

Design and Performance of the Vacuum Chambers for the Undulator of the VUV FEL at the TESLA Test Facility at DESY

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Abstract

Three vacuum chambers for the VUV SASE FEL undulator sections at the TESLA Test Facility (TTF) were designed, built, tested and installed. Each chamber is 4.5 m long and of 11.5 mm thick. The inner diameter of the beam pipe is 9.5 mm. The rectangular chamber profile with a width of 128mm is used to integrate beam position monitors and steerers. This is needed to provide a good overlap between the electron and the photon beam over the entire undulator length. The chambers are built in an aluminum extrusion technology developed for the insertion device vacuum chambers of the Advanced Photon Source. After manufacturing special processing was performed to reach low outgassing rates ($<1 \cdot 10^{-11}$ mbar·l/sec·cm²) and particle-free chambers. Mounting of the chambers at TTF were performed under clean room conditions better class 100.

Keywords: Vacuum Chamber, Undulator, Beam Position Monitor, Corrector Coils

1. INTRODUCTION

At the TESLA Test Facility (TTF) at DESY the phase I of the VUV free electron laser (FEL) [1,2] operating down to 42 nm, is completed. The major component for the generation of the FEL photon beam is the 15 m long undulator. It consists of three 4.5-m long sections with integrated strong focusing quadrupoles. These undulators are permanent magnet structures with a fixed gap of 12 mm. Each section contains a FODO structure of 10 quadrupole magnets[3]. To correct the errors of the 30 quadrupoles, an electron beam position monitor and a steerer is installed for each quadrupole. The diagnostic and steering inside the undulator gap is necessary to achieve a sufficient ($< 12 \mu\text{m}$) overlap[4] between the particle beam and the photon beam. The three undulator vacuum chambers with an open aperture of 9.5 mm guide the electron beam through the undulator sections.

2. Vacuum Chamber Design

There are several criteria which influence the design of the chamber:

- the particle beam position must be monitored with respect to the magnetic quadrupoles in the 12mm undulator gap over the whole length of the undulator.
- steering of the particle beam in the undulator gap by correction coils.
- a chamber support which guarantees a precise straight alignment of the chambers within 0.1mm and must not affect the precision alignment of the undulators.
- low electrical resistance and small microroughness of the inner beam pipe are needed to minimize resistive wall and wake field effects on the beam[5].
- the vacuum chamber has to fulfil the specifications for the cleaning of vacuum components[6] for the TTF.

- The specific outgassing rate after cleaning of the chamber should be in the range of 10^{-11} mbar·l/sec·cm²

2.1 vacuum chamber

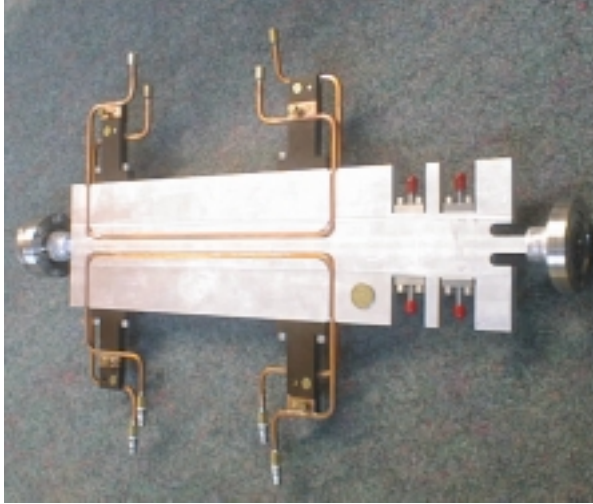


Figure 1: Prototype structure of the FEL vacuum chamber with steerers, pick up monitors and end flanges

The vacuum chamber is a flat long structure with the base dimensions of 11.5 mm x 128 mm x 4500. The central aperture for the beam has a diameter of 9.5-mm. The choice of aluminum as chamber material has the advantage of the low electrical resistance. Aluminum extrusion profiles specifically tailored for this application could be obtained. The previous Advanced Photon Source (APS) experience with the design of aluminum vacuum chambers for insertion devices was widely used [7]. Figure 1 shows the prototype structure of a single chamber period with four electrodes of a beam position monitor (BPM) and the four water cooled steerer windings. The pick up electrodes of the BPM are special UHV compatible RF feed throughs[8] which are connected to the chamber body using special all metal seals[9]. The chamber flange on the right hand is the longitudinal chamber fix point. The connection of the ConFlat flange to the chamber body is formed by a bimetallic welding joint and a flexible junction which allows an elastic bending of the flange for alignment purposes. A more detailed description of the manufacturing and cleaning of the chamber is given in [10].

2.2 monitors and steerers

In order to guarantee a tough control of the electron beam orbit inside the undulator one BPM and corrector are required per FODO quadrupol (every 0.478m). All these components have to fit inside the 12mm undulator gap. In total 10 BPM's and 9 correctors are required per undulator chamber.

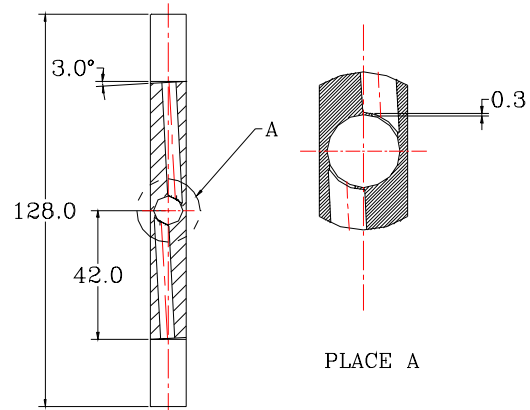


Figure 2: Cross section of the vacuum chamber at the position of the waveguide BPM.

Two kinds of BPM's will be used[11]. For TTF phase I inside the first two chambers button type pick up monitors will be used. These monitors were successfully tested at the CLIC facility at CERN.



Figure 3 : The prototype chamber profile with the waveguide monitor which will be installed in the third chamber

For the 250μm long bunches which will be available in Phase I these monitors are believed to be a safe and reliable system. For even shorter bunches new solutions have to be found. Therefore in the chamber of the third undulator segment a new type of monitor will be tested which has been

described in[12]. It uses outcoupling slits inside the vacuum chamber and waveguides to detect the exact position of the electron beam. These monitors decouple the beam induced RF through four small RF windows. The position information is derived from the four signals. In contrast to the button type monitor this method is not restricted by a lower limit of the bunch length. This new design has a large potential for a use in Phase II when the bunch length will be further reduced to $50\mu\text{m}$. The drawback of the waveguide type monitor is its complicated design. It requires complex contours to be manufactured inside the undulator chamber. A more sophisticated RF detection electronics allows to define the relative beam position within a few μm . Successful tests of the first prototype at CERN and the second improved design at DESY have proven the capability of this monitor type. Figure 2 and 3 show the waveguide monitor design after machining by an electrical discharge machining (EDM) process. At the end of the U-type waveguide an asymmetric window couples into the beam pipe.

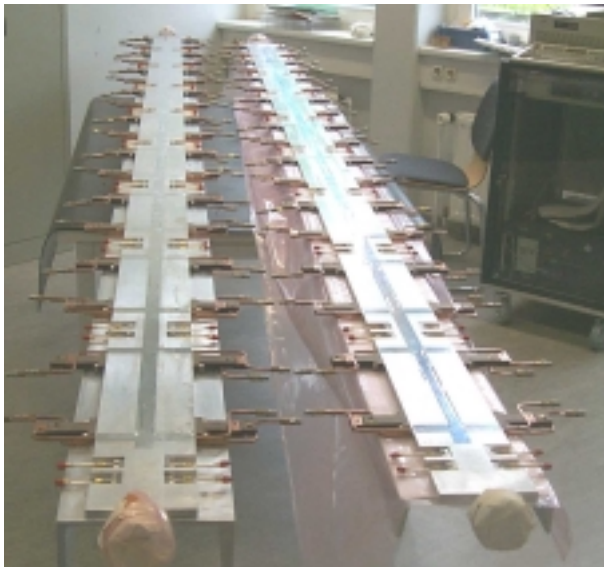


Figure 4: Two vacuum chambers ready for installation into the undulator.

The correctors coils are located in between the BPM's. The generation of corrector fields to the electron beam is complicated by the presence of soft iron poles inside the undulator and soft iron girders. So no external coils could be used. Therefore the so called "Four Wire Steering" principle was chosen. Per corrector there are four

single turn coils of 0.3m length.. They are made from a $4\times 4\times 2.5\text{ mm}$ hollow copper profile which is insulated against the vacuum chamber. All four wires are grouped symmetrically around the electron beam tube and are inside the undulator gap. These four wire steerers can in principle provide horizontal and vertical steering when properly connected to two power supplies. But it was found sufficient that horizontal steering is applied for the horizontal focusing quadrupoles and vertical steering for the vertical ones. Only the last corrector in each chamber is a double steerer as described above. In this way five horizontal and five vertical steerers are available in each undulator segment. The steering strength of one corrector is about 0.3 Tmm . The hollow copper coils are connected to cooling water which transports off the ohmic heat produced by the current in the corrector coils and RF losses caused by the BPM's. A worst case estimate for the total dissipated power is less than about 30W . A second purpose of the cooling is to thermally stabilize the undulator chamber in order to avoid temperature gradients through the undulator. Therefore the temperature of the cooling water is controlled by precise thermostats.

2.3 The support structure

Special mounting, alignment and supporting systems for the flat and longitudinal very flexible chamber were designed and built.

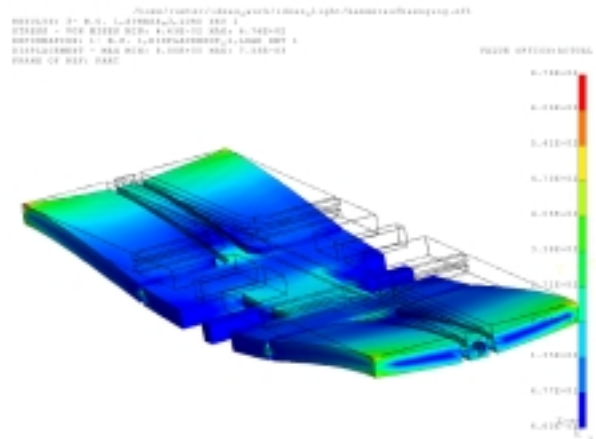


Figure 5: The FEM calculation shows the vertical displacement of one chamber period between two chamber supports. It is smaller than $10\mu\text{m}$

The chamber is flanged directly to the diagnostic block on one side. This defines the longitudinal position of the chamber. In the undulator the

chamber is held by 9 cardanical sliding supports which are connected to the undulator support system. Each support allows to align the chamber within a tenth of a mm in vertical and horizontal direction. The number of supports were defined by finite element model calculations. Figure 3 shows the calculation for one supporting period. The vertical deviation due to gravity bending is of the order of 6 μm .

3. Chamber mounting

Since the chamber tube must reach a specific outgassing rate $<1 \cdot 10^{-11} \text{mbar} \cdot \text{l/sec} \cdot \text{cm}^2$, careful cleaning of the chamber is mandatory. To fulfil the stringent particle free requirements of the TTF cleaning, assembling, and mounting of the chamber was made inside a clean room better than class 100. This chamber processing step was done at the APS[10].



Figure 6: The insertion of the vacuum chamber

A special problem was the insertion of the chamber in the undulator gap. A special 4.5 m long sliding system was built. After alignment the chamber was moved into the undulator gap (see Fig. 6) and then connected to the chamber support. The vacuum chamber together with the undulator module were transferred into the TTF linac tunnel. The vacuum connections to the monitor blocks on both ends of the vacuum chamber were made in a local clean room better class 100. After pumping down of the undulator vacuum system at the undulator ends a pressure $< 2 \cdot 10^{-8} \text{mbar}$ was reached.

4. Conclusion

Three FEL vacuum chambers were successfully installed in the undulator section of the TTF linac. The vacuum system has reached the anticipated pressure, so that the first FEL beam can be produced.

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