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Radio telescope manufacturing with adaptive aluminum thermoforming and fringe projection metrology

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ABSTRACT

Large-scale radio telescope projects will be important in answering modern astronomical questions like those of the National Academies' Astro2020 survey. We propose an efficient and cost-effective thermoforming process with fringe projection metrology (FPM) as an alternative to current panel fabrication methods.

In our thermoforming process, we use a flexure plate with actuated tiles to create an adjustable mold inside an oven. Unshaped panels are placed on the adjustable mold and heat is applied, thermoforming the panel to the mold shape. This process allows for the rapid prototyping and production of many panel shapes with sufficient accuracy and reduced recurring costs. We apply FPM to evaluate the mold and panel shapes. FPM applies phase-shifted fiducial patterns, camera stereo vision, and triangulation to measure the thermoformed panel.

We applied these technologies in beginning the construction of the Public Outreach Radio Telescope (PORT) and its off-axis dish of 26, 0.5 m^2, 1/8" thick panels. The PORT is designed for 30dB of gain at $\lambda = 21$ cm wavelength, and the dish was toleranced to $\lambda = 3$ cm wavelength for future observations. In this proof of concept, we have installed thermoformed panels measured with FPM on a radio telescope.

Keywords: radio telescope, thermoforming, adjustable mold, fringe projection, metrology

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1. INTRODUCTION

1.1 Radio astronomy

Modern radio astronomy is directed at some of the most foundational scientific questions of the 21st century. These goals often demand immense collection areas as well as accurately shaped dishes – which are usually prohibitively expensive and time consuming. This paper will focus on the Steward Observatory Solar Lab's ongoing research, which currently aims to develop more cost-effective, fast, and accurate ways to create panels for radio telescopes.

1.2 Telescope manufacturing

The Student Radio Telescope (SRT) mount and dish were donated to Chris Walker at the University of Arizona in 1991 for the educational and experiential enrichment of undergraduate students[1]. However, the SRT saw no use after 2013 – until the University of Arizona senior design team (SDT) 21039 began work on its restoration and upgrade, thus converting it into what we now call the Public Outreach Radio Telescope (PORT). Our goal with the PORT is to test our panel fabrication and metrology processes and provide an on-campus radio telescope for University of Arizona students and researchers.

Table 1. Key PORT optical design characteristics[2]

Characteristic	PORT dish
entrance pupil diameter (EPD)	2.4 m
focal length	-1.125 m
operational wavelength	21 cm
resolution at full width half maximum (FWHM)	5.11°
dish angle offset	56.007°
F number	0.46875
illumination angle	86.653°
gain (21 cm wavelength)	30 dB
loss from panel gaps	0.0411 dB

Our thermoforming process uses an oven to heat aluminum panels until they conform to the controlled shape of our adjustable mold. Inside the oven, a hexagonally tiled flexure plate with an array of actuators enables manual adjustment of the mold shape. Once the mold is prepared, a flat aluminum panel is placed on the shaped flexure plate, weighted down, and heated. Once the thermal cycle is complete, the panel is shaped and ready to be measured and installed.

After thermoforming, we utilize FPM to measure the accuracy of our panel shape. Deviation from ideal antenna shape reduces radio telescope effectiveness; thus, we want to ensure that the final panel is sufficiently similar to the intended shape. We also prefer to be able to quickly measure the mold shape error for iterative adjustments. Our solution is found in FPM, which can measure the mold or panel shape to RMS ≤ 40 μm, satisfying RMS ≤ $\sim\lambda_{shortest}$ / 25 for the 3 cm wavelength of the PORT[3].

2. METHODOLOGY

The Steward Observatory Solar Lab worked to implement and build on the work of the SDT 21039. To do so, the PORT and truss structure were installed on the roof of Steward Observatory, and construction of the 26 panels was begun.

2.1 Adaptive aluminum thermoforming

For each panel, the adjustable mold is adjusted and measured with FPM until improvements in mold shape accuracy diminish. A panel is thermoformed in our adjustable mold under a 50 lb steel chain at around ~575 °C. The entire thermal cycle for one panel is ~10 hours, and the panel is brought to room temperature slowly to reduce springback errors.

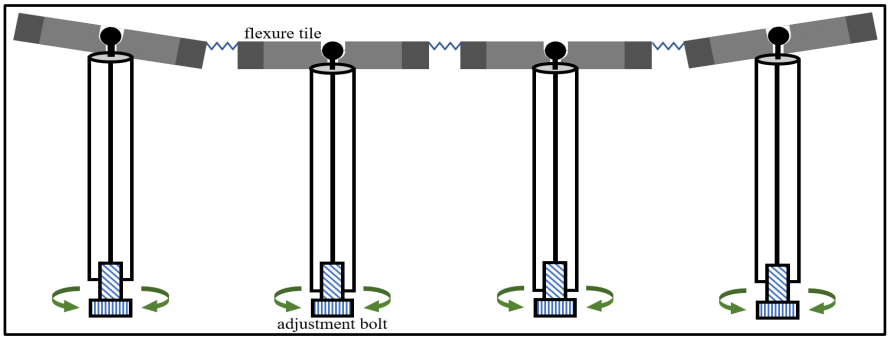
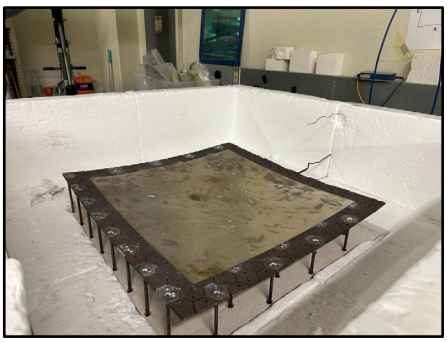
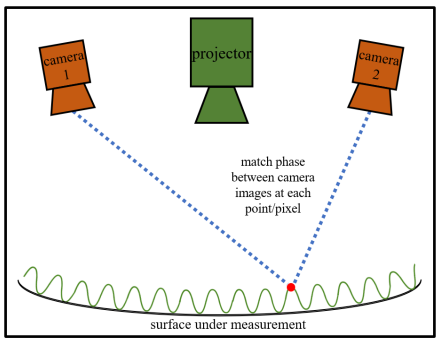


Figure 1. Adjustable mold diagram

2.2 Fringe projection metrology

Once the panels have completed thermoforming, their shape error can be measured. Our FPM application utilizes stereo camera vision and a projected pattern to create a three-dimensional point cloud of the measured surface. The projection of a phase-shifted fiducial pattern (e.g., sinusoidal, binary bar) reduces the uncertainty in point matching between camera views. After applying a phase unwrapping algorithm, points can be matched and triangulated with the known parameters of the optical system[4], ensuring sufficient accuracy of panel shape.





Figures 1-2. Thermoformed panel (left) and FPM diagram (right)

2.2 Panel installation

Once a panel is thermoformed and measured to confirm its accuracy, four threaded swivel feet are epoxied to the corners of the panel. These feet are then secured to the PORT with spherical washers and nuts. The swivel feet allow for each panel to be adjusted for precise alignment.

Figure 3. Installation of PORT panels

3. RESULTS and CONCLUSIONS

The manufacturing and metrology process employed by the Steward Observatory Solar Lab achieved an RMS of 250 µm for test panels using a 5th order polynomial fit. Construction of the PORT has so far enabled the demonstration and refinement of our adaptive mold, thermoforming process, and FPM applications. The Steward Observatory Solar Lab will continue work on the PORT – a resource that will serve future radio astronomers on the University of Arizona campus. Among the most significant next steps for the PORT is the testing of an on-site panel alignment method. Furthermore, the cost analysis of this particular manufacturing process will be substantiated as it concludes.

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