Plc Modification for Fill and Close Stopping Sequence Improvement

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Abstract *— From November 2020 to January 2021, an analysis was made looking for the best way to increase the yield of the machines in charge of the dry process when making a contact lens. In this analysis, it was discovered that there was overwhelming evidence that the biggest offender was curing losses. Curing losses are defined as all molds out of the curing ovens divided by the amount picked up by the CUA (Control Unit Acquisition). An analysis of the PLC code that corresponded to the affected areas determined that best course of action to save the greatest number of molds possible and reduce or possibly eliminate curing losses. After implementation of only a plc code modification an expected improvement on the curing losses should be between 1-2%.*

Key terms *— contact lenses, fill & close, PLC, SCADA*

PROBLEM STATEMENT

The first step was to identify which was our goal. It was defined that the improvement of the yield was the best alternative since the pandemic have affected the demand for the contact lenses specially as a daily disposable alternative.

After understanding we wanted to work with the yield we analyzed which were the highest offenders using a pareto. After understanding that the curing losses were the highest offenders by a big margin, we went on to analyze how could we improve it.

In the analysis we found that mechanically the machine was sound an any improvement on it would be a high-end cost one specially when it would have to be implemented in more than 15 similar machines. Since we understood where the curing losses were happening. We shifted into look opportunities in the PLC code and how we could prevent from the molds being discarded into the waste bins.

The machine constantly wasted molds in the bins and adjustments were made in the PLC (Programmable Logic Controller) to prevent molds being lost in areas when the machine was stopped or faulted. This will save daily thousands of molds in a single machine and the results would be even greater when a deployment of this code adjustments is applied to the rest of the dry machines.

For the control phase the machine yield will continued to be monitor and confirm that the curing losses are reduced by an approximate of 1% - 2%. This fix will not eliminate all curing losses because there are cases like when a fault occurs in the Oven Loading of Oven 1 & 2 when it would be impossible to load the good molds into the oven and the machine will discard them once it reference/home the position of its components.

During the creation of a contact lens, there are many steps. The first step is the creation of a plastic mold which are made of polymer. These molds will be the vessel of the monomer which will be enclosed inside of it. This monomer which is in liquid form when dispensed inside the polymer will go through a curing process which will harden the monomer and give it its form before the hydration process. During the Fill & Close of the monomer into the polymer mold there is a process in the machine that have been found could be improved. The machine is designed to stop immediately once it is stopped and reference its belts and move every robot to its home position once it goes from a stop/fault to a start. This represent losses in the Fill & Close section of the machine because molds are present in the Fill & Close and are discarded every time the machine recovers from a stop/fault to a start.

Research Description

The importance of this study is to fix the Stopping/Fault Sequence, so it does not discard good molds ready for the curing process. This loss of filled molds results in the loss of yield, reduction of line rates, costly materials, and production time. The research will focus to eliminate or improve the process with a simple modification of the Programmable Logic Controller (PLC) programming without adding any additional parts or cost to the machine.

Research Objectives

Identify areas in the code that can be modified to allow the machine to either not reference/home or give it additional time to process all the molds through the Fill & Close before stopping and when a fault occurs segmentate the areas that are faulted to allow the other to continue work until the not faulted areas are empty of molds. Everything must be done without affecting the molds' quality and safety guidelines.

Research Contributions

The main contribution would be to modify the stopping sequence of the machine to give it additional time to process all the molds through the Fill & Close before stopping and when a fault occurs segmentate the areas that are faulted to allow the other to continue work until the not faulted areas are empty of molds. This would result in an improvement of the curing losses which affect yield, line rate would be improved, and material waste would be reduced.

LITERATURE REVIEW

Contact lenses story start as early as 1508 with Leonardo da Vinci with the "Codex of the Eye". Leonard, ahead of his time, created a glass lens with a large funnel to pour water into it. This was obviously highly impractical at that time and Leonardo did not have the technology to perfect his idea. In 1633 René Descartes was the first to suggest putting a lens filled with water directly into the cornea. In 1823 Herschel not only suggest using a gel filling that would sit between the cornea and lens, but also make it custom made to each individual. This would help with the fitting and prevent damage to the eye. In 1887 the first contact lens became a reality, but it was used for visual correction. The German F.A. Muller created the contact lens to protect diseased eyes. Some of the other drawbacks that this crystal lens had was the constant artificial lubrication, how uncomfortable they were because of their rigid structure and how dangerous they were because any trauma to the eye could easily break them and cause serious injury to the eye with the glass shards [1].

In 1936 the first plastic contact lens was created by William Feinbloom. This was the first contact lens without risk of breaking in the eye. It was a better lens than crystal almost in every way. In 1971 Bausch & Lomb was the first to get approval from the FDA (Food & Drug Administration) to sell their soft hydrogel lenses. This lenses kickstarted the modern age of contact lenses and are to this day part of the current offering.

In 1980 CooperVision was incorporated with its soft contact lenses which they make to this day. Currently producing hydrogels and silicone-based products. These contacts lenses are being sold in over 100 countries around the world which ranges from China, Europe, Africa and the Americas. Their #1 client being Japan at this moment.

METHODOLOGY

When trying to improve a process usually a pareto of the biggest offenders is produced to understand where are the biggest improvement opportunities. In the case of CooperVision–Hydrogels, it was determined that the biggest area of opportunity existed in curing losses [2].

Figures 1 to 3 show some of the Dry Yield Offender paretos that were made during the last three months that will show curing as the biggest issue with an average of 3.28%.

After understanding that curing was the biggest offender, we focused on what is curing losses. It defined as all the molds that arrived in the bags as final products after the curing oven, divided by all the molds picked up by the CUA (Control Unit Acquisition).

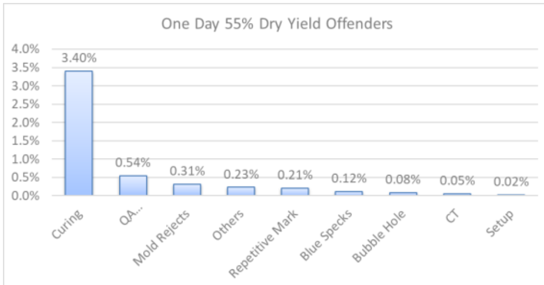

Figure 1
Dry Yield Offenders Pareto - November 2020

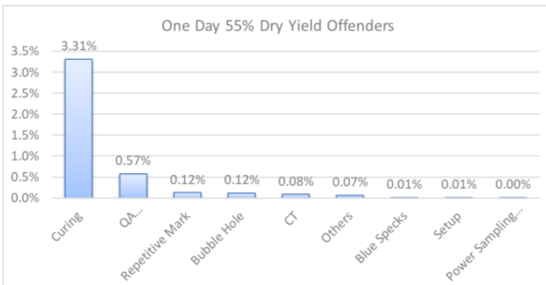

Figure 2
Dry Yield Offenders Pareto - December 2020

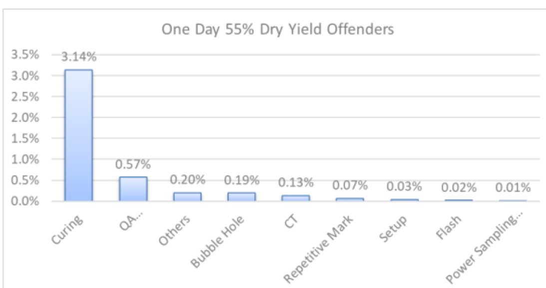

Figure 3
Dry Yield Offenders Pareto - January 2021

There are four waste bins where these molds can be discarded between the CUA and the bagger system after the curing oven. These are:

- **Reject 1:** the steel conveyor waste bin. Molds that weren't picked up the CUA this can be because of misalignment, defective molds or problems with the CUA.
- **Reject 2:** the walking beam waste bin. Molds here are discarded because mold/female were not opened, could not deposit the monomer or the sealing pressure was not right.
- **Loading conveyor oven 1:** molds not picked up by the oven 1 robot. This can also be because of a robot fault or the oven is faulted and cannot pickup those molds. It will continually be discarded until the fault is fixed and reset.
- **Loading conveyor oven 2:** molds not picked up by the oven 2 robot. This can also be because of a robot fault or the oven is faulted and cannot pickup those molds. It will continually be discarded until the fault is fixed and reset.

The main reason for these bins to be full are because when faults or interventions by the mechanics/operators occur, they stop with good product. Every time the machine starts it reference/home all its parts and discard all product present in the walking beam and loading conveyor. This varies from machine to machine since they vary their performance and how often they present problems.

A test machine would be used in the beginning to modify its PLC code and understand how it reacts to tests like eliminating the referencing and home when the machine is stopped. If the machine code for referencing and home is tied hardwired to the safety components of the machine or if the machine doesn't have the mechanical capabilities to understand the position of its components at all times, then we would shift our focus creating a delay when the machine is stopped or faulted when the machine is running in remote mode (this means the machine would have a production lot). This would allow us to process all molds before the machine is stopped and when it references or home it would result in no product loss.

RESULTS AND DISCUSSIONS

The process starts with two injection molding machines from the brand Netstal. In the injection molding process polymer balls are loaded, heated, and then pushed through pressure into what is known as the inserts (male and female). These two molds are then brought together one on top of the other with minimal pressure. Since they come out hot from the injection molding process, they are placed horizontally in what is called the steel conveyor, which is an approximately 15-feet-long conveyor and transports the molds from the injection molding machines to the walking beam. After five minutes, they reach the area where they will be picked up by a robot known as the CUA. This robot is the one in charge of picking up the mold lanes and depositing them in the first slot of the walking beam.

The walking beam is the part of the machine that is in charge of opening the molds, then depositing the monomer inside the polymer and then sealing it with pressure. This is do not through various stages inside what is known the walking beam. Once the molds have been sealed, they are transferred to the loading conveyor through the loading robots. The loading conveyor is the one responsible to transfer the molds from the walking beam to the trays that will be going inside the curing oven for its final process. This whole process is known as the dry process when making contact lenses.

In the current state of the stopping/fault process when a Stop Button which can be in the SCADA (Supervisory control and data acquisition), HMI (Human Machine Interface) or Door Unlock Push Buttons.

1. **The CUA stops loading molds into the walking beam.** The walking beam stops immediately and remains with all molds that it was processing including the ones that are already filled with monomer and sealed.
2. **The loading conveyors to both curing ovens stop and remain with 2 or 3 nests of 8 molds that contains monomer and are sealed and ready to be placed in the oven trays.** Once the reason the machine was stopped, or the fault is cleared the operator starts the machine again. Once the machine start button is pressed the first thing the CUA, Walking Beam, Loading Robots and Loading Conveyors do are reference all the conveyors and home the robots. This is done because once the machine is stopped it does not save the positions of all its components. After reviewing the reference/homing section of the PLC I understood that the original programmers wanted to make sure that all the parts of the machine would return to a specific home position.

The main problem found to modify the reference position was that the machine only had 1 physical point of reference for the conveyors. Meaning that once the machine does not store position of its conveyor but moves in specific distance and when stopped it would not know where it was and would need to reference to understand the position it was in. Another big problem founded was that some of the parts of the machine ran on compressed air, this is not ideal for position storage because once the machine stops it stops sending compressed air to multiple areas and they move from the position they were in. This is contrary to robot servos which move position is being always read and can be send to any position at any time.

Once is understood that could not modify the PLC programming to start the machine without homing/referencing, the approach would be to delay the stopping time and segregate the areas faulted as much as it could allow the machine to process as many molds possible. The first step that had to be achieve this was to stop the CUA immediately once a stop button was pushed but let the rest of the machine continue processing for a delayed time until there were no molds. This was achieved by modifying the PLC Code by delaying the signal that would send the stop bit sequence (figure 4) to the rest of the machine but allowing it to be delivered without delay to the CUA [3].

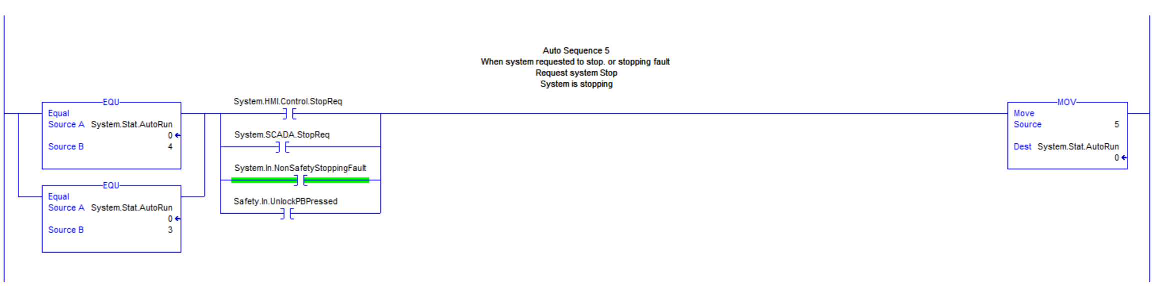

Figure 4

Sequence of the machine that would oversee sending the stop signal to every area

After some run tests were performed, 75 seconds was determined to be the time needed for the walking beam and loading conveyor to process all the remaining molds once the CUA was stopped loading molds into the walking beam.

Once the stop buttons fix was in place, the focus goes to the faults. Every time any area of the machine is faulted, it would stop the whole machine, that is, any time something faults, it would result in molds losses. Identifying the areas of the machine per the PLC it was find:

- Injection Molding
- Steel Conveyor (Transport from injection molding to
- Reject 1 – Steel Conveyor Discards
- CUA
- Walking Beam
- MCR (Molds pressure open and close device)
- Needles (Deliver monomer)
- Anvil
- Oven Loading 1
- Oven Loading 2

The first segregation would come from everything that is before the CUA loading molds into the walking beam. These areas are injection molding, steel conveyor, reject 1 and CUA. Each of these parts have their own faults, but each of them is grouped together to signal if one area of the machine is faulted. These areas do not stop the functional capabilities of the walking beam and loading conveyor, that is, once faulted, a fault alarm will indeed go off and stop these areas immediately, but will not stop the walking beam or loading conveyors. Doing this allowed the walking beam and loading conveyor ample time to process the molds that are in their areas and load them into the oven. This is already a great step into the right direction. Any stop or faults before the walking beam or loading conveyor at this point, are saving good product.

Now if there is a fault in the walking beam, it cannot run the walking beam because it could break something. For example, a needle depositing monomer in a mold remains extended could get pinched if the machine moves while in that position or if a mold get stuck under the metal plate it cannot continue transporting the rest without being miss aligned and could cause further problems. In this case the CUA and walking beam must be stopped immediately but there is still good product in the loading conveyor of the first and second oven. To be exact there could be from 2-3 nest of 8 molds at a time. For a total of 32-48 still good molds filled with product that could be discarded. After further testing it was found that the Loading Conveyors only needed between 25-30 seconds to deliver all molds nest to the curing oven. Meaning that even though could not save all the molds in the walking beam, the new process are indeed saving molds and reducing the time if it is a fault in the loading conveyor from our initial 75 seconds to around 30 seconds.

This have successfully saved molds and segregated the part of the machine to stop correctly when a stop button or fault occurs. This all happens when we have a lot running in the machine. This is when the machine is in production or in terms of the PLC in remote mode. When the machine is in maintenance and mechanics or operators are making adjustment, they usually do it in local mode. One of the first questions received was that when the machine was not in production if the delay would still be present? Because when they are intervening with a machine, they usually want things to be moved fast. Since the machine is not in production, a distinction was made in the programming so it can determine the stopping sequence depending if it is on Local or Remote. When it is in local mode it will stop all areas immediately once they have reached the stop position (figure 6).

In the new stopping logic sequence, it can be seen that it was not only segregated by local or remote mode but also alarms were segregated in a way that could be identified as the sections before the CUA and the sections after the CUA. This would give the distinction between what delay would be assigned depending on the area that is faulted. In the case of the OVL1 (Oven Loading 1) and OVL2 (Oven Loading 2) there is no delay because if one of these areas are not working loading molds into the curing oven would be impossible.

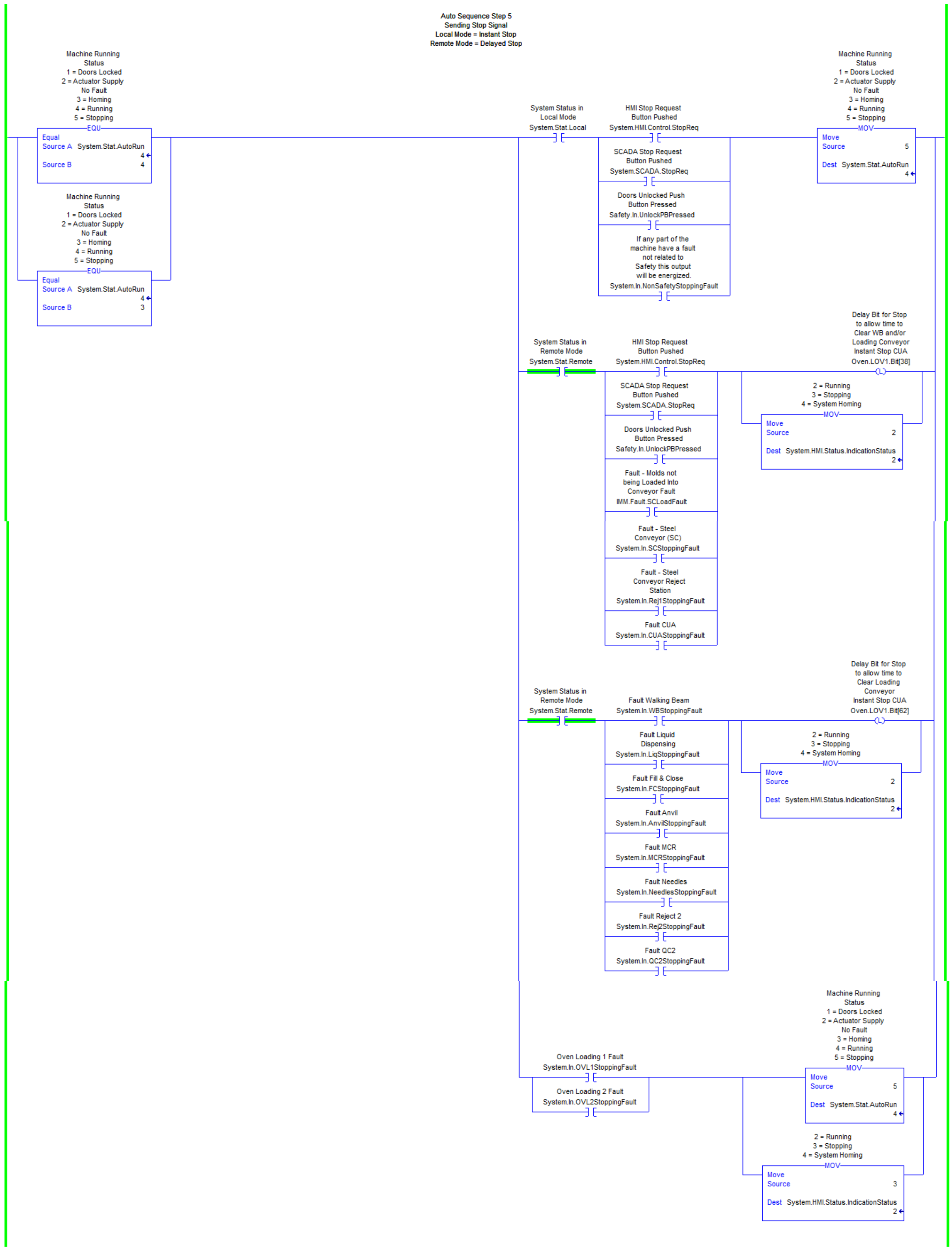

Figure 5
New Stopping Logic Sequence

CONCLUSIONS

This project will have a huge impact on not good performing machines which have continuous faults and/or are intervened consistently for some reason by the operators. This faults/stops impact directly to what is known as curing losses which are any molds picked up by the CUA but not delivered to the bags after going through the curing ovens. This curing losses vary from machines from 1% up to 3.28% depending on the day. It is estimated that this project will have an impact of more than 2% reduction in this overall metric and will increase machine yield, increase machine line rate, and reduce waste in the form of polymer and monomer. Since most the faults are not attended immediately that 75 seconds delay time added would result in a no loss situation. By the time the operator arrives to the machine that molds would have been processed, he can open any door and fix any current issue, start the machine through its normal sequence without the results of any losses but the time it took him to intervene.

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