

THE VACUUM CHAMBERS FOR THE VUV SASE FEL AT THE TESLA TEST FACILITY (TTF FEL) AT DESY*

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Abstract

A vacuum chamber for the VUV SASE FEL undulators at the TESLA Test Facility (TTF) was designed, a prototype was built and tested, and seven complete chambers were manufactured. The chambers use the aluminum extrusion technology developed for the insertion device vacuum chambers of the Advanced Photon Source. Each chamber is 4.5 m long with a beam aperture of 9.5 mm and an external thickness of 11.5 mm. Three of the chambers include ports for integral beam position monitors (10 horizontal and vertical pairs) inserted into the chambers, and all of the chambers include grooves for mounting correction coils. Bimetallic flanges (stainless steel to aluminum) are welded to the ends of the chamber for connection to the beamline. Special processing was performed to meet the stringent vacuum and particle-free requirements of the TTF.

1 INTRODUCTION

At DESY, a VUV free-electron laser (FEL) based on the principle of self-amplified spontaneous emission (SASE) is under construction [1] to make use of the unique electron beam properties of the TESLA Test Facility (TTF). The FEL will be built in two phases [2]. Phase one, with a FEL operating down to 42 nm, is under construction. The major component for the generation of the FEL photon beam is the undulator, which will consist of three 4.5-m-long modules separated by 0.3-m-long beam diagnostic sections. The undulators are permanent magnet structures with a fixed gap of 12 mm. The electron beam must be kept small over the entire undulator length by an added sequence of focusing and defocusing quadrupoles (FODO lattice) [3]. Additionally, electron beam position monitoring and steering in the undulator gap is needed to achieve a sufficient ($< 12 \mu\text{m}$) overlap [4] between the particle beam and the photon beam. Three 4.5-m-long

vacuum chambers with an open aperture of 9.5 mm guide the electron beam through the undulator sections. The simple vacuum pipe becomes rather complicated by the addition of 40 electrodes for the beam position monitors required for each chamber and the related 36 correction coils. A special alignment system for the flat, flexible chamber is also needed. Because the chamber tube must reach a specific outgassing rate $< 1 \cdot 10^{-11} \text{ mbar} \cdot \text{l/sec} \cdot \text{cm}^2$, the cleaning and assembly of the chamber was made inside a clean room better than class 100 [5].

2 VACUUM CHAMBER DESIGN

There are several design criteria for the undulator vacuum chamber:

- The undulator gap size is 12 mm.
- The chamber has to permit beam position measurement and steering in the gap.
- The chamber has to be vertically and horizontally aligned within 0.1 mm.
- Low electrical resistance and small micro-roughness of the inner beam pipe are needed to minimize resistive wall wake field effects on the beam.

Therefore, the vacuum chamber for the DESY FEL un-

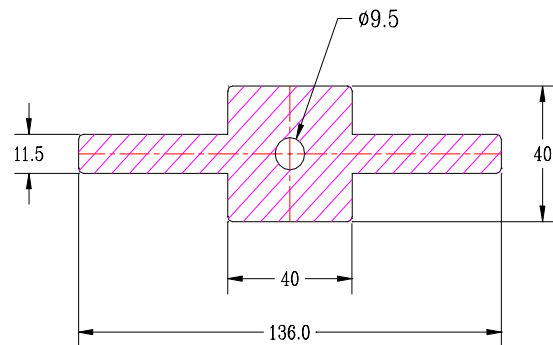


Figure 1: Cross section of the aluminum extrusion for the FEL vacuum chamber.

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dulators is a flat, long structure with the base dimensions of 11.5 mm x 128 mm x 4500 mm. The central aperture for the beam has a diameter of 9.5 mm. Aluminum was the first choice as chamber material because of the low electrical resistance and because extrusion profiles specifically tailored for this application could be obtained. The previous Advanced Photon Source (APS) experience

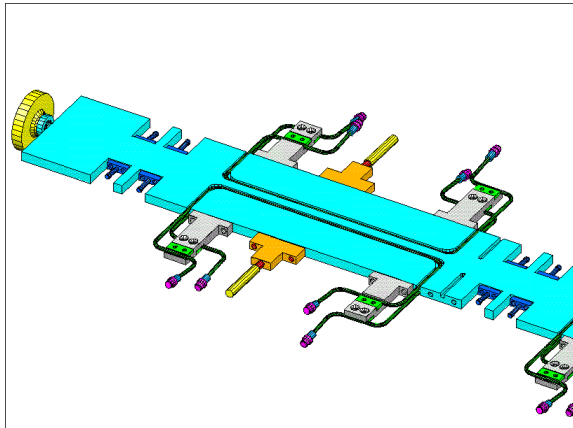


Figure 2: General layout of the undulator vacuum chamber, with pickup monitors, correction coils, and chamber support.

with the design of aluminium vacuum chambers for insertion devices was extremely helpful [6].

Considerable care was exercised to maintain the flatness of this intrinsically nonrigid structure and to ensure the precision of the location of the central aperture as required for precise measurements with the beam position monitors (BPMs). A special extrusion of aluminium alloy 6063-T5 was prepared for these chambers. The cross section chosen is shown in Fig. 1. The cross design adds rigidity to the extrusion and helps to decrease twist and bow. Machining of this alloy progresses readily, so the additional stock did not add unduly to the fabrication cost and schedule. Additionally, the material at the ends was used effectively to form the welding joints to bimetallic ConFlat flanges. The general layout of the chamber is

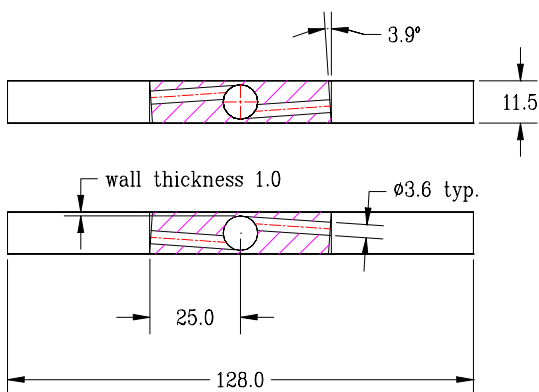


Figure 3: Cross section of the vacuum chamber at the position of the button BPM

shown in Fig. 2. Before machining, the flatness of the extrusion was further improved by bending with a hydraulic press. As a result, we were able to achieve a vertical wall

thickness precision of 1.0 ± 0.1 mm. The thickness was checked by slicing and then measuring a short prototype extrusion. Production chambers were checked ultrasonically in the vertical direction.

The inclusion of integral BPMs, which would fit within the 12-mm undulator pole gap, along the chamber was a major challenge in the design and manufacturing. Two types of BPMs were developed: a button-type pickup monitor [7] for two chambers and a wave guide monitor that couples to the rf of the beam via small rectangular slots for a third chamber. The cross sections at

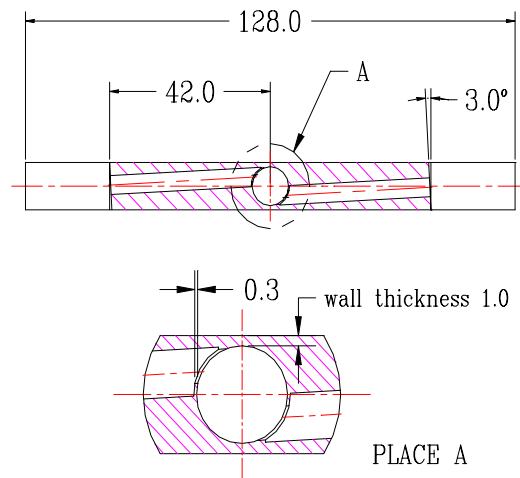


Figure 4: Cross section of the vacuum chamber at the position of the waveguide BPM.

the locations of these devices in the vacuum chamber are shown in Fig. 3 and Fig. 4, correspondingly. The complicated structure of the waveguide monitors was machined using EDM. Small prototype chambers of both monitor types were successfully tested. Each vacuum chamber has ten sections designated for BPMs, and each section consists of four BPMs. The remaining four chambers were fabricated without provision for BPMs. The final decision on the BPM type for these chambers is contingent on the results of beam tests.

Custom thin metal seals [8] were used to make the electrical feedthroughs of the BPM vacuum tight. The seals were manufactured especially for the purpose of the monitor sealing. The hardness of the chamber material is about B60 (Rockwell). This is sufficient to work with the silver-plated copper seals.

Each vacuum chamber has 36 grooves on the top and side for installation of the correction coils. Additional grooves for thermocouples to control the chamber temperature are located between BPM areas. Precise fi-

ducial holes in each BPM section will be used for alignment of the vacuum chamber in the undulator gap.

It was realized that the surface finish of the aperture would be very important because small beam emittance, high beam peak currents, and very short beam pulses are expected [1]. Rough surfaces can cause wake field effects that are deleterious to the beam quality. On the other hand, small burrs on the button BPM holes could be a source of arcing related to the very high field strength induced by the beam pulse. Therefore, the surface quality was carefully checked after the extrusion was fabricated. An additional electrochemical polishing of the aperture was performed on the pick-up monitor chambers after machining the BPM holes. A sample was measured with a stylus profiler. Before polishing, the RMS inner surface roughness was $\sim 1.6 \mu\text{m}$ along the extrusion direction. After polishing, the RMS roughness was improved to $\sim 0.8 \mu\text{m}$. Optical measurements show that the roughness transverse to the extrusion direction is about two times larger than along the extrusion, but surface smoothness in this direction is less important.

One of the main objectives of the assembly process for the FEL vacuum chambers was to preserve the cleanliness of the superconducting cavities of the TTF. This means that the chambers should be vacuum clean and dust free according to the class 100 clean room specification. After manufacturing, the vacuum chambers were cleaned in a 2% solution of Ridoline 18 and then rinsed in purified DI water which was filtered to $25 \mu\text{m}$. The chambers finally were dried with high purity and particle free ($1\text{-}\mu\text{m}$ filtered) dry nitrogen in a class 100 clean room. The procedure was continuously controlled by a particle counter. The final assembly of the chambers was performed in a class 100 clean room as well. During the assembly and subsequently during each pumping cycle, a strict venting procedure will be used to prevent contamination of the TTF.

3 CONCLUSION

The extruded aluminum vacuum chamber technology developed for the Advanced Photon Source has been successfully applied to a new and challenging application, the vacuum chambers for the TTF FEL. Seven vacuum chambers have been fully machined, cleaned, tested, and shipped to DESY. First beam tests are scheduled for early summer of 1999.

4 ACKNOWLEDGMENTS

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