# MANUFACTURING AND WELDING PROCESS OF STRAIGHT SECTION OF ALUMINUM ALLOY UHV CHAMBERS FOR TAIWAN PHOTON SOURCE

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*Abstract*

This paper describes the manufacturing process and welding sequence for the aluminum extrusion vacuum chamber for the straight sections in Taiwan Photon Source. The straight section composes of aluminum extrusion chamber of A6063 and BPM chamber of A6061 aluminum alloys. The straightness and flatness of these extrusion chambers are controlled under 0.1mm/m and 0.2mm/m, respectively. The BPM chambers are manufactured precisely in oil-free environment, which provide clean surface and a precise sealing surface after machining. All the components are assembled in pre-aligned support system through the welding process. The aluminum chamber for 24 straight sections has been welded. The results show the straightness of < 0.15mm/m, flatness of < 0.3mm/m, and leakage rates of < $2 \times 10^{-10}$ mbar • l/sec. were achieved.

## INTRODUCTION

Taiwan Photon Source (TPS) at the National Synchrotron Radiation Research Center (NSRRC) is constructing a third-generation accelerator. For the ultra high vacuum (UHV) chamber material of a large accelerator, aluminum alloy are often chosen for it many advantage, such as aluminum alloy has very low surface outgassing rate, low photon-induced desorption rate, without residual radiation, and are suitable for synchrotron[1-3].

The electron storage ring has a circumference of 518.4m, divided into 24 cells, each cell is divided into two bending section and two straight section chamber(S-chamber). The bending chamber has been described previously[4]. In this paper, the composition of the straight section chamber are described, including the chamber design, manufacturing methods and material selection, welding preparation and testing, welding procedures and results.

## DESIGN AND MANUFACTURING

The straight section chambers are to provide the electron beam an UHV operation environment. In design, it's simple cross section and geometry symmetry, an ellipses with a dimension 68mm(W) × 30mm(H) and wall thickness 4mm, the cooling channel are designed and extruded on the both side of the S-chamber, providing to remove the synchrotron radiation power. as shown in Figure1(a). The beam duct is made of the aluminum alloy A6063-T5 by the extrusion method. The chemical compositions are listed in Table 1.

Figure 1(b) shows the pumping port of the S-chamber, the pumping port chambers will be machined out the same cross section as the drift chamber on the body for inserting the drift chamber and then welding. The part of drift chamber inside the pumping chamber will be drilled many holes, 3 mm in diameter and 4 mm in depth, for pumping the gases out of the beam duct and shielding the HOM field.

Figure 1(c) shows the BPM chamber structure of the S-chamber, Each S-chamber is designed and required with one BPM chamber where the precise machining is performed to < 0.01 mm[5]. The sealing surface of BPM chamber is fabricated and achieved the lower roughness on the machining surface, as show the relation of the machining parameters and surface roughness in Figure 2. A stainless steel BPM flange block is precisely machined to accommodate two sets of the BPM feedthrough with button which is under welding test by Nd-YAG laser beam[6]. The assembly of BPM flange block will be inserted to the BPM chamber sealed with home-made diamond gasket after leakage test and the electrical measurement.

Table 1: Chemical Composition of A6063 Aluminium Alloy, wt%

| Item | Al | Cr | Cu | Fe | Mg | Mn | Si | Ti | Zn |
|---|---|---|---|---|---|---|---|---|---|
| A6063 | Bal. | 0.04-0.35 | 0.15-0.4 | Max. 0.7 | 0.8-1.2 | Max. 0.15 | 0.4-0.8 | Max. 0.15 | Max. 0.25 |

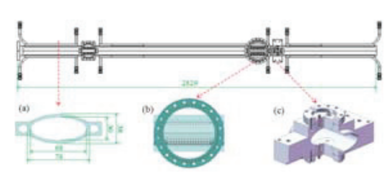

Figure 1: (a) the cross section of S-chamber, (b) the pumping port structure of S-chamber, (c) BPM assembly.

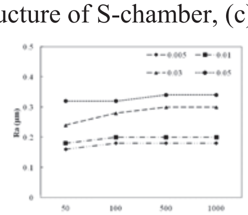

Figure 2: The relation of the machining parameters and surface roughness.




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## WELDING PROCEDURE

### *Cleaning*

After the straight chamber is made, a conventional chemical cleaning with strong alkaline and mix-acid etching is applied to remove surface contamination and to produce a fresh oxide layer. Therefore, the S-chamber were all cleaned chemically, according to the following procedures: soap and water cleaning → caustic cleaning (2 min)→ clean water air-bubble bath (5 min) → acid solution cleaning (2 min) → clean water air-bubble bath (5 min) → ultrasonic oscillation cleaning with de-ionized water (2 min). After the above procedures were completed, the oxide layer was removed with a stainless-steel brush before welding. On the other hand, Both fabrication and cleaning of the BPM chamber differ those of S-chamber. The BPM chamber was machined with oil-free processes, thus the chamber are cleaned with ozonized water[7]. Cleaning with ozonized water is an alternative process to remove surface contamination in the manufacture of BPM chambers, before welding and assembly.

### *Dimension Check*

Before welding, the dimension of all components of S-chamber were carried out measurement and inspection by Coordinate Measuring Machine(CMM). The S-chamber were considered the effect of shrinkage of aluminum alloy during welding process; therefore, the chamber must be longer than the original size 0.4mm in unilateral to fit design dimensions of chamber as shows in Figure 3. Before welding sequence, the absorber must be welded to the chamber inner wall and confirmed that height dimension, the cooling pipe also must be welded and leak tested. In addition, each beam duct of S-chamber was controlled flatness < 0.2mm, straightness < 0.1mm before welding.

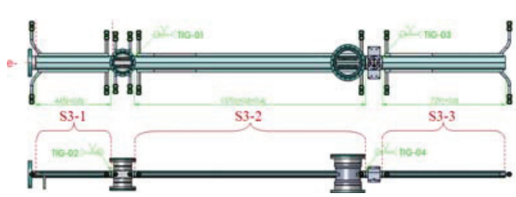



Figure 3: The schematic graph of the S-chamber.

### *Welding Jig*

An important issue that how to control the post-weld of the deformation of the S-chamber (flatness and straightness). The welding jig and long-span I beam were designed and applied in the welding processes of the S-chamber as shows in Figure 4. The main datum plane was defined in the I-beam upper surface, the welding jig was installed in the upper surface of the I-beam. In the welding jig, the secondary datum plane was established and precise machined to control those secondary datum plane flatness < 0.03mm. In the welding sequence, those jigs play micro-adjustment and alignment in each chamber welding processes.

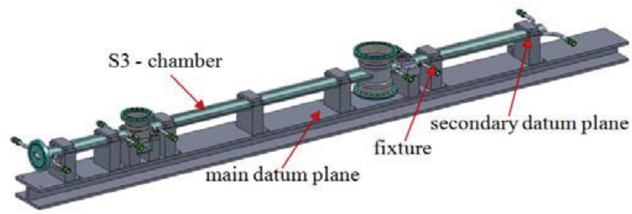


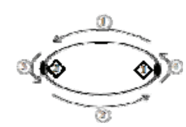

Figure 4: The schematic graph of welding jig of S-chamber.

### *Welding Sequence*

After dimension checking and then each chamber putting on the secondary datum plane of the jig to carry out welding, the welding sequence including five steps as follows:

***S3-1 welding***

The S3-1 is part of the S-chamber including the cooling pipe (straight and curved shape, 2 sets), plug (4 ea), 100CF Flange (1 ea), the support plate of chamber (1ea) as shown in Fig 3. First, the S3-1 chamber must finish the cooling pipes and plugs welding processes and leak check. Figure 5 shows the spot and segmented welding sequences, the S3-1 chamber and ellipse shape beam duct welding were carried out in the 2nd steps. The weldments have been recognized by leak detection (< 2 x $10^{-10}$ mbar・1/sec.) in the post-welding and then fulfilled the flatness and straightness by CMM, the S3-1chamber of the flatness and straightness has been controlled < 0.15mm and < 0.05mm, respectively. The welding parameters of S3-1 chamber show in the Table 2.



◇: spot welding ; ⊙:segmented welding

Figure 5: The spot and segmented welding sequences for the ellipse shape beam duct.

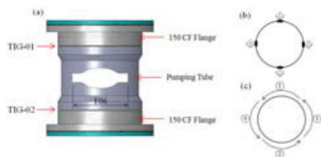
Table 2: The Welding Parameters of S3-1 Chamber

| Welding Current (A) | Welding Voltage (V) | Travel Speed (mm/min.) | Flow rate (L/min.) |
|---|---|---|---|
| 160 | 6.5 | 180 | 15 |

***S3-2 welding***

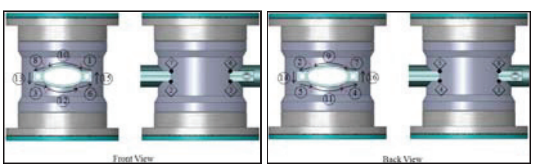
These parts of the S3-2 chamber are including, cooling pipe (4 ea), plug (4 ea), 150CF Flange (2 ea), pumping port (1ea). Before welding for the pumping port, the tube of the pumping port must to be machined into an ellipse shape fitting the beam duct cross-section as shown in Figure 6(a). The S3-2 chamber welding sequence as follow: first, the 180A of welding current is priority carried out in the TIG-01 and 02 weldment to joint 150 CF flange, the 150CF flange pumping port welding sequence is shown the Figure 6(b) and (c). To complete and then insert the ellipse shape beam duct and to confirm positioning. Next, the cooling pipes, plugs and absorber components will be weld and confirm no leakage concerns. The welding conditions such as described in the previous section Table 2.

Finally, the pumping port will be to carry out welding with the ellipse shape beam duct. This welding process is an important procedure because it will be effect the straightness and flatness. Therefore, before segment welding, the spot welding procedure will be adopt and fix the ellipse shape beam duct in the pumping port as shown in Figure 7. The welding parameters of the ellipse shape beam duct insert into the pumping port segment welding sequence as shown in the Table 3.




◇: spot welding ; ⊙:segmented welding

Figure 6: The 150CF pumping port welding sequence (a)the tube was machined into beam duct cross section, (b)the spot welding process, (c)the segmented welding process.




◇: spot welding ; ⊙:segmented welding

Figure 7: The ellipse shape beam duct insert into the pumping port spot and segment welding sequence.

Table 3: The Welding Parameter of the Ellipse Shape Beam Duct Insert into the Pumping Port Segment Welding Sequence

| No. | Current (A) | No. | Current (A) | No. | Current (A) | No. | Current (A) |
|---|---|---|---|---|---|---|---|
| 1 | 220→240→200 | 5 | 220→240→200 | 9 | 200 | 13 | 220 |
| 2 | 200→240→220 | 6 | 200→240→220 | 10 | 200 | 14 | 220 |
| 3 | 220→240→200 | 7 | 220→240→200 | 11 | 200 | 15 | 220 |
| 4 | 200→240→220 | 8 | 200→240→220 | 12 | 200 | 16 | 220 |

*S3-3 welding*

The S3-3 chamber components are including the cooling pipe (straight and curved shape, 2 sets), plug (4 ea) as shown in Fig 3. The welding procedures are consistent with S3-1 chamber. Therefore, each component welding is completed, and then confirm no leakage(each weldment ) and the deformation comply with the design request. The dimensional inspection after welding as shown in Table 4.

*100CF Pumping port welding*

The 100 CF pumping chamber was designed located at between quadrupole and sextupole magnets. Due to space was limited, therefore all-in-one of function design for pumping chamber was considered. This chamber was fabricated to adopt CNC machine with oil-free process. In the welding sequence, the 100CF flange must to be finish (welding current is 170A, sequence as shown in Figure 6(b-c)) and then carry out to connect with each the sub-assembly chamber.

*Each sub-assembly chamber welding*

The aforementioned sections indicate, each sub-assembly chamber has been welded in sequence composition. All sub-assembly chamber must be inspected and tested, they can be carried out welding procedure as shown in Figure 3. The welding sequence and parameters of the each sub-assembly chamber can refer same condition in the Figure 5 and Table 2. As a result of all assembly welding processes has been completed in the fixture, therefore depend on the datum plane of the jig, the chamber straightness and flatness can be controlled < 0.3mm and < 0.15mm, respectively. The leakage rate of the post-weld were achieved < $2 \times 10^{-10}$ mbar・l/sec. The each sub-assembly of the deformation and leak rate has shown in Table 4.

Table 4: The Deformation and Leak Rate of Each Sub-Assembly Chamber

| Item | Length (mm) | | Flatness(mm) | | Straightness (mm) | | Leak rate (mbar・l/sec.) | Remark |
|---|---|---|---|---|---|---|---|---|
| | Before welding | Post-weld | Before welding | Post-weld | Before welding | Post-weld | | |
| S3-1 | 490.8 | 490.38 | 0.06 | 0.10 | 0.03 | 0.05 | <$5 \times 10^{-10}$ | |
| S3-2 | 1371.2 | 1370.75 | 0.11 | 0.23 | 0.04 | 0.10 | <$5 \times 10^{-10}$ | |
| S3-3 | 729.8 | 729.8 | 0.05 | 0.09 | 0.04 | 0.08 | – | Upstream and downstream is not yet connected |
| Assembly (S3) | 2829 | 2829.5 | – | 0.24 | – | 0.13 | <$2 \times 10^{-10}$ | Reserve for downstream welding shrinkage |

## CONCLUSION

The straight section of aluminum alloy vacuum chamber has been fabricated and welded for the TPS storage ring. From the manufacturing and welding processes, a small deformation and leak-free welding were controlled for the straight section chamber. The results indicate that the deformation of straightness and flatness in the each welding procedure will be controlled < 0.3mm and < 0.15mm, respectively. Each welding leak rate was < $2 \times 10^{-10}$ mbar・l/sec. These deformation and welding results just meet the requirement for the accelerator UHV chamber specifications.

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