Team 502: The Material Handling of Ceramics

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***Abstract*—Corning produces brittle, cylindrical ceramic filters for vehicles with internal combustion engines to filter exhaust air. They discovered that these ceramic filters are often damaged when moved from one manufacturing stage to another, typically occurring when the filter's skin is crushed, making the filters unusable. We were tasked with providing a solution for handling ceramic filters without introducing damage during the production process. Our design prevents visible damage at the location where the production handler contacts the filter's outer walls.**

Our handler design has three fingers that approach the filter's surface in separate places around the its circumference. The design is adjustable depending on the size of the filter it is handling. There is compliant padding attached to the design that contacts the filter's surface to lessen the contact forces applied on the filter. Force sensors indicate when the handler should stop applying pressure, allowing for part movement. This procedure is quick and consistent with the use of motors and a computer, making it usable in a lean manufacturing system. The linear motion of the padded three-finger design also allows the handler to pick and place various sizes of these ceramic filters with a controlled motion.

We valuated the handler performance with sample filters provided by Corning. A successful test resulted in the handler not causing damage to the ceramic parts after contact by regulating the forces applied by the handler, adding cushioning to the interface, and increasing the contact area.

***Index Terms*—ceramic, handling, EOAT, material handling, ceramic filters**

I. Introduction

A. Project Objective

Team 502 was tasked with creating a device that could move brittle ceramic filters from one manufacturing stage to another without inflicting damage.

B. Key Goals

The project has an emphasis on producing innovative ideas to service the automatic handling process. One of the key goals of the project is that the final system should reduce damage to parts. The current process Corning is using is too damaging to parts and may not be sufficient for production as materials exhibit reduced strength in favor of higher porosity. Damage to parts must be avoided to remain in compliance with part specifications. Another key goal is to produce a design that accommodates a lean manufacturing process. A secondary goal of this project is for the system to be adaptable for handling of any fragile materials.

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C. Assumptions

The material will have characteristics of solid ceramics: brittle, high melting point, high wear resistance, low impact strength. The materials being maneuvered are cylindrical extrusions with parallel channels. These assumptions are based on the samples provided by Corning. The current manufacturing process is automated. The manufacturing environment is under ambient conditions. This project cannot leverage any existing handling processes used by Corning, so the developed product must not rely on these processes.

II. Targets and Metrics

The established functions must have associated numerical targets to evaluate the system performance. Each target quantifies the extent that each function should accomplish an action. The entirety of the targets and metrics can be found in the Target Catalog Appendix C. Within the functional decomposition subsystems, there are certain targets that are identified as mission critical. They are critical because they play a key role in demonstrating success for the project as defined by the customer needs. Each target has a corresponding metric which defines the measurement system for each target quantity. For identifying the targets and metrics, each function's physical action was considered. For instance, for the Function "Receive Power", the metric associated is identified by the standard quantity in the S.I. metric system for power – Watts. Then the associated target was identified by the amount of power available to the Handler system, 30 Watts. The following sections include a summary of the critical targets and metrics within their corresponding subsystem.

A. *Move*

For the system to be able to move the part, it is crucial for the Handler to have the capability to accommodate the orientation relative to the part. The target assigned for this function is 90 degrees because the Handler must be able to reach the part horizontally and vertically. To test this target, we will observe the manipulation to verify if the Handler system successfully orients to the part from horizontal and vertical positions. The system must successfully relocate the part by lifting the part from its starting position. The target for this function is 0.5 inches because that is the minimum vertical distance required to translate the part. To test this value, the team will measure the vertical distance achieved from the part's starting position, making sure that it is at least 0.5 inches. To avoid damage to the part during manipulation, the system must be able to place the part carefully. Half an inch is the target for this function because to place the part, the final Handler needs to place the part back down the same vertical distance it was lifted. The team will measure the success of this target by examining the part after placement, making sure it was placed the minimum distance without damage. To verify these distances, a ruler or measuring tape will be used.

B. *Support*

For successful manipulation, the end Handler will be able to support the part load. Since Corning has provided that the ceramic part will weigh a maximum of 40 pounds, this mass is a necessary target for the Carry Part Load function. The team will know if this target is met based on whether the Handler can maintain position when a ceramic weighing 40 pounds is being tested. Additionally, applied pressure is causing damage to the part, so it is crucial that the pressure on the part applied by the handler is regulated. The target range of 100-150Mpa for applied pressure allows the handler to successfully engage with the part without crushing but can maintain enough to not disengage with the part. To test this function, the team would use a load cell to measure the applied pressure, making sure it remains in the desired range.

C. *Navigate*

The system is expected to correct misalignment with the part given the part's initial position and orientation. The Handler target for response to misalignment is within 0.5inches. This allows the system to be misaligned due to any errors in positioning, and still accomplish the functions. The team will ensure that this target is met by using a vernier caliper to measure the misalignment, verifying that it stays under 0.5inches.

D. *Targets outside of Functions*

Some targets are set for metrics outside of the system functions. However, it does not make them any less important as these targets are important to the end factor. The first target outside the functional decomposition is durability. For the system to be durable, a target of one million cycles was determined, based on how large the plant is and how many times the ceramics are moved. Another target based off customer needs is the acceleration difference between the part and the Handler system. The part cannot slip out of the Handler's engagement and become substantially misaligned or out of the Handler's hold. This acceleration difference should not exceed 0.01g since this would not fulfil the needs of the customer and the part would be more likely to slip out of hold. This target may be validated with at least two 3-axis accelerometers and observing the difference. An additional target was identified for the response of the system to loading. This is the amount of time it takes for the system to fall within 2 percent of the steady state values. The settling time of the system response to loading should not exceed 100 ms. This is assuming that the system response is stable and can maintain the desired value.

III. Concept Generation

A. *Concept Generation Tools*

In coming up with 100 different concepts for the ceramic part handler, Team 502 used a variety of concept generation tools. One tool that was used was biomimicry. Biomimicry gave many useful concepts that were not thought of during the initial brainstorm. By looking into nature and seeing how nature deals with problems, Team 502 was able to find inspiration. Another concept generation tool that was utilized was targeted solution research. Team 502 assigned each member to research ways that the ceramic part could be moved without damage. The findings were presented during a group meeting, where the group used this research to generate project specific ideas. Much of the research involved different state of the art End of Arm Tooling (EOAT) grippers, adhesion-based part securing methods, levitation methods and soft material research. These items from research were considered and organized in an Affinity Diagram where similar ideas were grouped and the relationships between each idea were pointed out through shapes, arrows, and colors. This Affinity Diagram was helpful for visualizing the means of achieving successful proof of concept for the project. After all of these tools were used, including brainstorming sessions, one hundred concepts were assimilated in a list which is included in Team 502's Evidence Manual. These concepts were organized into three different classes: low, medium, and high fidelity concepts. Low fidelity concepts demonstrate a potentially implementable concept but do not have a strong case to be competitive with the high and medium fidelity concepts. Medium fidelity concepts are plausible for concept selection consideration but are not to be among the high-performance concepts. The high fidelity concepts are very strong ideas that have potential to be the principal concept for embodiment and detailed design.

IV. Concept Selection

After the concept generation, Team 502 used a variety of tools to select a concept. These tools all vary in processes, but they all relate to each other. In this concept selection, the tools were used in specific ways since they are sequential.

The selection tools in order are the binary pairwise comparison, House of Quality (HOQ), Pugh charts, and Analytical Hierarchy Process (AHP).

A. High Fidelity Concepts

1) Concept 3 – Vacuum Suction Gripper Array: This concept consisted of a parallel gripper, lined with vacuum suction cups to latch on to the part. An additional expulsion of air may be necessary to clear out debris.

2) Concept 2 – Parallel Grippers with Internal Sensing Feedback: This concept consists of padded grippers that would use sensors to adjust the pressure of the grip upon engagement with the part.

3) Concept 1 - Three Point Sensing Gripper: This concept consisted of three padded grippers, with sensors behind the padding at the center of each point. The three points are positioned 120 degrees about the cylinders axis.

B. Final Concept

After going through with the concept selection processes, the winning concept for this design was concept 1, the three point sensing gripper. Some key benefits of this design included, good force distribution, no need for extra air, and large contact area.

V. Design Description

After several design iterations, Team 502 developed a final design to base their physical model on. The design iterations consisted of switching from DC motors to linear actuators, curved grippers becoming hinged flaps, and a vertical chassis design switching to a sideways chassis design.

A. Final Design

The final design consists of a rectangular chassis with supports at each corner. At the bottom end of the chassis, two mounting bars have been added at a 120 degree angle, to support the linear actuators. The three linear actuators are 120 degrees about the cylinder ceramic's axis and are connected to the chassis via mounting brackets.Below each actuator is a linear rod and bearing system to support parallel linear motion and distribute the force transmitted by the linear actuator. On the end of each of the linear actuators and rods, are aluminum flaps connected by friction hinges. The flaps can be added or subtracted based on the diameter of the cylinder being manipulated. Additionally, the resistance of the hinges can be adjusted for varying diameters. On the center flap of each set of flaps is a force sensing resistor. On top of the force sensing resistor is PORON urethane padding and a fabric faced rubber material. The final design is shown below in Figure 1.

B. Design Operation

Once turned on and set to the correct position for closing in, the three force resistors will begin reading in values. These values will be negligible until the linear actuator pushes the padding into contact with the cylinder ceramic. Upon contact with the ceramic, the force sensors will read in values. Once a desired value is reached (will be different for each sample), the gripper will stop closing in and the test fixture will be used to manipulate the fixture as well as the ceramic to a location. At this stage, data will be collected and each of the targets will be validated.

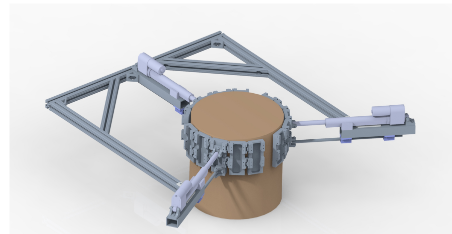

Fig. 1. Final Gripper Design

VI. Results

A. Test Operation

The test operation consists of 6 stages. The test fixture will hoist the fixture and ceramic upwards and safely place it back down after being transported horizontally. Damage will be assessed before and after operation.

1) Stage 1: Pre-test: During this stage, the ceramic is marked on its outer skin at its 120 degree marks with three different colored markers. These three marks are lined up with corresponding marks on a flat wooden palette. The ceramic at this point is evaluated for damage, and all damage is noted in the lab notebook. Additionally, photos at each marked point of the ceramic are taken.

2) Stage 2: Gripper Engagement with Ceramic: Once in the correct position, the computer operator will type the code word to begin the motion of the linear actuators. Once the force sensing resistors read in the desired value, the gripper stops closing in. At this stage, the regulate pressure target is evaluated based on any damage caused during engagement.

3) Stage 3: Vertical Motion of Gripper and Ceramic: During this stage, the test fixture will move the part vertically 18 inches. The target evaluated at this stage will be the support of part load, because if the filter drops, the part load is not supported.

4) Stage 4: Horizontal Motion of Gripper and Ceramic: At this point in the test operation, the wheels on the bottom of the test fixture will be used to roll the test fixture, gripper and ceramic horizontally 18 inches. The target evaluated at this stage is part displacement.

5) Stage 5: Placing the Ceramic and Fixture Down: Now that the ceramic and fixture have been successfully lifted and moved, the ceramic must be lowered back down and the gripper must successfully disengage with the part.

6) Stage 6: Damage Evaluation: After safe disengagement, the ceramic can be placed back on the wooden palette for evaluation of the damage inflicted. New pictures are taken at each point and compared with the original photos.

B. Data

Data collected from the images of three test trials is tabulated below. The team tested with an 8 inch diameter ceramic, an 11 inch diameter ceramic, and a 14 inch diameter ceramic.

Table 1: 8inch diameter ceramic filter

Point	Damage
Red	N
Blue	N
Green	N

Table 2: 11inch diameter ceramic filter

Point	Damage
Red	N
Blue	N
Green	N

Table 3: 14inch diameter ceramic filter

Point	Damage
Red	N
Blue	N
Green	N

C. Discussion

After testing with the three varying diameters, it was concluded that damage occurred at some point during the manipulation of the ceramic. When evaluated after stage 2 and after stage 5, it was difficult to determine if any damage had been inflicted. The damage was difficult to identify

1) Error: While the testing proved the gripper to be mostly effective in reducing damage, there are some elements of error that could ensure even more precision. One of these errors could be using hand cut wood for the test fixture. Wood is hard to cut precisely, and therefore could have caused misalignment in the motion of the ceramic and gripper. More room for error was caused by the padding, as it was not cut by a machine. This caused some overlapping of the padding, specifically when working with small diameter ceramics. More error to note occurred in the force sensing resistors because the readings they were outputting had substantial noise. After including a transducer circuit for each force sensor the output was less noisy but there were still some fluctuations. After taking the RMS value, the data contained less oscillations.

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