Development of Automatic Welding System for TPS Aluminium Bending Chambers

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Abstract

Two novel automatic Gas Tungsten Arc Welding (GTAW) systems have been developed at National Synchrotron Radiation Research Center for welding Taiwan Photon Source (TPS) aluminium bending chambers. One automatic system is designed by using two welding torches to implement two parallel welds on each side of an aluminium chamber simultaneously. The other is to use an industrial 6-axis robot with a unique welding configuration. This robot can be used to weld some complicated geometries, such as circular weld of pumping ports or curvature weld near dipole magnet portion. These two automatic TIG welding systems are designed to use in a various range of welding geometries to save labour costs and to provide high quality welds. Several experiments have been conducted to obtain optimum welding parameters for leakage-free bending chambers. In this paper, a real-time thermal and deformation monitoring measurements will be introduced for analyzing the temperature distribution along the chamber surface and the thermal deformation during and after the welding processes. A maximum temperature on the chamber surface is controlled to minimize the thermal deflection due to the high energy heating loads. The welded chambers are checked with leakage-free (leakage rate $<1\times10^{-10}$ mbar·l/s) and the maximum deformation is controlled under 300μm. Moreover, these measurements are also used to validate with computational simulation results, done by a finite element analysis software (ANSYS).

1. Introduction

The 3 GeV Taiwan Photon Source (TPS) is a new facility at the National Synchrotron Radiation Research Center (NSRRC), which will incorporate a storage ring 518.4 meters in circumference. This synchrotron light accelerator is design for a beam emittance of <2 nmrad at a beam current of 400 mA. The vacuum system for the electron storage ring provides a pressure of lower than 1 nTorr for the electron beam with a long beam lifetime and small disturbance from trapped ions [2]. In order to have an ultra high vacuum system, the vacuum chambers are the most important components. Aluminium alloy is chosen as storage ring chamber's material due to its easy machine ability, good thermal conductivity, low outgas rate, and low residual radioactivity [2,3]. Together with a proper manufacture process, such as precise CNC machine with pure alcohol lubrication and ozone cleaning, the aluminium chambers have an oil-free interior surface finished for the ultra high vacuum environment prior to aluminium weld [4]. The bending chamber consists with two symmetry plants which are welded together by using AC Tungsten Inert Gas (TIG) welding method, as known as GTAW, for forming a vacuum chamber. The average size of vacuum chambers to be welded is about 4 meters in length and 600 mm in width.

During the manual welding process, it is difficult to control the shrinkage deformation or thermal cracks due to high energy input from TIG torch. It is important to have automatic welding system, which can control the welding input current, torch movement speed, and provide the welding seam path control, longer welding length. Together with a real-time monitoring system, both thermal variation and shrinkage deformation can be measured. An automatic welding system has been studying at NSRRC for developing a leakage-free and high throughput welding process. In this paper, two new automotive welding systems are introduced to meet the above requirements.

2. Automatic Aluminium Welding System

2.1. Material Preparation

Aluminium alloy (A6061-T6) is used as chamber's material. Prior to aluminium welding, it is important to maintain the cleanliness of the aluminium chamber's surface. There are five factors which may influence the welding results: hydrogen solubility, aluminium oxides, thermal conductivity, thermal expansion, and solidification shrinkage [5]. Hydrogen solubility and aluminium oxides must be taken into account for causing the quality of welds. In order to prevent hydrogen contamination and thick aluminium oxide layer, the parts to be welded must be cleaned well before welding and the welding process must be completed within a certain period after cleaning. The welding parts are cleaned with a proper cleaning process after receiving from machine-shop. Because the aluminium oxide can act as an insulator, it results in an erratic welding arc and causes poor welding quality. Moreover, this oxide layer is porous and tends to trap moisture [6]. This aluminium oxide layer must be scraped away manually before welding process.

2.2. Welding Equipment

Gas Tungsten Arc Welding (GTAW), as known as Tungsten Inert Gas welding (TIG), is chosen for aluminium welding. A commercial welder, OTC Daihen 500P, is used for welding all vacuum chambers. An AC mode TIG welding process is used in the automatic welding system. The weld electrode head's material is pure tungsten with a diameter of 3.2mm. 10 Liter/min Argon is used as the shielding gas for protecting electrode and over-flow inside of sample chamber. This can provide high quality welding seams. A4043 wire with a diameter of 3.2mm is used as filler material.

2.3. Automatic TIG Working Platforms

There are approximately 2700 aluminium welds for 48 TPS bending chambers. It is a heavy working load if these 2700 weld seams must be completed by hands. Therefore, a new automatic system, which can provide great promise as a replacement for hand arc welding, is required. As we may know, arc welding is a continuous process in which the torch and filler is carried along the seam to be welded. NSRRC have developed two automatic welding systems for aluminium TIG arc welding. One automatic system is designed by using two welding torches to implement two welding seams on each side of an aluminium chamber simultaneously. The other is to use an industrial 6-axis robot with a unique welding configuration. Figure 1 shows the two-axis welding system and Figure 2 shows the industrial 6-axis robot with a unique welding configuration. These two auto welding systems allow the welding torch to be manipulated in almost the same fashion as a human being would manipulate it. The torch angle can be changed to make good quality welds in all positions. Moreover, a single welding length can be longer than manual welding. The following sections will discuss these two auto welding system in detail.

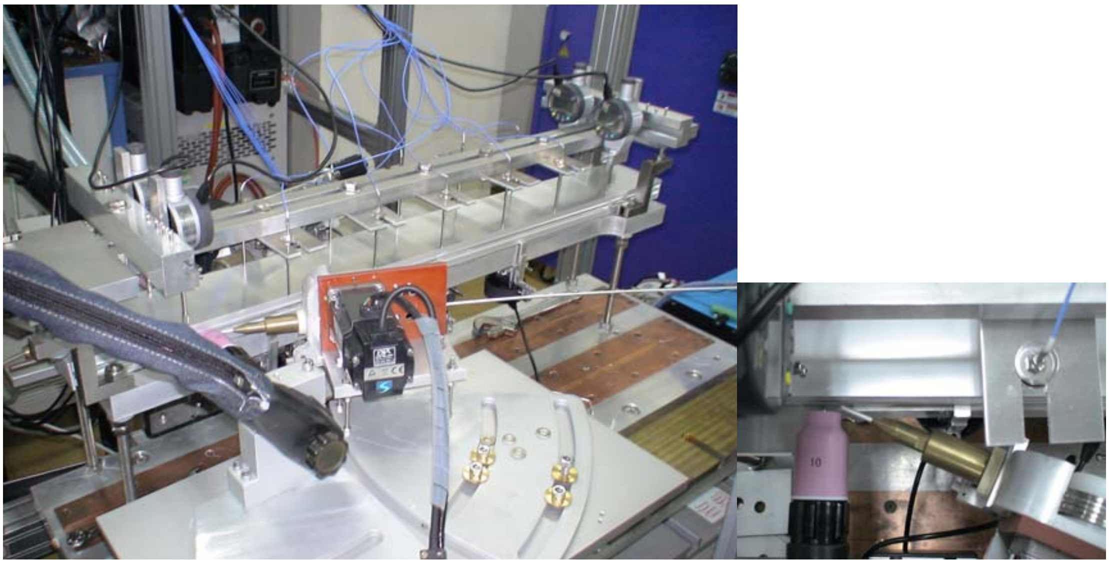

Figure 1 Two-axis welding system with two TIG torches, and real-time monitoring sensors.

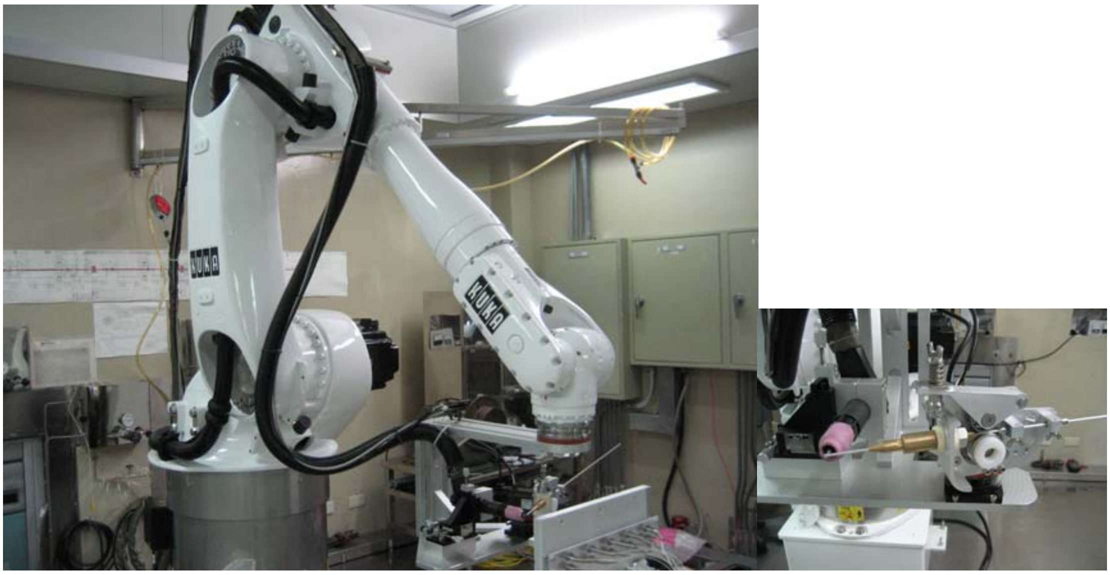

Figure 2 Industrial 6-axis robot with a unique welding configuration

2.3.1. Two-Axis Auto Welding System

Two-axis motion system ensures accuracy of welding position. Rectangular arms are sometimes called "Cartesian" because the arm's axes can be described by using the X and Y coordinate system. It is claimed that the Cartesian design will produce the most accurate movements. One axis is used to control the chamber's movement in X direction. The other one is to move the torch perpendicular the chamber moving axis in Y direction. Therefore, an X-Y horizontal working plane can be achieved. In additional to this, there are two welding torches with filler mechanisms on each side of vacuum chamber. These two opposite torches can be switched on to implement two welds on each side of an aluminium chamber simultaneously. Figure 1 indicates the two axis' movement directions and the welding configuration of torch and filler. The position between torch and filler in the two-axis auto welding system is evaluated carefully which is similar to human welding position. Both axes are driven by two step motors. These two motors are controlled by LabVIEW motion program, which provides a high accurate welding position.

2.3.2. Six-Axis Robot for TIG Welding

Robot welding means welding that is performed and controlled by robotic equipment. Similar to Two-Axis auto welding system, robot arc welding is designed of using the same welding configuration. Figure 3 shows the arc welding configuration which is mounted to robot arm. This system provides high duty cycles for more complicated weld geometry. In addition, the equipment components must have the necessary features and controls to interface with the main robotic control system. The robot's arm has a trunk, shoulder, upper arm, forearm, and wrist. All joints in the arm can rotate, creating six degrees of freedom. Three are the X, Y, and Z axes. The other three are pitch, yaw, and roll. This helps the arc to weld in areas that are difficult to reach.

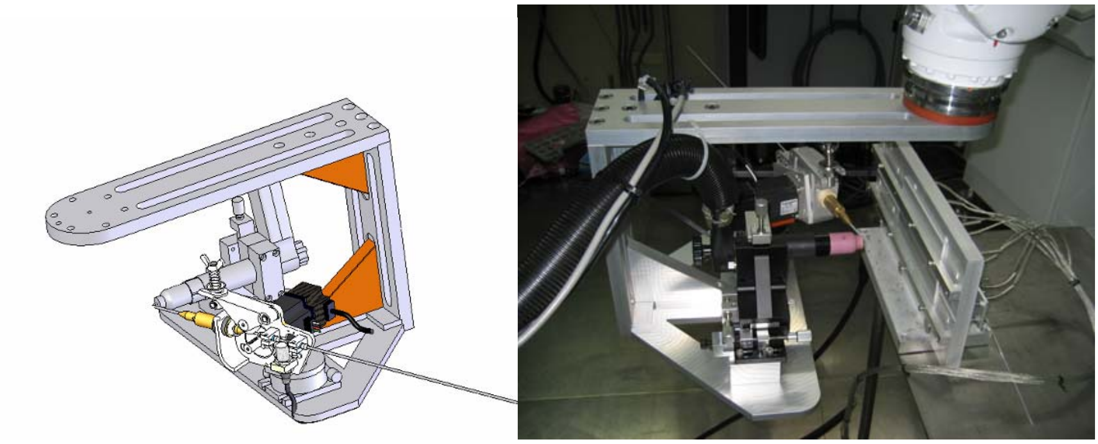

Figure 3 Arc welding configuration which is mounted to robot arm

2.4. Real-time Thermal and Deformation Monitoring Measurements

A real-time thermal and deformation monitoring system is established for the automatic welding system. In order to obtain the welding variations, it is necessary to monitor the thermal and deformation changes of the vacuum chamber. These thermal and deformation data are valuable to analysis the quality of welding seams. These data also can be used to optimize the welding parameters. In the measuring system, there are 8 K-Type thermocouples which are mounted near the welding seam for measuring the chamber's surface temperature distribution while the welding process is conducting. For deformation measurement, there are 12 dial gages, which are commercially available from Mitutoyo. These dial gages are used to measure both horizontal and vertical deformations while welding process is conducting. The detail setup is shown in Figure 4. There are four dial gages which are mounted on the four corners of the top plates to measure the vertical bending deformation. The rest 8 dial gages are located along the two welding seams to measure the horizontal bending deformation.

Figure 4 Real-time thermal and deformation measurement setup

2.5. Welding Test

A 1000mm long aluminium chamber is fabricated. It consists of two A6061 plates. This sample chamber overall dimensions are 97W×1000L×32H (in mm), and internal chamber size is 85W×1000L× 20H (in mm). This sample chamber's weld join is similar to most of the joint designs on the storage ring's vacuum chambers. These two plates are assembled by the 2 axis auto welding system. Figure 5 illustrates the dimensions of the sample chamber and the weld joins. Figure 6 shows the locations of thermocouples and dial gages. Both thermal and deformation data are collected while and after welding process is conducting. In the following section, the thermal and deformation results will be discussed.

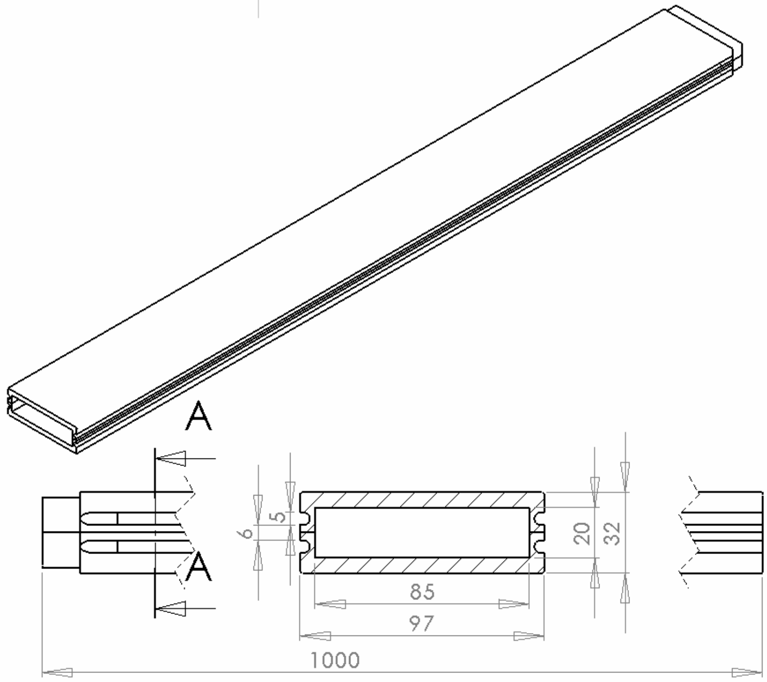

Figure 5 Dimensions for sample chamber

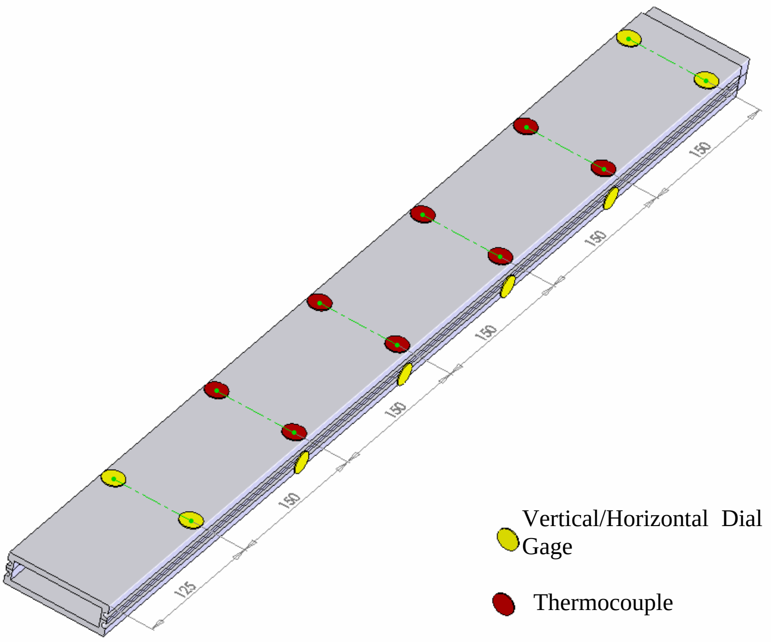

Figure 6 Locations for thermocouple, dial gage measuring position

3. Results and Discussion

All welding conditions are listed in Table 1. From Figure 7, it indicates the temperature rises rapidly when the torch is passing by. The temperature on the top surface of sample chamber can be reached at about 160°C. After the torch leaves the measured position, the chamber is cooled down with a stable cooling rate due to the heat dispersion to air or fixtures. Figure 7 shows the relationships between temperature and horizontal/vertical deformation during the welding process. The deformation measurements show the sample chamber is expanded due to heat energy is added. The maximum deformation is 0.3mm, located at X23. However, the sample chamber shrinks when the chamber is cooled to room temperature. According to the deformation data, there is still an irreversible deformation which is 0.15mm after the welding process is completed and the sample chamber is cooled down to room temperature. This is still acceptable for this welding method. The sample chamber is leak tested to 1×10^{-10} mbar·l/s helium and passed the leakage check.

Table 1 TIG Welding Conditions

Welding System Used	2-axis auto welding system
TIG Machine	Two AC TIG torches
Base Metal	A6061
Filler	A4043 ϕ3.2mm
Torch Type	Pure Tungsten ϕ3.2mm
Start Current	140 A
Final Current	130 A
Welding Length	750 mm
Temperature Before Welding	Room temperature
Welding Speed	180 mm/min
Sample Fixture Type	Floating method
Ar Protection Flow Rate	10 l/min
Humidity	50%
Room Temperature	23ºC

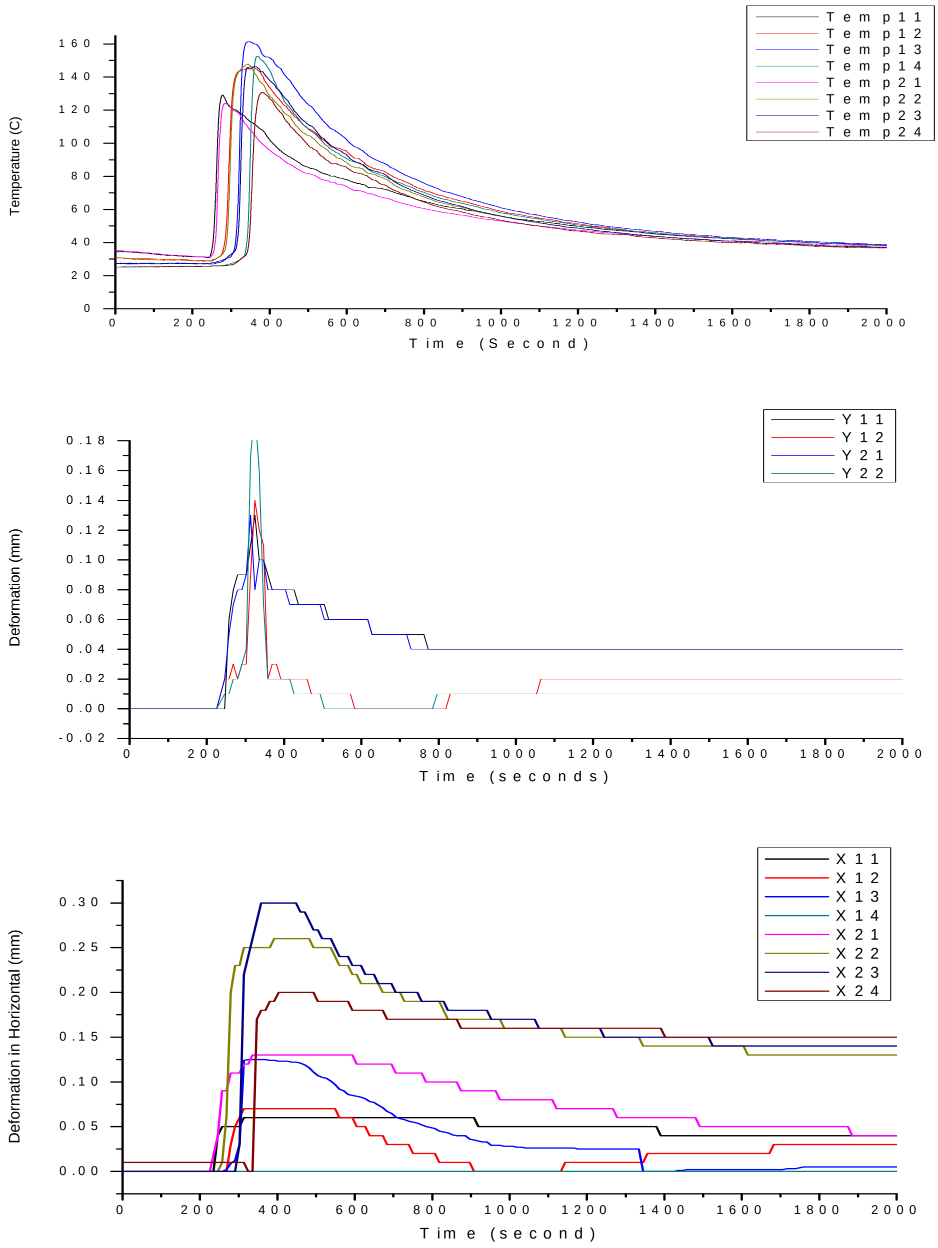

Figure 7 Thermal and vertical(Y)/horizontal (X) deformation curves

In addition, computational simulation results are obtained by using ANSYS to understand the thermal distribution and deformation during the welding process. Figure 8 shows both the thermal distribution of the top sample chamber and the vertical deformation. The simulation results are matched with the experimental data. The maximum temperature is shown in the middle of the test chamber and the maximum deformations are located on the two ends of the test chamber.

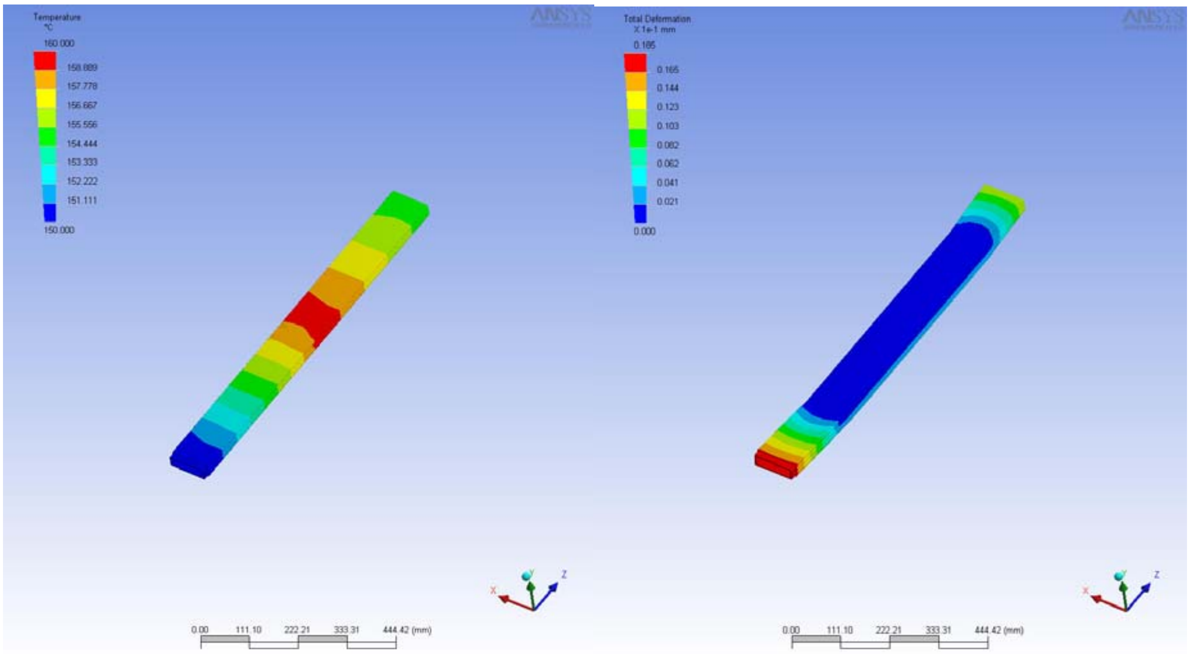

Figure 8 Thermal (left figure) and deformation (right figure) simulation results

4. Conclusion

Two automatic TIG welding systems are introduced in this paper. 6 axis robot can provide high duty cycles for more complicated weld geometry. Moreover, two-axis automatic system is using two welding torches to implement two parallel welds on each side of an aluminium chamber simultaneously. According to the thermal and deformation data, this welding method provides a promise of welding TPS aluminium vacuum chambers with the development of automatic welding system at NSRRC.

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