2nd International Workshop on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI02)
September 5-6, 2002 – Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois U.S.A.

Deformation Under Bake of Extruded Aluminum Narrow-Gap Vacuum Chambers at the ESRF

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Abstract

The ESRF uses NEG-coated vacuum chambers made of extruded aluminum in six of 32 straight sections. These chambers are internally coated with a so-called NEG (Non-Evaporable Getter) film to support the pumping of the chamber and reduce photon-stimulated desorption. This film needs to be activated by heating it up to 180°C. Finite-element simulations show that during this activation bake the elastic limit of the chamber under vacuum is approached. A setup of laser distance sensors based on the triangulation principle has been used in lab to compare the real deflection of the chamber to the prediction of the finite element analysis when simulating the bake of the vacuum chamber in lab prior to installation.

Keywords: insertion device, vacuum chamber, aluminum, NEG coating

1. Extruded Aluminum Chambers and Low Gap Chambers Made of Stainless Steel 316 LN installed on the ESRF Storage Ring

1.1 The "15 mm" Extrusion Chambers

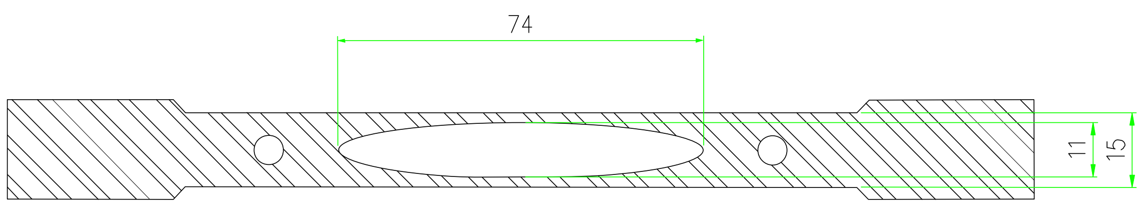

Figure 1: Cross section of 15 mm type extruded Al chamber.

Six out of the twenty-nine straight sections available for generation of intense Synchrotron Radiation are equipped with Insertion Device Vacuum Chambers made out of extruded aluminum 6060: Cells 9, 13, 22 and 29 with two meter long chambers for conventional Insertion Devices upstream the two meter long In Vacuum Undulators and cell 2 and 8 with the 5 m long chambers made of the same extrusion (Figure 1) but due to the length capable of taking three conventional insertion devices (typically undulators) of 1,6 m.

1.2 *The "10 mm" Stainless Steel Chambers* (Figure 2)

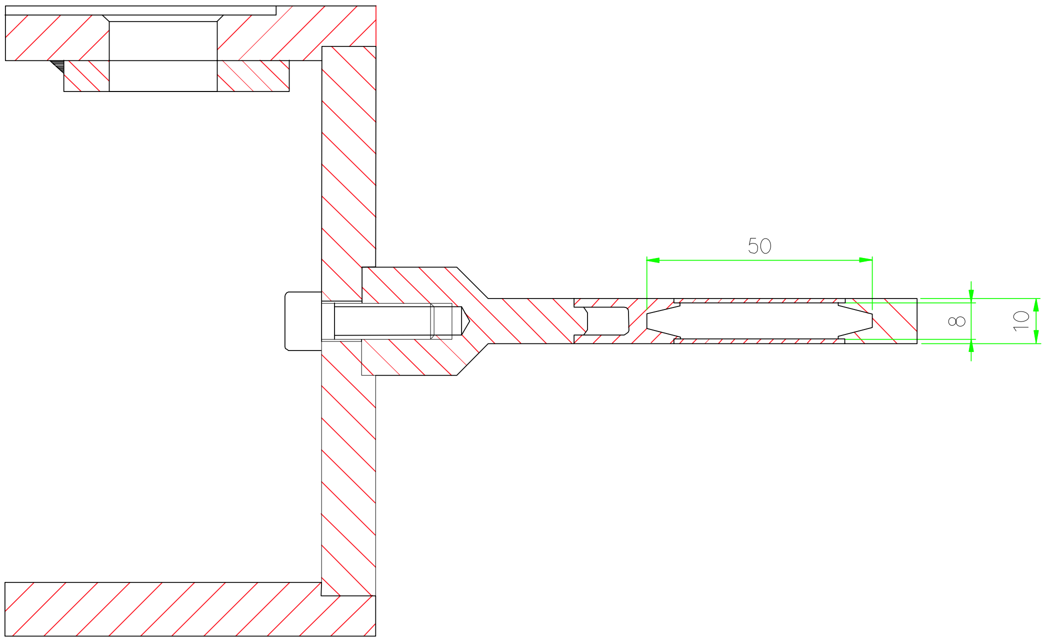

Figure 2: Cross section of 10 mm type stainless steel chamber.

Five insertion device straight sections (cells 6, 16, 18, 28, 31) are equipped with chambers of 5m in length made of stainless steel with an external vertical height of 10 mm (internal 8 mm): These chambers with an external u-shaped reinforcement were produced in 1997 / 1998. As they are conductance-limited (0.94 l m/s for the 1st generation of 10 mm chambers) the effective pumping speed along the chamber when pumping by means of sputtering ion pumps from their extremities was not sufficient to allow the connected beamline the operation even after several days of vacuum conditioning with the beam [1]. Only after applying a thin film of non-evaporable getter (NEG) film as distributed on the inner surfaces of the vacuum chamber the conditioning time decreased to a few days and the chambers were installed on the storage ring.

Apart from the Bremsstrahlung radiation problems there was also a mechanical problem with those chambers before applying the NEG coating: High temperatures appeared right after the installation of those chambers on the accelerator in 16 bunch operation and increased electron losses on the upstream and downstream chambers were observed. A gammagraphie analysis carried out on the upstream and downstream vacuum chambers containing elastic elements for the transport of the image return current, the so-called "contact fingers" showed that these had been completely destroyed in horizontal plane. A 1st set of deformation measurements on a simulation of the bakeout procedure in lab by means of potentiometer encoders showed that a lateral deflection in the order of >10 mm when ramping the chamber temperature with 1K/min to the target temperature of 400°C was responsible for these damages.

The baking materials (glass fiber based electrical heating ribbons on chamber and reinforcing "U" connected to a PID controller, thermal insulation coat) were not suited for the homogeneous ramping up of chamber and "U" with the desired ramp. Reducing the heating and cooling ramps to 0.5K/min and using a Master/Slave baking system ensuring that the gradient from beam chamber to "U" did not exceed 5K solved the problem. After application of the NEG coating also the target temperature and baking duration could be reduced to 180°C for a few days which increased the efficiency of the installation procedure.

1.3 The "10 mm" Extrusion Chamber

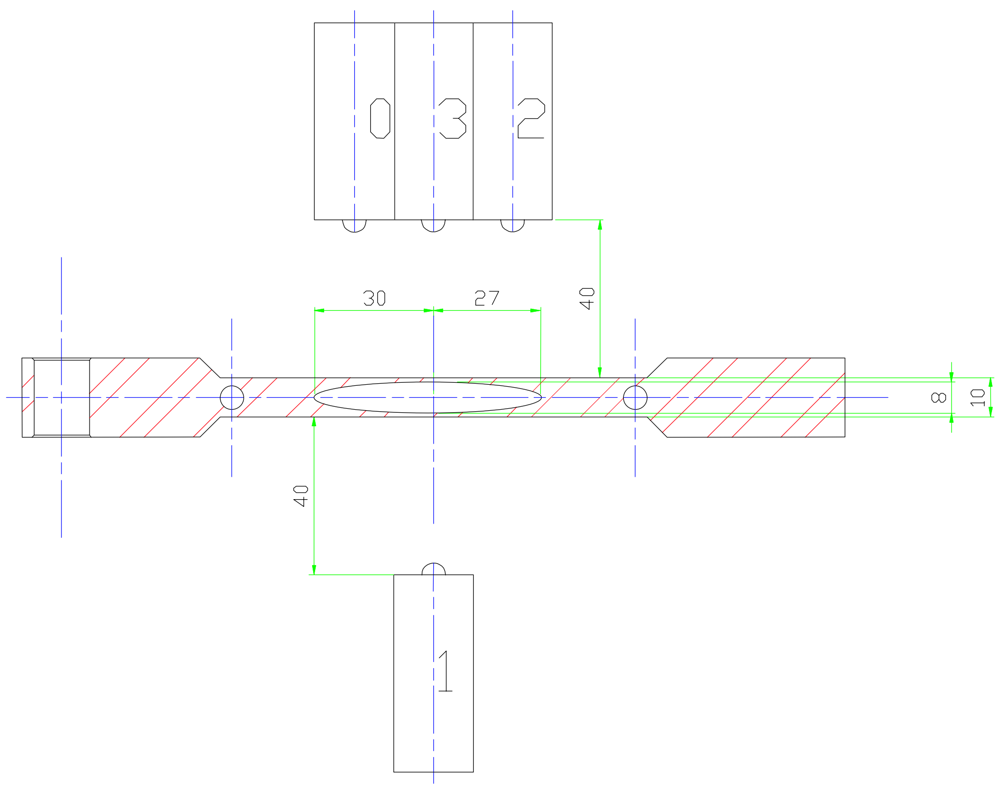

Figure 3: Cross section of 10 mm type extruded Al chamber with distance sensors.

The latest generation of ID vacuum chambers for the ESRF follows the same principle like used for the 15 mm extrusion: Starting from a profile of 208 by 20 mm^2 material is removed by milling down to an outside vertical height of 10 mm leaving 1 mm of Al material top side and 1 mm bottom side in between the beam chamber in form of an ellipse of 57 by 8 mm^2 and atmospheric pressure side. Finite element analysis [2] predicts that with a nominal position of the ellipse well centered in respect to the electron beam axis the safety factor between the maximum stress developing on the chamber under vacuum and the yield strength of the Al6060T6 alloy is in the order of four. For a "worst case" scenario of a chamber under bake at 180°C with a vertical offset of the ellipse of 0.3 mm the safety factor should be still bigger than two.

The temperature of 180°C has been chosen because on one hand it guarantees a full activation of a low temperature getter coating applied to the beam chamber and on the other hand it still leaves enough yield strength margin for the 6060T6 aluminum alloy.

The way the vacuum chamber is baked in-situ does not guarantee a homogeneous insertion of the heating power neither a perfect temperature distribution, it has therefore been decided to study the real deflection behavior of the chamber in lab and compare it with the FEM analysis.

2. Deposition of NEG films at ESRF

The eleven Insertion Device Vacuum Chambers installed on the ESRF Storage Ring have been coated at CERN Division EST-SM by the group of Christofero Benvenuti and co-workers [3,4]. Today there is also a coating facility operational at the ESRF. First coatings have been produced in Diode configuration on copper, aluminum and stainless steel substrates. Qualification of a Diode-coated stainless steel vacuum chamber on the ESRF photodesorption experiment D31 is on the way. A first two meter long extruded Aluminum Insertion Device Chamber has been coated in Magnetron configuration. A deposition tool for coating of chambers up to five meters in length will be installed in an adapted, new-constructed building in September 2002.

3. Measurement Setup

3.1 Laser Distance Sensors

The Triangulation laser measuring sensors consists of a semiconductor laser emitting visible light and a CCD array as a detector. The laser produces a light spot on the surface of the vacuum chamber. The light scattered by the material is imaged to a specific point on the CCD array by a lens (Figure 4).

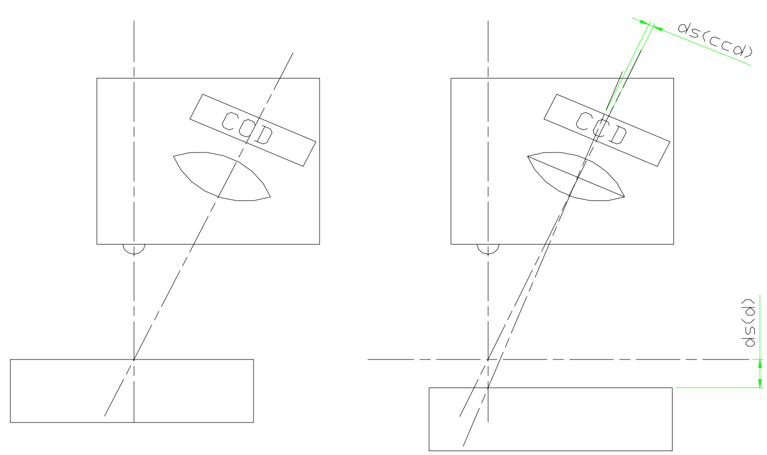

Figure 4: Triangulation principle.

The distance sensors used for this measurement (Baumer electric OADM 20l4440/S14C) convert a distance information from 30 to 50 mm into a DC current signal of 4 to 20 mA. The red (675nm) laser diode spot has a diameter of about 1 mm, the resolution specification is one hundredth of a mm within a temperature range of 0…+50°C.

3.2 Connection of Sensors to the Computer for Data Acquisition

The distance sensors are connected to the inputs of an eight channel 16bit data acquisition module. In order to convert the 4…20 mA signal into a voltage signal of 1 to 5 Volts high precision resistors have been connected in parallel to the inputs.

As the addressable acquisition modules (Advantech® ADAM4000 Series) communicate by means of a RS485 serial bus a RS485/RS232 serial converter is used to connect them to the PC. A National Instruments LabVIEW® application with adjustable sample rate controls the display of the measurement on the screen and the saving to file.

4. Results

4.1 Pumping / Venting Cycles at Room Temperature

The chamber was installed in lab on the support set for the installation on the storage ring, no baking materials were attached. When the chamber was pumped by a roughing pump to $1 \times 10e^{-05}$ mbar, the change in vertical height on top and bottom of the ellipse under vacuum was -0.15 mm corresponding to the prediction of the finite elements analysis by Lin Zhang (-0.134 mm at room temperature) [2]. This measurement was repeated three times, there was no sign of plastic deformation. The two sensors measuring the deformation on the top side of the vacuum chamber 20 mm away from the center of the ellipse (sensor 0 and sensor 2 in Fig. 3) did not detect any deformation.

4.2 Deformation Measurement During Bake to 180°C (Figure 5)

The interpretation of the curves obtained during the bake has to be handled with care: Due to the thermal expansion of the Al vacuum chamber there is one portion of symmetrical expansion which is seen by the top and bottom sensors but there is also a portion of thermal expansion only in positive (top) direction due to the warming of the steel support feet of the chamber which results in an additional displacement for the top sheet sensors and a counteracting effect on the bottom side of the vacuum chamber.

The fact that the biggest total displacement is seen by the top sensor 3 located over the middle of the ellipse allows the statement that there is no sign of collapsing of the vacuum chamber or a “creeping” to the inside, also not for longer baking durations.

Within the limits of the measurement there is no evidence of a remaining plastic deformation of the vacuum chamber. The prediction of the finite element analysis saying that with an offset of 0.1 mm of the ellipse in respect to the theoretical electron beam axis there should be still as safety factor of three between the elastic limit of the Al6060 at

180°C and the real stresses developing under those baking conditions can be considered realistic.

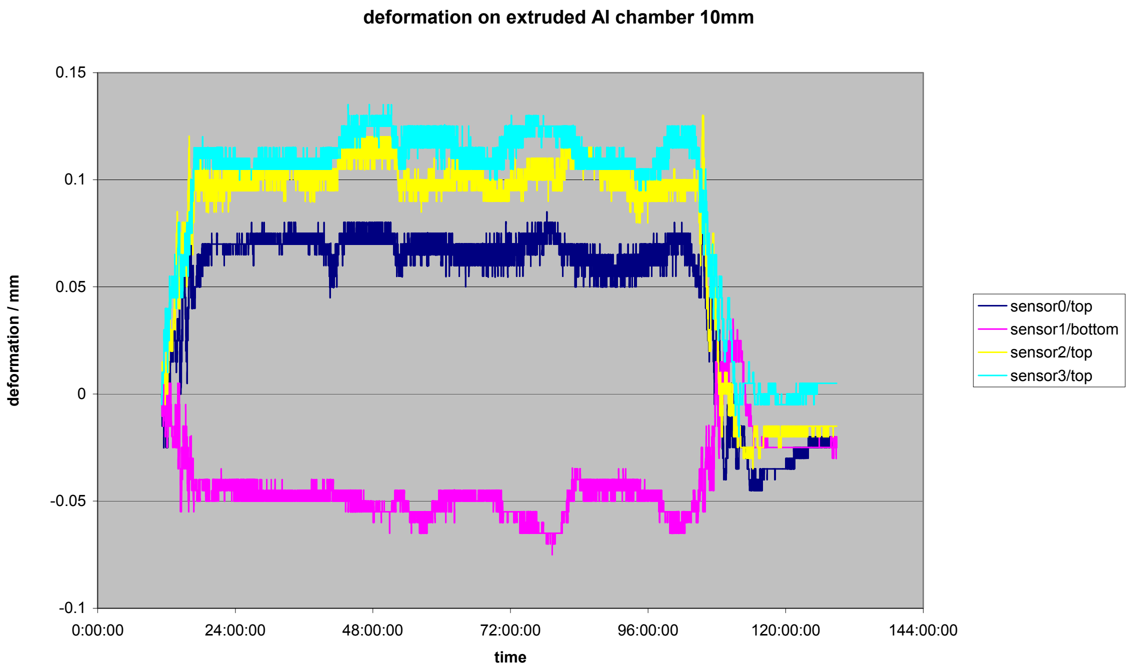

Figure 5: Deformation curves obtained during bake to 180°C.

5. Acknowledgments

The authors thank B. Plan (ESRF) for the mechanical design and following the production of all vacuum chambers and Lin Zhang (ESRF) for the finite element studies and helpful discussions. This report is written on behalf of the ESRF vacuum group: Daniela Schmied, Isabelle Parat, Pierre Guerin, Emmanuel Burtin, Dominique Cognie, Gerard Luce, Michel Garrec, Francis Bodart, Jacques Duvoisin, Gildas LeFlem, Jean-Louis Bersier, Franck Demarcq, Gilles Debut and Vincent Marion (trainee).

6. References

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