the appropriate radiation wavelength, and even though the spectral resolution for the selected wavelengths is quite low, it is still acceptable for this task.

The multilayer for observation of the carbon spectral line consist of 90 layers of W/Si, for the boron line 100 Cr/Sc layers and for nitrogen 150 Cr/C layers. While for the C, B and N elements the MLMs were chosen, the reflectivity of the TlAP crystal for the oxygen measurements is sufficient. The curvatures of the dispersive elements corresponding to the observation of those lines are adjusted in a such way, that it will be possible to observe (on the active surface of the detector) the spectral line as well as its far wings. Some of the details are presented in the table 1.

TABLE I. Channels of the "C/O Monitor" system.

Channel	**O VIII**	**N VII**	**C VI**	**B V**
Line wave-length [nm]	1.89	2.48	3.37	4.86
Wave-length range [nm]	1.86 – 2.00	2.25 – 2.66	3.08 – 3.50	4.65 – 5.19
Radius of curvature [mm]	680	880	1720	1419
Bragg angle [°]	49.88	29.71	24.94	29.07
Dispersive element	TlAP	MLM	MLM	MLM

Each dispersive element has 10 cm length and 2 cm height and they are mounted in the chamber one over another (see fig. 6) by means of the specially designed crystal holders. Their rotation axes are identical with the axes of the vacuum chambers. While the reflectivity of the dispersive elements strongly depends on the angle of incidents of incoming light, it is crucial to set their position very accurately (for MLMs as well as TlAP it is approx. 0.2°). This fact indicates the necessity of implementation of the rotational piezoelectrical drives that could achieve the required movement accuracy.

The drives (and hence dispersive elements attached to them) are positioned one over another on the specially designed crystal holder (see fig. 6). Their purpose is to ensure the fine-tuning of the MLMs/crystal angular position. Such drives provide sufficient resolution (14 µrad), what is suitable for the purpose of this spectrometer. Once the optimum angular positions for all dispersive elements is found, they remain fixed. Moreover, the piezoelectrical drives should be grease free systems suitable for the high-vacuum application.

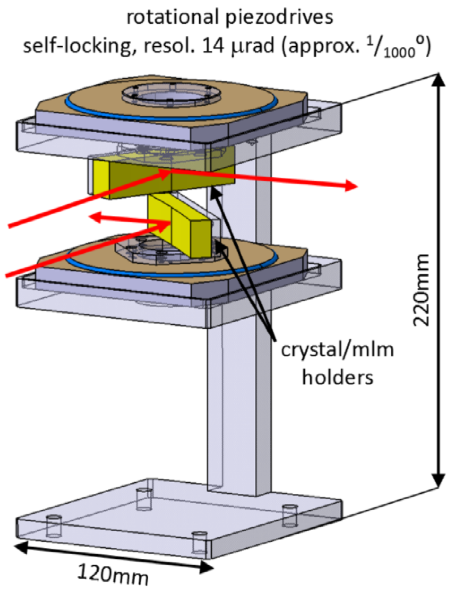

FIG. 6. CAD model of the crystal holder with rotational piezoelectrical drives and crystals. Red arrows indicate the direction of the incoming light.

The observed plasma cross-section in a horizontal/toroidal direction (parallel to the magnetic axis) is slightly divergent and varies for different channels from 0.3 m up to 0.5 m in the plasma center. Those limitations have been dictated by the curvature of the crystals as well as the AEK30 port size (see fig.1) and the dimension of an active area of the detector. In the vertical direction, the observed plasma is determined by multigrid collimator, which is designed as a set of horizontal slits (blue meshes with 1 mm spacing - see fig. 7) [10]. This solution reduces an acceptance angle to 1.43° in the vertical direction, therefore the height of observation is approximately 10 cm in the plasma center. The collimator will be positioned in front of the crystal holders inside the vacuum chambers (see fig. 4).

The grid collimator should minimize the problem of the stray light to the negligible level, since the reaching amount of radiation will be reduced by a half, while the signal corresponding to the line intensity will be strong. For that reason, no additional protection against stray visible light were presumed. Nevertheless, additional protection shields or even filters can be added if necessary.

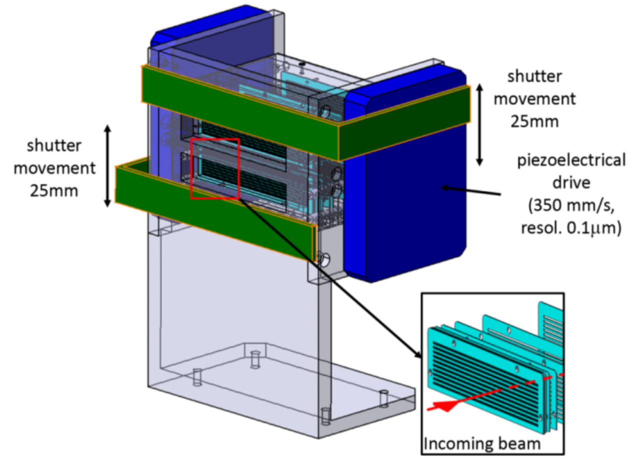

FIG. 7. CAD model of the collimator

In order to reduce the intense radiation coming from the plasma as well as to adjust and extend the dynamic range of the system, the input aperture will be equipped with the vertical shutters. For each channel an independent piezoelectrical drive controlling shutters/slits will be applied (see fig. 7). Their movement velocity equals 350 mm/s with resolution 0.1 μm. Total movement range is 25 mm what allows to cutoff the incoming light.

Due to the fact that the "C/O Monitor" will be positioned closely to the stellarator in the high magnetic field area, it was necessary to check, whether the piezoelectrical drives are able to withstand such conditions. For this purpose, both types of the drives were exposed to the electromagnetic field level reaching 75 mT. No anomaly in their operation was noticed during the tests.

The detectors are connected to the chambers via bellows, nevertheless their orientation is not tangential [9] to the Rowland circle, but perpendicular to the incoming radiation reflected by the dispersive elements. This distorts the shape of the line, but eliminate technical problems associated with the proper adjustment of the detector. They are supported by the specially designed supporting structures that carries the loads generated by the detectors own weight and withstand the vacuum forces. Moreover, the support structure allows to adjust the proper position (see fig. 8) of the detector's photosensitive areas in the range of ±2.5 cm in the focal plane. This solution ensures the freedom to apply different types of detectors.

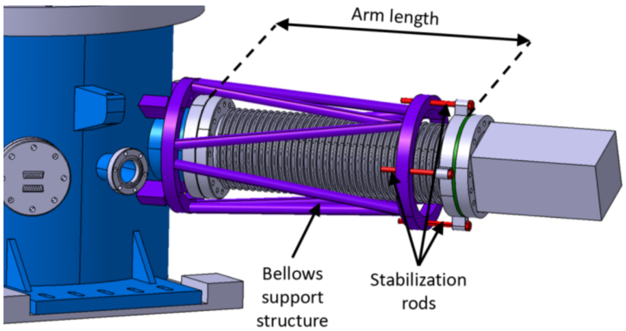

FIG. 8. Output arm of the detector

At some of the diagnostic systems working in magnetically-confined plasma fusion devices (e.g. KT4 and KT7 spectrometers on JET), the Micro Channel Plates (MCPs) combined with the luminescent phosphor and set of photodiodes are used [11]. Nevertheless, for the detection system based on MCPs, it is necessary to ensure sufficient vacuum level (not worse than 10^{-6} mbar), since too high pressure in the vacuum system could damage the detectors. In order to avoid this hazard, an additional pumping system, dedicated for the detectors only, should be applied. Therefore, it was decided to implement more simple solution. Several types of position sensitive detectors were considered [12]. One of them was Gas Electron Multiplier (GEM) detector [13, 14], which was successfully applied for the other spectrometers, e.g., KX1 at JET [15] as a part of soft x-ray plasma spectroscopic system. Another possibility was to use Multi Strip Gaseous Chamber (MSGC), which is applied at ASDEX-U machine and is devoted for monitoring of carbon and oxygen lines [6]. There are also commercially available Charge-Coupled Device (CCD cameras) designed for the XUV detection.

In case of the "C/O Monitor" for the initial phase, the CCD cameras (Andor Newton DO920P) have been chosen in view of its sensitivity in the wavelength range of interest (varying from 60 to 90%), high time resolution (better than 1 ms) and its commercial availability. Nevertheless, for the latter phase of operation, the MCPs, GEM or MSGC detectors are considered [12]. Due to the strong magnetic field in the spectrometers area, it is not possible to apply any air-cooling system for the detector, since there exists a risk of damage of its fan. Therefore, it was decided that the CCD cameras will be equipped by an independent water-cooling system.

In order to check, whether the radiance influx of the measured O VIII line will be strong enough for its detection by the "C/O Monitor" system, some calculations have been performed. The methodology was based on the mapping of the observed plasma volume by selected energy channel. For each of those points, the effective radius (Reff) has been calculated, and hence the determination of Te and ne was performed for the selected heating scenario of the W7-X . The total radiance flux was then determined based on the Photon Emissivity Coefficients (PEC) and Fractional Abundance for the selected line. Since the photon emission from the observed plasma volume was calculated, it was assumed (based on the geometry of the system and reflectivity of the dispersive element), that it is approximately in the range of $2*10^6$ counts/ms. This simplified methodology allowed for the estimation of the upper limit of incoming radiance flux, nevertheless it was important to check, whether the order of magnitude of incoming radiation will be acceptable.

Furthermore, the signal-to-noise ratio (SNR) has been determined for the selected model of CCD camera. The noise level (for the detection system cooled to its optimal value) has been estimated to ~10 counts/s for each pixel. Therefore, while the active surface of the detector is 1024*255 pixels, the total noise is expected $2.6*10^6$ counts/s. Taking all this into account, the achievable SNR is approximately 174, what is sufficient value for the pupose of "C/O Monitor".

4.2. Support structure with adjustment system tools

Another important aspect was the design of the structure supporting the load generated by whole system and assuring the accurate position of the chambers. In order to reduce the transfer of vibration from the vacuum system to the crystal chambers, it was decided to divide the whole structure into two separate sections – one is dedicated for the vacuum part whereas the second one for the spectrometer (see fig. 9).

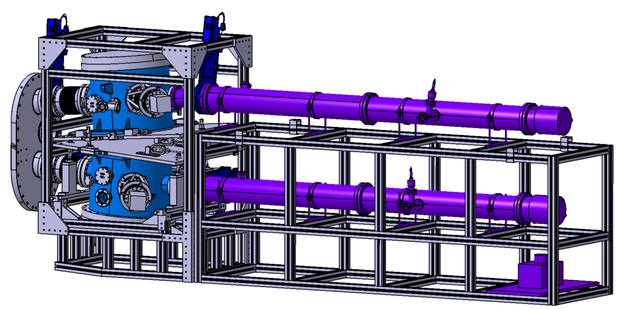

FIG. 9. CAD model of entire system

The turbomolecular pumps are situated at approximately 3 m from spectrometer section. The whole support structure was designed on a basis of aluminum item profiles with the rectangular cross-section 50 mm × 50 mm. Such designed structure is easy to assemble, thus can be installed in the laboratory and then, using the crane, independently transported to Torus Hall of the W7-X.

The entire load generated by the spectrometer part is estimated at around 500 kg, hence it was necessary to perform the computational analysis indicating the possible overload of the support structure (see fig. 10). Such construction has been tested using the Finite Element Analysis (FEM). During the calculations, also the vacuum forces (which are estimated around 1800 N per one sub-spectrometer) were taken into account.

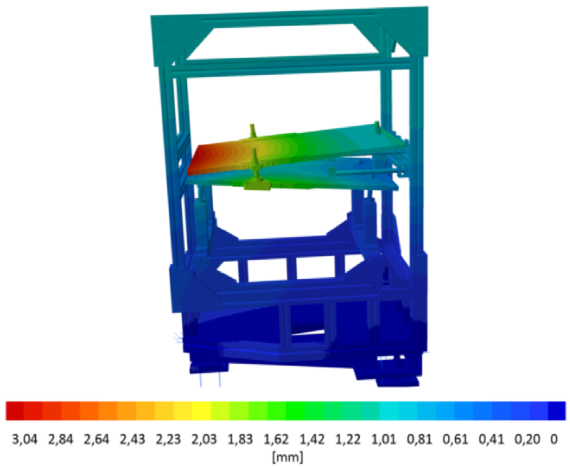

FIG. 10. Deformations of the support structure

The maximum displacement of the chambers was calculated and equals approximately 3 mm. Such low value can be easily compensated by applying the adjustment system tools, which is implemented into the spectrometer support structure.

In order to assure the proper position of each component, special tools for the adjustment had to be developed. One mechanism allows to move the whole system (both sub-spectrometers), while the second one enables to change the position of one (upper) chamber only (see fig. 11).

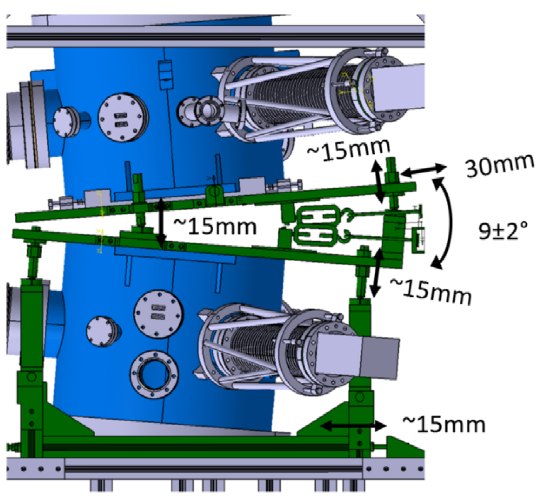

FIG. 11. CAD model positioning system

This design allows to change the angular position of both chambers as well as assures the possibility of their independent movement in X and Y direction in the range of approx. 3 cm. This value is sufficient in order to properly set the position of the chambers.

4.3 Vacuum system

While the soft X-ray radiation is strongly absorbed by any matter, the spectrometer interior is directly connected to the plasma vessel (without any window) and the constant high vacuum has to be assured. For this purpose, the set of two vacuum lines equipped with two turbomolecular pumps (TMP) was designed. In order to avoid possible contamination of the spectrometer by the grease from the bearing of the TMPs, they will be equipped with magnetic bearings instead of regular ones. The proper operation of the selected TMPs is guaranteed since the magnetic field level does not exceed 5 mT. While for the whole spectrometer system (which is placed about 3.2 m from main magnetic axis) this value varies in the range of 50 – 100 mT, it was necessary to prolong the vacuum line and place the TMPs at the distance about 3 m far from the spectrometers, in the area with lower electromagnetic field level.

During the design process of the vacuum system, an efficiency of the TMPs which had to be adapted appropriately to the vacuum conductance of the system, had to be taken into account. Once the system needs to reach the pressure below 10^{-7} mbar, a compromise about the system design (e.g. diameter of the pipes and the pump speed) needed to be determined. On the one hand, the larger diameter of the pipe, the lower is cnductance of the system and the faster the system will reach sufficient vacuum level. On the other hand, the larger diameter of the pipe, the larger area of the inner walls of the pipes outgassing when the system reaches high vacuum range. Taking all this into account, it was decided to use the TMPs with efficiency 400 l/s mounted via DN 160 CF flanges at the end of the vacuum lines. Both vacuum lines are connected with the spectrometers via bellows in order to guarantee some flexibility and reduce pump vibrations that could be transferred to the spectrometers section.

5. Summary

To deliver an important information about the plasma content and hence ensure the proper operation of magnetically confined plasma fusion device, a special spectroscopic system monitoring the radiation from Lyman-a Carbon, Oxygen, Nitrogen and Boron had been developed. Its construction is based on Johann geometry, and consists of 2 independent sub-spectrometers and 4 channels dedicated for the measurements of Lyman-αlines of H-like atoms of carbon, oxygen, nitrogen and boron respectively. All the design work has been already finished and the project entered into the final executive stage. The installation of the "C/O Monitor" system on the W7-X is foreseen before the next operational phase OP2.

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