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Ultra high vacuum ZnSe window flange design for the Phase Contrast Imaging diagnostics for the Wendelstein 7-X stellarator

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This paper describes the Phase Contrast Imaging (PCI) diagnostics with the focus on the atmospheric-vacuum transition realized by a ZnSe window. The PCI system is used to measure plasma density fluctuations in the W7-X stellarator at the Max-Planck-Institut für Plasmaphysik (IPP) in Greifswald, Germany.

1. Phase-contrast imaging at Wendelstein 7-X

The phase-contrast (PCI) diagnostic measures plasma density fluctuations via the associated changes of the plasma refractive index [1]. An expanded CO_2 laser beam is radiated through the plasma, which is scattered on the density fluctuations. The intensity and angle of the resulting scattering orders are a function of the amplitude and wavenumber, respectively, of the density fluctuations. *Figure 01* the arrangement at Wendelstein 7-X is depicted. Shown are a section of the outer cryostat vessel and the ports, which are used for the PCI observation.

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The laser beam is expanded on an optical table (blue optical table) by a telescope optics to the desired beam diameter. A mirror system (1) directs the beam through a zinc selenide (ZnSe) window (2) at the entry port flange directly through the plasma (3) center.
Through a second ZnSe window on the exit port flange, the beam is directed via a similar set of mirrors to the receiver optical table (yellow optical table) where the measurement takes place.

A typical diameter of the laser beam is approx. 120mm. Due to the wavelength (10.6µm 30THz) of the laser beam ZnSe windows must be used.

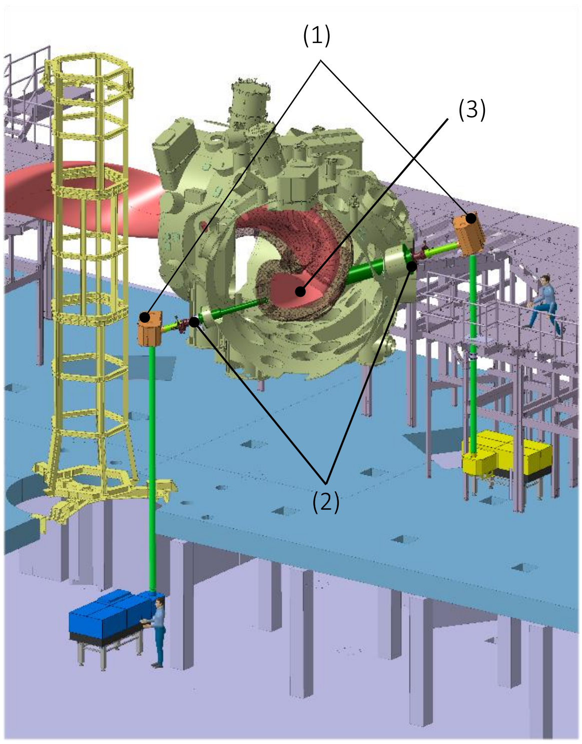

Figure 01: Diagnostic in the torus hall

2. The vacuum barrier

The vacuum barrier at both ports AEZ-50 and AET-50 consists, respectively, of an adapter piece to reduce the port diameter to a DN160CF, a pneumatic gate valve with pressure instrumentation and a ZnSe window. The purpose of both gate valves is to provide a reliable vacuum barrier in case of leakage of the windows. In all other operation scenarios the gate valves stay open. In case of a closed gate valve and a pressure difference of $<10^{-5}$ mbar, an all-

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metal sealed valve is installed to pump down the volume between window and gate valve via mobile vacuum pumps. No permanent pumping is installed.

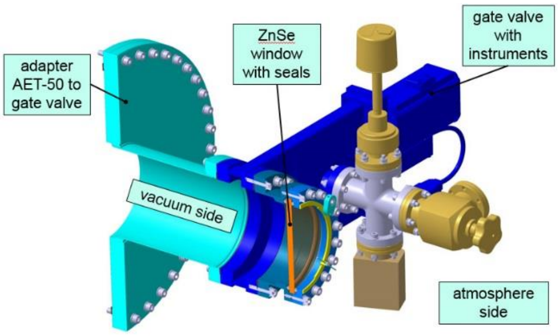

Figure 02: Vacuum barrier

The approx. 2 meter long diagnostic ports have conflat flange (CF) seals. The challenge is to seal the window, which represents the vacuum barrier, into the counter flange ultra high vacuum (UHV) tight. Additionally, the seal needs to fulfill W7-X requirements as compatibility with the bake-out temperature of 180°C and compatibility with electron-cyclotron-resonance-heating (ECRH) stray radiation power densities, demanding for all-metal seals.

3. Sealing concept

Windows are required to observe the plasma and the components in the plasma vessel on the W7-X. These windows are usually mounted at the ends of the ports.
The windows must meet the mechanical, thermal, radiation protection and vacuum requirements of the W7-X.

Commercially available sight glasses (windows) do not generally meet all of these requirements in their. For this reason, special solutions must be found. One solution is the HELICOFLEX® sealing concept.

[2]The Helicoflex® seal is an elastic metallic seal, which has proven its efficiency in many fields ranging from research to industry. Its basic concept (sealing lining + spring) allows to adjust the characteristics and the shapes of the seal to your assembly and to meet the sealing requirements.

The sealing principle of the Helicoflex® family is based on the plastic deformation of a jacket of greater ductility than the flange materials. This occurs between the sealing face of a flange and an elastic core composed of a close-wound helical spring. The spring is selected to have a specific compression resistance. During compression, the resulting specific pressure forces the jacket to yield and fill the flange imperfections while ensuring positive contact with the flange sealing faces. Each coil of the helical spring acts independently and allows the seal even the surface irregularities on the flange surface.

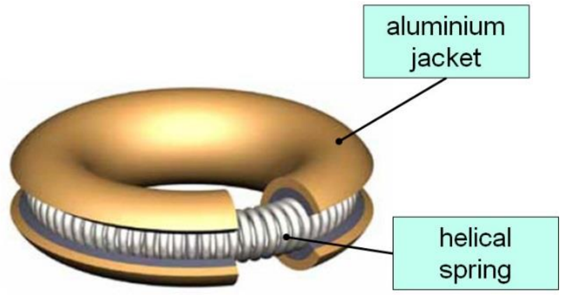

Figure 03: Helicoflex® seal

4. The window design

In the following construction two different seals from the elastic metallic seal family were used and tested. In addition, further parameters were changed after the first failure.

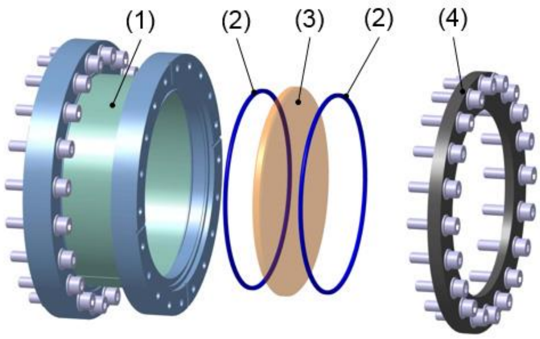

Figure 04: General design

In the first attempt, a stainless steel welded construction was chosen as the basis [1] for the ZnSe window *Figure 04* (3). On one side the connection to the vacuum slider (CF DN 160 standard) must be established and on the other side the window is installed.

A type of double sealing system is selected to hold the window accurately defined. From a purely vacuum-technical point of view, it is not necessary to seal the window with two seals, but in order not to brace it and create defined surfaces, the somewhat costly solution was chosen here. The window is thus floating between the seals.

To obtain as large an apperture as possible, a gasket with a very small cross-section is selected. The Delta seal from the Helicoflex® sealing family, which has proven itself for Saphier windows in the past, is selected for this design. The pressing force for the seal required to enter the UHV range is set via the groove depth. For this purpose, the manufacturer has issued an installation guideline.

Design of the double sealing system:

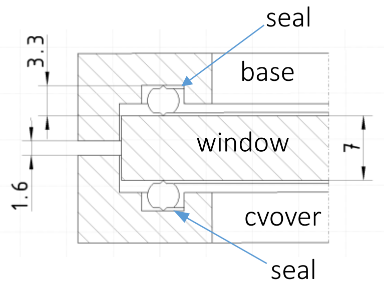

Figure 04: Dimensioning of groove depth

Construction of the Helicoflex- Delta® seal:

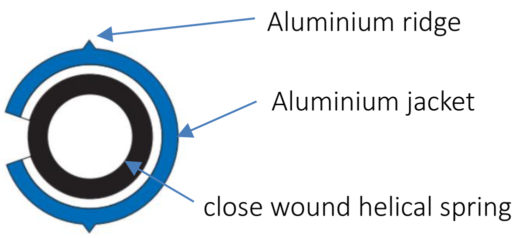

Figure 05: Geometrical shape

The Delta® seal is unique by using two small ridges on the face of the seal. The load required to plastically deform the jacket material is greatly reduced by concen-trating the compression load on the ridges.

Pressing force (Y) groove depth (e) diagram of the manufacturer:

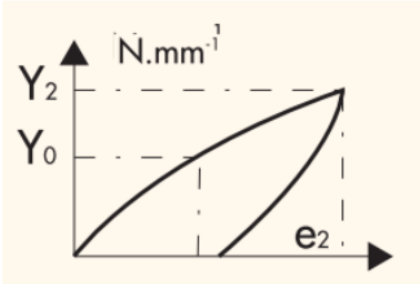

Figure 05: Force-groove depth diagram

The 1.6mm from *Figure 04* corresponds here to the 2 x e2 in *Figure 05* from the diagram. After tightening the screw connection, the maximum pressing force of Y2 = 140N/mm is reached. Unfortunately, the construction of the window construction did not lead to success. As *Figure 06* shows, the ZnSe window is broken after assembly and thermal heating to 180° C in the place of the seal. The break of the window happened during the vacuum test.

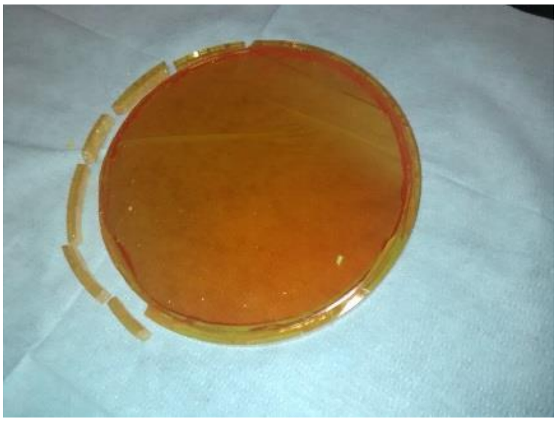

Figure 06: Window from the first attempt

After the first attempt failed, the construction, the seals and the window were changed. Here the welded construction was replaced by a purely machined CNC turned construction (only the base [1]), so that no problems can arise with welding distortions. The window thickness has been increased from 7mm to 10mm to counteract a possible amorphousness. The window diameter has been increased to reduce the edge load on the window. Finally, a different seal was chosen from the Helicoflex® sealing family and different dimensions and type.

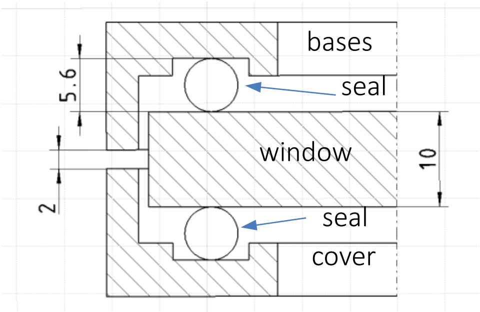

Figure 07: Dimensioning of groove depth

The Helicoflex seal without ridge is selected as the seal. In addition, the cross-section of the seal is increased, so that the bearing surface between window and seal is also increased. The screw connection of the cover is no longer tightened to the block to compensate for settlement properties, especially after baking out.

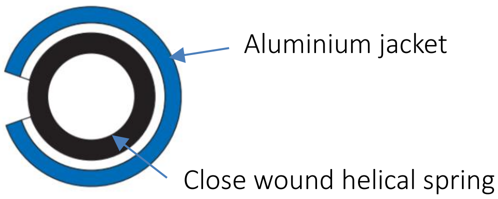

Figure 08: Geometrical shape

The cover is tightened via the screw connection so that the gap dimension of 2 x e2=2mm is reduced to a residual gap of 0.8mm. We are now at Y3 and e3 (see *Figure 09)* on the force-groove depth diagram.

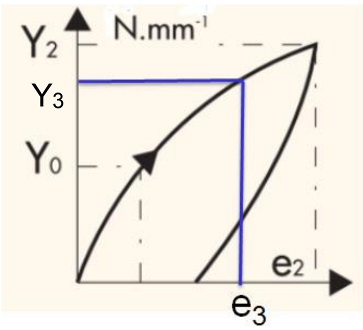

Figure 09: Force-groove depth diagram

The subsequent leak test showed a leak rate of UHV helium-tight < 1E-9 mbar-l/s and thus fulfilled the specification.

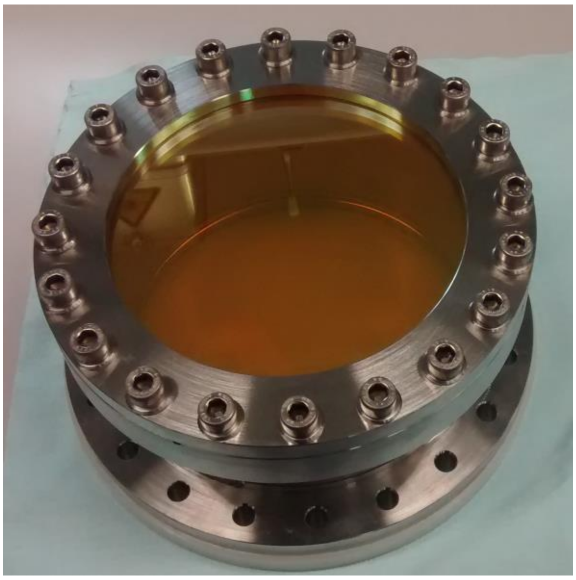

Figure 10: Finaly mounted ZnSe-window

5. Conclusion

Unfortunately, the first attempt did not lead to success. Whether it was due to the welding distortion, the seal, the dimensions or the glass cannot be said with certainly.

For the second attempt, the construction was redesigned, another gasket was chosen, change the dimensions of the window and during assembly the cover was not screwed down to the stop but so that a gap of 0.8mm (e3) remained. The following leak test showed a leak rate of UHV helium-tight < 1E-9 mbar-l/s and thus fulfilled the specification.

Acknowledgments

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References

[1] O. Grulke 1-QOC-S0002.0 Projektspezifikation Phase Contrast Imaging; 1-QOC-Y0000.0 Conceptual Design Review Phase Contrast Imaging (IPP-Greifswald PLM System internal)

[2] TECHNETICS Group booklet of Helicoflex® seals