MANUFACTURING PROCESS FOR SIT SOLAR FAÇADE PANEL SYSTEMS

MECHANICAL ENGINEERING 450 – DESIGN AND MANUFACTURING III
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Project #23
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Authors' Note: *This is a short summary of the final report that was submitted at the conclusion of the project. The façade panel product described herein is patent-pending, and certain technical aspects of the product are proprietary information. As such, this summary has been compiled to exclude content that the project sponsor wishes not to disclose to the public. However, the general ideas presented here remain essentially unchanged.*

– B.F., N.F., J.N., T.T.

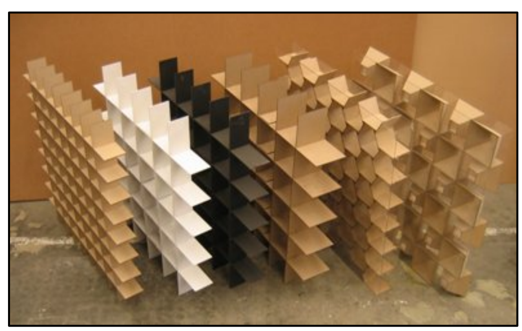
INTRODUCTION

The main goal of this design project was to develop a semi-automated process to assemble Structurally Integrated Transparent (SIT) solar façade panels. These panels consist of an open cellular core sandwiched between two transparent sheets that are secured with an adhesive. The previous process for applying this adhesive by hand was slow and imprecise. Our challenge was to develop a process that used machinery to accurately apply this adhesive and to fabricate large panels that would otherwise prove impossible to make by hand. This document summarizes the work we performed to accomplish this goal.

The sponsor for this design project was Professor Harry Giles of the Taubman College of Architecture and Urban Planning at The University of Michigan in Ann Arbor.

BACKGROUND

SIT solar façade panels are a patent-pending technology developed by the sponsor. These panels are generally intended for the cladding of building exteriors, and they help to provide a measure of sunlight and thermal management to the building interior while simultaneously introducing a visually appealing aesthetic element to the building design. The sponsor had been fabricating test samples, using a slow and tedious manual process that utilized handheld tools. To facilitate the testing of these panels on a larger scale, the sponsor asked our team to develop a faster and more accurate process for fabricating large samples.



Structurally Integrated Transparent (SIT) Solar Façade Panels (Photo courtesy Prof. Harry Giles)

INFORMATION SEARCH

Our information search focused on the sponsor's request for a process to apply and cure the adhesive on a panel with some level of mechanical automation. We conducted research to find information and cost data on computer numerical control (CNC) systems, components, and controllers. A list of manufacturers and suppliers was compiled, and these companies were contacted to obtain product information and recommendations for this application. However, we found that most commercially available systems were far beyond our desired budget range. So, we also conducted research to find controllable motor systems that could be used to custom-assemble a CNC-like machine for a lower-cost solution.

Based on numerous consultations with Professor R. Brent Gillespie of the Department of Mechanical Engineering at the University of Michigan, we decided that the best way to do this would be to use a certain kind of motor that was linked to a controller. These special motors are highly precise. This high level of precision is achieved as a result of the ability of the controller software to adjust the motor speed during startup and operation [1].

We also looked at three different configurations to interface the motors with the panel assembly system: linear actuator, ball-screw, and rack-and-pinion. We decided to use a rack-and-pinion configuration because of its robustness and low number of moving parts. The implementation of this configuration requires mounting the motor onto the object to be moved. The motor rotates a simple gear (pinion) that meshes with a ridged bar (rack). The rack-and-pinion is designed such that linear movement is very smooth. The major advantage of this configuration in our case is that multiple racks can be placed end-to-end in order to achieve linear motion over theoretically limitless lengths. They can also be placed on a flat surface such that bowing is not an issue [3].

CUSTOMER REQUIREMENTS AND DESIGN SPECIFICATIONS

To facilitate the determination of appropriate design specifications, we identified three distinct phases in the assembly of an SIT panel: (1) adhesive application, (2) component joining, and (3) curing.

The adhesive application phase of panel assembly required the ability of the process to apply a smooth and straight bead of adhesive onto the core within a relatively tight tolerance, and at a rate that facilitated automated production. Accuracy in this phase was critical, and the assembly system needed to accommodate almost any core geometry. The component joining phase of panel assembly required the outer sheets to be placed onto the core in a very careful and precise manner. The curing phase of panel assembly required less accuracy than the adhesive application phase, but the speed needed to be carefully controlled in order for the adhesive to cure properly.

DESIGN CONCEPT GENERATION

Our design concepts focused on a CNC-like system that would utilize computer-controlled motors to provide a one or two-axis system for adhesive application and curing. Our one-axis concept, utilized a large linear roller for adhesive application. Our two-axis concept, utilized a pressurized adhesive nozzle that would apply the adhesive along a precise path.

CONCEPT SELECTION

Although the roller concept would result in a much faster overall process than the nozzle concept, we felt that the roller might be too messy and splatter adhesive into undesired areas. We also were concerned that the roller would not deposit the adhesive uniformly, and that the rate of adhesive dispensation would be rather difficult to control, thus leading to possible unnecessary wasting of the adhesive. We therefore decided to implement the two-axis concept. This decision was also partly motivated by the sponsor's desire to incorporate equipment that he had already acquired prior to the start of this project.

ENGINEERING ANALYSIS

Our primary engineering analysis was to properly size the motors for the prototype. In order to move the panel assembly jig components in the desired directions, we utilized a total of two motors. The goal was to provide an acceptable amount of accuracy when turning corners, stopping, and reversing direction. To determine the appropriate motor sizes, we estimated system parameters in order to calculate the motor loading torque (T) and the force required to move the jig with all its components (F).

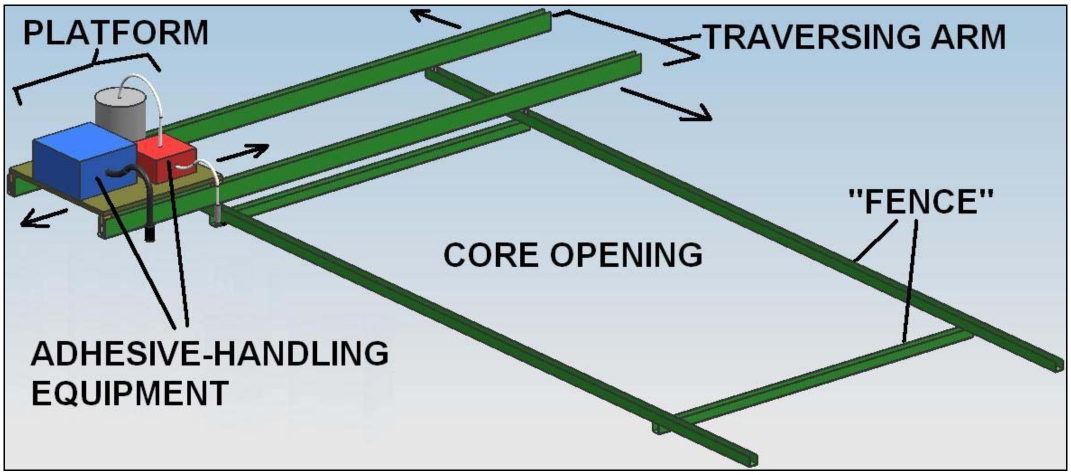
The key variables needed to calculate T and F for a rack-and-pinion configuration are the total mass (m) of the traversing arm, the frictional coefficient (μ) between the rolling components, the angle of inclination (α), the pitch diameter of the pinion (D), the efficiency (η), and the gear ratio (i). By estimating these parameters, we used Equations 1 and 2 [2] to calculate a force F of 5.00 lbs and a torque T of 51.87 oz-in.

$$F = m(\sin\alpha + \mu\cos\alpha) \qquad \text{Eq. 1}$$

$$T = \frac{FD}{2\eta i} \qquad \text{Eq. 2}$$

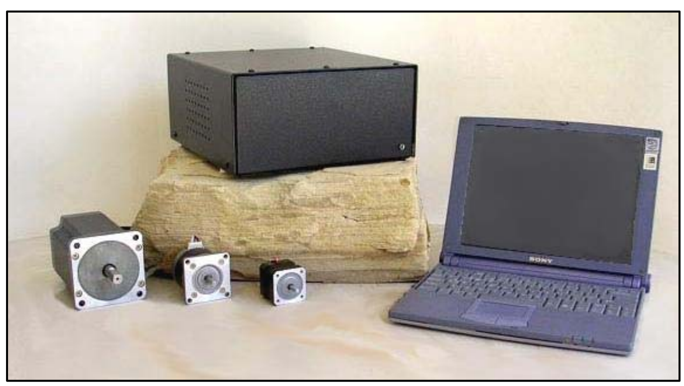
FINAL DESIGN

The final design consisted of a traversing arm providing motion in one direction, which supported an independently driven platform providing motion in the other direction, upon which the adhesive-handling equipment was mounted. A conceptual CAD model of our final design is shown in the following diagram.



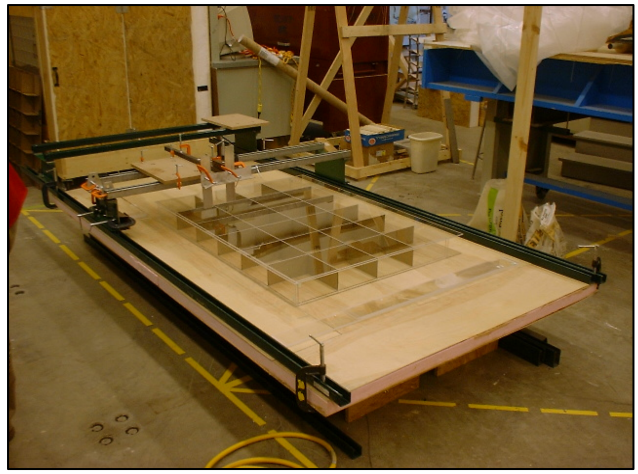
Conceptual CAD Model of Prototype

To motorize our final design, we selected a two-axis programmable motor control system. This system was selected because it was a relatively simple "all-in-one-box" system that could be set up quickly and operated with a manual remote controller. For the development and testing phases we opted to utilize a remote controller in order to keep manual control of the system easy and intuitive. Future plans included the downloading of pre-programmed patterns to the system such that no direct user input would be needed.



A Programmable Motor Control System

MANUFACTURING AND TESTING



Early Prototype Under Construction

An experimental prototype that was based on our final design was constructed in conjunction with the sponsor's research group. The major difference between our final design and the prototype was that adhesive-handling equipment was placed on two separate "bridges," allowing independent adhesive-handling processes to be carried out for the purposes of optimizing production time.

Initial testing of this prototype utilized manual actuation of the moving components with a grid-pattern core. The next round of testing incorporated the motorized components, which were controlled via the remote controller. The sponsor reported to us that testing of the system up to this point went extremely well with virtually no problems, and he was very pleased with the results. Further testing in the future planned to incorporate more complex core geometries, and attempts to pre-program the controller such that the system could operate autonomously with only general human oversight.

FUTURE IMPROVEMENTS

Even though our experimental prototype yielded a vast improvement over the previous manual method, we identified a few ways in which improvements could be made. Currently, alignment of the core geometry on the assembly jig is done on more-or-less of a trail-and-error basis using the sides of the jig as alignment guides. Since accuracy is an integral part of the success the adhesive application phase, it would be highly beneficial to develop a method to keep the core geometry correctly aligned and locked into place, thus reducing the likelihood of adhesive application error and preventing any chance of movement when applying the adhesive.

Another issue that was identified was the lack of some sort of automatic "feedback loop" that would make real-time adjustments to the system if it started to go out of alignment.

CONCLUSION

From the need for a better alternative to manual SIT solar façade panel assembly, we developed a semi-automated assembly process that we believe is both relatively simple and effective, and yet leaves plenty of room for future improvements, including the possibility of scaling up to mass-production. In a mass-production setting, it would be desirable to further automate and speed up the process using a more accurate framework to better guide the traversing arms as well as the development of CAD-based data translators to convert core geometries into automated controller commands.

ACKNOWLEDGEMENTS

First and foremost, we wish to thank our project sponsor, Professor Harry Giles of the Taubman College of Architecture and Urban Planning at the University of Michigan for providing the real driving force behind nearly every aspect of this project, and for taking upon himself much of the work that was involved in making it a success.

We would also like to thank Professor R. Brent Gillespie of the Department of Mechanical Engineering at the University of Michigan for his expertise and assistance in helping us to better understand electric motors and select the right system for this project.

Finally, we wish to thank Professor Kazuhiro Saitou (and the rest of the ME450 faculty and staff) of the Department of Mechanical Engineering at the University of Michigan for his efforts in the organization of the ME450 course and preparation of lecture material, and for his understanding of the unique challenges that we faced throughout the course of the semester.

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[1] Gillespie, R. Brent. Personal Consultations. Mar 2007.

[2] Oriental Motor U.S.A. Corp. “Motor Sizing Calculations”. Online. Internet. Oriental Motor U.S.A. Corp. 13 Mar 2007. <http://www.orientalmotor.com/support/mtr_sizing_formulas.htm>

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