# Glass Ampoule Filling Machine

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College of Engineering and Applied Science
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In partial fulfillment of the
Requirements for the degree of

Bachelor of Science
In Mechanical Engineering Technology

By

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## Problem Definition and Research

### *Problem Statement*

With the current setup, Luxfer utilizes four partially functional Cozzoli Machines to produce their entire inventory of onion skin glass ampoules to be used in their M256 air chemical detection kits. These machines have had many iterations of redesign, that often involve finding parts to use in creative ways to solve the recurring issues for a little longer each time. The idea with our project was to take on what we deemed to be the most approachable problems and produce solutions to those individual components. Overall, we set out to create a tangible design to further modify an Ampoule Filling & Sealing Machine in order to address the issues in simplifying the manufacturing process, the inconsistent flame heat seal, and the ability to adjust small ampoule heights as needed in glass ampoule production.

### *Background and Scope of the Problem*

Address issues with onion skin glass ampoule manufacturing for ampoules sized 0.88" to 1.25" such as the incredibly thin glass and the high breakability rate that comes along with the glass thickness. The current machine is produced by Cozzoli Machine Company that focuses on "precise volume fill with FPS Ampoule filling and sealing monoblock." [1] Onion skin glass is highly breakable by nature and will contain a range of chemical solutions that include flammable liquids and gasses.

Similar to the Cozzoli machine being worked on, Lodha has an Onion Skin Ampoule Filling Machine, which they point out is "widely used in pharmaceutical, biotech, cosmetic, veterinary & chemical industry… The machine [is] built on principle of slant travel of ampoules while filling and sealing to take care of a wide variation of ampoule neck dimensions, thicknesses and ovality of available ampoules." [3] In the process of examining these issues, we are willing to look into utilizing operations or parts from similar machines in an attempt to combine the best practices and machine operations for the task at hand, but also make the overall manufacturing processes cost and time efficient.

Due to the production quality of the Cozzoli, approximately 13.1% ampoules failed the seal inspection in September 2021 alone, high glass breakage rates impact several distinct groups of people. The first group impacted is the glass tube bottomer operator and assemblers due to the high accumulation of glass shards that have a potential for workplace injuries. The second group of people, like the first, are the ampoule machine operators and maintenance personnel. The ampoule machine operators are not only exposed to the accumulated glass build up but also contaminated glass containing toxic and volatile chemicals. Currently the excess buildup of glass and chemical contaminants is wearing down and eroding critical mechanical components of the Cozzoli's. For September 2021 Luxfer Magtech recorded a total machine availability of 45.6% over five (5) Cozzoli's. The third group of people include the general population and the US military. The US military is only one of a handful of organizations that utilize these particular size ampoules and type of glass. Due to the high breakage rates, product orders that would go out to support troops in the field are delayed causing an overall larger impact than what is allowed to be described in this document due to US security.

This problem is currently being addressed with trial-and-error applications to a specially designed machine. At Luxfer Magtech in particular, they have a machine that was customized by a machinery manufacturer who, even with customization, could not achieve the desired ampoule specifications. Currently Luxfer has tried temperature-controlled environments, various timing belt componentry exchanges, changes in gearbox materials and designs, and other changes to the current equipment that overall produce the same quantity of broken glass.

Current solutions are inadequate because all equipment that is well designed for this size ampoule range is better suited for lab production of average production rates of 1,800 ampoules/hour, not large-scale manufacturing where production rates are needed to be near 5,000 ampoules/hour. In addition to the small output, most onion skin glass ampoule machinery is considered a two-step process. There is one machine designated to flame seal the bottom of a glass straw. After the bottom is sealed it then goes into the ampoule filling machine that dispenses the desired components and then flame seals the tops. Current machinery that is available for the size range 0.88" - 1.25" dates mostly from the 1950s which features a mechanical focused design with no current computer interfaces for flame temperature control nor height adjustment. This senior design project will fill the production gap of touch point reduction. Given Cozzoli's "accessibility of parts and minimal changeover times," [2] the hope is there is an excess of strategies to begin researching as solutions. The sole focus of this project will be to combine the current two-step process of bottom sealing and the solution injection with the top sealing, into a one step process using a single machine design.

## Applicable Standards

The following project is recorded and discussed per the International Traffic in Arms Regulations (ITAR) instituted by the United States Department of State Bureau of Political-Military Affairs. Due to these regulations, some information has been deemed proprietary and cannot be disclosed. Anything we are unable to publish will be noted as proprietary information, but appropriate reasoning and discussion of our thoughts and work will be described in as much detail as possible.

## State of the Art

### *Flame Components*

Currently the configuration utilized on the ampoule manufacturing equipment at Luxfer Magtech is comprised of a propane torch tip, a set of clamping arms, and spinner wheels for the ampoule. In this configuration, a recently filled ampoule is indexed in front of the flame manifold where the glass is then heated as it is spun by the spinner wheels. The flame is positioned around the desired height of the completed ampoule. After a 2-3 seconds of dwell time the clamping arms then grip the excess glass above the heated portion and being to form a stretch seal by pulling away the excess glass for dispose into an off chute. Maintaining the same spinning configuration during the dwell time, an inventor by the name of Wang patented a design which focuses on stationing the heated ampoule between two electrically charged heat sinks that "can effectively reduce the temperature in the ampoule, and avoid the temperature increase in the ampoule and the solvent volatilization caused by the heat-melt seal" [4]

### *Ampoule Loading*

The current machinery at Luxfer did not come with an ampoule loading apparatus, thus there was a brief design period where a former maintenance person configured a gravity fed transfer system. The disadvantage of the current design is the ampoule straws but be loaded by hand via an operator and positioned in a specific way for it to orient appropriately at the exit point onto the roller chain. An inventory by the name of Chen, developed a loading attachment that favors the design of the Lodha Ampoule equipment. A critical difference between the two is Chen's consideration of the abrasiveness of the glass stating " the material of the inner rotor is hard rubber or hard plastic, so as to avoid the glass bottle body from being broken" [5]. This is currently a problem with the Lodha configuration consisting of solid stainless steel that otherwise traps glass debris resulting in additional broken ampoules.

### *Robotic Configuration*

Any type of robotic implementation will greatly improve the current ampoule production process. The current machinery available, whether that be from Lodha Pharmaceuticals or Cozzoli, do not come equipped with any robotic configurations. After considering the most labor-intensive portion of the process it has been concluded that a six-axis robot would be sufficient to replace part of the inspection process after the flame sealing of the ampoule. Currently, operators are responsible for removing any defective ampoules. Defects of ampoule vary greatly but most often include broken glass, low chemical fill, soft-tops (breakage after slight applied force), and color change in the chemical solution. Due to the small work area surrounding the current ampoule indexing mechanism, a small robot arm would be needed to perform the nonconformance removals. One of the most ideal solutions provided on the market is a six-axis robot arm produced by Mecademic. Due to an array of solutions manufactured into ampoules at Luxfer Magtech, a robotic system with easy programming and adjustments is exactly what is needed. Mecademic' s Meca500 "…is a plug-and-work automation component, east to interface with any computer or PLC. Easily operate the robot using any programming language you prefer" [6]. Any type of easily reconfigurable robot configuration would be the best suited for all of the solution and product changes that occur throughout the manufacturing process of the ampoule machines.

***Ampoule Indexing***

The current ampoule indexing system involves a roller chain system in which the pill shaped ampoules are rolled along the conveyor to get filled and sealed. This system works respectively well but the company is still seeing high breakage rates due to the ampoules getting caught in the roller chains. While the current system is decently easy to replace due to the cheaper material, the hope is to replace the conveyor type with a more reliable option. Keeping with the same concept, a rubberized roller system is one being considered to replace the roller chain to allow for greater accuracy when heat sealing and filling the ampoules. Star Glo Industries, Inc. produces specialized rubber rollers that are "high pressure injection molded on the most modern machinery in the industry… this process allows us to offer a limitless range of thermoset and/or thermoplastic polymers designed to provide maximum service for any application." [6]

***Visual System***

There is currently no visual system beyond a human operator glancing at each filled ampoule to do a general check for defects. There are hopes to implement a sophisticated machine vision system to detect defects such as cracks, holes, discoloration, and appropriate fill height. KEYENCE produces a vision sensor with built-in AI which is a surface defect detection vision system that they ensure has a high return on investment "by solving common bottlenecks in manual quality and grading operations."

[7] This vision system would be able to detect unique, pre-programmed quality control requirements and are specialized to be used on reflective surfaces. There are many pros to implementing this kind of sensor including higher accuracy rates, less pressure on operators to check microscopic defects, and overall, a more efficient operating system. The cons would involve the initial investment costs, but the improvement will warrant the cost.

### ***Safety Guards***

The current system has a single pane of plastic safety guard to block the operator from direct exposure to the flame and potential glass breakage. The problem with the current guards is that they do not cover enough area, leaving the operator still exposed to glass shards. The plan is to add additional safety guards around the open flame but also spanning the entire table to allow for every station of the assembly to be blocked, with access panels to allow for important steps to be reached and worked on if necessary.

## End User

The end user of this project will be Luxfer Magtech and its employees. The company specializes in a unique product and the manufacturing concepts and designs will not be useful outside of the specific machine on which we will be working. However, a secondary end user are the operators that will be working intimately with the machine. The current concerns of the machine are overall low efficiency and lack of safety for the operators. While the company is technically the end user, while working on this project the focus will be on the ones working on and with the machine to ensure their overall safety, as opposed to ignoring those safety measures in the name of faster production rates.

## Summary of Research

In summary, there are many viable options to consider for rebuilding the Cozzoli machine from the ground up. We need to take the four main components mentioned in the State of the Art into consideration first before considering other issues with the current Cozzoli. Our machine needs a better conveyor system, a mechanized visual system, an alternative sealing technique, and a better flame component set up. The options discussed will prove to be decent starting points, but the nature of the project might require more customized solutions that may not come from off the shelf products or at low costs.

## Quality Function Deployment

### *Customer Features*

Efficiency

Safety

Ease of Use

Maneuverability

Initial Investment

### *Engineering Characteristics*

Material Selection

Sensor Type

Conveyor Belt Configuration

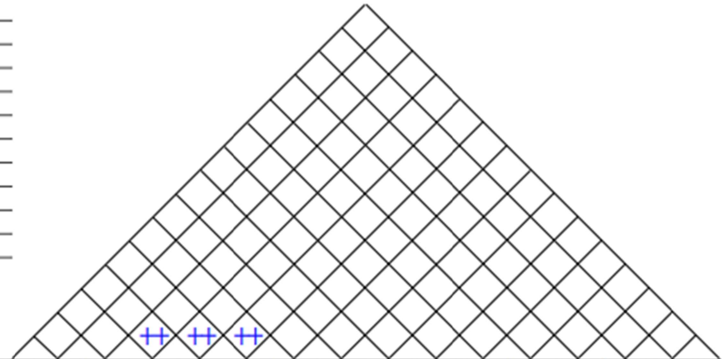
Ampoule Loading Design

Smart User Interface Selection

Safety Guards

# House of Quality

Title: House of Quality of Ampoule Filling Machine
Author: Lainey Sage and Leah Gebara
Date: 9/25/2021
Notes:



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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Column # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Competitive Analysis (0=Worst, 5=Best) | | | |
| | | | | Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x) | X | X | ▲ | ▲ | ▲ | ▲ | | | | | | | | | | | | | |
| Row # | Max Relationship Value in Row | Relative Weight | Weight / Importance | Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") | Material Selection | Sensor Type | Conveyor Belt Configuration | Ampoule Loading Design | Smart User Interface Selection | Safety Guards | | | | | | | | | | Our Company | Competitor 1 | Competitor 2 | Competitor 3 | Competitor 4 | Competitor 5 |
| 1 | 9 | 37.5 | 9.0 | Efficiency | O | Θ | Θ | Θ | ▲ | ▲ | | | | | | | | | | 5 | 1 | 4 | | | |
| 2 | 9 | 29.2 | 7.0 | Safety | Θ | O | O | O | ▲ | Θ | | | | | | | | | | 5 | 1 | 1 | | | |
| 3 | 9 | 16.7 | 4.0 | Ease of Use | ▲ | ▲ | Θ | O | Θ | O | | | | | | | | | | 3 | 3 | 5 | | | |
| 4 | 9 | 8.3 | 2.0 | Maneuverability | ▲ | ▲ | ▲ | ▲ | Θ | O | | | | | | | | | | 3 | 3 | 3 | | | |
| 5 | 9 | 8.3 | 2.0 | Initial Investment | Θ | Θ | Θ | O | Θ | O | | | | | | | | | | 5 | 2 | 5 | | | |
| 6 | | | | | | | | | | | | | | | | | | | | | | | | | |
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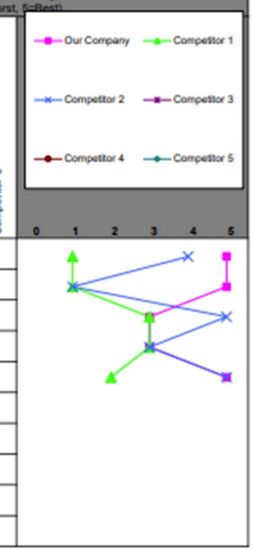
| | | | | Target or Limit Value | | | | | | | | | | | | | | | | | | | | | |
| | | | | Difficulty (0=Easy to Accomplish, 10=Extremely Difficult) | 7 | 2 | 9 | 3 | 8 | 0 | | | | | | | | | | | | | | | |
| | | | | Max Relationship Value in Column | 9 | 9 | 9 | 9 | 9 | 9 | | | | | | | | | | | | | | | |
| | | | | Weight / Importance | 475.0 | 525.0 | 658.3 | 508.3 | 366.7 | 400.0 | | | | | | | | | | | | | | | |
| | | | | Relative Weight | 16.2 | 17.9 | 22.4 | 17.3 | 12.5 | 13.6 | | | | | | | | | | | | | | | |




| Legend | | |
|---|---|---|
| Θ | Strong Relationship | 9 |
| O | Moderate Relationship | 3 |
| ▲ | Weak Relationship | 1 |
| ++ | Strong Positive Correlation | |
| + | Positive Correlation | |
| — | Negative Correlation | |
| ▼ | Strong Negative Correlation | |
| ▼ | Objective Is To Minimize | |
| ▲ | Objective Is To Maximize | |
| X | Objective Is To Hit Target | |

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***Product Objectives***

Efficiency (37.5%)

This feature will be improved upon by the selection of the conveyor belt configuration and ampoule loading design. Both items contain mechanisms that technically work but could improve.

Safety (29.2%)

To establish the highest safety standards for operators, additional safety shields will be installed as well as the potential addition of a visual sensor to ensure all glass shards and chemicals are in the appropriate place and are not being discarded in an area where they would become a danger to the operator.

Ease of Use (16.7%)

While decided not as crucial in our design, operator training will be a factor in the design process to make sure the machine is constructed in a straightforward way that any operator or engineer would be able to work on or with it.

Maneuverability (8.3%)

Wheels will be installed on the bottom of the machine to have the ability to move from location to location based on the company’s needs, as well as have accessibility panels to easily reach the machine’s inner components.

Initial Investment (8.3%)

Most components will need to be purchased new or otherwise custom made as the machine needs to be built from the ground up. Features such as material selection, complex custom part making opportunities, and sensor types will be taken into consideration primarily when it comes to costs.

# Design

## *Design Alternatives and Selection*

| Concept 1 | Concept 2 |
| --- | --- |
| Componentry<br>• Pneumatic actuators<br>• Reorientation of glass hopper<br>• Vision sensor<br>• SCARA robot for nonconforming part removal<br>• Copper cold plate<br>• Safety shields | Componentry<br>• Stepper motors<br>• CO2 laser heat seal<br>• Nonconforming part rejection diverter<br>• Copper cold-plate<br>• Safety shields |

## *Bill of Materials*

| Item | Description | Source | Qty. | Price |
| --- | --- | --- | --- | --- |
| Item # 5PEY6 MFRG Model # CRB1BW50-270S | Anodized Aluminum Vane Style Rotary Actuator: 50 mm (about 1.97 in) Bore | CBT | 3 | $401.37 |
| FQ2S20050F | Vision Sensor | Omron – MQ Automation | 1 | $1,584.94 |
| SKU: 411021 | Safety Guarding: Danray Shield | Stronghold Safety Engineering | 2 | $578.00 |
| 35035K32 | Cold Plate Heat Sink | McMaster-Carr | 1 | $141.36 |
| | Misc. Materials (Nuts, bolts, metal) | McMaster-Carr | - | $100.00 |
| Hopper and Components | | In house – do not purchase | - | - |
| Fill needle and pump | | In house – do not purchase | - | - |
| Flame seal manifold | | In house – do not purchase | - | - |

| | | | | |
|---|---|---|---|---|
| Cozzoli Frame | | In house – do not purchase | - | - |
| Conveyor chain | | In house – do not purchase | - | - |
| Gearing | | In house – do not purchase | - | - |

## Build, Test and Results

Upon comparing our two primary design concepts the decision was made to pursue design Concept 1 with the major focus surrounding operator safety and faster thruput. Starting the build phase our team was quickly met with a hurdle of budget cuts. From the original projected budget of ~$25,000 we were now reduced to producing our design for under $5,000. In an attempt to save some major design ideas from the original concept we opted to create a third concept that incorporated a combination of the original two concepts. This third concept went on to include pneumatic actuators, a stepper motor, original glass hopper hardware, a vision sensor, a copper cold plate, safety shields, nonconformance diverter chute and the original propane flame seal.

Throughout the building phase there were numerous hiccups, primarily these occurred with the current supply chain issues due to the Covid-19 pandemic. As each primary component was delivered there was individual testing parameters to help integrate all the parts together. For the vision sensor we needed to be able to detect the edges of the sealed ampoules to measure the completed height in ratio to the chain in order to identify nonconformities. This was proven to be a feasible process through the provided camera simulator software prior to installation. As seen in Figure 1, the sensor was able to detect this height variance, showing that the short ampoule pictured is ‘Not Good’ (NG) as it did not meet the requirements. In Figure 2, we see that the appropriate height ampoule passed with an ‘OK.’

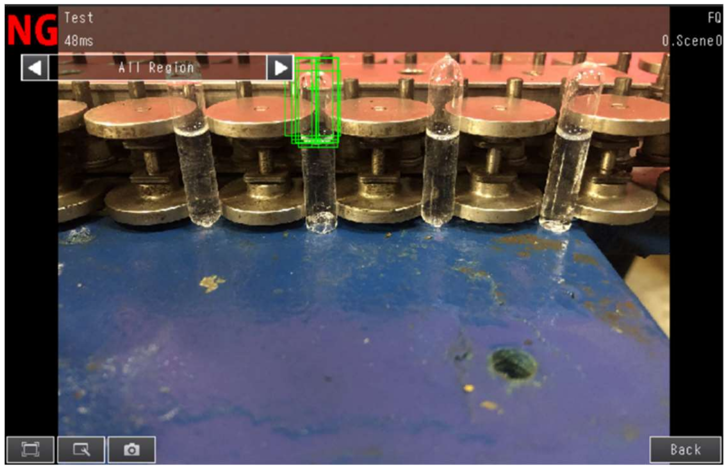


*Figure 1 - Sensor detecting a 'Not Good' Ampoule*

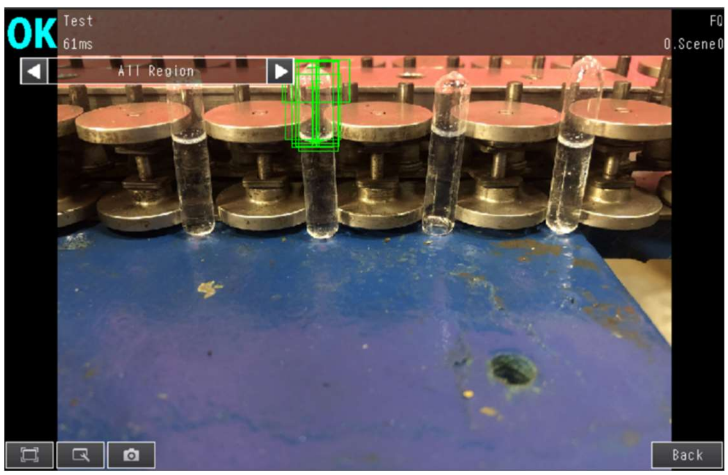


*Figure 2 - Sensor detecting an 'OK' Ampoule*

The pneumatic actuators and stepper motor needed to prove the component could turn freely to the desired positions. This was able to be evaluated on the pneumatic actuator with one of the compressed air hoses and some tubing available in the Luxfer Magtech maintenance shop. Unfortunately, the stepper motor was unable to be assessed due to our PLC not being delivered as well as the shaft diameter being too small for the drive chain sprocket.

The cold plate was successfully installed, as pictured in Figure 3. After running water through the plate to cool the chain and ambient air, we measured a 6$^{o}$F drop in temperature between the portion of the chain located underneath the plate and where the chemical fill needle is placed. This temperature was taken using an infrared thermometer. We did not have the flame manifold installed and running as we tested, so this temperature differentiation would have measured differently had there been an applied heat source. While that is not a significant change, it was a good start in developing a system to cool down the chain and ambient air. Given more time was allotted, we would choose to test different coolant solutions to see the difference in temperature drops.

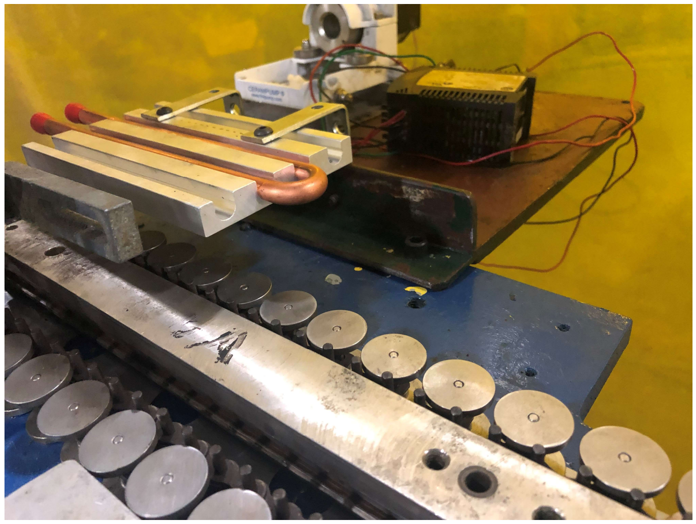

*Figure 3 - Cold Plate installed over roller chain*

In the end, our team was unable to complete our build due to struggle with the current supply chain and demand. Critical custom components such as the flame seal armature and the volumetric fill apparatus became unavailable for us to use and needed to be reordered with a lead time of 18 weeks (about 4 months). Due to the inability to perform heat seals we were unable to evaluate the cold plate. Ultimately, the results of improved product quality and thruput is inconclusive because the machine was not able to be completed.

## Project Management

### *Budget, Proposed vs Actual*

After meeting with Luxfer Magtech's director of operations, financial director, and vice president, a budget of $5,000 excluding components and structural frames that can be found around the plant, was established in order to redesign an ampoule filling and sealing machine. Due to budget cutbacks and constraints, the actual budget ended up around $3,000. This significantly impacted the scope of our project and while we were able to follow through on a few of our design elements, we had to cut back on many elements and lost some support from the maintenance staff in the process which impacted things.

***Schedule, Proposed vs Actual***

| Proposed | |
|---|---|
| Objective | Date |
| Per budget approval, order all major components | 12/10/2022 |
| Maintenance Team meeting for construction / assembly start and project timeline | 01/13/2022 |
| Implement all major components (based on arrival) | 02/28/2022 |
| Finalize documentation & report for final ITAR review | 03/24/2022 |
| Complete machine testing and start small production runs | 03/30/2022 |
| Senior Design Tech Expo | 04/14/2022 |

| Actual | |
|---|---|
| Objective | Date |
| Per budget approval, order all major components | 01/03/2022 |
| Maintenance Team meeting for construction / assembly start and project timeline | 01/08/2022 |
| Implement all major components (based on arrival) | 02/18/2022 |
| Finalize documentation & report for final ITAR review | 04/22/2022 |
| Complete machine testing and start small production runs | -- |
| Senior Design Tech Expo | 04/14/2022 |

## Conclusion

While the proposed solutions were not all fully implemented, overall, our project was just a small glimpse at the progress that could be made to the Cozzoli machines being utilized at Luxfer Magtech. We researched and attempted to implement new safety features, a visual system, changes to the ampoule indexing setup and temperature regulation, quality inspection procedure, and ampoule loading. Of those components, we were able to utilize the safety shielding, sensor inspection camera, and the cold plate into the machines on the production floor.

The Cozzoli machines are custom built and, even when bought brand new, still need thousands of dollars spent on special upgrades and alterations to get them working properly. Often the issue with the current machines is that one to two components would break at a time, meaning a myriad of pieced together objects were thrown onto the machine to get it through the next production day, week, or month. Knowing that these custom pieces are subject to break, the temporary solutions were produced very quickly and cheaply, and often took the place of the custom pieces all together. Working with this type of mindset, it is difficult to integrate new pieces to a machine that already feels a bit patchworked together. We tried our best to offer solutions to the proposed problems and came to the decision that given the time and budget restraints, our solutions stayed as ideas worth looking into, rather than a completed new machine that could be used on the production floor.

We learned about how important project management and proper research is when dealing with any project, regardless of the size. Making sure the correct items are purchased, triple checking the dimensions of everything, and having an action plan you stay dedicated to are non-negotiable. We got a glimpse at the inner workings of the manufacturing industry, specifically when it comes to companies that work with the U.S. military, and how complicated it can get to change certain processes and tools. This project was a colossal learning opportunity that had its challenges but gave us crucial insight into the engineering world.

## Works Cited


1. "Ampoule Filling and Sealing Case Study." *Cozzoli Machine Company*, 16 May 2019, www.cozzoli.com/ampoule-filling-and-sealing-case-study/.

2. "Ampoule Filling Machines, Pharmaceutical." *Cozzoli Machine Company*, www.cozzoli.com/type/ampoule-filling-machines/.

3. "Onion Skin Ampoule Filling Machine." *Lodha International*, www.lodhapharma.com/onion-skin-ampoule-filler.php.

4. "Low-temperature melting and sealing device for ampoule bottles." *Wang Lijian,* 18 December 2020, https://worldwide-espacenetcom.uc.idm.oclc.org/publicationDetails/biblio?FT=D&date=20201218&DB=EPODOC&CC=CN&NR=212174797U#

5. "Ampoule loading attachment.", *Chen Shishan,* 05 February 2019, https://worldwide-espacenet-com.uc.idm.oclc.org/publicationDetails/biblio?CC=CN&NR=208470901U&KC=U&FT=D&ND=&date=20190205&DB=EPODOC&locale=#

6. STAR GLO INDUSTRIES, INC. Rubber rollers - Redi Rollers. *Rubber Rollers – Redi Rollers - Star Glo* [online]. [Accessed 15 September 2021]. Available from: https://www.starglo.com/rollers?_vsrefdom=ppcgoogle&utm_source=google&utm_medium=cpc&utm_term=industrial+rubber+rollers&utm_campaign=Priority&gclid=Cj0KCQjws4aKBhDPARIsAIWH0JVmPWiTA01mE9TVul6hgKyTml9AnQTr2qn6SxttuVBA-3V-Ce7hnfwaAhmrEALw_wcB

7. KEYENCE. Machine Vision Systems for Manufacturing. *KEYENCE* [online]. 5 May 2021. [Accessed 15 September 2021]. Available from: https://www.keyence.com/products/sensor/vision-sensor/iv2/models/iv2-g500ca/?search_dl=1