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Stainless Steel Vacuum Chambers

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STAINLESS STEEL VACUUM CHAMBERS
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Abstract

The vacuum properties of stainless steel are excellent. The fabrication and welding process can be handled easily by a large number of vacuum manufacturers. In particular, the use for intermediate energy light sources gives a lot of advantages, which leads to a cost effective and industrial vacuum system design. Several design solutions are compared in this paper. The common fabrication and vacuum conditioning processes are discussed.

1 INTRODUCTION

For storage ring light sources the vacuum system has to provide the required vacuum pressure of about 1 nTorr in order to achieve beam lifetimes greater than 10 hours with beam current in the range of 400 mA. The vacuum pressure strongly depends on the photo desorption of the synchrotron radiation.
The photons which are stopped by the photon absorbers or the wall of the vacuum chamber, produce photoelectrons with energies from some 10 eV up to few KeV. These photoelectrons can desorb residual gas molecules from the chamber walls. The desorption rate is time dependent and decreases as a function of the accumulated beam dose.
A characteristic feature of vacuum chamber designs for 3rd generation synchrotron light sources is the use of the antechamber design. The vacuum chamber consists of an electron beam chamber and an antechamber. The electron chamber is open to the side of the antechamber. The synchrotron radiation can pass through to the antechamber where discrete absorbers intercept the photons that are not used. The design principle of the 2nd generation light sources with a vacuum chamber without antechamber where the photons hit on distributed absorbers in the chamber wall is used partially only in the chambers of the straight lines where is lower synchrotron power density.
Especially for storage ring light sources in the intermediate energy range stainless steel is an ideal vacuum chamber material. This presentation wants to give an overview of the design, manufacturing, and operation of some stainless steel vacuum systems.

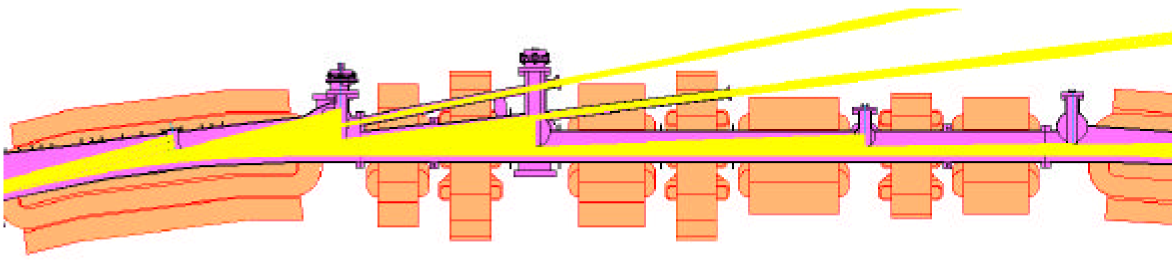

Fig. 1a Full Antechamber Design (SLS)

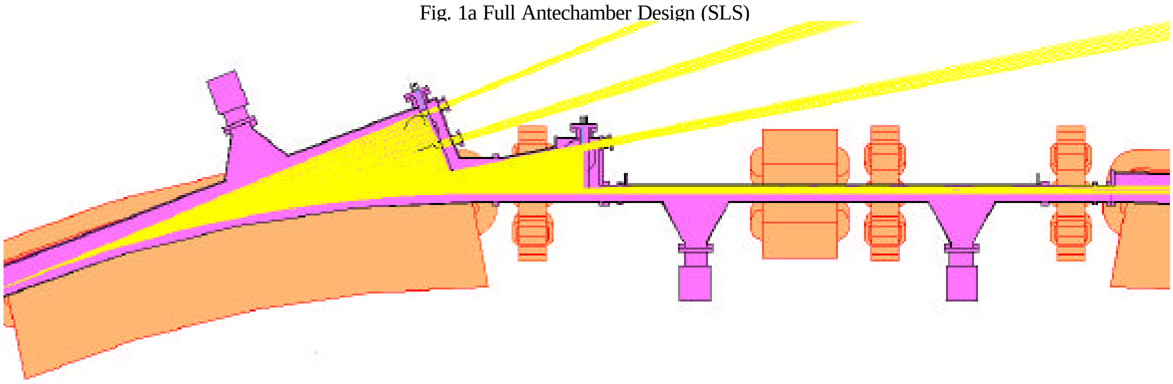

Fig. 1b Antechamber in Bending Magnet (ANKA)

2 MATERIAL PROPERTIES

The thermal conductivity of stainless steel is very poor. That is the reason why in stainless steel vacuum systems copper is used for photon absorbers.

The value of the electrical conductivity is also very low. This leads on one side to a contribution to the resistive wall effects and can pose a real problem in undulator vessels with very small apertures which eventually can be cured with a copper coating on the inner chamber surface [1]. On the other hand the low electrical conductivity results in low eddy current effects which have to be taken into account when the global closed orbit correction system works at frequencies of 100 Hz and higher [2].

The photo desorption coefficient of stainless steel is similar to copper but at the beginning it is one order of magnitude lower compared to aluminum [3].

The austenitic low carbon steel AISI 316 LN is the most commonly used material for stainless steel vacuum chambers of synchrotron light sources because of its low magnetic permeability and high yield strength. The electro-slag remelting process is used for the manufacturing of the raw material [4]. For flanges, solid blocks, and milled pieces only forged material is used. To arrive at a grain size of 3.5 according to the ASTM E 112-88 standard all steel blocks are forged in all axes.

A low magnetic permeability of the vacuum chamber is very important for the use in a storage ring. Values of $\mu_{rel} = 1.005$ can also be achieved in the chamber welds and in the cold forming zones.

The mechanical properties with a tensile strength $R_{p0.2} = 300$ N/mm^2 are very good. The material can easily be welded and many manufacturers have a lot of experience with it.

3 CHAMBER DESIGN

The vacuum system of 3rd generation light sources can be classified into the magnet sections with the bending and focussing magnets of a ring and the straight sections where the injection-, RF-, and insertion devices are installed. This paper will focus on the vacuum chambers for the bending and focussing magnets of a ring.

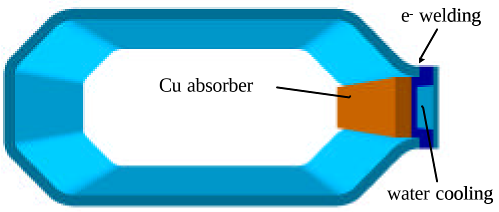

Fig. 2a Vacuum Chamber with indirectly cooled Cu absorber (ANKA, BESSY II)

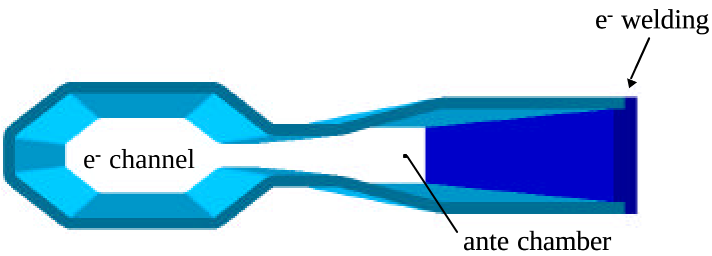

Fig. 2b Full Antechamber Design (SLS)

Fig. 1a and 1b shows as an example the two different design principles. Fig. 1a with a full antechamber design and Fig. 1 b with a vacuum chamber design where the antechamber is only in the bending- and the first following focussing magnets and a single chamber vacuum vessel with a distributed photon absorber is in the rest of the ring [5, 6].

In the antechamber with discrete photon absorbers the absorber length is much shorter compared to the circumference of the ring. Though this leads to a higher linear power density on the absorber which must be compensated with an enforced cooling it reduces the conditioning time due to a higher photon flux on a shorter absorber length which in turn leads to a concentration of photon desorption at the immediate vicinity of the absorber. Finally this design gives the possibility to install distributed pumps with high pumping speed without conductance limitations close to the photo desorption area of the absorbers (the main source of gas load). Unfortunately this design leads to a larger chamber width. To withstand the outer atmospheric pressure and hold the chamber deformations at a certain level the chamber must be reinforced with ribs and the wall thickness may have to be increased.

Stainless steel vacuum chambers in the majority of cases are made of sheet metal. The production of the chamber profiles takes place with an edge bending die or with a deep-drawing die and a following laser cutting of the outlines. TIG welding (tungsten inert gas) and electron beam welding are the common welding processes. The energy density of electron beam welding is much higher and leads to less chamber deformations compared to TIG welding. Usually all longitudinal vacuum chamber welds are done with electron beam. This limits the maximum chamber length to a value of about 5 m which is usually no problem for synchrotron light sources.
To achieve a low chamber impedance the electron channel has mostly an uniform cross section. Fig. 2 a shows as an example the cross section of an ANKA straight vacuum chamber and Fig. 2 b shows the cross section of a SLS straight vacuum chamber. In both examples, the electron channel profile is formed in one piece and closed with a welded flat plate. In Fig. 2 a the water-cooling channel is integrated into the stainless steel plate and an explosion bonded OFHC copper plate is used as a photon absorber in longitudinal direction.
For the dimensioning of the height of the slit between electron channel and antechamber a good compromise must be found. A low chamber impedance favors a smaller height of the slit but the photon fan of non planar insertion devices which have a larger vertical opening angle and also photons from the upstream bending magnet can lead to a high thermal load in the following downstream bending magnet chamber. This can lead to high local thermal stress because of the low thermal conductance of stainless steel. This problem can be solved with a higher gap in the slit, or with a water-cooled copper shield similar to the SLS design (see Fig. 3). There the shield could be installed into the finished dipole chamber and fixed with screws to the flanges at both sides of the chamber. Between the flanges several clamps hold the copper shield in vertical position.

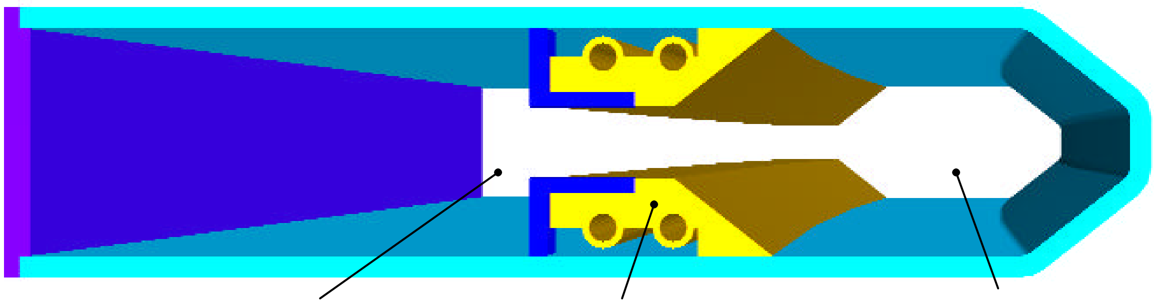

Fig. 3 Dipole chamber with water-cooled copper shield

The electrodes of the beam position monitors (BPM) are usually installed in solid stainless steel blocks, which are part of the vacuum chamber. The electrodes can thereby be welded directly into the BPM-block (ESRF, ANKA, SLS) or installed in a separate flange, which is connected and sealed with a gasket to the BPM -block (BESSY II).
Misreadings of the BPM system which are induced by movements of the vacuum chamber itself can be avoided with two different strategies:

- The BPM -blocks are bolted rigidly to the magnet girder and are decoupled with bellows from the vacuum chamber (Max II) [7].
- A large number of bellows leads to high costs and has a risk of potential failure sources within the RF-shielded bellows. As a consequence at SLS there are no bellows in the 18 m long vacuum sections in the magnet girders. The BPM blocks are also bolted to the magnet girders but movements of the vacuum chamber are detected with individual optical sensors in both transverse directions. The BPM system compensates the readings of the optical sensors with the beam position reading of the BPM electrodes [8].

4 FLANGES

Conflat flanges (CF) are used in most of the storage rings. A pair of standard CF flanges provides a small cavity between the two flanges and the gasket, which increases the total impedance and can lead besides local heating to beam instabilities. This problem can be solved with several solutions:

a) The gaps between the flanges can be bridged with a metallic seal (see Fig. 4a).
b) A change of the flange geometry, which results in a smaller gap between the flanges of a few 100 µm, is used for example at ESRF and ANKA (see Fig. 4b).

c) With a completely different flange system the problem is solved at Delta and SLS by using flat seal flanges [9] with no gaps between the flat flanges and the copper gasket which has two lips for sealing (Fig. 4c).

A further advantage of flat seal flanges is that very small tolerances of about ± 0.05 mm longitudinal and ± 0.1 mrad angular could be achieved. This is possible with a final finish of the surfaces of the flat flanges when the welding of the chamber body has been finished.

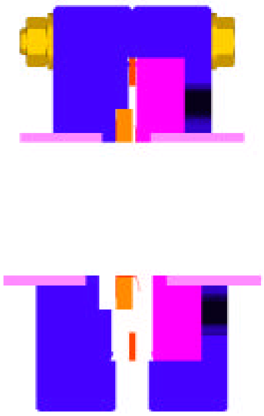
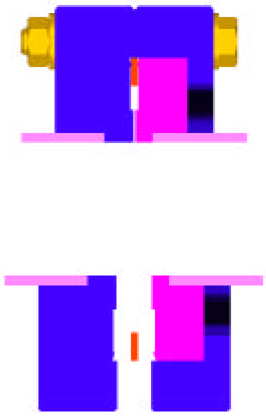
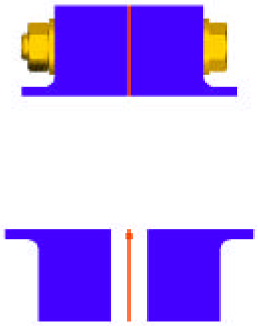

Fig. 4a CF Flange with RF bridge Fig. 4b CF Flange with 0.5 mm gap Fig. 4c Flat Seal Flange

5 CONDITIONING

For the conditioning of vacuum chambers several procedures are necessary. It is self-evident that for the chamber fabrication a clean environment and several cleaning steps are necessary. When the fabrication process is finished the final cleaning of the chambers starts at first with a chemical cleaning. Because of environmental concerns the cleaning with detergents is preferable to solvents for UHV applications [10, 11]. The thermal desorption of pure stainless steel chambers can also be reduced with a vacuum firing of the chambers at 900 °C under a vacuum of less than 10^{-5} torr. BPM buttons and water-cooled copper parts can be installed after the annealing.


Fig. 5a SLS vacuum section on the way into the bake-out tent

Fig. 5a Bake-out of SLS vacuum section in a tent at 250 °C

The question of in situ bake-out for synchrotron light sources is a controversial issue in the community. A classical in situ bake-out system for the vacuum chambers of a light source consists of resistive heaters with electrical and thermal insulation. The typical thickness for heaters and insulation is in the range of about 5 mm and requires a larger aperture of the magnets. This leads to higher costs for the vacuum system itself and also for the other accelerator components. On the other hand, it was observed at other synchrotron light sources that bake-out would only give improvements in the early stages of a vacuum cycle.

The result of the SLS commissioning shows the advantage of a bake-out of the whole storage ring before the start of the commissioning. Several other machines have started the commissioning without an in situ bake-out but take much longer to achieve comparable maximal currents and lifetimes.
The SLS bake-out concept consists on an external bake of the vacuum chambers and an installation into the storage ring under vacuum. Each vacuum section is equipped with gate valves at both ends and each synchrotron radiation beam port. The upper parts of all magnets in each section and also the roof of the tunnel can be removed.
After the assembly in a clean assembly hutch the complete vacuum section was evacuated and lifted with a lifting tool and transported hanging on a crane into a big bake-out tent. In this tent, the sections are baked at 250 °C. During the bake-out, the vacuum sections hung on chains in the tent so that the thermal expansion of the 18 m long sections could take place freely.
During the cool down the sputter ion pumps were started at a temperature of 150 C. At room temperature, each vacuum section typically reached a base pressure in the low 10^{-10} mbar ranges within one day. The vacuum sections are then transported and installed under vacuum into the open magnet sections.
The vacuum chambers of the straight sections could be baked after their installation into the storage ring with a moveable and modular oven.
Compared with an in situ bake-out the external bake-out procedure in an oven is more effective because the vacuum chamber can be baked at 250 °C, which is higher than a typical in situ bake-out system and a very homogeneous temperature distribution can be achieved.

6 CONCLUSIONS

With the development in the design of stainless steel vacuum chambers for synchrotron light sources especially with the full antechamber design and the reduction of the number of installed bellows a simplification could be achieved which could increase the performance and also lead to cost savings.
The external bake-out of complete vacuum sectors and installation into the magnet sections under vacuum is an effective way to save time and achieve the maximum design current and beam lifetime in a much shorter time compared to a vacuum system without in situ bake-out. With this method it may be also in the future possible to establish the NEG-coating [12] of vacuum chambers for synchrotron light sources, where activation temperatures of about 200 °C are required.

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