The Influences of Material Properties to Micro Damages on Vacuum Chamber CF Flanges

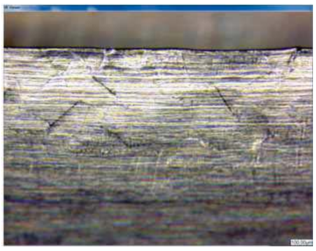
Max Holz, Martin Lemke, Dirk Nölle, Christian Wiebers Silke Vilcins (DESY Hamburg, Germany)

Abstract

The European-XFEL, a 3.3 km long X-Ray laser facility, powered by a 17.5 GeV superconducting linear accelerator, is located at DESY in Hamburg. For the diagnostics ultra-high vacuum components with high mechanical precision and strict requirements on particle cleanliness had to be developed, designed and produced. For the screen system of the facility, enabling to observe the size and shape of the electron beam, massive vessels, precisely milled out of stainless steel blocks 1.4435 (316L) have been produced. For these chambers all flange-connections are milled into these blocks. This paper will report on micro damages in these integrated knife edges and will present simulations of the damage mechanisms. It will also describe the influences of material properties of two different stainless steel brands, effects on the "knife edge" due to the penetration into the gaskets as well as the non-elastic deformation of the sealing area. The dependence of tightening forces under special conditions, like the very clean conditions in particle free applications due to the non-lubricated conditions will be reported. A "cooking recipe" to avoid such micro damages will be given.

„Orange skin" - effect

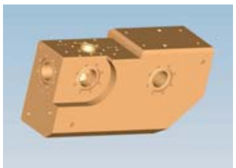
This phenomenon was detected on most of the Conflat knife edges of the scintillation screen monitor vacuum chambers. On the surfaces of the knife edge slightly dents were detected and the knife edge corners were destroyed.



3D picture of microscope inspected the knife edge of CF flange (rectangle to the 20 ° knife position)

Introduction

Particle accelerators are used as standard as well as and special diagnostics, also for the European XFEL (E-XFEL) at DESY, Hamburg. A scintillation screen monitor system has been designed for diagnostic purposes in particle beams. For this system two different types of special vacuum chambers have been fabricated. More than 50 vacuum chamber with weights over 50 kg have been fabricated out of massive blocks. The geometry of these chambers had to be chosen so that they match the requirements of independency and stability; therefore a massive stainless steel (SST) block was used. The dimensions of these vessels are bigger than all designs at DESY have been in the past. Since it was very difficult to find any supplier for material in 316 LN, a compromise was found to use 316 L. In the material certification the value for the hardness was a little bit under the minimum bounder of DESY's specifications with 158 HB.



This picture shows a type B vacuum chamber

General information

Stainless steel material (SST):

- Development around 1910
- Non magnetic property
- Durability of surface condition
- Good welding properties
- Corrosion and oxidation resistance
- Standard material on market
- High temperature mechanical strength

Producing of SST:

- Vacuum Melting process (VAR)
- Electro-Slag-Melting process (ESR)
- Annealed
- Forged multidirectional
- 3.1 certificated to described requirements
- High metal SST alloys 316 L/316 LN

Vacuum sealing technology:

- Gasket sealing technology defined by the American Vacuum Society
- Vacuum connections effectively by compressing a gasket
- Metal gasket or non metal gaskets
- For one time use or multiple use
- Flat, wire or polygonal
- Used under pressure or shear
- Vacuum level from low to UHV and XHV vacuum requirements

Material specifications and manufacturing

All vacuum chambers are made by outside vendors.

Material specifications

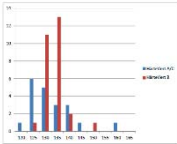
- Raw material 316 L (ESR)
- Hardness 158 HB, documented in 3.1 certification
- 2D forged bar
- Ni > 12 %
- N > 0.14 %
- Grain size 3 to 4
- Yield strength Rp $_{0.2}$ > 300 N/mm^2
- Tensile strength > 600 N/mm^2
- Non – metallic inclusion DIN 50602 K1 < 2
- Magnetism < 1.005

Hardness check

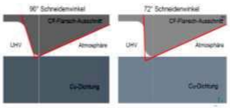
To find the reason for the "orange skin" one Type B chamber the hardness was checked. This first test showed a discriminated value to raw material certification. The results varied between 145 and maximum 154 HB.
One type A/C chamber with 164 HB had the highest value. The minimum value was 122 HB. The average of 20 chambers type A/C was 135 HB. The type B vessels didn't show different results. The minimum value was 129 HB and one chamber had a maximum of 151 HB. The average of type B was 137 HB. Moreover the hardness of the raw material was checked, too. The results were in the same bounders of the chambers. Minimum value was 141 HB and maximum was 152 HB. The measurements have been done at DNV GL in Hamburg.

Test procedures, FEM analysis and material analysis

FEM analysis, done by Martin Lemke, DESY



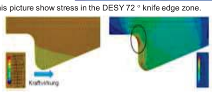
Hardness check of the 50 vacuum chambers



ISO/TS 3669-2 DESY standard knife edge

This picture show stress in the ISO/TS 3996-2 knife edge zone

This picture show stress in the DESY 72 ° knife edge zone.

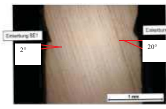


These pictures are shown the direction of forces and the value due to the assembling of flanges

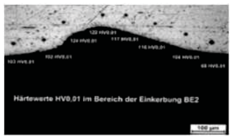
This picture show twisted copper gasket.

This picture is presented pairing of DESY knife edge with ISO/TS 3669-2 knife edge

Polished cut image of DESY 72° knife edge contour



3D picture of microscope inspected the knife edge of CF flange



Polished cut image of ISO/TS 3996-2 90° knife edge

Results and Conclusion

The results are presented in this chapter. After several months ramp-up time of testing, investigations and analysis the new production went smoothly. The newly selected material had a significant higher hardness than the DESY specifications had prescribed.
The FEM simulation results gave a lot of new aspects in several iteration steps all critical forces and zones were pointed out. The FEM simulation gave excellent results for deeper understanding both common knife edge versions used at DESY.
Furthermore the deformations of the copper gaskets are not negligible. The behavior of copper during cold hardening under pressure is a serious problem especially if the minimum boundary of flange material is close to the consistency of copper gaskets after they were assembled under pressure.

All of the hardness tests, analysis and measurements have shown that the raw material certification is not enough for accepting the material. All tolerances were pointed out and had to be integrated in specification for ordering raw materials.
The sealing areas of knife edges receive a lot of power transmission and radial forces. These forces will be never noticed until micro damages on sealing area on the surfaces of flanges happen.

The proper material for manufacturing massive vacuum chambers has to be well defined and very painstakingly and carefully inspected before starting serial productions.
Typical material certifications are made before the raw materials are forged, deformed and annealed. A lot of material specifications are focused on tensile and yield strength, but the hardness of this material mustn`t be ignored. Hardness is a significant property of reliable vacuum tightness, and also for reusing vacuum flange connections. If the hardness of the copper gaskets is under pressure in the order of the stainless steel hardness boundary, serious vacuum problems may appear.
FEM analysis gave a better understanding material stresses and forces of several gasket knife edges.

This picture show Max during the final assembling a type B chamber in the XFEL tunnel

Lessons Learned

One lesson learned was to say good bye to constructions of massive blocks like these two designs with integrated Conflat flanges. Running into serious problems in case of having to rework these chambers is one aspect for using vacuum chambers made of standard Conflat flanges with normal standard SST pipes.

Cooking recipe:

- First clarify, concentrate and be precise about all requirements to the design (incl. all environment conditions, to be bake out, movements, cleanness requirements…)
- Clarify and require the raw material specifications
- Use standard norms, references or guidelines
- Earliest decision "Make" or "Buy"!
- Use pipes and standard Conflat flanges if you can!
- Make a requirement matrix and estimate the technical functions, write out the results
- Before ordering raw material, check very painstakingly and carefully the material properties which will be documented in the 3.1 material raw certification. This 3.1 certification should be related to your delivered batch!
- Hardness for secure and reliable UHV or higher vacuum applications should be over **170 HB, better up to 185 HB** (results of many experience and tests)
- N better 0,14 %, Cr not over 17,5 % and Ni more than 12 %
- ESR = Electro-Slag-Remelting, forged multidirectional and annealed is mandatory, full austenitic structure
- Early integration of material producers or vendors, manufactures and purchase office
- If you make your own design, build more than one prototype for serial productions
- In according to ASTM E112-13 the grain size shall be better than 3, but for machinability not better than 8!
- Independent material tests of the raw material should be done after delivering the material
- Make Quality Audits with suitable vendors or manufactures
- Make a risk analysis and if you can use project management competences

GOOD LUCK!

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