WELDING CHARACTERISTICS OF PLS U10 UNDULATOR VACUUM CHAMBER

M. S. Hong, K. R. Kim, H. C. Kwon, C. K. Kim and C. W. Chung
Pohang Accelerator Laboratory, POSTECH, Pohang, Korea, 790-784

Abstract

With the U10 undulator beamline at PLS, a newly designed vacuum chamber for insertion device is needed to replace an existing straight vacuum chamber in the storage ring. We have designed and fabricated a 4.44 m long straight vacuum chamber made of Al alloy A5083-H321. The gas tungsten arc welding parameters were firstly optimised with a test chamber and then applied into the main chamber. The chamber performances were achieved with leak rate less than 10^{-10} Torr-*l*/sec and vacuum pressure below 10^{-10} Torr with bakeout. The mechanical integrity of welded chamber was maintained without severe weld discontinuities as in porosity, incomplete fusion or cracks.

1 INTRODUCTION

The Pohang Light Source (PLS) has been operated successfully with the raised beam energy of 2.5 GeV and a maximum beam current of 170 mA after energy ramping up from the injected energy of 2.0 GeV in 2000 [1]. At present, fourteen beamlines are in user-service and seven beamlines including an U10 are under construction. The U10 beamline is for micro-beam photoemission spectroscopy with photon energy of 10 to 1000 eV and a maximum photon flux of 10^{12}. The U10 undulator consists of wedge type of permanent magnet arrays to achieve a maximum magnetic field of 1.49 Tesla and has a period length of 10 cm, with a pole gap range of 16 to 100 mm and a total length of 1.6 m.

The newly designed vacuum chamber for an U10 insertion device is to replace the existing straight vacuum chamber (3A beam port) in PLS storage ring. A 4.44 m U10 vacuum chamber is required to assure a stable UHV operation of storage ring in order to conduct beam lifetime of more than 10 hours with a circulating current of 170 mA at 2.5 GeV. With the reliability in UHV, the tolerable mechanical accuracy of BPM centre on the chamber has to be maintained within 50 µm to measure precisely the electron beam orbit position. According to these requirements, an UHV-quality chamber consisting of aluminium extrusion of A5083-H321 alloy has been designed and fabricated using welds combined with gas tungsten arc welding (GTAW) equipment. The welding features and the mechanical integrity of aluminum vacuum chamber are discussed and the results of vacuum performance test also shown in this article.

2 VACUUM CHAMBER DESIGN

2.1 Mechanical Design

The design specifications of U10 undulator vacuum chamber are listed in Table 1. The cross section view of vacuum chamber is also shown Fig. 1. The inner cross section for the electron beam channel is an elliptical shape with 12 mm vertical height and 72 mm horizontal width. Two pumping channels for assembling each set of 60 *l*/s sputter ion pumps are located at the upstream and the downstream. The 4 m NEG strip in antechamber is installed to compensate a small conductance due to shallow thickness at undulator location. In addition to the NEG strips of ID chamber, a total of 500 *l*/s capacity including a turbo molecular pump is applied to evacuate the whole system.

Table 1 Design specifications of U10 undulator vacuum chamber

Parameters	Designed Values
Insertion device	Undulator (U10)
Chamber length	4.44 m
Outside vertical length	16 mm
Inner cross section for electron orbit	12 mm × 72 mm (H × W)
Fabrication	Extrusion
Distributed pumping in ID chamber	Strip NEG (ST707)
Chamber material	A5083-H321

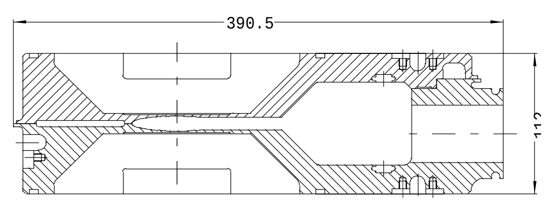


Figure 1: The cross section view of U10 undulator vacuum chamber

2.2 Machining and Cleaning

The precise chamber machining process using CNC works was performed to meet the mechanical dimensions with removing the extruded layer of aluminium alloy at dry conditions. Cleaning of the machined aluminium vacuum chamber was well conducted by PLS cleaning procedures; i) degreasing in trichloroethylene vapor, ii) rinsing with a jet of hot demineralised water, iii) immersion in alkaline (*p*H=10) with a 8% solution of Diversey 909 for 10 min., iv) rinsing in cold demineralised water, v) dry with nitrogen gas.

3 CHAMBER WELDING FABRICATION

3.1 Aluminum Welding Features

The main features of aluminium welding are hydrogen solubility, aluminium oxide, thermal conductivity, thermal expansion and solidification shrinkage [2]. The hydrogen trapped from the weld causes the pores or voids that can connect to form leak paths in vacuum chamber. Especially, hydrogen contamination usually comes from moisture or hydrocarbon on the surface being welded. Even if a heavy layer of aluminium oxide is scraped away during machining and cleaning processes, it will rapidly reform an oxide layer that leads to weld porosity and an erratic welding arc. So, it is prerequisite that the relative humidity in welding works should be maintained less than 60% in positive air pressure conditions. High thermal conductivity and thermal expansion of aluminium during welding result in part distortion by excessive heat and solidification shrinkage. Thus, it is necessary to have the optimised welding parameters as in welding sequence, torch position, arc voltage and wire feed speed, etc., depending on the joint configuration of aluminium chamber to be welded.

3.2 TIG Welding Processes

The upper and lower plates of chamber were assembled to confirm the aligned accuracy within 100 μm in holes location of the beam position monitors before welding. The offsets of BPM holes were aligned to 40 μm and –10 μm in x- and y-directions in first BPM hole, and -50 μm and –15 μm in x- and y-directions in second BPM hole. The weld rib clearance was maintained in 2.7–2.8 mm outside, 2.65-2.7 mm inside, compared to the referenced dimension of 2.5 mm. The welding process adopted for U10 undulator chamber was gas tungsten arc welding (GTAW), kwon as tungsten inert gas welding (TIG). Table 2 lists the optimised welding parameters resulted from the test of model chamber performances.

Figure 2 shows the welding processes of chamber plates using back-step sequences with an argon gas purging (high purity of 99.999%). The ending part of weld bead was overlapped into around 2 cm to keep it from crater or cracking. After all-around welding of plates, the vacuum chamber flanges were then welded at final stage of process to avoid excessive residual stress concentration due to the repetition of welding sequences.

Table 2 Optimised TIG welding parameters

Parameters	Conditions
Filler wire	ER 5356 (ϕ1.6 mm)
Arc current	120-130 A
Arc voltage	18-20 V
Ar purging gas flow	10 *l*/min (99.999%)
Welding speed	1.5-2.0 mm/s
Post flow time	20 sec
Electrode	Zr (ϕ3.2 mm)
Relative humidity	40-60% @ 23 °C

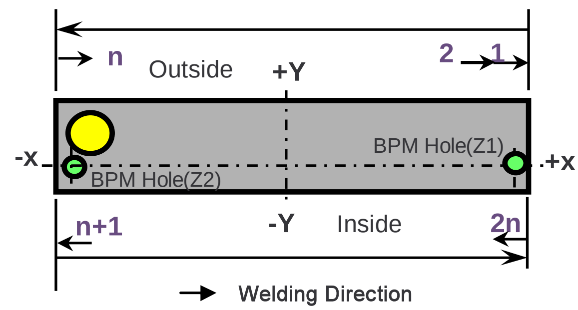


Figure 2: The back-step sequences of TIG welding processes (outside first welded, and inside then welded)

4 WELD INTEGRITY TESTING AND PERFORMANCES

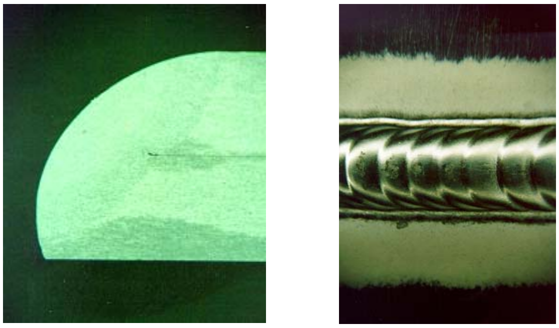
4.1 Chamber Deformation and Weld Zones

The chamber deformations by welding process were measured to evaluate the structural integrity using precision dial gages. Table 3 lists the results of a high deformation at PBM hole locations.

Table 3 Comparison of chamber deformations during each fabrication process

Location / Process	BPM Hole (μm)	
	Z1	Z2
X-dir, (assembly)	40	-50
X-dir, (pre-weld)	30	-40
X-dir, (after weld)	20	-40
Y-dir, (assembly)	-10	-15
Y-dir, (pre-weld)	-5	-30
Y-dir, (after weld)	15	-45

The deformation of BPM holes (Z1, Z2) during pre-weld appeared 10 μm shrinking in x-direction, and 5 μm expansion in y-direction (Z1), 10 μm shrinking in y-direction, and 15 μm expansion in y-direction (Z2). For the whole weld, there were 20 μm and 10 μm deformations in x-direction at Z1 and Z2, respectively. Figure 3(a) and (b) show the welded fusion zone in fully penetrated joints and weld bead formation under the optimised welding conditions, as previously indicated in Table 2. The fusion zones have no indication of blow holes or partial melting, which derive the virtual vacuum leak or cracking.



(a) (b)

Figure 3: (a) Optical photos of the weld metal zone in fully penetrated joints, (b) appearance of weld beads as applied high purity Ar gas

4.2 Leak Test and Vacuum Performances

The helium leak rate of welded vacuum chamber was less than 1×10^{-10} Torr-*l*/sec, conducted by He leak tester, as shown in Fig. 4. We also carried out the vacuum performance test using the set-up consisting of the fabricated vacuum chamber, two sets of 60 *l*/s sputter ion pumps, NEG, BA gauges and other auxiliary accessories.

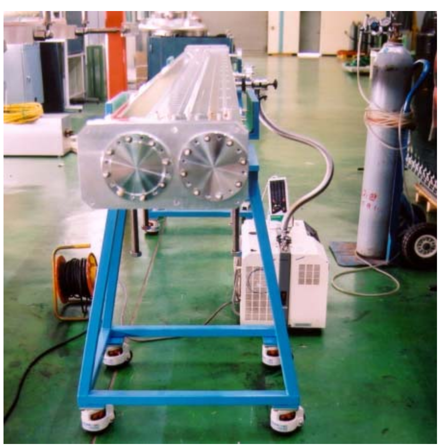


Figure 4: Set-up of He leak tester and the fabricated vacuum chamber

The pump down curve through bakeout and NEG activation is shown in Fig. 5. The NEG was activated at 350 °C for 24 hours with bakeout simultaneously and then the base pressure reached near 1×10^{-10} Torr. From the test, we confirmed that the UHV environment of chamber should be maintained, considering its structural integrity and RGA spectra of the chamber, as shown in Fig. 6. The constituents of residual gases after 100 °C bakeout, was hydrogen, water vapour, CO, and CO_2.

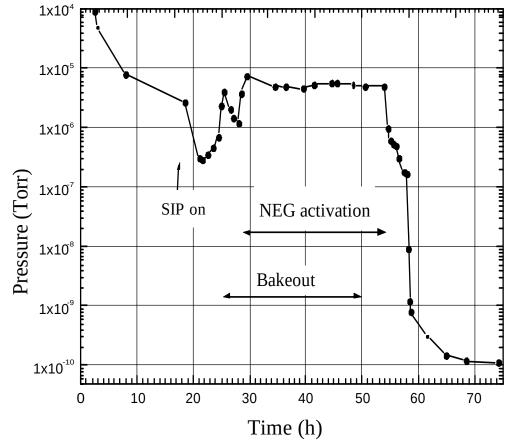


Figure 5: The vacuum pressure profile of chamber

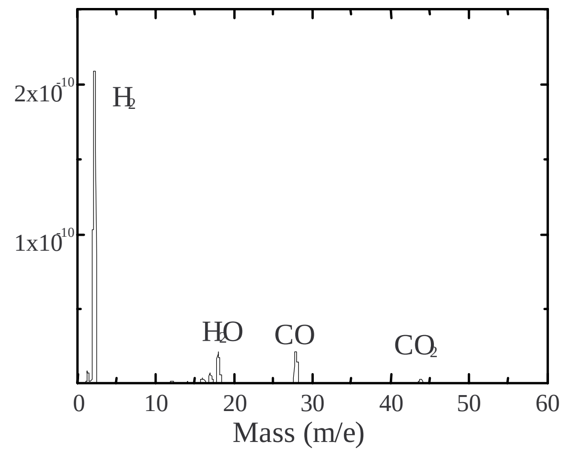


Figure 6: Analysis of residual gas spectra of chamber

5 SUMMARY

We have designed and fabricated a 4.44 m long straight vacuum chamber made of Al alloy A5083-H321. The chamber performances were achieved with leak rate less than 10^{-10} Torr-*l*/sec and vacuum pressure below 10^{-10} Torr with bakeout. The mechanical deformation and integrity of welded chamber were maintained within designed tolerances without severe weld discontinuities as in porosity, incomplete fusion or cracks. The U10 chamber has been installed in the PLS storage ring tunnel in August 2001, and are under undulator commissioning.

REFERENCES

[1] J. H Hwang, et al., "The Operation Status of PLS", PAC2001, Chicago, June 2001.

[2] P. Dickeration et al., "Welding Aluminum: It's Not As Difficult As It Sounds", Welding Journal, pp. 48, 1992.