Adaptive Aluminum Thermoforming for Precision Millimeter Wave Telescope Panels

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Abstract: Researchers at the University of Arizona have developed a technology for precision radio telescope panel fabrication involving an adjustable mold-based thermoforming process. The motivation, technology, and experimental results will be presented.

1. Introduction

Radio telescopes are instruments that allow for astronomical sources to be studied by receiving emitted radio waves and focusing them to a receiver where the signals may be analyzed in a computer. The radio frequency spectrum is often split into multiple bands, but broadly covers frequencies ranging from 10 KHz to 300 GHZ. “Millimeter wave” refers to the range of frequencies within the broader radio spectrum that correspond to wavelengths on the scale of millimeters. Because these wavelengths are much longer compared to the visible or infrared spectrum, diffraction effects lead these telescopes to require much larger primary mirrors, many of which are parabolic or freeform in shape. This primary mirror is typically followed by a smaller secondary mirror mounted above it which focuses waves reflected off the primary down to the receiver [1].

Because the wavelengths of interest are longer, the surface quality generally does not need to be as precise as what is typically required in optical telescopes [2]. As a result, the material used to manufacture these mirrors is often aluminum, and constructing the full dish is achieved by patterning many curved aluminum panels together to form the full parabolic dish. Historically there are several different ways in which these aluminum panels can be manufactured to approximate the surface desired, however all have their own accompanying limitations and challenges [3].

This paper focuses on the process known as thermoforming, which involves placing flat aluminum sheets on a freeform mold designed to approximate a particular shape, then heating up the whole setup in an oven until the panel gets hot enough to conform to the mold. Cooling the system back down yields panels which approximately match the shape of the mold. One of the limitations in this process is that it generally requires a separate unique mold to be machined for every nonidentical panel. This has the effect of increasing cost and severely limiting reusability of the materials created to manufacture the panels. Another technical challenge is the phenomenon known as springback, which describes the tendency for aluminum to relax back into its original pre-thermoformed shape by some non-trivial amount upon cooling, creating significant surface figure error [4].

2. Adaptive Freeform Mold for Millimeter Wave Panel Thermoforming

This paper addresses these issues through the presentation of progress on a new technology and experimental study involving an adjustable/adaptable mold with the ability to approximate many different compound freeform curvatures. We also present the results of using it to thermoform panels, accompanied by accuracy, precision, and repeatability studies, as well as an experimentally developed algorithm to pre-correct for the spring-back phenomena and fabricate panels of the desired surface figure to high precision.

The driving technology presented is an adjustable mold used to thermoform panels with varying compound freeform curvatures. This mold consists of a flexure sheet described as a patterning of individual hexagon-shaped tiles, each connected to its neighbors via thin, deformable, spring-like members as shown in Figure 1. An array of actuators connects to these tiles which are controlled to move independently of one another in the vertical direction, allowing for varying surface curvatures to be approximated by the flexure. An image of a prototype of this technology that we developed and tested is shown in Figure 1 (left), along with a drawing showing how the individual tiles can be controlled with the actuators to approximate surface curvature [5].

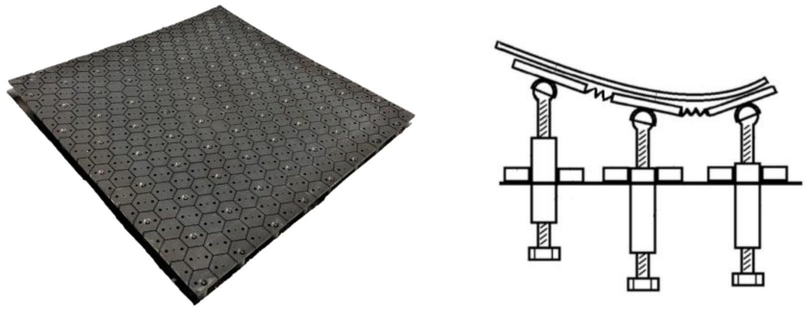

Fig 1. 50 cm × 50 cm adjustable mold prototype with hexagon-patterned flexure connected via bolt actuators to a steel backup structure (left); adjustable mold concept drawing showing side view of actuator-driven shape deformation and panel conformation on top (right).

3. Experimental Demonstration of Thermoformed Radio Panel

We have completed numerous tests on several different prototype iterations of the adjustable mold technology depicted in Section 2. These tests consisted of shaping the adjustable mold to a prescribed surface figure over many adjustment iterations and measuring the surface with a Coordinate Measuring Machine (CMM) and/or portable CMM to calculate surface error and the residual data needed to improve the mold shape and design as presented in Figure 2. Of course, once the thermoformed panel is within its manufacturing tolerance, the iterative steps are completed and the adaptable mold is fixed for mass production of the specific surface shape panels. Additionally, thermoforming tests have been performed while the mold is set to a specific shape in order to measure and characterize the resultant panel shape accuracy, repeatability, and springback effects. Below are figures showing the results of shaping one of the prototype adjustable molds to a prescribed parabolic surface over several adjustment iterations.

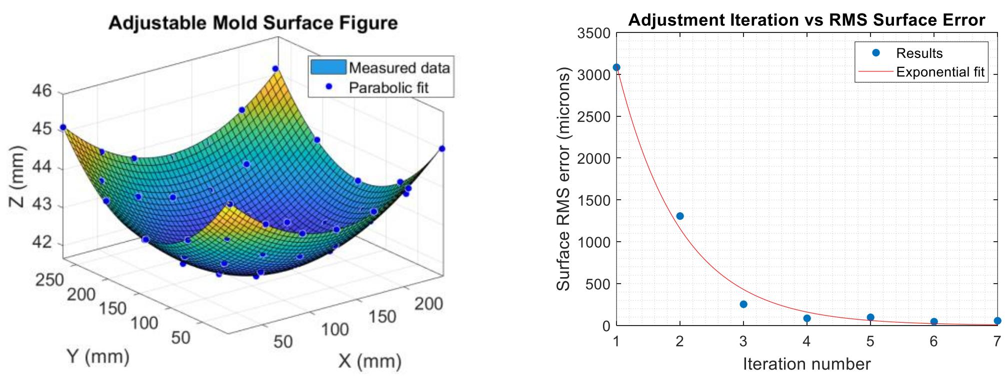

Fig 2. Portable CMM point cloud data and parabolic surface fit for prototype mold best iteration (left); adjustment iteration number vs surface figure RMS error showing an exponentially decreasing trend bottoming out at 45 μm.

3. References

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Acknowledgement: This work was funded by NSF (National Science Foundation).