Fabrication of a Low Temperature Vacuum Chamber for an In-Achromat Superconducting Wiggler at TLS

C. C. Chang[a,b], S. N. Hsu[a], G. Y. Hsiung[a], C. K. Chan[a], C. L. Chen[a],, C. S. Hwang[a], J. R. Chen[a,c], C. P. Chou[b]

[a] National Synchrotron Radiation Research Center, Hsinchu 30077, Taiwan

[b] Department of Mechanical Engineering, National Chiao Tung University

[c] Department of Biomedical Engineering and Environmental Sciences, National Tsing Hua University, Hsinchu 30013, Taiwan

Abstract

A vacuum chamber, made of aluminum alloy A6063-T5, was installed for a superconducting wiggler (SCW) at National Synchrotron Radiation Research Center (NSRRC). The chamber was designed, fabricated, tested, and installed successfully in the storage ring. The chamber is 960mm long with a racetrack interior dimension of 98mm x 11mm and a minimum wall thickness of 2mm. Several fabrication techniques have been used, including extrusion, computer numerical control (CNC) machining, chemical cleaning, and tungsten insert gas (TIG) welding methods. The chamber deformation under vacuum was less than 0.2mm, which is matched with the ANSYS simulation results. In order not to "short-cut" the heat transfer route between the 100K vacuum chamber and the 4.2K SCW housing, the deformation of the vacuum chamber was carefully controlled. A stainless steel bellows and a piece of transition material were used to increase the heat transfer distance between the room temperature component and the 100K aluminum chamber. A pressure of less than 2×10^{-10} mbar was achieved after the installation in Taiwan Light Source (TLS) at NSRRC.

Introduction

In order to generate higher energy of x-ray on synchrotron radiation source; therefore, a serial of the superconducting wiggler was considered to design, fabricate, and install in limit a space of bending section of storage ring at TLS, to meet a growing demand for X-ray research in the fields of protein crystallography and advanced material research [1,2]. Owing to the unique characteristics of aluminum alloys with great thermal conductivity, zero residual radioactivity, and other useful properties support their applications in synchrotron accelerators; consequently, the development of various aluminum beam ducts for insertion devices and bending section chambers has been successful [3]. On the other hand, an aluminum alloy extrusion vacuum chamber was used to install in low temperature environment of superconducting wiggler, which was considered between 4.2K SCW housing and low temperature vacuum chamber precise gap to avoid touching each other, surface cleaning control and treatment in manufacturing process, small deformation control in welding process and designing to simulate carry out by ANSYS program and so on [4]. Because the operation experience differs greatly from the room temperature vacuum environment as well it must operate synchrotron radiation environment, each design and fabrication conditions must care respectively.

Design of the low temperature vacuum chamber

Low temperature vacuum chamber of the Superconducting wiggler was considered to design, fabricate, and install in a limit space of bending section of storage ring at TLS. The components of ultra high vacuum chamber are in three layers at temperature of 4.2K, 100K and 300K. They were built and assembled, as shown in Fig.1. The total length of chamber is 960mm, which includes an aluminum alloy A6063-T5 vacuum chamber with extrusion length of 656 mm. A racetrack interior dimension of 98mm x 11mm and a minimum wall thickness of 2mm, provides for installing in rectangle internal dimensions 16.6 x 107.6 mm of the 4.2K SCW housing to keep tolerance 0.8mm in single side. Meanwhile, in order to avoid touch each other when they were deformed. Eight bumper rods, made of glass fiber are used; they are 3.5mm high, with a diameter of 1 mm on the beam duct. as shown in Fig. 2. The stainless steel / aluminum alloy transition metals were used to connect between aluminum alloy and stainless steel, which extends to liquid nitrogen layer at 100K and then reducing heat consumption in low temperature environment with lower heat conductivity of the stainless steel. The stainless steel taper was designed to fit taper scale 1:7, which reduces impedance effect. The taper and the stainless steel part of transition metal was welded reducing the heat load conducting, providing temperature difference and decreasing heat consumption between liquid nitrogen layer and room temperature, and linked to the flanges of the storage ring. The welded bellows were used between the flanges of the storage ring and the flanges of SCW providing when the magnet cooling process lead to shrinkage by low temperature chamber and the vacuum system baking process lead to expansion by low temperature chamber, as shown in Fig. 3.

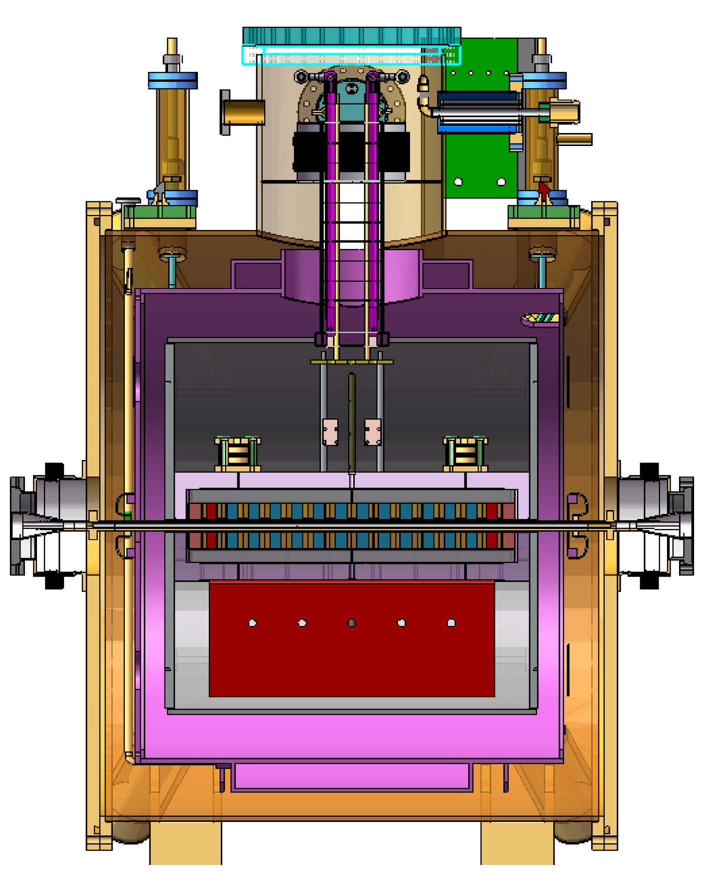

Figure1. The structure of SCW

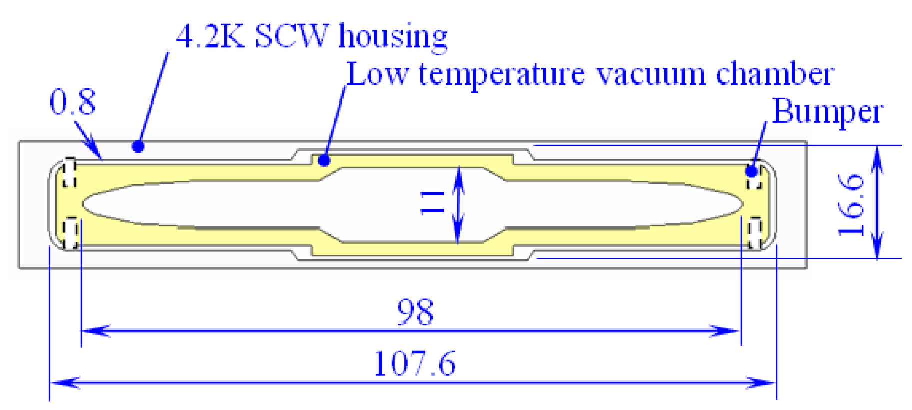

Figure2. Cross section of low temperature vacuum chamber, 4.2 K SCW hosing and bumpers.

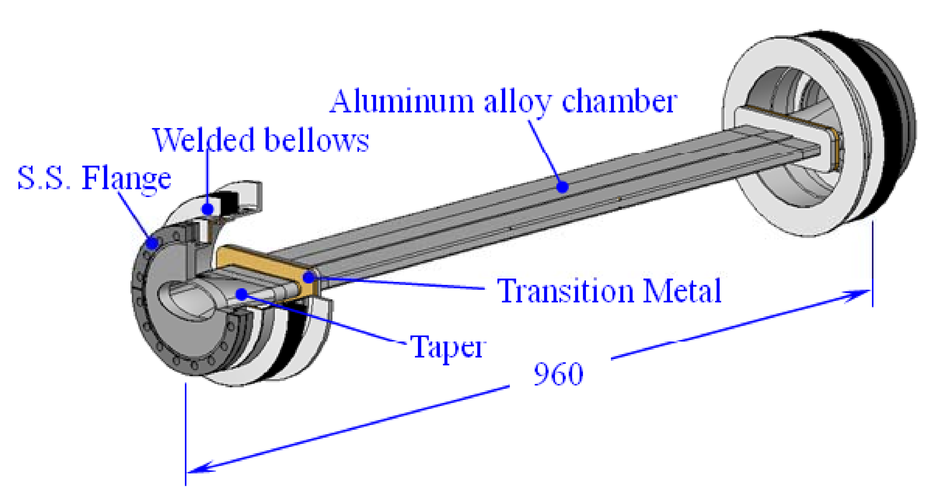

Figure3. The assembly of the components of low temperature vacuum chamber.

Finite Element Analysis

A three-dimensional finite element model was calculated to simulate the chamber deformation process for the pumping into vacuum state using the commercial program ANSYS, which predicts the strain and the stress distribution of the chamber. The analytical model was made by 3D Solidworks professional software, which can obtain the format for ANSYS code. The free mesh manner was adopted with a number of nodes 15000. The element type was used the 20 nodes of Solid95 which is suitable to mesh with subdivision for the model of irregular shape. An atmosphere pressure was distributed uniform on surface of the low temperature vacuum chamber. Fig.4 (a) shows the result of deformation of the aluminum alloy chamber, that the cross-section structure of width 106mm, height 15mm, thickness 2mm deformation less than 0.2mm was calculated, and then the most stress create in two sides of aluminum chamber, which achieve to 86.2 MPa less than aluminum alloy yield strength, as shown in Fig.4 (b).

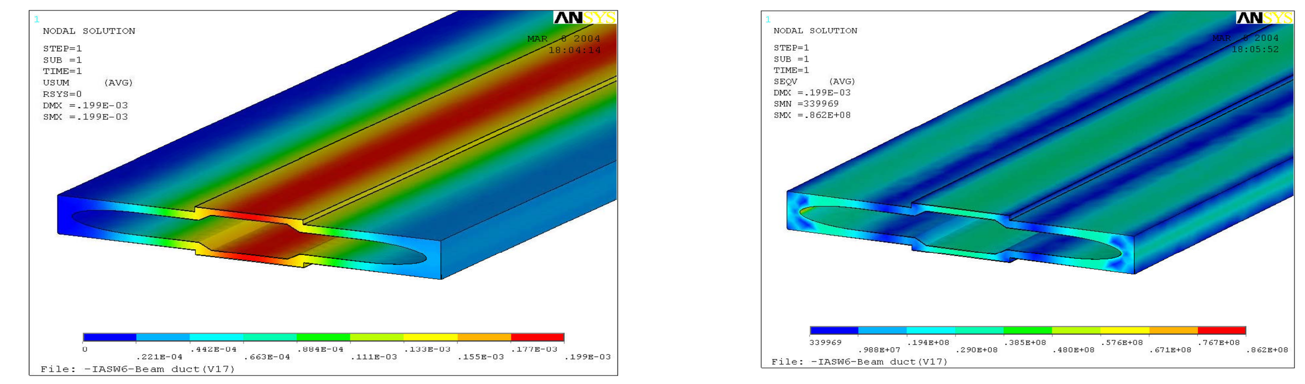

Figure4. Analyzed of (a) deformation, (b) stress distribution.

Fabrication of low temperature vacuum chamber

For the sake of achieving controls the interior dimensions of low temperature vacuum chamber, this was fabricated through the extrusion technology. The ingot of aluminum alloy was preheated higher than 450℃; moreover the manufacturing process will be adopted high pressure shaping to chamber configuration. The mechanical strength of aluminum chamber was treated to achieve T5 degree after extrusion processing by artificial aging. Owing to the external dimensions of low temperature vacuum chamber restricted the interior geometric appearance of SCW housing; thus, the extrusion chamber must be machined by CNC system. In extrusion processing, these chambers are bended in the two extremities or sagged in the middle so that the deformation in the two ends was fitting to carry out by machining. The slight deformation can achieve an objective with the feed of cutting less than 0.05~0.1mm and the spindle speed operate between 5000 and 9000 revolutions per minute. The extrusion chamber was machined to compare with previous one; the slight deformation and excellent flatness were obtained by Coordinate Measuring Machine, as shown in Fig. 5.

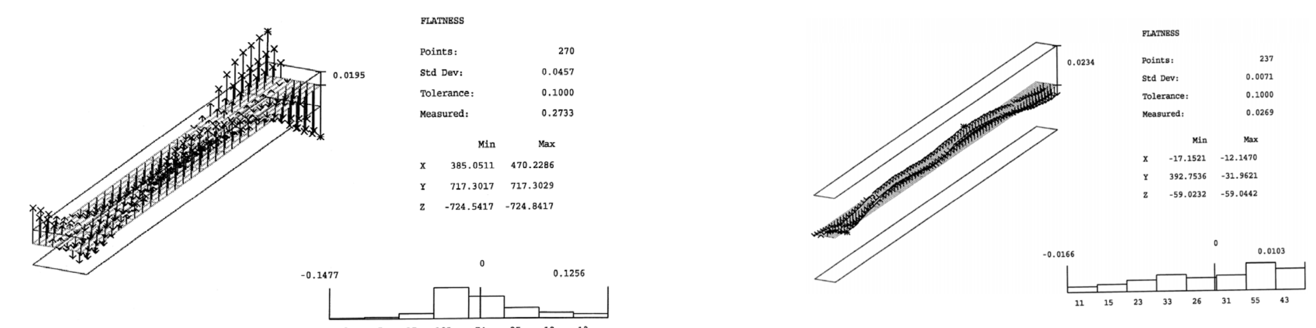

Figure5. Measurements of flatness of extrusion chamber after (a) extrusion, and (b) machining.

Welding for the components of low temperature vacuum chamber

The welding processing arrangement and control are important in the components of low temperature vacuum chamber, respectively, because of welding process leads to the deformation which results in the problems of installation and leakage. All the weld seams of transition metals had been passed the test of thermal shock at the temperatures between 77K of liquid nitrogen and 300K of room temperature for more than 5 cycles. Each weld seam of the vacuum chamber has achieved a leakage rate of welded lower than 1×10^{-9} mbar·l/sec., conducted by He leak detector, as shown in Fig. 6.The vacuum chamber had been welded the transition metal and taper on the side and confirmed the leak tight and precise flatness in the laboratory will be inserted to the SCW and completed the welding of the rest parts on the other side. The on-site measurement method was used to survey the horizontal and the vertical positions of low temperature vacuum chamber by a spirit level and a theodolite. Finally, the assemblies of welded bellows were welded with the flanges of SCW and then completed leakage testing to achieve ultra high vacuum requirements.

Figure6. Leakage testing of each weld seam

Conclusion

The low temperature vacuum chamber was installed for a superconducting wiggler at storage ring successfully. Numerous processes, its welding space were restricted, that is difficult to joint. The narrow situation also affects to control the precision of the deformation but the deformation of fabrication by CNC machining and the welding deformation gain of the low temperature vacuum chamber are reasonable. That the measured and simulated deformations are getting on for design requirement. The results for fabrication, installation processes and ultra high vacuum of the storage ring are fitting the wishes.

Reference

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