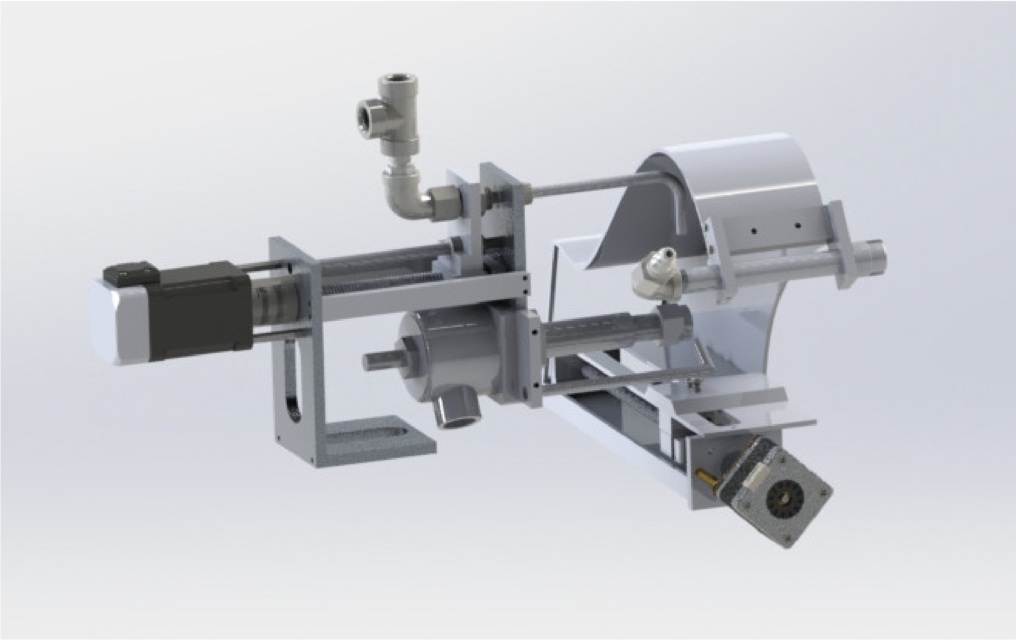
Ball Corporation
Robotic Automation of Cleaning Production Equipment



Team 3 Ball Corporation
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Client: Joseph Gress

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Project Background

In the manufacturing of aluminum cans, a coating called the IC spray, is applied to the interior of the can to ensure the ingredients of the contents do not react with the aluminum itself. This process occurs at an IC spray booth, using an IC nozzle. As the coating sprays into the cans, there is a significant amount of blowback. Spray that did not adhere to the can rebounds, which causes buildup on and around the machine. A vacuum in the booth helps suck away any excess spray. However, this results in a large amount of buildup around the entrance to the vacuum. An example of this buildup is shown in Figure 2.

Currently, operators on the production floor clean the nozzle and spray booth manually. Production is paused during the cleaning process, cutting opportunity cost in the production line. Nozzles need to be cleaned once an hour, taking 10-60 seconds each, whereas the booth is cleaned once every 12 hours, taking 25 minutes.

The goal of this project is to automate the cleaning of both the IC nozzle and the vacuum entrance. These locations are called out in Figure 1. The IC nozzle takes top priority as buildup affects quality of the applied IC spray. The vacuum entrance is a lower priority than the nozzle as it does not directly affect the quality of IC spray, but has been identified as an area of greater buildup. The team's goal has been to design and manufacture prototypes to clean both the vacuum entrance and the nozzle.

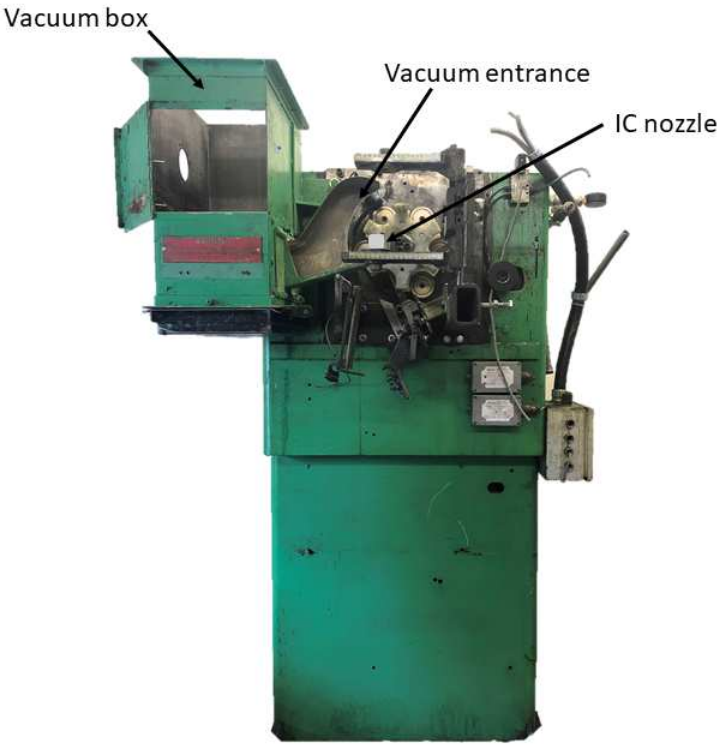

Figure 1: IC Spray Booth

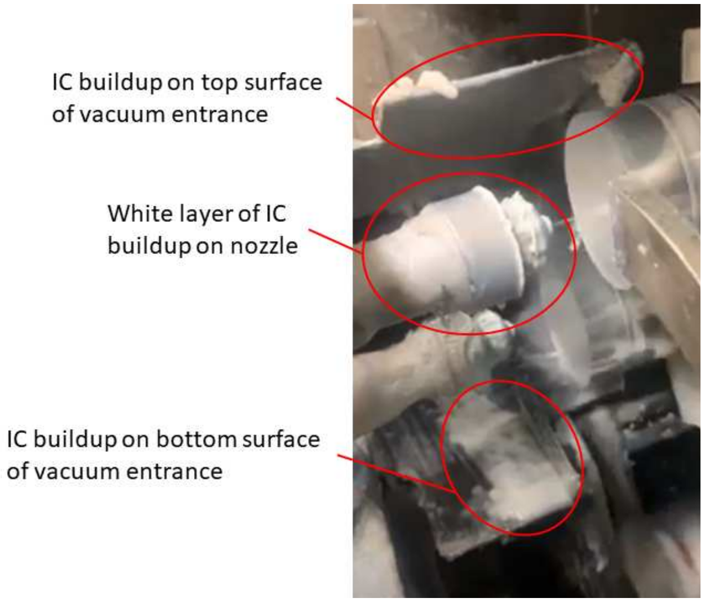

Figure 2: Buildup on machine

Design Priorities and Requirements

In order of importance:

1. **Limit buildup on IC nozzle to an acceptable level**
   Excess buildup leads to a clogged or partially blocked nozzle which affects the quality of coating on cans. The prototype directly addresses the issue of nozzle cleanliness.
2. **Protection Against Heat and Humidity on the Prototype**
   Operating temperature on the production floor ranges between 50°F-115°F. Moreover, humidity is high around the IC booths as water evaporates out of the IC spray. These levels affected some cleaning methods we decided to use
3. **Limit Buildup Around IC Vacuum Entrance**
   Buildup on the vacuum entrance does not directly affect the quality of the applied interior coating. Yet, automating the process of cleaning the vacuum entrance would save on costs.
4. **Expedient Cleaning**
   Currently, workers manually wipe off the nozzle every hour. This takes roughly 10 to 60 seconds. Cleaning the booth takes around 25 minutes and occurs every 12 hours. A similar time frame would then be used to compare the speed of our prototype.

Design Overview: Nozzle

The prototype comprises of three subsystems, one devoted to cleaning the IC nozzle, and two devoted to cleaning the vacuum entrance.

The nozzle cleaning system utilizes compressed air to blow buildup off the nozzle. This system is shown in Figure 3. Cleaning is achieved using a tube that directs the compressed air towards the nozzle tip and body. This tube is mounted on a linear actuator.

The linear actuator moves the cleaning tube backwards when not in use to avoid buildup on and around it. Every ten minutes, the cleaning tube actuates forward and blows compressed air onto the nozzle.'s body and tip.

The team chose to use compressed air because it has no negative impact on the IC spraying process or material. Moreover, the design avoids a physical cleaning mechanism which would be hard to implement due to tight size constraints around the nozzle head and the circular shape of the IC nozzle.

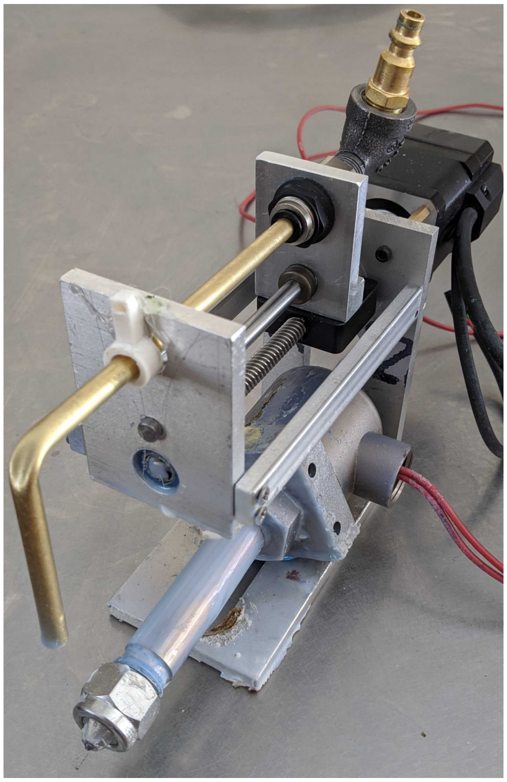

Figure 3: Built Nozzle cleaner

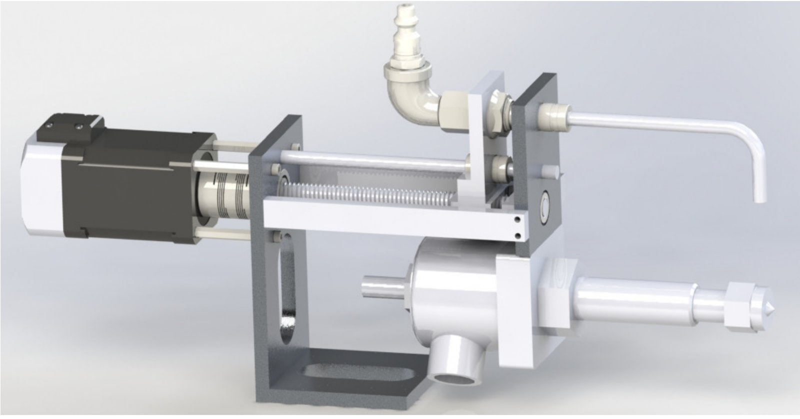

Figure 4: Nozzle cleaner CAD render

Design Overview: Scraper

The first subsystem devoted to cleaning the vacuum entrance is the "scraper."

The largest amount of IC spray buildup forms on the bottom surface of the vacuum entrance. If this buildup is permitted to sit and dry, it becomes time consuming to remove.

To avoid this situation, the scraper's blade is actuated back and forth to push away any buildup before a large layer can form.

A linear actuator drives the scraper across the the bottom of the vacuum entrance. This subsystem can run simultaneously with the IC nozzle which means that canning production need not be stopped.

It is necessary to have two layers for the scraper. Figure 5 shows that there is a slope and irregular geometry in the vacuum entrance, making it impossible for the scraper to access the bottom surface without the additional flat surface.

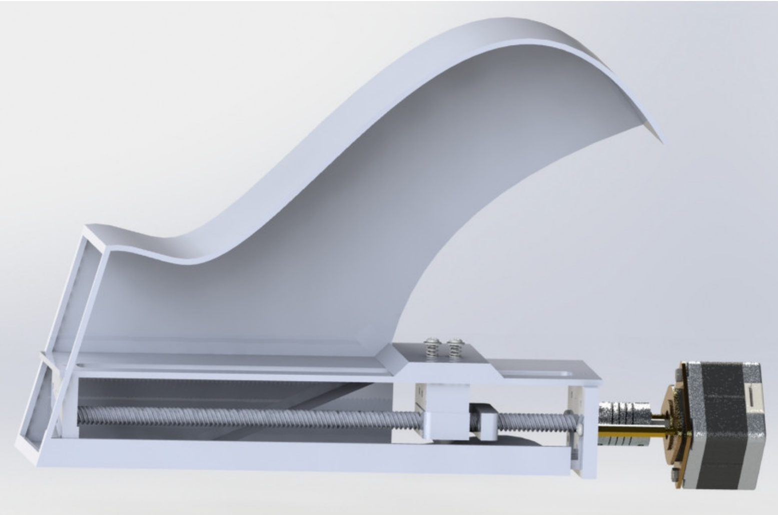

Figure 5: Scraper CAD render

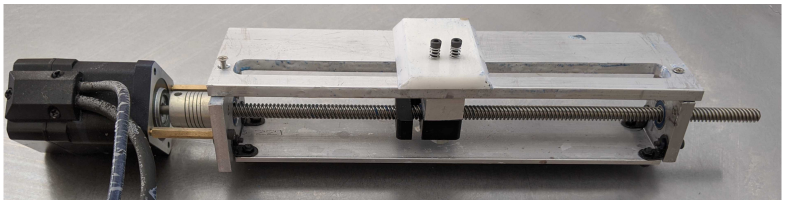

Figure 6: Built Scraper

Design Overview: Air Manifold

The second system devoted to the vacuum entrance is the "air manifold."

Due to the complex geometry on the top surface of the vacuum entrance, it is not possible to design a physical mechanism similar to that on the bottom surface.

The air manifold provides a layer of air that redirects IC particles traveling through the vacuum entrance away from the top surface and towards the bottom where they can then be cleared away by the scraper.

The air manifold itself is an aluminum tube with a series of holes. The tube is capped off at one end and is connected to an air compressor at the other.

An advantage of this design is that it can run simultaneously with production.

Based on the preliminary test results, the air manifold does not affect the quantity of buildup on the vacuum entrance and reduces buildup on the top surface of the vacuum entrance.

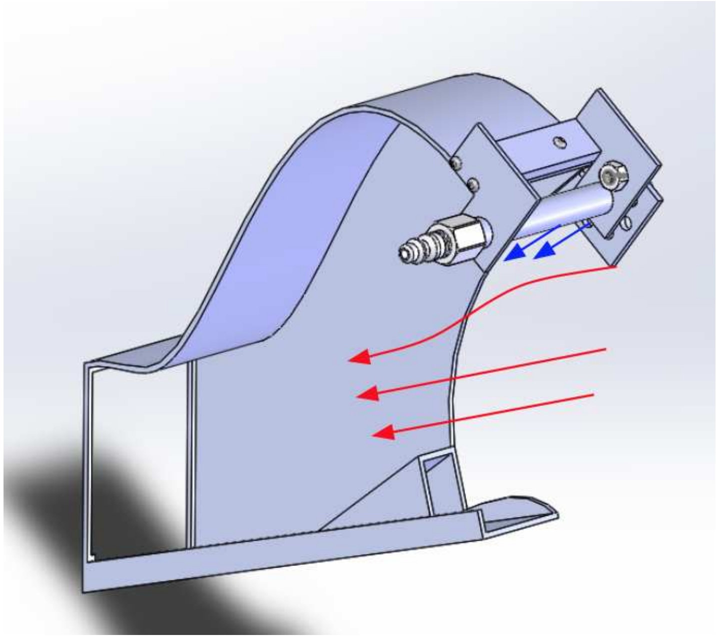

Figure 7: IC particles are redirected

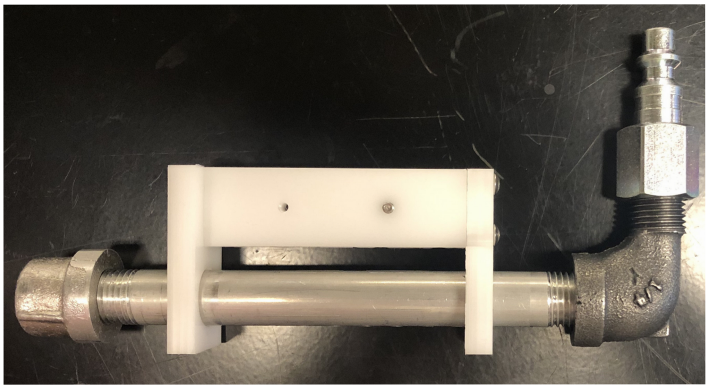

Figure 8: Built air manifold

Design Overview: Circuitry and Logic

The electronic control of the prototype relies on an Arduino Uno Microcontroller and a 24 V power source to actuate the motors and solenoids. Both stepper motor controllers actuate the scraper and nozzle cleaning head according to their respective timing. A motor encoder then determines if the motors have finished the cleaning cycle.

The outputs from the system give a boolean signal if the system successfully completed a clean or if the motors did not actuate properly. This allows for the system to properly stop or continue canning production after a cleaning cycle terminates.

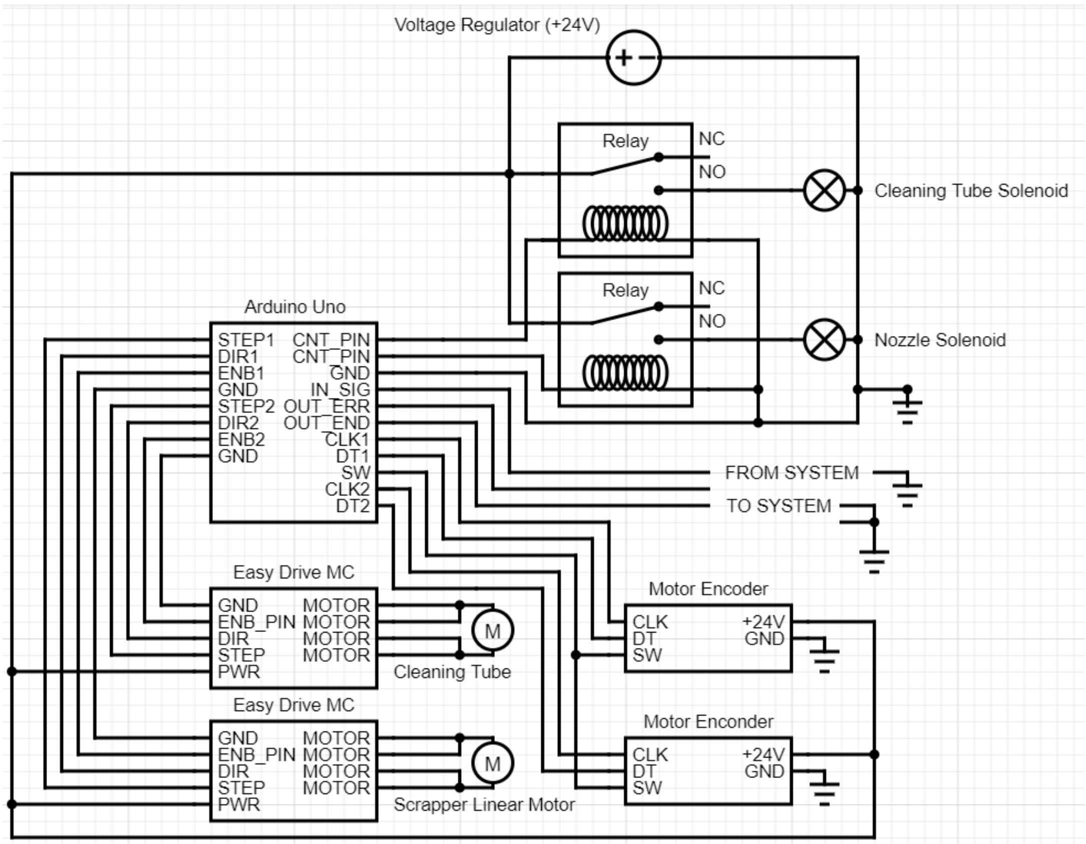

Figure 9: Circuit Diagram

Challenges

Humidity on production floor
Humidity affects quality of cans and corrosion progresses rapidly when humidity exceeds 60%. This limits options to using compressed air and physical mechanisms, which are less effective than using liquid options, such as acetone and steam.

Operating in a limited space
The cleaning prototype must not interfere with the function of existing equipment nor the workers' maintenance on the booth. This drove the design for a smaller scraper subsystem due to the size of lead screw and bearing diameters.

Maintain cleanliness of the cleaning devices
The prototype itself will get IC buildup overtime if not cleaned. This steered the design to have easily detachable devices for ease of cleaning.

Complex geometries in vacuum entrance
It is difficult to design a physical scraping mechanism for the top surface. Therefore the design deflects buildup to bottom surface for ease of cleaning.

Confirmation of successful clean
In the current situation, users evaluate cleanliness through visual inspection. This is challenging due to subjective ratings from each user. The goal is to keep the IC spray booth functioning properly for as long as possible before manual cleaning is required.

Test Results: Nozzle

During preliminary tests, the nozzle cleaner successfully cleaned the top half of the IC nozzle with an interval of 30 minutes during standard spray intervals; however, after the cleaning cycle there remained buildup on the bottom half of the IC nozzle.

The cleaning cycle was measured to be effective at a period of 30 minutes with the nozzle cleaner moving back and forth 2 times. The air pressure leading into the nozzle cleaner was set at 150 psi. The cleaning cycle was timed to be 1 minute.

The team recommends the addition of another cleaning tube that targets the bottom of the IC nozzle. A duo-tube cleaning system could provide a more thorough cleaning of the IC nozzle.

Figure 10: Before nozzle cleaner test

Figure 11: After nozzle cleaner test

Test Results: Scraper

While testing, some issues with the current design arose. One issue was the lead screw in the blade jamming due to IC accumulation. The bellows did not effectively protect the linear actuation screw.The team recommends that the bellows be replaced with a corrugated plastic tube mounted covering more of the mechanism's inner working.

Based on preliminary testing, it is recommended to engage the scraper every 40 minutes during standard spraying intervals in order to obtain best cleanliness results. As shown in Figure 12, the buildup of the IC mass increases after 40 minutes. Hence it will be healthier on the motor to engage it earlier rather than later, as it will take less force to remove a smaller mass of still unhardened IC spray rather than removing it later when it starts to cure and accumulates more mass.

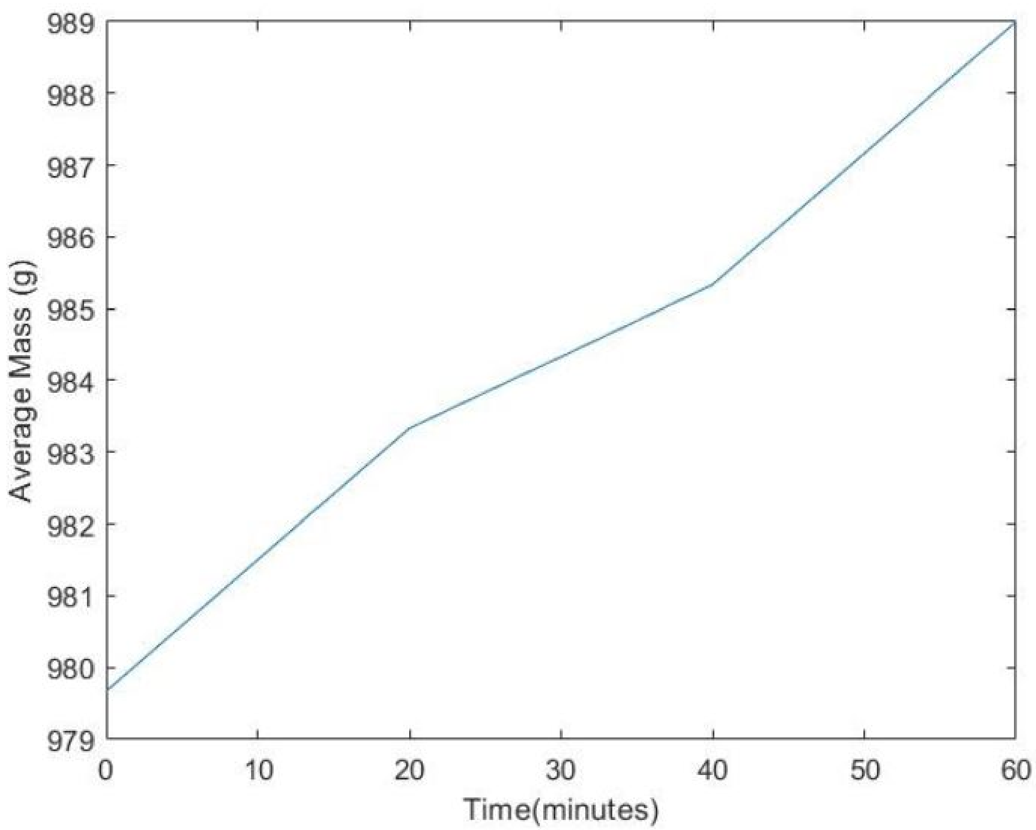

Figure 12. The IC and Scrapper's mass over time without the motor running

Test Results: Air Manifold

Testing for the manifold needs to determine two things: 1) the effectiveness of the manifold and 2) if it interferes with the IC spraying. The effectiveness of the manifold has not been tested yet.

Preliminary test results suggest that the manifold does not significantly affect the spray pattern. This was tested by comparing the weight of IC spray deposited in a can with the manifold running and with it off. The results are summarized in Table 1. Listed is the p value for an analysis of variance between the mean weights.

Manifold On	Manifold Off
10 ± 0.667 grams	9.6 ± 0.6992 grams
ANOVA p value = 0.21	

Table 1: Summary of air manifold test results

Conclusion

Next steps include continued testing to determine the effectiveness of the Scraper and Air Manifold. Larger sample sizes are needed to draw any definitive conclusions for these subsystems. In addition, tests that span longer time periods are required as well as tests where each of the three subsystems are running simultaneously.

The Scraper design could benefit from a more thorough way of protecting the lead screw. The bellows currently employed allow a small amount of IC spray to reach the screw. If allowed to sit for a long enough period, this can jam the motor.

Preliminary results for the Nozzle Cleaner are promising. The addition of a second tube to target the bottom of the IC nozzle could further improve this subsystem's effectiveness.

Meet the Team

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