A NEW SEALING TECHNOLOGY FOR HIGH PRECISION WIDE OPEN UHV VACUUM FLANGE AND WAVEGUIDE CONNECTIONS WITH METAL GASKETS

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Abstract

The European-XFEL X-Ray laser facility is located in Hamburg. Since its commissioning in September 2017, this large X-ray laser opens new research opportunities for industrial users and scientists. For many beam diagnostic devices ultra-high vacuum components with high mechanical precision and additional strict requirements on particle cleanliness were produced. A vacuum chamber for the bunch compressor (BC) with a cross section of 400 mm*40.5 mm made of stainless steel blocks 1.4429 (316 LN) has been installed. These chambers have integrated flange-connections for large VATSEAL® gaskets. The tolerances for these flanges are extremely tight to ensure save vacuum tight sealing.

This contribution will report of a new technology for such large rectangular or other large flange surfaces. Furthermore this contribution will compare the present with this new technology. This new technology can be used as well for other vacuum flange metals like aluminium or titanium. Using of this technology for applications under special conditions, like particle free applications due to the non-lubricated conditions, are conceivable.

INTRODUCTION

The European X-ray Free-Electron Laser (E-XFEL) [1] is a 3.4 km long international facility, starting from DESY in Hamburg/Lurup and ending in Schenefeld (Schleswig-Holstein) in Germany. The bunch is compressed in two of three magnetic chicanes by factors of 20 and 5, respectively. Details about the chicane properties can be found in [2].

Particle accelerators like the E-XFEL are using various beam diagnostics, e.g. Beam Position Monitors (BPM) for measuring the beam orbit and diagnostics to measure longitudinal beam properties [3]. The XFEL bunch compressor (BC) incorporated three magnetic chicanes. These BC's are equipped with large vacuum chambers to ensure a beam transport with no losses under different conditions. In each of the straight sections of BC 1 and BC 2 beam diagnostic elements are located, namely an 'Energy' BPM (BPMS) and an Optical Transition Radiation (OTR) station. The vacuum chamber for these devices had to be extended to a rectangular cross section of 400 mm * 40.5 mm to fit the large vacuum beam pipe. This big cross section causes a new sealing technology of the vacuum chambers and their flanges. The flange connections have to be leak tight up to Ultra-High-Vacuum (UHV) properties better than $1*10^{-10}$ mbar leak rate.

GASKETS FOR NON SYMMETRICALLY APERTURES

For wide open or non-symmetrically flange apertures flange connections with VATSEAL [4] gaskets are used, instead of normal Conflat (CF) with copper gasket rings. VATSEAL connections are made for special vacuum connections, RF structures and as well as for synchrotron beamlines. Further requirements for all-metal seal connections with VATSEAT gaskets are low permeation, low outgassing, baked-able, no hydrocarbons, low particle emission and radiation resistive. Fig. 1 shows a few VATSEAL gaskets.

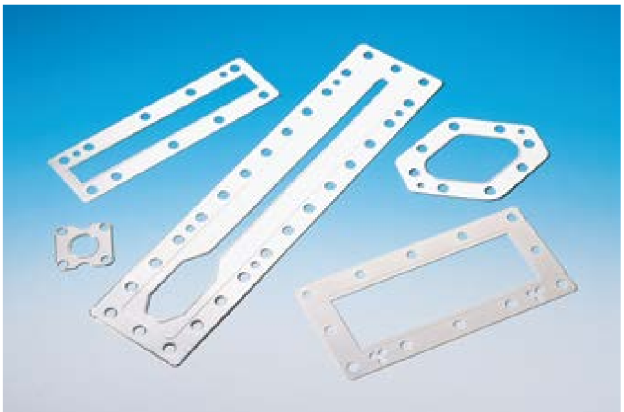

Figure 1: VATSEAL gaskets from VAT, CH [4]

A VATSEAL gasket consists of an all-metal gasket with a raised, contiguous "gasket lip" on both sides. The cross section of the raised sealing strip is highly precise and designed to follow the real vacuum outline, close to the inner diameter. Most of VATSEAL gaskets are conceptual costumer design. The major factor of reliable vacuum connections is the quality and appearance of the stainless steel flange surfaces. The applied manufacturing process after machining vacuum chambers is a handmade process step! This technology will be described in the next chapter before the new technology will be discussed.

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Table 1: VATSEAL Parameter [5]

Parameter	Value
Maximum flange size	500 mm*600 mm
Distance edge to flange	1 mm
Flange material	Stainless steel
Flatness over largest length	**Max. 0.2 mm**
Flatness over 50 mm	**Max. 0.02 mm**
Surface finish	**N4 (Ra=0.2 µm)**
Distance between holes	Max. 50 mm
Sealing force	Min. 2000 N/cm sealing line

STATE OF THE ART

The vacuum tightness and reliability of VATSEAL connections are direct consequence to the flange design and the appearance of sealing surfaces. Therefore critical issues are surface finish, roughness and flatness of the flange sealing area.

While the former is a matter of applying correct processes during fabrication, the latter requires consideration of the forces required to adequately compress the seal. In addition, because the seal protrudes only 70 µm on either side of the gasket body, flanges with insufficient rigidity will interfere with the seal gasket or opposing flange face during tightening before sufficient sealing forces are achieved [6]. The technology parameter and boundaries are written in table 1.

The leading fabrication process is a milling technology for pre-fabrication of rectangular or beam pipes with multi geometric cross section. The second step is leveling the surface to get a very good flatness and roughness of the surface. In this process the defined surface parameter will be prepared. Then the parts will hand over to the last step for finishing the surface in a manual made grinding step. Therefore special grinding oil, a special grinding machine and several sand papers are necessary. The surfaces will be sprinkled with this oil before the manual grinding process starts. Slowly and with the right pressure the grinding machine has to slip over the flange surface with consistent circular motions.

The risks of this manual finalizing process are pressing too strong or too soft and producing dents or rising surfaces. Furthermore oil will introduce in the sealing face, which causes that hydrocarbons will penetrate into the materials. This can be a negative impact to UHV requirements.

These conditions could produce many possibilities of higher failure rates and implicates often reworking of components. This increases the cost, time delays or sometimes defective devices. Therefore a new technology has to be formed to produce these special diagnostic BC vacuum chambers for the E-XFEL BC. This technology has to be a reliable, repeatable and well documented machining process. In close cooperation with the DESY Zeuthen mechanical division a new sealing technology for high precision had been worked out.

OPJECTS

The 16 special vacuum chambers have been fabricated completely in DESY Zeuthen as an in-house fabrication. Each vacuum chamber with weight over 35 kg have been fabricated out of a single massive 316 LN block.

The vacuum leak requirement for the XFEL UHV system rate has to be below $1*10^{-10}$ mbar l/s.

The geometry of these chambers had to be chosen such that they match the requirements of independency and stability; therefore this massive stainless steel (SST) block was used. Two vacuum chambers are shown in Fig. 2. The first production step was pre-milling of outer contour and wire eroding of the inner geometric, followed by heating of blocks and the second turn of milling and wire eroding. After these steps the pre-chambers were cleaned by electro polishing. Continued by final wire eroding, milling of knife edges and final outer geometric. The next chapter will describe the new technology.

NEW SEALING TECHNOLOGY

Many man-hours and efforts are necessary to build these vacuum chambers. 8 to 10 weeks of production time are necessary for one chamber; therefore the last finishing step has to be a machined technology with high repeatability.

The new technology should cover the following requirements:

- Easily repeatable, easy feasibility
- High processability and well documented
- UHV suitable and low particle emission
- No hydrocarbons
- Long-time stability and suitable for VATSEAL gaskets and wide flange apertures
  For multi-use designed and re-machinable
- And at least non-abrasive process

Starting from these requirements the project was started with a benchmark of sealing technologies. And after this benchmark a new idea arises from the mechanical technique of roller burnishing, which serves to smooth the surface as well as to increase the surface hardness for strain- hardening.

The new technology consists of a hardened metallic pin rounded, at the tip, describes a previously programmed desired path. This pin follows a defined contour with an exactly determined contact pressure and uninterrupted process speed. The pin formed a “groove” into the sealing surface. Beginning from the inside-vacuum contour, as a groove of a long-playing-record, it follows the predefined path outwards evenly. This new technique gives many positive aspects, like no use of any oil or lubrication.

Following **positive aspects** are carried out:

- Easily repeatable, well documented, high processability and easy feasibility by used well-known machining processes and CNC technology
- UHV suitable, no oil, no lubrication or other liquids
- Higher vacuum tightness due to this special (long-playing-record) rill
- Smoothing of sealing surfaces in one step, no further manufacturing steps necessary (no pre-smoothing the surfaces or getting highly flatness)
- Eliminated the manual process steps of finishing sealing surface, reducing of failure rate
- Re-machinable and non-abrasive process

The Fig. 2 shows the two different types of vacuum chambers at two significate process studies, pre-machining, final wire-eroding and electro polishing. On the right OTR chamber with the "sealing grove" is shown. It covers and protects the beam pipe vacuum to atmosphere. The aperture is large and therefore more screws are used to bring up the tightening forces. The sealing areas follow as close as feasible the inner vacuum structure. The radius of the grove is designed for easy production. The width of the grove is bigger than the sealing edge of gasket to have an overlap.

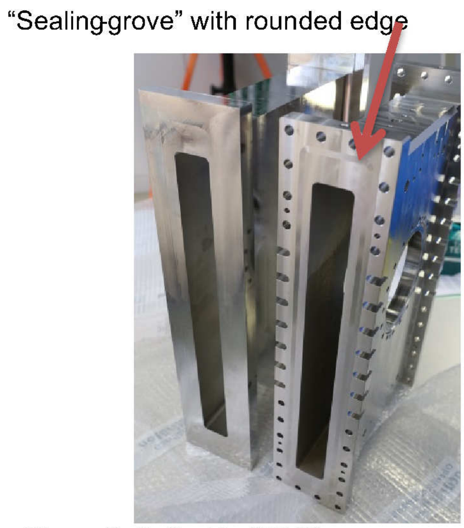

Figure 2: Left side BPMS as pre-part and on right a "ready part" of OTRS chamber with integrated "sealing grove", see arrow. (Photo taken by D. Nölle, DESY, Hamburg)

By using this technology it is not necessary to finish the surface. The require VATSEAL parameters for roughness and flatness, shown in Table 1 are much more relaxed. The surface has to be milled conventionally with using normal machining tools for SST materials. A roughness in the range of Ra 0.6 µm is sufficient.

Figure 3: A macro image 10:1 of the "sealing grove"

In the Fig. 3 the concentrically rills are visible. The positive effect of cold-hardening and smoothing of surface are challenges of this method.

QUALITY TESTS

In a first step some test flanges with this technology were made. These flanges, see Fig. 4, were used for vacuum leakage test and first microscope inspections. Later one of the flanges was used for further quality inspections like white light interferometry (WLI), shown in Fig 6 and micro hardness measurements, see Fig 5. WLI is a non-contact optical method for surface height measurement on 3-D structures. Surface profiles between tens of nanometres and a few centimetres can be observed.

Figure 4: A special vacuum test adapter for all principle tests and for the final acceptation test like rest gas analysis and leak check.

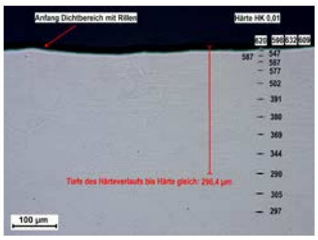

Figure 5: The micro hardness (HK 0.01) profile measurement. (BAM [7], Berlin, Germany).

In Fig. 5 the deepness of the hardness profile is approximately 0.3 mm. The hardness increases from 297 HK 0.01 to 587 HK 0.01. After 30 µm the hardness dropped down a little bit. Between 30 and 100 µm the hardness dropped down 200 points. The raw material has been a value between 300 and 400 maximum.

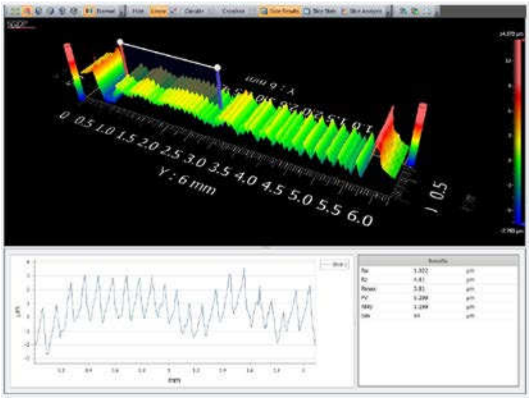

Figure 6: Special white light interferometry profile. (BAM [7], Berlin, Germany)

In Fig. 6 the continuously profile roughness is shown. The width of the “sealing-grove” is between 0.5 mm up to 6.0 mm. The profile show peaks up to 3 µm and the roughness is Ra 1.022 µm.

CONCLUSION

This new technology is created and worked out for easily repeatability, high processability and easy feasibility by using well-known machining process of CNC technology. This method was tested for SST flange material. Other materials like aluminium or titanium seems to be possible, too. All flange profiles can be realise. This technique is suitable for vacuum, fluids and solid particles too. The patent for this technology is pending.

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