MECH ENG 4143A: Project Level IV

PROJECT 1395

Development of an Automated Lubrication System for the Amcor Glass Bottle Making Machine

Final Report

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Executive Summary

Amcor Glass wishes to develop an automated lubrication system to replicate and replace the current manual swabbing process to improve safety and productivity. The current manual lubrication process poses a safety risk to the line operators conducting it. Furthermore the amount of lubricant applied can significantly influence the product surface quality and as a consequence of the manual process, the quality is highly dependent on the experience of the operator.

The project aim is to assess the feasibility of replicating the manual swabbing process with an automated lubrication system. This investigation includes a comparison of a commercial off the shelf (COTS) robot and a bespoke system comprising of individual components. Associated costs, safety requirements, system constraints and performance are assessed for both automated lubrication systems to provide Amcor the most effective solution. Additionally an alternative lubrication method is assessed to provide a more consistent coverage of lubricant onto the blank mould cavities compared with the current swab design.

The author worked in conjunction with Robotics and Specialised Machinery Australia (RASM) to identify a suitable COTS system. Liquid Robotics, for the conduction of a robot simulation. The author also worked in conjunction with other external suppliers of Amcor Glass including Festo for the suitable selection of components for the bespoke system and Josco Solutions for the development of an alternative swab design.

This report will include a detailed background research into existing automated lubrication system inventions, alternative methods of lubrication and current developments. This report will also detail the analysis for producing conceptual designs for an automated lubrication system for the bespoke and COTS system respectively. Additionally this report will detail investigation into an alternative lubrication method, providing a review of the design and manufacture of an alternative swab design, detailing trials undertaken and the resulting outcomes. Furthermore, this project will detail the feasibility analysis for both automated lubrication system concepts whereby the most suitable system is recommended to Amcor Glass.
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Disclaimer

The content of this report is entirely the work of the following student of the University of Adelaide. All other content has been referenced accordingly.

Michele Ciccone

Date:
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Glossary

Baffles: Component on IS machine assists in forming the bottom shape of the parison.

Bespoke: A system tailored for a specific process

Blank Mould: Mould used to form the parison.


Blank Side: Blank mould gear located on IS machine.

Blow and blow: Glass bottle forming process where air is used to blow the molten glass into the shape of the blow mould.

Blow Mould: Mould used to form the final shape of a bottle.

Cold End: Process in Glass forming process, where cold bottles are delivered to.

Colour Change: Bottles are produced off colour all bottles are rejected and recycled until the correct colour change occurs.

Commercial off the Shelf (COTS) systems: An industrial robot available to order

Degree of Freedom: Number of joints or movements available to a mechanism

Deflector: A mechanism used to guide molten glass into the blank mould

Dry Swab: The swab contains an insufficient amount of lubricant.

Finish: Thread located on the top of the bottle

Forming: A process in each the molten glass is formed into bottles.

Futronics: Control System of the IS machine

Funnel Mechanism: A mechanism used to assist in guiding the gobs into the blanks.

Gob: A piece of molten glass cut by shears during the forming process.

IS Machine: Independent Section Machine, this machine contains the essential mould gear to assist in the forming process.
1 Introduction

Amcor Glass manufacture a range of different types of glass bottles for both the wine and brewery industries. The glass manufacturing process is predominantly automated. As molten glass is used in the process, there is a need for frequent lubrication to ensure equipment operation and product quality. However, the lubrication process is undertaken manually, leading to higher risk of injury to the operators, inconsistency in lubrication and delays in manufacture. Therefore an automated lubrication system is required.

1.1 Background

To produce glass bottles, molten glass gobs are injected into an automated Independent Section (IS) machine, Figure 1.1 is a schematic representation of the IS machine for the blow and blow process. The first stage of the bottle forming process is where a molten glass gob is injected into the blank side of the IS machine. The blank side consists of two blank moulds where the two parisons are formed as compressed air from the plunger forces the gob to fit to the blank mould cavity. The parison is then transferred to the mould side of the IS machine where the final bottle shape is produced. There are two types of bottle processes performed at the Amcor Glass facility, these are referred to as blow and blow described above and the narrow neck press and blow (NNPB). For the NNPB using a plunger the parison is pressed into shape rather than blown. The current project focuses on the IS machines that perform the blow and blow process.

Figure 1-1: Bottle forming process (Wikimedia 2009)
1.2 Project Description

The blank mould equipment is currently all lubricated manually, this process is referred to as *swabbing*. The components which are frequently lubricated are the *baffles*, the blank mould cavities and the *neckrings*. This is illustrated in Appendix A.

The swabbing process consists of an operator entering the IS machine (see Appendix A for an image of this), during the *swab cycle* which is a single IS machine cycle where no molten glass is injected into the blank moulds. The available timing in the swab cycle is approximately five to six seconds and is dependent on the bottle production rate (Barreau 2013, pers. comm. 17 September). During the swab cycle the blank moulds remain in an open position divided into four separate *blank mould halves* as depicted in Figure 1-2, allowing access to the blank mould cavities and neckrings. Using a cotton swab containing the lubrication liquid the operator manually applies the lubricant to the blank mould cavities. A series of images demonstrating the swabbing process sequence is provided in Appendix A. The swabbing process is repeated at 15 to 20 minute intervals, depending on the type of bottle being produced and the bottle production rate (Barreau 2013, pers. comm. 17 September). The swabbing process is repeated for each of the sixteen IS machines per line. An image of the line demonstrating the eight IS sections in a row is provided in Appendix A. An automated lubrication system needs to simulate the swabbing procedure closely to provide the necessary quantity of lubrication coverage onto the blank mould cavities, to maintain product quality and IS machine equipment operation.

![Blank mould half and Baffle mechanism](image)

Figure 1-2: Blank moulds in open position.
The lubricant used during the swabbing process for the lubrication of the blank mould gear is *Kleenmold 170*. This is a petroleum-oil based swabbing compound containing graphite, sulfur and proprietary additives (Total Lubricants 2005). A product information sheet is provided in Appendix A. The operator prepares the swabs for lubrication in a *swabbing bay*, this is completed by dipping the swabs into a bucket of this lubricant and removing any excess lubricant ready for lubrication. An image of this process is provided in Appendix A.

During the swabbing process, the task that raises high safety concerns for the operator is the lubrication of the blank mould cavities. The repetitive nature of the task can lead to possible repetitive strain injuries (Barreau 2012, pers. comm. 17 September). Furthermore the operator is also exposed to a hot environment and potential presence of molten glass. For these reasons Amcor Glass has been considering for some time to investigate the feasibility of replacing the swabbing process with an automated lubrication system that can closely replicate this process. This system will look at specifically the lubrication of the blank mould cavities.

Currently this is no existing fully automated lubricated system present in glass bottle manufacturing industries around the world (Barreau 2012, pers. comm. 17 September). The IS machines operate with molten glass and therefore function around high ambient temperatures. Additionally there is limited spatial constraints around the IS machines, these constraints have therefore limited the possible opportunity to automate the swabbing process. Amcor Glass, wish to investigate two types of automated systems. The first is a bespoke system comprising of an assembly of individual components which may provide Amcor a simple, affordable, alternative to automate the swabbing process. The second automated system is to select a commercial off the shelf (COTS) robot. Both systems would integrate the use of the cotton swab as this is a proven effective method for the lubrication of the blank mould cavities.

If an automated lubrication system can replicate the swabbing process for the lubrication of the blank mould cavities it is possible to reduce the chances of a line operator developing repetitive strain injuries and reduce the time the operator is exposed to a hazardous working environment. Additionally the use of the automated system will provide a more consistent process for applying lubricant onto the blank mould cavities therefore removing the inconsistency of application when applying lubricant manually.
1.3 Project Aim

The project aim is to assess the feasibility of replicating the manual swabbing process with an automated lubrication system. This investigation includes a comparison of a commercial off the shelf (COTS) robot and a bespoke system comprising of individual components. Associated costs, safety requirements, system constraints and performance are assessed for both automated lubrication systems to provide Amcor the most effective solution. Additionally an alternative lubrication method is assessed to provide a more consistent coverage of lubricant onto the blank mould cavities compared with the current swab design.

1.4 Project Goals

The project goals as described in the Project Charter are:

To assess the feasibility of an automated lubrication system that is able to replicate the current manual swabbing process to improve safety and productivity for Amcor Glass. This includes the concept development of two automated lubrication systems. A bespoke system comprising individual components and the selection of a suitable COTS robot.

This goal will be achieved through developing a conceptual design for a bespoke system comprising of individual components and demonstrating that this chosen system can be incorporated into the current IS machine set-up, including spatial limitations, time restrictions, temperature constraints and safety requirements. A COTS robot is to be selected with conformation assistance from an external consultant of Amcor Glass Robotic and Specialised Machinery Australia (RASM). A comparison assessment is to be completed for the two automated lubrication system concepts, comparing associated costs, safety requirements and calculated performance.

The second goal is to develop new swabs that are able to provide a more consistent coverage of lubricant and detail a conceptual design for integrating these swabs into the automated lubrication systems. This goal will be achieved through the success of trials conducted, to determining the suitability of replacing these with the existing swabs.
1.5 Project Scope

The project components are outlined in the work breakdown structure provided in Appendix B, Figure B-1. For the design of the bespoke system only the research, conceptual design and feasibility of the system will be completed. Using provided data sheets of components the performance and constraints are assessed. For the investigation of the COTS system this selection will be verified with the assistance of an external consultant of Amcor Glass, Robotics and Specialised Machinery Australia (RASM). A comparison assessment is to be completed for the two automated lubrication system concepts, comparing associated costs, safety requirements and calculated performance. For the lubrication application all scopes of the project will be completed including design, manufacture of a prototype and the completion of trials.

The current project does not include the programming integration of controls within the IS machine for both automated lubrication system concepts. Additionally for the lubrication application this project does not include the investigation into spray systems and self lubricating materials for the blank moulds, only alternative swab designs are assessed.

1.6 Report Outline

This report outlines a literature review, this is presented in Chapter 2. The review provides a background into existing automated lubrication system inventions, alternative methods of lubrication and current developments. Chapter 3 outlines the specifications and limitations to the project, specifically looking at constraints presented on the IS machine, where a potential automated lubrication system could be placed. Chapter 4 details the investigation into an alternative lubrication method. This chapter provides a review of the design and manufacture of an alternative swab design, detailing trials undertaken and the resulting outcomes. Chapters 5 and 6 details the analysis for producing conceptual designs for an automated lubrication system for the bespoke and COTS system respectively. Chapter 7 provides a feasibility analysis for both automated lubrication system concepts whereby the most suitable system is recommended to Amcor Glass.
2 Literature Review

2.1 Automated Lubrication Inventions

There are a number of existing patents for automated lubrication systems, these possess both advantages and disadvantages. The investigation into the current ideas and inventions available assists in developing a more suitable design for Amcor Glass.

2.1.1 Tohjo (1997)

A patent by Tohjo (1997) discusses a robot comprising of five degrees of freedom, which is able to hold a swabbing brush to apply lubricant to the blank mould cavity. The ability for the robot to have multiple axes allows it to replicate the movement, similar to that of an operator performing the swabbing process. The robot is attached to an external axis which is a straight linear guide located on the beam above the IS machine, this is shown in Figure 2-1. This additional axis allows the robot to relocate to different IS machines. The robot consists of motors to control the movements of each of the joints and using a microcomputer with a series of sensors, allows the robot to identify the correct position required. The gripper component on the robot contains a chuck which allows a swabbing brush to be attached and removed for when the swabs are required to be replenished. The lubrication method described in the patent by Tohjo (1997) demonstrates the use of a swabbing brush similar to that used in the current manual process. However, lubricant is instead injected into the brush through a pipe, allowing lubricant to seep into the material of the swab as shown in Figure 2-2. The amount of lubricant impregnated into the brush is controlled by the use of air pressure, where by the lubricant is held in a container which moves along with the robot.

The robot described in the patent by Tohjo, is very suitable design, as it removes the need for the operator to be present in a hazardous environment during the swabbing process. Furthermore the additional linear guide axis located on the beam of the IS machine provides the opportunity for one robot to travel across multiple IS machines, eliminating the need for additional automated lubrication systems for each IS machine. However, the robot comprising of six degrees of freedom would lead to higher associated costs. Additionally
how this robot is positioned in the IS machine, exposes the robot to potential interference with operating IS machine components.

Figure 2-1: Five degree freedom robot (Tohjo 1997)

Figure 2-2: Swabbing brush mechanism (Tohjo 1997)

2.1.2 Keller 1973

A patent by Keller (1973) describes a spraying mechanism which is stated to be a simplified inexpensive add on, attached on an IS machine. This system consists of a spraying mechanism enabling lubricant to be sprayed onto the blank mould cavities, when the blank moulds are in the closed position, this is detailed further in Chapter 3. This is accomplished through a guided funnel positioned above the blank mould and with the use of a retractable spray nozzle carried by the funnel support. The mechanism is able to retract and this is achieved with the use of a pneumatically actuated piston containing a hollow piston rod
allowing for a predetermined amount of lubricant to be distributed to the nozzle in the required timing sequence. This mechanism is able to retract prior to the loading of the molten glass gob and is able to be rotated out of the way when not in use which is accomplished with the use of air motors, situated on a rotating shaft. The mechanism also contains a lubricant distribution block this is described as a "T-shape" device allowing lubricant to be simultaneously applied to the two blank mould cavities. The lubricant distribution block is able to be modified to suit a different configuration to lubricate a single blank mould or three or more blank moulds.

The Keller 1973 automated lubrication system is a suitable as it also provides a cheaper alternative to that of a complex robot comprising of multiple axes as described in the patent by (Tohji 1997). Additionally as the system is able to retract, it therefore consumes less space on the IS machine. Furthermore it is able to lubricate two blank mould cavities simultaneously enabling it to operate efficiently within the timing restrictions in the swab cycle. However, there are a number of limitations to this system. As it is defined to be a mechanism that is attached to a single IS machine, multiple mechanisms would be required to lubricate a series of sixteen IS machines, this would result in additional costs. Furthermore, the mechanisms are permanently positioned on the IS machine, this may create interference problems when maintenance operations are required on the IS machines.

### 2.1.3 Gifu and Hashima (1991)

A patent by Gifu and Hashima (1991) describes a spray apparatus mechanism similar to that detailed in the patent by Keller (1973). The Gifu and Hashima system, comprises of two spray nozzles which are able to apply a mist of lubricant onto the blank cavities in the closed position. However, this system is located on a beam above the IS machine as shown in Figure 2-3 and uses a linear rail guide to enable the system to travel to multiple IS machines.

There are numerous advantages for the Gifu and Hashima 1991 automated lubrication system. The system described has the ability to travel across multiple IS machines and therefore only one system is needed to function across multiple IS machines. Additionally, the system is able to retract to a smaller size by the use of a hydraulic cylinder (see Figure 2-
3), therefore consuming less space on the IS machine. However, there are a number of limitations of this system. The spray nozzles on the system are constrained at a set height above the blank mould cavities a major concern is as the lubricant is sprayed, lubricant may be distributed onto unnecessary areas resulting in lubricant build up, leading to potential maintenance concerns.

![Diagram of automated swabbing device](image)

**Figure 2-3 : Automated swabbing device (Gifu & Hashima 1991).**

### 2.1.4 Lichok (1969)

A patent by Lichok (1969) describes an apparatus that removes the need of complex spray nozzles. The apparatus comprises of a pop-up valve shown in Figure 2–4, situated underneath of the blank moulds, allowing lubricant to be applied to the blank moulds. This is achieved when the pop-up valve is in a raised position and lubricant is transferred onto the blank mould while the blank moulds are in the closed position. This system operates during a timely sequence, relative to the insertion of a glass gob (Lichok 1969).

The lubricant source consists of a conventional air fogging system, comprising of a supply line which is able to feed clean dry air into a fog unit from which a another line carries the combined air and atomized oil, forming the lubricant medium. An air operating lubrication valve which is controlled by the air supply of the IS machine, periodically discharges the lubricant through a line to the blank mould. There are a number of concerns with this
system. Firstly the system is required to be set-up for each of the sixteen IS machines adding associated costs. Additionally extra components added onto the IS machine may lead to maintenance concerns.

![Diagram of lubrication system](image)

Figure 2-4: Lubricating apparatus for lubrication of the blank moulds (Lichok 1969).

### 2.2 Alternative Methods

The lubrication process is significant to assist in ensuring the IS machine can run effectively. As stated in Chapter 1 there is a great significance on lubrication due to its impact on product quality, operator health and safety. Therefore numerous alternatives to automated swabbing have been previously investigated.

There are a number of methods used as alternatives to swabbing. These possess both advantages and disadvantages compared to the current process. The alternative methods of lubrication investigate were blank sooting and to pre-coat the blank moulds.

Blank sooting, consists of igniting acetylene with the use of a flame which forms a lubrication layer on the blank mould cavity. Blank sooting is proven to be effective in avoiding the need for the swabbing process and has been used in competing glass bottle manufacturing plants; however, there are many limitations to this method. The heat produced during blank sooting creates a more hazardous environment for the operator in which to work. Another limitation is the high costs associated. The products required to create the flame used in blank sooting including oxygen and methane, which can be
expensive. (Morettin 1999). As this method raises high safety concerns, Amcor Glass is hesitant to use this method (Barreau 2012, pers. comm. 17 September).

Another alternative method that may reduce the frequency of swabbing is to pre-coat the blank mould cavities with a semi-permanent coating. Pre-coating consists of applying the blank mould cavities with a uniform coating of graphite. This method is effective in reducing the frequency of swabbing. It is also beneficial as it protects the blank mould surfaces from corrosion during the storage of the moulds when they are not in use. However, initial development of coatings resulted in only lasting a matter of hours. Additionally the coatings are said to be difficult to apply and hazardous both in the work environment and harmful to the environment (Roberts 1999).

2.3 Current Developments

There are a number of current developments existing in glass bottle manufacturing plants around the world. These developments possess both advantages and limitations. One of the systems investigated is the Autoswab.

The Autoswab is a blank mould lubrication system which was developed in the 1980's and 1990's to replace the process of manual swabbing. The Autoswab comprises of a special funnel mechanism and was used throughout the blow and blow forming process. The head of the Autoswab remains to the side of the IS machine during the loading process of the glass gob. This is illustrated in Appendix C.

The Autoswab was integrated into the IS machines at competing glass manufacturer plants and was set to a spray cycle when the glass gobs were ejected. The head of the device then position itself above the funnel mechanism. In this position, the Autoswab sprays a lubricant onto the funnel mechanism which was then transferred onto the blank mould cavities. The lubricant used for the autoswab consisted of a lower graphite particle content than Kleenmold 170 and therefore the lubricant was sprayed more frequently than if manual swabbing to apply an adequate coverage of lubricant onto the blank mould (Brown 2012).
The Autoswab has proven to be an effective device and provides a consistent amount of lubricant onto the blank mould cavities. However there are a number of limitations. As this system consists of a spray applicator, it was unable to accommodate changing production changes unlike with the use the swab, the swab is able to wipe the mould clean. Furthermore the graphite particles present in the lubricant, results in graphite build-up in the pipes for the spray applicator, raising maintenance concerns(Brown 2012).

A number of systems have been investigated to assist in designing a suitable automated lubrication system for Amcor Glass. The most effective system identified is the use of a robot arm to apply the lubricant with a cotton swab described by Tohjo (1997). This is a suitable system as only one system is be required to operate across multiple IS machines, eliminating the need for additional automated lubrication systems for each IS machine. Additionally the use of the cotton swab is able to accommodate the need for specific production changes and is able to clean the blank mould.
3 System Requirements

There are a number of constraints necessary to identify before a suitable automated swabbing system can be designed. The constraints for the automated lubrication system are; machine and timing constraints, temperature constraints, maintenance operation requirements and spatial constraints around the IS machine. These will be discussed in more detail in the following Chapter.

3.1 Machine and Timing Constraints

The IS machines used by Amcor Glass operate on a 360° timing system. This allows the functions of IS machines to be repeated periodically. The timing system is controlled by a Futronics system which is able to be controlled and regulate the pneumatic controls on the IS machine (Kalatzis 2010).

To perform the swabbing task the operator enters the machine in the swab cycle where the machine is shut down for one cycle which is approximately five to six seconds enabling the operator to enter the section to manually lubricant the four blanks moulds halves. The timing was verified using video footage during the project.

Additionally with the use of the Futronics system, the swab cycle is able to be modified to have the blank moulds closed with the same time available. This option was proposed as it could potentially simplify the movement required of a automated swabbing machine to successfully lubricant the blank moulds. During the project a IS machine was programmed to have the blank moulds close successfully during the swab cycle this is depicted in Figure 3-1.

![Blank moulds in closed position](image)

Figure 3-1: Blank moulds in closed position.
Chapter 3: System Requirements

The second timing scenario investigated, is on the IS machine during operation which is referred to as on the run. This was investigated as if the potential automated lubrication system is able to successfully lubricate the blank moulds within this time, it could lead to potentially removing the swab cycle. Removing the swab cycle would provide substantial cost benefits for Amcor, a cost benefit analysis conducted by Kalatzis 2010 and is provided in Appendix T, this is discussed further in Chapter 7. Additionally, removing the swab cycle would improve the bottle forming process as interruptions of stopping the IS machine are removed. When the IS machine is stopped the components begin to cool down and therefore the bottles are not able to form correctly, if the swab cycle was removed it would potential keep the machine running at consistent temperatures and therefore better quality bottles are produced (Barreau 2012, pers. comm. 17 September). It would only be possible to lubricant the blank moulds during the on the run cycle when the moulds are open as there is insufficient time for when the blanks are closed during the operation. Table 3-1 below, provides a summary of the measured timing scenarios considered for the project.

Table 3-1: Timing Measurements during IS machine operation.

<table>
<thead>
<tr>
<th>Timing Scenario</th>
<th>Time (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swab Cycle</td>
<td></td>
</tr>
<tr>
<td>Blanks moulds in open position</td>
<td>5</td>
</tr>
<tr>
<td>Blanks moulds in closed position</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>On the Run</td>
<td></td>
</tr>
<tr>
<td>Blanks in open position</td>
<td>1.5</td>
</tr>
<tr>
<td>Blanks moulds in closed position</td>
<td>0.2</td>
</tr>
</tbody>
</table>

3.2 Temperature Constraints

For the design of a suitable automated swabbing system it is required to work within the temperature constraints of the IS machine as it would be positioned closely to the blank side components located on the IS machine. Appendix D illustrates the ambient temperatures recorded during the project on line 11, G1 furnace IS machines. This was completed using an Easylog, positioned in the control box on the IS machine, a product overview of the Easylog is provided in Appendix D. The highest ambient temperature recorded was 68.5°C.
Additionally, the components of the IS machine can reach up to 500°C. Appendix D, shows the temperature range of a blank mould cavity for bottle type AG-007 can reach up to 500°C. This was recorded using a 558 IR thermometer thermal imaging camera. The baffle mechanism can reach up to temperatures of approximately 340°C; this is detailed in Appendix D.

### 3.3 Maintenance Operation Requirements

In the glass bottle manufacturing industry, IS machines require regular maintenance. These maintenance tasks include *job changes*, where operators are required to climb and reach into the IS machines to change over IS machine components including the baffle mechanisms and blank moulds. It is therefore important that operators must have regular access to these areas to maintain the performance of the IS machine. These factors are necessary to take into account when developing a suitable automated lubrication system, to ensure it does not interfere with access to the IS machine. The IS machines also have sufficient safety barriers in place, see Appendix A, Figure A-8 for illustration. As the operators are near the IS machines regularly, these safety barriers still must be present. It is a requirement that the automated swabbing machine be able to operate around these barriers.

### 3.4 Spatial Constraints

For the assessment of selecting a suitable automated swabbing machine, a 3D CAD model of blank side of the IS machine was developed by the author to assess the spatial constraints a illustration is provided in Figure 3-4. This model was produced using a 3D modelling program *AutoDesk Inventor 2011*. The dimensions for the IS machine were measured using a IS machine located in the training room at the Amcor Glass facility and 2D drawings provided. This model only represents the main components on the blank side of the IS machine for which the automated swabbing machine would operate near .The blank moulds, and hinges and invert arms were developed by Kalatzis (2010). The main concern for reaching the blank moulds is the limited access between the *deflectors* and blank moulds (see Figure 3-4) where there is approximately a distance of 414mm. Appendix E provides a selection of drawings for the IS machine CAD model developed demonstrating the main spatial constraints.
3.4.1 Mould Heights

Different types of blank moulds determine the available space between the deflector and *hook hinge height* of the blank mould. A table of measurements was constructed to identify the worst case scenario of limited space available, that the automated swabbing system is required to operate in. This was identified for the AG-020 blank mould comprising of a clearance of just 360.6mm. This is detailed in Appendix F.

3.4.2 Positioning Requirements

For automated lubrication system the selection of a suitable position for the system is essential. There are three possible positions for which a system could be placed, however each has limitations. For the position of these systems, it is essential that there would be regular access for maintenance operations. The three possible positions were on the floor plates next to the IS machine, on a base component on the IS machine and on the beam above the IS machine, illustrated in Appendix G, Figures G-1 and G-2. For both the floor plates and base of the machine although there is adequate space to place a automated lubrication system, regular access is required for maintenance operations and so these areas were defined as not being suitable. The third possible position identified was to place a system on the beam above the IS machine (see Appendix G for illustration). This position is a possible suitable position as it does not interfere with maintenance operations and would allow the system to move across multiple IS machines.
4 Lubrication Application

The current lubrication method provides an inconsistent application of lubricant onto the blank mould cavity, therefore bottle quality and machine operation. The development of an alternative swab design is necessary to provide a more consistent coverage of lubricant onto the blank mould cavity, therefore assisting in improved bottle quality. The current project investigated a suitable alternative swab design which aims to provide a more consistent coverage of lubricant onto the blank mould cavity.

Blank moulds are lubricated using a cotton swab where lubricant is applied to the swab and applied to the blank mould cavities. As the swabs are cotton, significant wear can occur after regular usage and so they are replaced approximately every two hours. Additionally the swab is not designed specifically to suit the shape and size of each of the different types of blank moulds and this results in an inconsistent amount of lubricant being applied onto the blank mould. This inconsistency can result in build up of lubricant onto unnecessary sections on the blank mould as shown in Figure 4-1. This build up of lubricant can result in difficulties for closing the mould during operation. As a result this can lead to air gaps being created between the blank mould halves as they close when forming the parison and therefore the parison is not formed correctly. Details of the resulting defects caused by inconsistent swabbing are provided in Appendix H. Additionally the current method for applying lubricant onto the swab is inconsistent, where the operator dips a swab in container of lubricant and excess lubricant is wiped off. It is inconsistent as there is no defined quantity of lubricant applied onto the swab, only a visual inspection to whether the swab is wet or dry is assessed. Provided in Section 4.4, details an extension goal for the project where a concept for an alternative application for applying lubricant onto the swab is discussed.
There is an opportunity to spray lubricant onto the blank mould cavities as discussed in literature review presented in Chapter 2. This method has been trialled in a number of different glass bottle manufacturing plants. However, there are a number of concerns with this method. Issues have risen whereby the graphite particles build up in the pipe system on the IS machines, leading to maintenance concerns (Barreau 2012, pers. comm. 17 September). Additionally other concerns with the spray method is, it is unable to accommodate specific production situations where unlike a swab, it is unable to clean the surface of the blank mould cavities during the forming process. There are continued investigations to improve the spray method, including developments of new spray nozzle designs and trialling different lubricant types. For these reasons the current project, investigated the design of a new swab which is able to provide a more consistent application of lubricant onto the blank mould cavity and have higher wear resistance compared to the current swab design.

### 4.1 System Variables

Variables which influence the design of a suitable alternative swab are the amount of lubricant applied onto the blank mould and the recommended frequency of swabbing. The
amount of lubricant applied to different types of blank moulds varied significantly depending on the size and shape of the bottle. There is no defined measured quantity of the lubricant applied to the different types of blank mould cavities and therefore it was necessary to undertake a trial to measure the approximate quantity of lubricant for different bottle types. Additionally the defects caused during these trials were also recorded to verify if the amount of lubricant was sufficient.

The trials consisted of the swab being weighed initially and after the swab had been used during the swabbing procedure. The common procedure for swabbing sixteen IS machines is one swab is used per four sections. The trials provided approximate lubricant quantities for different bottle types. However, there were a number of variables that limited the accuracy of the data collected, these were the different line operators that undertook the swabbing procedure and the wear of the swab during usage. Depending on the relevant experience of the line operator the amount of lubricant applied would vary. Additionally continuous use of the swab on the hot blank moulds lead to the swabs wearing frequently and therefore this would affect the quantity of lubricant measured. The data collected during these trials is provided in Appendix I. The data indicated that the larger the bottle the larger the quantity of lubricant necessary. A summary of this data is provided in Table 4.1 below, the lubricant quantity varied from 0.7g per blank mould half for an AG-041 bottle, to 0.17g for an AG-102 bottle which is a smaller bottle type.

<table>
<thead>
<tr>
<th>Bottle Type</th>
<th>Bottle Mass (grams)</th>
<th>Average Amount of Lubricant (grams) per blank mould half</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG-041</td>
<td>532</td>
<td>0.7 g</td>
</tr>
<tr>
<td>AG-066</td>
<td>418</td>
<td>0.47g</td>
</tr>
<tr>
<td>AG-102</td>
<td>205</td>
<td>0.17g</td>
</tr>
</tbody>
</table>

The blank moulds come in a variety of specific shapes and sizes all consisting of different inner surface areas depending on the specific bottle type. It is necessary to calculate the different heights and surface areas of the blank mould. This was completed using 2D drawings of different blank mould types provided by Amcor Glass see Appendix F for measurements calculated. The area requiring sufficient lubrication is defined between the load line and the bottom of the blank mould this is illustrated in Appendix F, Figure F-4.
Chapter 4: Lubrication Application

These measurements provided an indication to determine the suitable swab size and shape to accommodate the necessary swab area. Swabbing is repeated frequently to achieve the desired amount lubricant necessary to apply onto the blank moulds, to ensure the bottle forming process runs smoothly. Swabbing occurs approximately every 15 to 20 minutes. It was therefore necessary to trial different frequency rates of swabbing to determine if the lifespan of the swab could be increased. This would result in reducing the replenishment rate for the swabs, therefore providing both time and cost savings for Amcor Glass. A trial was conducted during the project to identify the affects of different swabbing frequencies, the data for these trials are provided in Appendix J. The trials concluded that decreasing the frequency of swabbing to every 30 minutes for the AG-40 bottle type, resulted in no significant defects caused compared with the normal swabbing frequency rates. Further trials would need to be conducted to verify these findings.

4.2 Conceptual Design

In conjunction with Josco Solutions, an external supplier of Amcor Glass, an alternative swab design was developed. The shape of the swab is able to conform to the shape of the blank mould and is designed to function when the blank moulds are in the closed position within the swab cycle. Using a motor, the swab is able to spin off the lubricant onto the blank mould cavities. The advantage of closing the blank moulds for this operation, prevents lubricant being applied to unnecessary areas of the blank mould.

The swab consists of mexican fibre bristles comprising of a spiral shape. Mexican fibre is a suitable material for the design as it is able to withstand high temperatures of up to 400°C (Josco 2013). To determine the suitability of this design, trials were conducted. The swabs manufactured are designed to accommodate the most common bottles produced in the plant, these are AG-007, AG-041, AG-043 and AG-048. These bottle types all consist of a similar size blank mould and therefore a swab was able to be manufactured to accommodate all these. The swab is constructed on a 4 by 2 frame wire, consisting of a handle which is able to attach into a chute suitable for a drill mechanism. Figure 4-2 illustrates the alternative swab manufactured. The total cost to manufacture this swab came to $80.00. If these swabs were bought in bulk the price would reduce substantially (Josco 2013). Drawings created to manufacture this swab and necessary quote information is provided in Appendix K.
4.3 Trials

Initial trials were conducted on a cold blank mould half to assess how the alternative swab applied lubricant onto the blank mould cavities. Using a drill the swab is able to spin the lubricant onto the blank mould cavities. The use of a motor to spin the lubricant added an additional variable to consider when determining the suitability of this design. Further trials were conducted to determine the rotational speed to provide an adequate quantity of lubricant onto the blank mould cavities. This is detailed further in Appendix K.

The initial trial for the alternative swab provided an indication of the expected application of lubricant coverage onto the blank mould, this was completed using an AG-041 blank mould shown in Figure 4–3. A visual comparison was made between the alternative swab and original swab. The alternative swab is able to provide a much more consistent coverage than the original swab, by a visual inspection, no excess lubricant was present on the sides on the blank moulds.

Figure 4–2: Manufactured alternative swab design.

Figure 4–3: Initial trial of alternative swab design on AG-041 blank mould.
Chapter 4: Lubrication Application

During the initial trials it was found, the application of lubricant onto the swab was inconsistent. Depicted in Appendix K, Figure K-1, evidently there is excess lubricant build up on the base of the blank mould cavity, this resulted from the because there was excess lubricant present within the wire on the swab, this is shown in Appendix K, Figure K-2. An alternative method of application was developed to apply the lubricant onto the swab this was done by rolling the swab in a tray of lubricant and ensuring no excess lubricant was present within the wire on the swab, shown in Appendix K, Figure K-3, evidently this provided a much more consistent coverage as seen in Appendix K, Figure K-4.

Further trials were conducted to measure the necessary speed required of the motor to apply the essential quantity of lubricant onto the blank mould, a graph is provided in a Appendix K, Figure K-5. This graph shows the relationship between the rotational speed of the drill and the lubricant quantity. This trial was conducted for a AG-007 blank mould using a tachometer to accurately determine the drill speed. The swab was rotated for a period of approximately 1.5 seconds for each trial as this replicated the approximate time needed in the swab cycle when the blanks moulds are closed. The results indicate that increasing the swab's rotational speed increases the lubricant deposition. The highest rotational speed the swab was rotated at was 1300 RPM providing approximately 0.3g of lubricant onto the blank mould half. These results also dependent on the amount of lubricant applied onto the swab, increasing the quantity of lubricant onto the swab resulted in more lubricant being spun off onto the blank mould cavity.

Several trials were conducted on the IS machines to determine the suitability of the alternative swab design. The first trials conducted were during a colour change, this is where bottles are not packed and therefore production is not affected. During these trials, defect data is recorded on the XPAR system. This system measures the defects located on five different zones on the bottle. The five zones are the finish, neck, shoulder, body and bottom. This is detailed in Appendix L, along with a discussion of defects identified during this trial.

At the time of these trials the blank moulds were closed manually (see Appendix M for Job safety environmental analysis document completed for these trials) therefore affecting the data collected. When the blank moulds are closed manually the blank moulds cool rapidly while they are being adjusted into position, therefore affecting the thermal requirements of
the blank mould during operation. This resulted in particular bottle defects occurring. The type of defect which occurred as result of this method was a *DG Intensity*, this is where the heat is distributed unevenly around the blank mould. This is illustrated in Appendix L. Figure 4-4 shows the percentage of number of bottles rejected due to bottle defects, during the colour change trial. This trial was conducted for the AG-007 bottle type. The alternative swab was trialled on Section 19 Front (19F), while the other sections remained using the original swab. During the interruption when manually closing the blank moulds during the trial, it was evident that the alternative swab caused no significant defects. Referring to Figure 4-4, 1.5% of bottles were rejected in the trial. A comparison with Section 4 Back (4B) where the original swab was used, concluded a higher percentage of bottles were rejected, where 3% of bottles were rejected during a period of one hour. Section 6 Back (6B) was interrupted during the colour change so these results were neglected when a comparison was made. Further trials would need to be conducted to confirm the accuracy of these results.

### Graph: Colour Change XPAR Data

![Colour Change XPAR Data](image)

**Figure 4-4**: Graph displaying moulds rejected on X-PAR (%).

During the project the swab cycle was programmed to have the blank moulds close. This allowed further trials to be conducted during production to provide a better indication for the suitability of the alternative swabs. By programming the blank moulds to close in the swab cycle, this eliminates interruptions during the trial and therefore less bottle defects are created. During production, defect data is recorded on the XPAR system and *management data system*. The management data system is where defects are measured at the *cold end* of the
Chapter 4: Lubrication Application

bottle forming process. This trial was conducted for the AG-045 bottle. The trial was performed on Section 16 Front (16F) on the G1 furnace, Line 12 the 16th of July 2013. During these trials no significant defects resulted when using the alternative swab. Shown in Figure 4-5, are the defects recorded during a period of two hours, only 0.31% of bottles on this section were rejected over a period of two hours. Figure 4-6 provides a breakdown of the defects, resulting for Section 16 Front. Of the 0.31%, 0.11% of defects were defect 501, this is classified as when the machine begins to recount the bottles rejected and so this is excluded from being a defect caused as a result of using the alternative swab. Two other types of defects identified during this trial is defect 47 (check defect) and defect 121 (bore defect) where only the bore defect may have been caused directly by the use of the alternative swab. A comparison was made with the original swab usage on section 5 Back (5B). Figure 4-7 provides a breakdown of the defects recorded. Defects created were 83 (thin side) and defect 82 (thin shoulder) and swabbing can be known to be a cause for these defects.(Maun, 2013, pers. comm. 18th September) Definitions of these defects are provided in Appendix N. On completion of the trials the wear of the swab was visually assessed, evidently the swab did not wear significantly. The swab was trialled equivalently to lubricating 82 blank mould halves. An original swab lubricates up to 128 blank mould halves in its life span, these results for the alternative swab wear indicate the potential for this swab to have a high wear resistance. Appendix O provides an image demonstrating this swab is still able to provide a consistent coverage of lubrication.

![Section 12 Bottle Rejection](image)

Figure 4–5: Bottle defects recorded on management system for AG-045.
The trials conducted for the alternative swab, demonstrated that this design did not cause any more significant defects related to swabbing when compared to the original swab. Initial results indicate the swab is able retain a lifespan close to that of original swab, where additional trials required to indicate this swab is potentially able to have a longer lifespan compared to the original swab.

Additionally the swab also had a higher wear resistance than the current swab. Future trials would need to be conducted to determine the accuracy of the results produced during these trials. Chapter 5 discusses a suitable concept developed to integrate this swab design into the bespoke system assembly. Discussion with RASM confirmed it is possible to integrate these alternative swabs into a COTS system with a suitable chuck attachment (Grocke 2013, pers. comm. 20th July). The cost to manufacture the swab is approximately $80.00 for a one off, this price would although reduce substantially if these swabs are manufactured in bulk (Andrewartha 2013, pers. comm. 17th March). The cost of a original swab compared to the alternative swab are approximately $1.60 each (Amcor 2013). Although the cost to produce
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this swab is substantially higher when compared to the original swab, initial results indicate this swab is able to provide a more consistent coverage of lubricant on the blank mould cavities, resulting in no significant bottle defects being caused. Future trials would need to be conducted to confirm the suitability of these swabs, but the initial results provided promising development for Amcor.

4.4 Lubrication Application onto Swab (Extension Goal)

An extension goal for the project was to investigate alternative lubrication methods. As discussed above, applying lubricant onto the swab is an inconsistent process for both the original swab and alternative swab investigated. A requirement for the alternative swab was to produce a new method of applying lubricant onto the swab in order to achieve a consistent coverage of lubricant onto the blank mould cavity. This was achieved by rolling the swab in a tray of lubricant to ensure no excess lubricant is present on the swab. (see Appendix K for details). Additionally for both swab designs (original and alternative) a concept was developed for applying lubricant onto the swab, this was discussed in conjunction with Lube Control an external supplier to Amcor Glass. This may assist in providing a more consistent coverage of lubricant. A particular method investigated consisted of designing a container for which the swab could sit and have spray injectors apply the necessary amount of lubricant onto the swab therefore providing a more consistent coverage onto the blank mould cavity. This is detailed further in Appendix P.
5 Bespoke System

A conceptual design was developed for a bespoke solution for an automated lubrication system, comprising of tailored selection, of individual components to specifically perform the swabbing process. This system was investigated to provide Amcor an alternative cost effective solution to purchasing a commercial available robot.

5.1 Conceptual Development

The objectives for the design of this concept, is to have it comprise of as less components as necessary, to reduce maintenance requirements and to keep the cost as low as possible. The spatial constraints on the IS machine meant that only one concept was fully developed as others were eliminated due to these constraints. The concept developed is designed to suit the positioning requirements around the IS machine as discussed in Chapter 3. The suitable position is to locate the bespoke system on the beam located above the IS machine. This would prevent interference with maintenance operations and provide the opportunity for the bespoke system to be relocated across multiple IS machines. The advantage of this design developed, eliminates the need to have multiple automated lubrication systems consuming space for each of the IS machines and therefore reducing additional costs for multiple systems and additional components.

The concept developed is designed to function with the current swab design, when the blank moulds are in the closed position therefore, reducing the degrees of freedom necessary to perform the swabbing procedure. As discussed in Chapter 4, an alternative swab design was developed providing a consistent coverage of lubricant onto the blank mould cavities. A conceptual design was produced for how the alternative swabs could be integrated into the bespoke system.

The final concept developed comprises of two linear drives a horizontal and vertical drive a illustration for this concept is provided in Appendix Q, Figure Q-1. The horizontal drives enables the swabs to reach above the blank mould, ready for lubrication. Additionally the vertical drive enables the swabs to be located into the blank moulds and successfully complete the lubrication process. An additional axis is also included in this design providing
a third degree of freedom. This was established by developing a carriage design which provides a similar function as the current carriage component designed for the existing blank mould lift equipment situation on the IS machine. This design provides the opportunity for the bespoke system to relocate across multiple IS machines. A rack and pinion concept was chosen to automate the third degree of freedom. This is discussed further in this Chapter.

5.2 Component Selection

The brand of components selected for the bespoke system, specifically for the linear drives and motors are Festo components. Festo, are an external supplier to Amcor Glass. Festo have available support software and technical data sheets enabling suitable components to be chosen. External suppliers were sourced for the selection of additional components such as the rack and pinion concept. While for other additional components such as the swab attachment and plate connector, suitable materials and dimensions were chosen to complete the concept design for the bespoke system.

For the linear drives two types are possible for the bespoke design, these are pneumatic drives and electrical drives. Amcor Glass has a readily available supply of compressed air, enabling the IS machines to operate electro-pneumatically. This availability of compressed air provided the option for the linear drives to be purely pneumatic. Pneumatic drives consist of pneumatic cylinders which are able to convert potential energy within a compressed air into kinetic energy. Pneumatic drives are available in a range of stroke lengths suitable for many applications. The advantage of pneumatic drives is they are able to operate in high ambient temperatures of up to 70°C (Festo 2013). There are two types of pneumatic drives available. These are standard pneumatic cylinders that contain a piston rod and rodless cylinders. Rodless cylinders perform identically to a standard pneumatic cylinder but consume less space, this is beneficial in an application where spatial constraints are limited (Festo 2013). However, there are a number of disadvantages when using a pneumatic drive for the swabbing application. The operating conditions around the IS machine are harsh with dirt and oil present on the IS machines, this can lead to contamination in the air leading to potential air blockages and air leaks which could affect the functionality and performance of the pneumatic drive (Festo 2013). As the swabbing procedure must be completed within set timing constraints has set timing constraints, if an air leak is present
this could result in bespoke system failing to complete the swabbing task successfully. This led to the investigation of an alternate driving mechanism, electrical drives. Electrical linear drives are able to provide a similar motion to a pneumatic drive. There are many advantages of electrical drives. Unlike pneumatic drives, electrical drives provide higher precision (Festo 2013) which is necessary for the swabbing procedure to be completed consistently each time.

Additionally unlike pneumatic drives, an electrical drive is able to be positioned anywhere within its length. This could be beneficial for future applications as it will enable the system to be positioned for lubricating, replenishment of lubricant onto the swabs and replacing the swabs. These jobs require the drive to be extended at different lengths, according to the spatial constraints on the IS machine. Furthermore, electrical drives are able to operate within ambient temperatures of up to 60°C (Festo 2013). For these reasons the bespoke system will comprise of electrical drives.

### 5.3 Solution

The design for the bespoke system comprises of four main components: a carriage, horizontal drive, vertical drive and a swab attachment. Information regarding additional components including a connector plate to connect the two drives is also discussed. Discussion of a suitable swab attachment, rack and pinion concept and a suitable concept for the alternative swabs is also provided. The linear drive components and additional swab attachment attach to the carriage allowing the system to travel and function across multiple IS machines.

For the selection of components necessary calculations were performed to confirm that the components are suitable for the bespoke system. This included bending moment calculations for both electrical drives selected. The electrical drives included additionally component selections such as a guide. Appropriate selections were made with reference to the Festo product manuals. Additionally, bolt calculations for necessary attachments onto the bespoke system were completed. Furthermore Finite Element Analysis (FEA) was performed on a simplified structure for the bespoke system to determine the possible stresses and deflection the design is able to operate with. Additional calculations were completed for the selection of a suitable rack and pinion were selected. All these calculations are provided in Appendix Q.
5.3.1 Carriage

The carriage concept is constructed from a welded assembly of steel rectangular hollow sections, consisting of rollers to enable it to travel across the beam located above the IS machine. These dimensions are provided on the drawings developed, shown in Appendix U. As discussed previously the carriage design comprises of a similar design to the existing carriage for the blank mould lift equipment which is shown in Appendix Q, Figure Q-2. The size and dimensions of this carriage were chosen to suit the spatial constraints around the beam above the IS machine as depicted in Figure 5-1.

![Carriage component](image)

Figure 5-1: Carriage position on IS machine.

5.3.2 Swab Attachment

The swab attachment concept is designed to be able hold two swabs set distance apart to that of the blank moulds (Measurements are provided in Appendix Q). The swab attachment must be light weight and able to fit within the spatial constraints of the IS machine. A container constructed of aluminium alloy 6061 is able to operate in the necessary temperature constraints around the IS machine and its density has a density of 2700kg/m³ therefore providing a suitable mass for the swab attachment design (Shigley 2008, p.1022). The container is able to be bolted to the horizontal drive a concept image is provided in Figure 5-2. The swabs are attached to the swab attachment using swab holders. The swab handles are able to be rotated into the holder and locked into place. An illustration of this design is depicted in Figure 5-3 The swab holders would be constructed of a similar aluminium material to suit the required weight requirements for the swab attachment and the dimensions of the holder would be made to suit the swab handle. The swab handles are
able to be modified to suit this design. This design is suitable as it eliminates unnecessary additional tools. Additional swab hold concepts were assessed a description of these is provided in Appendix Q

![Swab attachment design](image)

Figure 5-2: Swab attachment design.

![Swab holder design](image)

Figure 5-3: Swab holder design

### 5.3.3 Horizontal Drive

The electrical drive chosen for the horizontal movement for the bespoke system is the DGEA-25. This drive was selected as it is able to support a mass of up to 20kg and is able to operate at necessary speeds to meet the timing constraints for the swab cycle (Festo 2013). Additionally it is able to operate in ambient temperatures of up to 60°C (Festo 2013). Therefore suitable for the ambient temperatures around the IS machine. The mass of swab attachment mass is estimated to be 10kg, to cater for future alterations and additionally swabbing components. The stroke calculated for this drive is 550mm (see Appendix Q for calculations). This stroke length enables the bespoke system to reach directly above the blank moulds and align the swabs above the moulds ready for lubrication. Additionally the stroke length is sufficient to enable the system to retract to a suitable position when not in operation. Calculations were performed to ensure the horizontal drive is able to operate with the potential bending moments acting on the drive, these are provided in Appendix Q. The largest bending moment that would affect the horizontal drive is caused by the mass of the
swab attachment, which creates a moment of 77Nm. The DGEA-25 drive is able to support a moment in this direction of up to 230Nm, refer to Appendix Q for illustration (Festo 2013). A protective option for the DGEA drive is the IP40. This option prevents dirt build up, ensuring the drive is able to run smoothly. The total mass for the DGEA drive is estimated at approximately 17kg excluding motor attachments (Festo 2013).

5.3.4 Vertical Drive

The type of drive chosen for the vertical movement for the bespoke system is the EGC-120. This drive was selected as it is able to support a mass of up to 75kg and therefore is sufficient to support the mass of both the horizontal drive and swab attachment, which is an estimated combined total of 20kg (see Appendix Q, Table Q-1 for details). Additionally it is able to operate in ambient temperatures of up to 60°C (Festo 2013) Therefore suitable for the ambient temperatures around the IS machine. The stroke calculated is 946mm (see Appendix Q for calculations). This stroke length enables the bespoke system to reach in and above the blank moulds. Additional stroke was incorporated to enable the system to retract away from the blank moulds when the IS machine is in operation. Therefore reducing the temperature exposure when the bespoke system is not in operation. An illustration is provided in Appendix Q. Calculations were performed to assess the potential bending moments acting on the drive. The largest moment that would affect the guide is the bending moment acting in the Z-axis (see Appendix Q for illustration) which is created by the combined mass of the horizontal drive and swab attachment component. This bending moment calculated is 167.41Nm. For the EGC-120 drive type, it is necessary to select a suitable guide which is able to accommodate the bending moments acting on the drive. The appropriate guide selected is the GQ. This guide is able to support a moment in the Z-axis of up to 680Nm. The EGC-120 is also able to comes with a protective option of IP40, which is necessary to prevent dirt build up, ensuring the drive is able to run smoothly (Festo 2013).

5.3.5 Connector Plate

A connector plate was designed to connect and attach the horizontal and vertical drives together. This plate would be constructed of an aluminium material with bolt holes to connect both drives. The Festo electrical drives are designed to be attached using M6 bolts of a suitable length. Necessary bolt calculations including shear stress calculations were
performed to validate if the bolt selection is adequate, these calculations are provided in Appendix Q.

### 5.3.6 Additional Components

Festo electrical drives are available with additional mounting equipment. Suitable EGC-120 profile mounts and foot mounts were selected to attach the vertical drive onto the bespoke carriage design. Calculations were performed, approximating the total weight of the assembled bespoke system to be 50kg, to determine that these profile mounts are able to support the required mass. Appendix Q, Table Q-1 provides the estimated mass calculations for the bespoke system. The overall concept developed in shown in Figure 5-4. A list of the components is provided in drawings found in Appendix U.

![Figure 5-4: Bespoke concept assembly.](image)

### 5.3.7 FEA Analysis

FEA analysis was performed on the completed bespoke system concept. This was completed to determine the potential stresses that would act on the system as it would perform the swabbing procedure. Additionally the deflection caused by forces applied as the system is in operation was also assessed. As the system is to operate at high speeds, there is a concern for possible deflection on components. The electrical drives in the bespoke system comprise of complex shaped components, therefore simplified structures were produced, ensuring the
material properties and dimensions of the simplified model matched that closely to the actual components. The resulting stress acting on both of the horizontal and vertical drives are minimum, whereby the largest approximated stress acting on the system is 18MPa. (see Appendix Q for review). The greatest deflection observed on the horizontal and vertical drive is 0.5mm.

5.4 Third Degree of Freedom

A rack and pinion concept was incorporated into the carriage design to enable the carriage with the attached vertical and horizontal electrical drives with additional components to travel across multiple IS machines. It is possible to integrate a rack onto the beam above the IS machine, by the removal of the current bar located on top of the beam above the IS machine (see Appendix Q, Figure Q-1). A suitable rack and pinion selection was made by performing calculations for the estimated travel time expected to travel to each IS machine to perform the swabbing procedure and the total estimated mass of the bespoke system the rack and pinion is required to transfer. Atlanta rack and pinion data sheets were used to select a suitable rack and pinion concept able to match these requirements. See Appendix Q for necessary calculations. The rack and pinion combination consists of a pinion comprising of 20 teeth with a tooth pitch of 5mm. A concept was developed for a suitable motor holder able to be attached to the carriage to correspond with the rack and pinion concept, an illustration is provided in Figure 5-5. A suitable motor selected is a Festo motor, product model EMMS-AS-70-S-LS-RS which is able to provide the necessary speed in order for the system to travel along. The rack, pinion and motor selection would enable the bespoke system to travel a distance of 9600mm per minute. A prototype would need to be produced to verify these calculations.

![Figure 5-5: Carriage component with additional motor holder for rack and pinion concept.](image)
5.4.1 Alternative Swab Design Integration

The alternative method of lubrication was successfully trialled with no significant defects caused, as discussed in Chapter 4. A suitable concept was developed for this method to integrate the alternative swabs onto the bespoke system.

The design comprises two pulleys and motor connected to the swab attachment with additional shafts for each swab to allow for rotation of the swabs. The motor selected is a pancake motor which is able to accommodate the ambient temperatures and spatial constraints around the IS machine. The motor would be positioned onto the swab attachment, an illustration showing this is provided in Figure 5-6. An assumption for this concept is that there would be cables of a suitable length to enable the function of this motor when the bespoke system both retracted and extended. The pancake motor is chosen specifically for its size consisting of a width of approximately 27mm. The product details for a possible motor are provided in Appendix Q. The pulleys were selected using Naismith product manual. The pulleys would consist of an aluminium material with a diameter of 15mm and width of 25mm suitable for the spatial constraints for the swab attachment. These pulleys are designed for a belt size of 9.3mm. A prototype would need to be produced and tested to verify the functionality of this design.

![Figure 5-6: Motor pulley concept for alternative swab design.](image)
5.5 Performance Analysis

An analysis was completed to verify if the bespoke system concept is able to operate within the system constraints for the swabbing cycle. These are spatial and timing constraints. For the spatial constraints, a 3D model representing the main components was developed for the bespoke system using Autodesk Inventor, this was then inserted into the IS machine 3D CAD model and located into the positions, required to perform the swabbing process. These positions were analysed by identifying if any components for the bespoke system would interfere with the blank side equipment on the IS machine. Drawings for these scenarios are provided in Appendix U.

Timing constraints were analysed using product data sheets for both the electrical drive components and an Festo software program Positioning Drives. A report is produced from the Festo positioning drive software for each of the timing scenarios assessed, this is provided in this Appendix Q.

5.5.1 Spatial

Demonstrated in Appendix Q Figures Q-28 to Q30 are the expected positions required for the bespoke system to reach and lubricate the blank moulds. Detailed drawings for these positions are provided in Appendix U. Evidently there is no major interfaces observed between the IS machine and bespoke system. For position 2, provided in Figure Q-27 the main concern of clearance is between the deflectors and blank mould hook hinge height. Appendix F demonstrates the available clearance for the largest bottle produced being the AG-20, the provided clearance is approximately only 70mm. It is possible to modify the height of the deflectors to allow more clearance if required.

5.5.2 Timing

The timing for which the bespoke system is able to perform the swabbing procedure, was calculated using Festo positioning drives. Additionally this software is able to assist in selecting suitable motors and controllers to match the timing calculations. The motors and controllers selected for the bespoke system are provided in Appendix Q, Table Q-4. The relevant data was inputted including the required stroke length, orientation of the drive and
mass the drive is required to support. The calculations for these are provided in Appendix Q. For Position 1 (see Figure Q-28) to reach Position 2 (see Figure Q-29) the system is lowered underneath the deflectors and this is able to be completed outside of the swab cycle as there is no interferences with machine components in this position. Table 5.1 provides the timing results for the bespoke system to enter into the blank moulds and out of the blank moulds. The total time calculated is 3.4 seconds. It is necessary to conduct trials on how long is required to apply an adequate amount of lubricant onto the blank moulds, this may lead to increasing the time necessary to complete the swabbing process to achieve the correct lubrication coverage onto the blank moulds, this is a future goal for the project.

Table 5.1: Timing measurements for the bespoke system.

<table>
<thead>
<tr>
<th>Position</th>
<th>Description</th>
<th>Drive Orientation</th>
<th>Estimated Stroke</th>
<th>Timing calculated (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Reaching above the blank moulds</td>
<td>Horizontal</td>
<td>400mm</td>
<td>0.825</td>
</tr>
<tr>
<td>3</td>
<td>Above blank moulds to reaching into blank moulds.</td>
<td>Vertical</td>
<td>316mm</td>
<td>0.875</td>
</tr>
<tr>
<td>2</td>
<td>Reaching out of blank moulds to above</td>
<td>Vertical</td>
<td>316mm</td>
<td>0.875</td>
</tr>
<tr>
<td>1</td>
<td>Travelling back to stationary position.</td>
<td>Horizontal</td>
<td>400mm</td>
<td>0.825</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>3.4 seconds</td>
</tr>
</tbody>
</table>

5.6 Conclusion

The bespoke system, presents a possible solution for an automating the swabbing process. The functionality of this design described in this report would need to be verified with the development of a prototype. The calculations performed demonstrated that the bespoke system concept is able operate within the ambient temperatures surrounding the IS machine, restricted spatial limitations machine and the timing constraints within the swab cycle. Additional mitigation strategies such as the use of a fan and motor heat shields would be necessary to ensure this system is able to operate successfully within the ambient temperatures of the IS machine (Festo 2013).
Chapter 5: Bespoke System

As the bespoke system is still in the conceptual stage of design, the function of the bespoke system described, does not eliminate the operator completely from the swabbing task. The operator would still be required to replace the swabs when they are required to be replenished. The current manual swabbing process requires the operator to reach into the machine every 15 minutes. For the replacement of the swab on the bespoke system this would only be required approximately every two hours, therefore reducing the exposure time the operator is exposed to a hazardous environment. This concept does not include the control or safety integration onto the IS machine. The control integration of this system is a future goal of the project and would be completed using a selection of Festo controllers to program the components to match their required function. Chapter 7 discusses the potential safety risks raised for this design and what guarding would be required to minimise the safety hazards for this system.
6 Commercial Off The Shelf (COTS) System

A second concept was developed for automated lubrication system, by selecting a commercial off the shelf (COTS) robot able to operate within environmental constraints on the IS machine. This option was assessed as it may provide Amcor an already built solution, preventing the need to select and integrate a combination of different components to suit. A suitable commercial off the shelf robot was selected in coordination with Robotics and Specialised Machinery Australia (RASM). With the provided system constraints a suitable COTS was selected. The system constraints are temperature, timing, spatial as well as maintenance operation requirements. The 3D CAD model of the IS machine developed assisted in confirming the spatial constraints the COTS is able to operate within. Additionally an extension to the project was a robot simulation was completed by an external company Liquid Robotics to confirm the timing constraints.

6.1 Specifications

There are a number of identified specifications used to select a suitable robot for the swabbing process. These are the payload of the robot, the reach of the robot, speed, repeatability, weight and size. The payload is defined as the maximum mass at which a robot can carry without contributing to a stress on the joints (Sclater & Chironis 2007). The mass of the cotton swabs are approximately 200 grams each, which provides the option to select a
robot with a small payload capacity. The reach of the robot is defined as the maximum length at which all links on the robot extend. It is essential that the robot is able to reach all desired positions or otherwise the swabbing task cannot be completed successfully. Repeatability of a robot is defined as the precision at which a robot is able to obtain (Sclater & Chironis 2007). It is essential that the robot is able to complete the swabbing task consistently each time as inconsistency of lubrication applied to the blank moulds can result in bottle defects. The speed of the robot is defined as the maximum speed at which the robot is able to move all the joints simultaneously (Sclater & Chironis 2007). For the swabbing process, it is necessary that the robot is able to operate within the timing constraints of the swab cycle, any longer then this will affect production rates.

6.2 Investigation and Selection

On the 26th of April, 2013, a visit was arranged with RASM to begin the initial investigation for selecting a suitable robot able to replicate the manual swabbing process. As discussed in Chapter 3, the most suitable position for an automated lubrication system is to locate it on the beam above the IS machine. This position provides the opportunity for the robot to travel across multiple IS machines. RASM work with a number of different robotic companies, a suitable robot selected is an ABB IRB 140 Industrial Robot shown in Appendix R, Figure R-1. This robot was specifically chosen for a number of reasons. Firstly this robot has an additional option of foundry plus protection, this enables the robot to function around high ambient temperatures of up to 100°C (ABB 2013). Additionally the dimensions of the robot are well suited to the spatial constraints on the IS machine. This was confirmed integrating the robot concept into the 3D CAD model developed. Furthermore the robot is able to operate at speeds of up to 2.5m/s (ABB 2013). The timing constraints the robot is able to operate within were confirmed with the completion of a robot simulation. This is detailed in further in this Chapter.

The attachment design for the robot was completed using this estimate whilst ensuring it was able to fit within the spatial limitations. The most suitable concept design developed was to have two rail attachments and then mount the robot on the frame connected to this as shown in Figure 6-1. The frame was designed to suit the required height and reach of the robot, taking into account the robot movement when swabbing the moulds. The next stage of the investigation was to assess how the frame and robot would move along. In
conjunction with RASM a number of linear motion solutions from ABB were investigated, the most suitable solution chosen was to have a servo motor rotating along a rack and pinion as depicted Appendix R, Figure R-2. The rack will be mounted to the support beam as shown in Appendix R, Figure R-2, this solution was chosen as it could be integrated with the ABB robot and would result in reducing programming and installation timing. Final considerations to the concept design were for the location of the accessory items of the system. This included how and where to locate the cables to the robot servo motor, where to locate the lubricant application station, how to attach the swabbing brush to the robot arm and develop a concept for suitable machine guiding.

Figure 6-1: Robot positioning concept (RASM 2013).

The cables are to be run in an energy chain along the inner top surface of the beam/rail. ABB are able to supply special length cables for the robot so that it can traverse the complete 16 stations of the IS machine, as well as flexible cables so that it can fit within the tight space requirements. The final length will be determined on how many stations the robot is able to work on, which is dependent upon the cycle time and operation of the system determined by future robot simulations (RASM 2013). For the robot to successfully apply lubricant to the swabs, the dimensions of the applicator station and the motion that the robot is required to follow in order to achieve the correct of amount of lubricant were examined. Additional space was allocated next to the robot within the frame for the applicator station to be placed. The final method and location is still to be determined which is a future goal of the project. Details of the application details are provided in Appendix A.
The concept for the safety requirements for the robot is based around AS4024 machine safety standards. The robot conforms to all applicable safety standards required for the operation and so the concept design looked at operator work areas and potential interaction with the operators (RASM 2013). Currently the frame will enclose the robot whenever it is traversing between positions. The traversing speed will be minimised so that it reduces the risk of injury to personnel within the work area. Stress calculations would be necessary to verify the suitability of the frame when the robot is travelling across the multiple IS machines, this would be a future goal of the project. Additionally trip sensors would need to be incorporated to meet the required safety standards. This is discussed in relevant detail in Chapter 7. The ABB brand of robot was chosen as this brand has available packages to program the robot in a 3D CAD environment and perform a robot simulation (RASM 2013). The ability robot in a 3D CAD environment allows confirmation therefore determining if the robot is able to perform the swabbing procedure within the provided spatial and timing constraints on the IS machine. The chosen robot was positioned into the 3D CAD model and a robot simulation was completed to determine the suitability of this concept.

6.3 Robot Simulation

The necessary components in order to complete a robot simulation were provided to Liquid Robotics. The components provided included the 3D CAD model of the IS machine and COTS system set-up, measurements of the different bottle heights, and videos demonstrating the available time within the swab cycle. Additionally videos were also provided when the IS machine is performing on the run to assess if it is possible that this COTS selection could perform the swabbing task during the on the run cycle. If the COTS system is able to perform the swab cycle on the run, this would provide Amcor substantial savings as discussed in Chapter 7. Appendix R details the measurements obtained for the blank mould length and timing scenarios.

There were a number of scenarios identified when performing the robot simulation. The first scenario assessed the robot reaching the four blank mould halves individually. It was proposed if the robot was able to successfully lubricate a blank mould half within the timing constraints for on the run cycle, it could lead to the possibility to lubricate each individual blank mould halves over a series of on the run cycles, therefore potentially removing the need for the swab cycle. For the robot simulation the worst case scenario was assessed. The
worst case scenario is defined as lubricating a blank mould half consisting of the longest length, this is approximately 300mm for the AG-20 bottle type. Using video footage of IS machines in operation the approximate time available is 1.5 seconds for the on the run cycle. This time is defined whereby there is no interference with the invert arm and the blank moulds are in the open position.

The robot simulation was completed in the robot simulation software to perform the swabbing task on one IS machine, an illustration for this is provided in Appendix R which is depicted in Figure R-3. Once this is verified, a future goal for the project would be to look at the possibility for the robot to travel across all 16 IS machine. An end attachment for the robot was created for the swab (an illustration of the attachment is provided in Appendix R). The concept is able to reduce the exposure the robot would have inside the IS machine. The swab is able to be constructed at any length or size suitable for the swabbing application. The end attachment would be constructed of an aluminium material to ensure it is light weight for the robot to hold, FEA analysis would need to be undertaken to determine the suitability of the design, this would be a future goal for the project, once the automated lubrication system is finalised.

The results of the robot simulation did not incorporate factors including the integration of the controls for the robot onto the IS machine Futronics system and the safety requirements including sensors and safety guarding. Once the robot simulation results are verified it would be necessary to perform a real life trial for the robot. This would be a future goal for the project.

In the robot simulation, the four blank mould halve were allocated a number to distinguish the different scenarios for the robot, an image provided in Appendix R. Table 6.2 provides the estimated timing results from the robot simulation to lubricate each of the four blank mould halves. The blank mould half presenting the most difficulties for the robot to reach is blank half 4 (see Appendix R, Figure R-5 for illustration). This is the most difficult blank mould half to apply the lubricant as there is the potential interference with the baffle mechanism. The robot simulation was able to demonstrate that each of the blank mould halves could be lubricated within the on the run cycle timing of approximately 1.5 seconds. The second robot simulation demonstrated was to lubricate the blank mould halves within the swab cycle timing constraints. The robot was able to successfully complete this within
approximately 3.2 seconds as depicted in Table. 6-2. A cost and safety analysis was conducted for the COTS system and this is provided in Chapter 7.

Table 6-1: Timing results from robot simulation.

<table>
<thead>
<tr>
<th>Mould Number</th>
<th>Timing (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mould 1</td>
<td>1.2</td>
</tr>
<tr>
<td>Mould 2</td>
<td>1.3</td>
</tr>
<tr>
<td>Mould 3</td>
<td>1.2</td>
</tr>
<tr>
<td>Mould 4</td>
<td>1.3</td>
</tr>
<tr>
<td>Lubricant all four moulds</td>
<td>3.2</td>
</tr>
</tbody>
</table>
7 Feasibility Analysis

For a suitable automated swabbing system to be selected a cost and performance comparison was evaluated. A discussion of relevant safety equipment was also assessed. The system providing higher performance and more suitable costs will be recommended to Amcor Glass. As both systems are in the conceptual stage it is difficult to determine the exact costs for installation, maintenance costs and relevant training costs for each automated lubrication system concept developed. Therefore the cost analysis conducted assessed the cost of the components for each automated lubrication system concept developed. Additionally RASM were able to provide a breakdown cost estimate for the design and development and approximated installation costs for the COTS system concept.

The analysis conducted for the performance assessed only the spatial and timing constraints of both systems at the conceptual stage. This excluded required safety equipment including safety guarding and equipment. The performance and costs calculated were made to assume that the system would be regularly maintained and adequate training performed for each system.

7.1 Cost Analysis

For Amcor to proceed with a suitable automated swabbing system it was important to identify the approximate costs of the each system. If the cost of the system is too high Amcor may need to look at alternative solutions for the project. A feasibility analysis was undertaken to compare the cost of the current manual process and the two automated swabbing systems investigated. Calculations were performed firstly for the manual swabbing process whereby an operator is assumed to earn approximately $26.00 an hour. (Amcor 2013). On average the operator will spend 8 minutes at a time, four times an hour every 15 minutes approximately 24 hours (two shifts of 12 hours) a day multiplied by 330 days a year. For 16 IS machines.

\[
\text{Cost of Operator} = \frac{8 \text{minutes} \times 4}{60} \times 26.00 (\text{per hour}) \times 24 \times 330 = 109,823.99.
\]

Using this estimate a comparison is able to be made between both the bespoke system and COTS system.
A cost break down of the estimated costs to install and use a COTS system was provided by RASM. The cost estimates assumed that the initial COTS system concept is able to be operational and operate across all of the sixteen IS machines. It would be required to perform further robot simulations to verify this possibility, this is a future goal of the project. The cost break down was estimated by approximating the scope of works for the complete installation and functioning of the COTS system, this is provided in Appendix T, Table T-1. The total approximated costs is $170,000 (RASM 2013). The approximated cost for the robot alone came to $45,000, this provides a suitable comparison for the costs estimated when comparing with the bespoke system, as the costs provided for the bespoke system only incorporated the cost of the system alone. Additional costs for the installation and program integration of both systems could be calculated once a selection of a suitable system is finalised. The costs conducted did not incorporate safety equipment and programming requirements this would be finalised when a prototype system is produced.

The combined selection of Festo components provided in Appendix T, Table T-2, provided a total cost of $20,665.00 (Monk 2013). This cost estimate excluded the cost of the swab attachment and carriage component and necessary safety guarding and equipment. Evidently the bespoke system would provide a cheaper alternative for Amcor.
Section 7.2: Safety Analysis

Both the COTS system and bespoke system are still in the conceptual stage of development and a future goal of the project is to design suitable safety guarding for each system to comply with Australian Safety Standards. Referring to the AS4024 a questionnaire for each system to identify potential risks and recommend suitable safety guarding was completed. As the designs are still in the conceptual phase, a number of assumptions were made prior to completing the questionnaire, these are detailed below.

The questionnaire for each system is provided in Appendix S. Both systems presented similar safety risks as it is the introduction of moving machinery which would pose a safety risk for the operators present. Both automated lubrication system concepts would require the operator to enter near the systems to replenish the swabs. This was an assumption incorporated into the safety questionnaire.

- The both systems would be able to move and be controlled with the use of controllers for each of the motors to move the system to a required position. Without a person present when the system is in operation.
- All controllers to operate the automated lubrication system would be located away from device and operated at a distance from the moving equipment.
- All electrical cables and attachments would be ensured to meet the Australian safety standards for both cable covers and cable positioning.
- An operator would only be present near the system when it was not in operation to replace the swabs as required and for maintenance operations.
- The IS machine would match the category of safety if a new robotic device was introduced.

Resulting from the questionnaires, two main hazards identified for the bespoke system and COTS system were mechanical, whereby the mass and velocity of the moving machinery in controlled motion and a thermal hazard whereby if an operator came into contact with the swab attachment.
Section 7.4: Conclusion

To overcome these hazards and other potential risks, the questionnaires provided direction to the type of guarding necessary for both these systems. The type of guarding necessary is a combination of interlocking guards and trip guards. This type of guarding prevents machinery from operating unless the guarding is in place. (Australian Standards 2013) Trip guarding and presence sensing stop the machine when a person gets into a position whereby they are liable to be injured, light curtains are a suitable option for trip guarding (Australian Standards 2013). The integration of suitable safety guarding is a future goal for the project once a final automated lubrication system is selected.

7.3 Performance

There are two main constraints which were assessed to compare the performance of two automated lubrication system concepts developed. The two constraints are spatial and timing. The performance constraints are provided below outlines a comparison for both these constraints.

<table>
<thead>
<tr>
<th>System Type</th>
<th>Timing (seconds)</th>
<th>Degrees of Movement</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>COTS</td>
<td>3.2</td>
<td>7</td>
<td>200kg</td>
</tr>
<tr>
<td>Bespoke</td>
<td>3.4</td>
<td>3</td>
<td>50kg</td>
</tr>
</tbody>
</table>

A comparison for both systems assessed the size and weight. The system consisting of a smaller size and weight would be easier to integrate within the required spatial constraints on the IS machine. It was found that although the COTS system comprised of a heavier mass than the bespoke system, both systems are able to work within the spatial constraints of the IS machine. Additionally the beam above the IS machine is able to support the necessary weight of each of these systems, so these constraints were neglected when selecting a suitable system. (Amcor 2013)

7.4 Conclusion

The bespoke system was chosen to consist of only 3 degrees of movement to provide a simpler and cheaper alternative for Amcor to operate within the swab cycle successfully. The bespoke system if integrated successfully could be complete the swab cycle within 3.4
Section 7.4: Conclusion

seconds. Integration into the CAD model demonstrated that no interferences would occur while performing the swabbing procedure. However, during the investigations of the project it was found the COTS system offered greater flexibly in both timing and movement. A robot simulation performed as discussed in Chapter 6 was able to confirm that the COTS system is able to potentially perform the swabbing process over a series of cycles during the on the run cycle in 1.5 seconds, this option could potentially offer Amcor substantial savings. A cost analysis performed by Kalatzis 2010 (see Appendix T) calculates the potential savings if swabbing is able to be performed during on the run and the swab cycle removed completely. This would provide Amcor savings of up to $500,000.(Kalatzis 2010) Additionally, Amcor wish to use the COTS system for other applications in the bottle forming process.
8 Project Outcomes and Future Work

8.1 Project Outcomes

At commencement of this project, several goals were identified to provide a measurement of the project's success, outlined in Section. All core goals defined have been achieved and the extension goal has also been partially achieved. Details of the achievements with respect to each goal follows.

8.1.1 Design and development of automated swabbing system:

This project successfully demonstrated the feasibility of developing an automated swabbing system to replicate the current process of manual swabbing. Two concepts developed are a bespoke system comprising of individual linear drive components offering a simpler and cheaper alternative to perform the swabbing task. Additionally the selection of a COTS system was also achieved offering more flexibility for available degrees of freedom. Both systems are able to meet the environmental constraints of the IS machine including spatial and temperature constraints. Additionally, calculations were performed to confirm the bespoke system is able to function within the timing constraints in the swab cycle. An extension to the project was the completion of a robot simulation by Boyer 2013, confirm that the COTS was able to perform in the required spatial and timing constraints in the swab cycle.

A cost and performance analysis were undertaken for both systems whereby the bespoke system offered cheaper alternative to the COTS system regarding components necessary to construct the system. However, the COTS system was able to provide higher flexibility in regards to movement and timing. A robot simulation demonstrated that this system could potentially operate during the on the run cycle providing substantial savings for Amcor Glass. Furthermore a relevant safety analysis was undertaken to identify suitable guarding for each system.
8.1.2 Development an alternative method of lubrication

An alternative method of lubrication was trialled successfully, where no significant bottle defects were caused and it provided a more consistent coverage of lubricant than the current swab design. Additionally, a concept design was developed to integrate this lubrication method into the bespoke system. Discussions with RASM confirmed this design could be integrated into a COTS system (RASM 2013).

8.1.3 Research of alternative methods of lubrication (Extension goal)

This goal was partially achieved whereby a successful investigation was completed to look at different concepts of applying lubricant onto the swab to provide a more consistent coverage onto the swab and therefore onto the blank mould cavity.

8.2 Future Work

In order to transition these developments to a fully functioning production unit the following actions are recommended these are divided within the following areas investigated:

**Bespoke System**

- Further research and development concerning:
- Suitable safety equipment to integrate onto the IS machine to meet relevant Australian standards
- Finalising design of components for manufacture and integration of the system.
- Integration of controls onto the IS machine
- Lubricant application onto the blank mould cavity within the timing operations of the bespoke system.

**COTS system:**

- Further testing by completion of robot simulations with the 3D CAD model developed to assess the feasibility of how the robot would work across multiply IS machines
Section 8.2: Future Work

- Further research and develop concerning suitable safety equipment to integrate onto the IS machine
- Complete necessary tests on real life robot on IS training machine to verify timing and movement from robot simulations
- Further research concerning a suitable swab attachment for the end effectors to suit the open blank mould application.
- Further research concerning the integration of controls onto IS machine
- Further research concerning lubricant application within the timing operations of the robot.

Lubrication Method

- Conduct further tests to verify the suitability of the alternative lubrication method developed assessing both wear and bottle defects obtained.
- Further research and develop concerning different swab materials and designs able to last longer than the current swab design and provide a more consistent coverage.
9 Conclusion

This project successfully demonstrates the feasibility of developing a automated lubrication system to replicate the current process of manual swabbing. Two concepts for an automated lubrication system were developed and assessed, a bespoke system comprising of individual electric linear drive components offered potentially a simpler and cheaper alternative to perform the swabbing process. Additionally the selection of a COTS system was also achieved offering more flexibility for available degrees of freedom for movement within the blank moulds. Both systems are able to meet the environmental constraints of the IS machine including spatial and temperature constraints.

The spatial constraints were identified using a CAD model developed by the author for the blank side of the IS machine. Additionally both systems are able to function within the timing constraints of the swab cycle as determined by calculations performed for the bespoke system and a robot simulation demonstrating the timing constraints for the COTS system.

A cost and performance analysis was undertaken for both systems whereby the bespoke system offered cheaper alternative to the COTS system. However, the COTS system was able to provide higher flexibility in regards to movement and timing. Additionally a robot simulation demonstrated that this system could potentially operate during the on the run cycle providing substantial savings for Amcor.

Furthermore a relevant safety analysis was undertaken to identify suitable guarding required for each system. Amcor have chosen to go further with the COTS system as it provided higher flexibility than the bespoke system as discussed above. Future robot simulations trials will be conducted to verify the suitability of this concept. As both designs are still in the conceptual phase, Amcor will use the information provided for the bespoke system to further develop this area of the project. Additionally an alternative method of lubrication was successfully trialled and although the swab costs calculated came at a higher price than the current swab design, this method provided a more consistent application with no significant bottle defects created. Amcor wish to proceed with further investigations into the determining the suitability of these swabs.
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**Invert Arm**: Mechanism on the IS machine which transfers the parisons from the blank side to the mould side of the machine.

**Job Changes**: Change over mould equipment on IS machine to suit changing bottle types being produced.

**Mould gear**: Equipment used in the forming process on the IS machine.

**Mould Side**: Where Mould gear is located on IS machine forming the final bottle shape.

**Neck Rings**: Used to form the finish (thread) of the bottle.

**Narrow Neck Press and Blow (NNPB)**: A separate forming process to that of the blow and blow, this process consists of plungers which force the molten glass to be shaped into the mould gear.

**On the Run**: Whilst the IS machines are in operation and there is no interference with stopping or starting the machine.

**On Site**: On the Amcor site

**Parison**: Glass molten formed by a blank mould, and is then passed to the mould side to form the final shaped bottle.

**Plunger**: Component on blank side of IS machine used to assist in forming parison.

**Swab**: Cotton mop which is used to apply the lubricate to the mould gear.

**Swabbing**: Lubrication of the blank mould gear undertaken by operator.

**Swabbing Bay**: Preparation of lubricant and swab ready for lubrication of blank moulds.

**Wet Swab**: The swab contains too much lubricant.
Appendix A-Lubrication of blank side components

This appendix illustrates the blank-side components on the IS machine that are regularly lubricated; these are the blank mould cavities, baffle mechanism and neckrings. Additionally highlighted is the swabbing sequence for each of the blank mould halves. Included also is a product data sheet of the lubricant used to lubricate these components.

Figure A-1: Demonstration of lubrication for the blank mould cavities.
Figure A-2: Lubrication of baffles with cotton swab (Amcor 2013, p.15)

Figure A-3: Lubrication of neck-rings using cotton swab (Amcor 2013, p.16)

A.2 Swabbing Sequence

The blank mould halves a generally lubricated beginning from the back of the machine to the front as demonstrated in Figures A-4 to A-7. These are labelled to correspond Chapter 6.

Figure A-4: Lubrication of blank mould half 4.
Figure A-5: Lubrication of blank mould half 2.

Figure A-6: Lubrication of blank mould half 1.

Figure A-7: Lubrication of blank mould half 3.
A.3 IS machine Sequence

Provided in this section is an image showing a series of eight IS machines situated together. Figure A-8. Also provided is an image demonstrating the operator reaching into the section to complete the swabbing procedure Figure A-9.

Figure A-8: Series of eight IS machines together.

Figure A-9: Series of sixteen IS machines together.
Figure A-10: Demonstration of operator performing swabbing task.
A.4 Preparation of Swab in Swabbing Bay

Provided below are images demonstrating the process for preparing the swab for ready for blank mould lubrication.

Figure A-11: Preparation of swab into lubricant.

Figure A-12: Wipe off of excess lubricant.
Figure A-13: Swab ready for blank mould lubrication.
Appendix B- Work Break Down Structure

This appendix provides work breakdown structure for the project in Figure B-1. The dashed lines indicate future work for the project.

Figure B-1: Work breakdown structure.
Appendix C- AutoSwab

Provided in this Appendix is an image for the Autoswab as discussed in Chapter 2.

Figure C-1: Autoswab (Brown 2012)

Figure C-2: Autoswab in operation (Brown 2012)
Appendix D- Temperature Analysis

This appendix provides data gathered for temperature of components on the IS machine and the ambient temperatures around the IS machine. Figures D-1 and D-2 show the temperatures the blanks moulds and baffle mechanism can reach up to while in operation.

Figure D-1: Thermal image of blank mould cavities for AG-007.

Figure D-2: Surface temperature of the baffles on the IS machine.

Figure D-3 shows the ambient temperatures measured around the IS machine as shown. This was recorded on the 26th of February at 12:00pm 2013 to the 28th of February 2013 9:10am on line 11, G1 furnace at the Amcor Glass facility. The temperature was measured using a "Easylog USB". A product overview is provided below in Figure D-4.
Figure D-3: Ambient temperature data.

Figure D-4: Product overview for EasyLog Usb (EasyLog 2012)
<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NO.</th>
<th>DESCRIPTION</th>
<th>QTY</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>C1</td>
<td>RRS 50X100 ORICON STEEL</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>C2</td>
<td>SUITABLE ROLLER ATTACHMENT</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>C3</td>
<td>RRS 100X200 ORICON STEEL</td>
<td>1</td>
</tr>
</tbody>
</table>

NOTE:
CONCEPT ONLY
NOTE:
REFER TO FESTO EGC MANUAL FOR
SPECIFIC DIMENSIONS MODEL NUMBER IS:
FESTO EGC-120-946-TB-KF-OH-GQ
NOTE:
PLEASE REFER TO FESTO EGC MANUAL FOR SPECIFIC DIMENSIONS AND MATERIAL SELECTION
NOTE:
CONCEPT ONLY
HOLES TO SUIT M6 BOLTS
MATERIAL IS ALUMINIUM ALLOY 6061
NOTE:
NOT ALL COMPONENTS SHOWN TO DEMONSTRATE
SPATIAL CONSTRAINTS OF INDEPENDENT SECTION MACHINE.
ALL DIMENSIONS ARE IN mm UNLESS OTHERWISE STATED
INDEPENDENT SECTION MACHINE

SIDE VIEW

FRONT VIEW

NOTE:
ALL DIMENSIONS ARE IN mm UNLESS OTHERWISE SPECIFIED
NOTE:
ONLY DIMENSIONS OF SPECIFIC AREAS HAVE BEEN DRAWN
TO DEMONSTRATE THE SPATIAL CONSTRAINTS ON
THE INDEPENDENT SECTION.
NOTE:
ONLY DIMENSIONS OF SPECIFIC AREAS HAVE BEEN DRAWN
TO DEMONSTRATE THE SPATIAL CONSTRAINTS ON
THE INDEPENDENT SECTION.
NOTE: CONCEPT ONLY
MATERIAL IS 6061 ALUMINIUM
NOTE:
CONCEPT ONLY
MATERIAL IS ALUMINIUM ALLOY 6061
ALL DIMENSIONS IN mm UNLESS SPECIFIED

SECTION B-B
SCALE 4:1
NOTE:
CONCEPT ONLY
REFER TO INDIVIDUAL DRAWINGS FOR MATERIAL SELECTION
NOTE:
CONCEPT ONLY

ATTACH USING M6 BOLTS TO SUIT

SWAB ATTACHMENT

FESTO DGEA-25-450-2R-GVL ELECTRIC DRIVE
NOTES:
ATTACH USING M6 BOLTS TO SUIT.
REFER TO FESTO MANUAL FOR EGC AND DGEA FOR SPECIFIC DIMENSIONS OF DRIVE ATTACHMENTS.
REFER TO DRAWING B9 FOR CONNECTOR PLATE DIMENSIONS.
Appendix F-Blank Mould Measurements

This appendix provides the measurements calculated for different bottle type blank moulds. Each blank mould consists of a different hook hinge height as shown in Figure F-1 and Figure F-2. Each of these were measured with provided 2D drawings of a selection of blank moulds used on G1 and G2 IS machines. The height at which the hook hinge height sits affects the access available between the blank moulds and the end of the deflector shown in Figure F-3. Table F-1 presents these findings. Additionally Figure F-4 and F-5 illustrate the defined lubrication area as discussed in Chapter 4, with a Matlab code developed in order to calculate various bottle types using Figure F-4 for defined dimensions.

Figure F-1: Blank mould drawing indicating measurements taken
Figure F-2: Blank mould hook hinge height.

Figure F-3: Deflector to mould hinge base distance
Table F.1: Measurements of available height between deflector and blank mould hook hinge height.

<table>
<thead>
<tr>
<th>Bottle type (G1 and G2 only)</th>
<th>Hook hinge height (mm)</th>
<th>Lubrication height area (mm)</th>
<th>Total length of blank mould (mm)</th>
<th>Height available between deflector (mm)</th>
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<td>AG-057</td>
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<td>AG-061</td>
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<td>400</td>
<td>390.9</td>
<td>387.9</td>
</tr>
</tbody>
</table>
Figure F-4: Defined lubrication area for blank mould.
% Michele Ciccone 25th February 2013
% Surface Area Calculation for 1 Side of Blank mould cavity
% AG-041 C02 Parison Mould Data given below (mm)

d1=58; % diameters of sections on the blank mould cavity
d2=40.02;
d3=37.3;
d4=37.7;
d5=27.7;
d6=27.3;
h1=59.75; % heights of the sections on the blank mould cavity
h2=53.25;
h3=30;
h4=64.5;
h5=30;

SA1 = 0.5*((d1 + d2)/2)*h1*0.5*pi; % surface area calculations in m
SA2=0.5*((d2 + d3)/2)*h2*pi;
SA3=0.5*((d3 + d4)/2)*h3*pi;
surface=(SA1 + SA2 + SA3 + SA4 + SA5)/1000000

Figure F-5: Matlab code for calculation of lubricant area on blank mould cavity
Appendix G Positioning Constraints

This appendix, illustrates the surrounding positions of the IS machine and where a possible automated lubrication system could be placed, this is detailed in Chapter 3.

Figure G-1: Surrounding components around IS machine.

Figure G-2: Beam located above IS machine.
Appendix H-Swabbing Quality

This appendix details the resulting defects that can be caused directly and indirectly by the manual swabbing process. As lubrication can significantly influence product surface quality, a consequence of the manual swabbing process is that the bottle quality is dependent on the experience of the line operator. As a result this can affect the production figures. Incorrect swabbing is defined as when there is too much lubricant applied to the blank moulds, or too little. Both can result in potential defects in bottles. Defects which have been identified to be caused by incorrect swabbing are provided below. The type of defects can be divided into two types, namely: defects created with, too much lubricant applied to the blanks; and defects created because of an insufficient amount of lubricant applied. Insufficient lubrication can occur if the swab is not changed over regularly. (Maun 2012, pers. comm. 18 September) Figure H-1 illustrates some of the swabbing defects.

The result of too much lubricant can result in the following potential defects:

- Heat marks
- Section jam ups
- Slug necks

For blanks coated with insufficient lubricant this can result in the following:

- Load marking
- Heat marks

Incorrect swabbing can lead to uneven temperatures of the blanks can result in the following defects:

- Thin side
- Thin shoulder
- Thin spot
Figure H.1: A selection of swabbing defects (Kalatzis 2010, p. 16)
## Appendix I-Lubrication Amount

This appendix illustrates selected data recorded during a swabbing trial shown in Tables I-1 through to I-3, to determine the approximate quantity of lubricant regularly applied to different bottle types for blank moulds. The trials were undertaken for bottles types, AG-041, AG-066 and AG-102. Each of the bottles consisted of different masses, which were 532g, 418g and 205g respectively.

Table I.1: Quantity of lubricant measured for AG-041.

<table>
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<tr>
<th>Time of swabbing</th>
<th>mass before Use (g)</th>
<th>mass After Use (g)</th>
<th>difference for 4 IS machines (g)</th>
<th>lubricant per IS machine(g)</th>
<th>lubricant per blank half(g) 4 blank halves in section</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.45am Operator 1</td>
<td>272</td>
<td>262</td>
<td>10</td>
<td>2.5</td>
<td>0.625</td>
</tr>
<tr>
<td>10.15am</td>
<td>268</td>
<td>260</td>
<td>8</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>286</td>
<td>272</td>
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<td>16</td>
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<td>1</td>
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<td>216</td>
<td>208</td>
<td>8</td>
<td>2</td>
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<td></td>
<td>216</td>
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<td>2</td>
<td>0.5</td>
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<td>11.45am</td>
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<td>2</td>
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</tr>
<tr>
<td></td>
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Table I.2: Quantity of lubricant measured for AG-066.

<table>
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<th>Time of swabbing</th>
<th>Mass before use (g)</th>
<th>Mass after Use (g)</th>
<th>Difference (g)</th>
<th>Lubricant per IS machine (g)</th>
<th>Lubricant per blank mould half (g)</th>
</tr>
</thead>
<tbody>
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Table I.3: Quantity of lubricant measured for AG-102.

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<th>Mass before use (g)</th>
<th>Mass after use (g)</th>
<th>Difference (g)</th>
<th>Lubricant per Section</th>
<th>Lubricant per Blank mould half (g)</th>
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</thead>
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<td>0.2</td>
</tr>
<tr>
<td>112g</td>
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<td>178</td>
<td>176</td>
<td>2</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>112g</td>
<td></td>
<td>184</td>
<td>182</td>
<td>2</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>112g</td>
<td></td>
<td>182</td>
<td>178</td>
<td>4</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>112g</td>
<td></td>
<td>186</td>
<td>182</td>
<td>4</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>8.45am</td>
<td>112g</td>
<td>186</td>
<td>182</td>
<td>4</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>112g</td>
<td></td>
<td>188</td>
<td>186</td>
<td>2</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>112g</td>
<td></td>
<td>190</td>
<td>186</td>
<td>4</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>112g</td>
<td></td>
<td>190</td>
<td>186</td>
<td>4</td>
<td>0.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Appendix J- Swabbing Frequency

This appendix illustrates selected data recorded during a swabbing trial shown in Table J-1, when varying the swabbing frequency, this was completed on the 20th of February 2013 for the AG-040 type bottle during a colour change on Line 23, G2 furnace. Two different swabbing frequencies were trialled this was for every 10 minutes and 30 minutes with the mass of lubricant a applied also measured a variable during the trial. A visual inspection of these bottles were observed once the swabbing had being completed. As only one operator was able to view the bottles for inspection only a few bottles were observed for defects. During these trials it was found no defects were recorded for swabbing every 30 minutes. Of the trials for the swabbing every 10 minutes consistent bore defects were caused an image of a bottle where this type of defect formed during the trial is provided in Figure J-1, Figure J-2 provides an image for a bottle produced during a swabbing frequency of 30 minutes with no defects present. Further trials would need to be conducted to verify these findings.

Table J-1: Data recorded during swabbing frequency trial.

<table>
<thead>
<tr>
<th>Time Recorded</th>
<th>Swabbing Frequency (Minutes)</th>
<th>Mass of Lubricant per blank half (g)</th>
<th>Defects Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.30am</td>
<td>10</td>
<td>1.3375</td>
<td>Bore</td>
</tr>
<tr>
<td>7.30am</td>
<td>10</td>
<td>1.5</td>
<td>Bore</td>
</tr>
<tr>
<td>7.40am</td>
<td>10</td>
<td>1.25</td>
<td>Bore</td>
</tr>
<tr>
<td>7.40am</td>
<td>10</td>
<td>0.75</td>
<td>Bore</td>
</tr>
<tr>
<td>7.50am</td>
<td>10</td>
<td>1.75</td>
<td>Bore</td>
</tr>
<tr>
<td>7.50am</td>
<td>10</td>
<td>1.375</td>
<td>Bore</td>
</tr>
<tr>
<td>8.00am</td>
<td>10</td>
<td>1.625</td>
<td>Bore</td>
</tr>
<tr>
<td>8.00am</td>
<td>30</td>
<td>1.5</td>
<td>No defect recorded</td>
</tr>
<tr>
<td>8.40am</td>
<td>30</td>
<td>1.375</td>
<td>No defect recorded</td>
</tr>
</tbody>
</table>
Figure J-1: Bore bottle defect for swabbing frequency 10 minutes.

Figure J-2: Bottle observed with no defects for swabbing frequency of 30 minutes.
Appendix K-Alternative Swab

Appendix details the initial trials undertaken for the alternative swab design. Additionally, this appendix illustrates the alternative swab drawings and quote information.

Figure K-1: Application of lubricant as a result of inconsistent amount of lubricant applied alternative swab design.

Figure K-2: Application of lubricant onto alternative swab design.
Figure K-3: New application method of lubricant applied to the swab.

Figure K-4: Resulting application of lubricant onto blank with new method of applying lubricant to swab

Figure K-5: Graph displaying the amount of lubricant relative to the speed of the drill
Appendix L-XPAR Measurements

This appendix provides the detail for the five different zones on measured on a bottle for defects, using the XPAR system. The five zones, are finish, neck shoulder, body and bottom shown in Figure L-1.

![Zones defined on bottle](image)

Figure L-1: Zones defined on bottle.

The XPAR system will identify defects on bottles divided in these sections. Figures L-2 to Figure L-5 are examples of bottles rejected during the trial of the alternative lubrication method. Table L-1 provides a description of each the defects recorded.

<table>
<thead>
<tr>
<th>Defect Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical total</td>
<td>Uneven should heights identified on bottle</td>
</tr>
<tr>
<td>DG intensity</td>
<td>Uneven distribution of glass thickness</td>
</tr>
<tr>
<td>Defect body</td>
<td>Uneven distribution of glass thickness</td>
</tr>
</tbody>
</table>
Uneven height distribution is an indication of vertical total.

Figure L-2: Vertical total defect identified on XPAR for AG-007 bottle.

Possible effect by swabbing.
Figure L-3: DG intensity 3 defect identified on X-PAR.

Figure L-4: Defect body defect for AG045 bottle type.
Appendix N Management System Defect Identification

This appendix provides a selection of common bottle defects identified on the management system at Amcor Glass, during the trials undertaken for the alternative lubrication method developed. These defects are caused indirectly by swabbing with associated descriptions provided.

Table N.1: Selection of bottle defects identified on management system (Amcor 2013).

<table>
<thead>
<tr>
<th>Defect Number</th>
<th>Defect Name</th>
<th>Description</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>Check under ring</td>
<td>A crack which occurs on or near the neck ring parting line, below the finish.</td>
<td>Checks can be mechanical or thermal in nature. A check finish suggest that the glass is not releasing from the mould equipment or that excessive heat is being drawn from the glass. Swabbing is an indirect cause.</td>
</tr>
<tr>
<td>82</td>
<td>Thin shoulder</td>
<td>The container has an area of glass in the shoulder which is not thick enough to enable it to fulfil the purpose for which it is designed.</td>
<td>Generally a thermal defect caused by uneven glass or blank temperatures. Swabbing is an indirect cause.</td>
</tr>
<tr>
<td>83</td>
<td>Thin side</td>
<td>The container has an area of glass in the sidewall which is not thick enough to enable it to fulfil the purpose for which it is designed.</td>
<td>Generally a thermal defect caused by uneven glass or blank temperatures. Swabbing is an indirect cause.</td>
</tr>
<tr>
<td>121</td>
<td>Undersize bore</td>
<td>The bore at entry is less than the specified diameter.</td>
<td>Glass inside the finish has not been blown away as expected by the counterblow leaving the inside diameter undersized. Normally indicates too much heat has been taken out of the glass before counterblow is activated. Swabbing is an indirect cause.</td>
</tr>
<tr>
<td>501</td>
<td>Vertical Total Status</td>
<td>Error reading on</td>
<td>Not applicable.</td>
</tr>
</tbody>
</table>
management system,
when bottles are
recounted
Appendix O-Alternative Swab Wear

This appendix illustrates the alternative swab wear after the swab was trialled to the equivalent to the current swab being used for a period of two hours, shown in Figure O-1. The wear of the swab is minimum and still provided a sufficient coverage of lubricant onto the blank mould cavity as shown Figure O-2.

Figure O-1: Wear of swab after trials were performed on the hot mould.

Figure O-2: Resulting lubricant application using worn swab.
Appendix P - Alternative Lubrication Applications

This appendix provides a discussion of concepts developed for providing an effective method of applying lubricant onto the swab. The current lubricant used for manual swabbing Kleenmold 170 comprises of a viscosity of 2500-4000 cps at 40°C (Linke 2013, pers. comm. 19th March).

An application method was investigated in conjunction with Lube Control. Because of the graphite content in the lubricant this lubrication devices were investigated. A concept was to have the brush be contained in a container with surrounding nozzles to apply the essential amount of lubricant onto the swab. A sketch is provided below. The device discussed is an oil injector, able to inject precise increments of lubricant onto a medium. (Linke 2013, pers. comm 19th March). The injector would function with controlled air consumption determining the necessary pressure to inject single shots of a precise amount of lubricant onto the swab. A possible product to perform this process is the PurgeX Spray Inject Pump. Comprising of a reservoir where the lubricant would be contained. As it is a graphite based lubricant, the reservoir would need to be continuously stirred to prevent graphite build up in the bottom of the container. The solenoid valve would be controlled electro-pneumatically allowing precise injections of lubricant onto the swab, therefore ready for lubrication. The estimated cost for this system can range to about $10,000 depending on how developed the system (Linke 2013, pers. comm 19th March).
Figure P-1: PurgeX Spray Injector Pump (Lube Control 2013)

Figure P-2: Application of lubricant onto swab concept.
Appendix Q- Bespoke System Design and Calculations

This appendix includes a detailed assessment and calculations performed to design the overall bespoke system conceptual design. The bespoke system consists of four components, a carriage, vertical drive, horizontal drive and swab attachment. Relevant information and calculations necessary for each of these components are provided in this appendix.

![Figure Q-1: Concept for bespoke system.](image)

Carriage Component

The carriage concept is constructed from a welded assembly of steel rectangular hollow sections, consisting of rollers to enable it to travel across the beam located above the IS machine. These dimensions are provided on the drawings developed, shown in Appendix U, and were chosen from One Steel’s standard size chart. As discussed previously the carriage design comprises of a similar design to the existing carriage for the blank mould lift equipment which is shown in Figure Q-2.
Figure Q-2: Carriage component on current lift equipment on IS machine.

![Rollers]

Figure Q-3: Bespoke system carriage design concept.

**Horizontal Drive**

To determine a suitable stroke length for the DGEA-25 electrical drive, using the 3D CAD model developed of the IS machine shown in Figure Q-4, measurements were taken to determine the horizontal reach to reach into the blank moulds. There is a set distance between the centre of the blank moulds to the centre of the carriage. The swab attachment was designed to contain two of the swabs, reducing the stroke required for this linear drive. The length from the centre of the furthest mould to the centre of the carriage was approximately 1050mm. The calculated stroke length for the DGEA-25 was completed
using the product manual guide, Figure Q-5 below demonstrates the dimensions of the drive. It was necessary to first determine the length of the slide on the drive which is 487.5mm (L1).

Figure Q-4: A selection of IS machine dimensions.
Stroke Calculation

\[
\text{Required Stroke Length} = 766 - \left(\frac{1}{2}\right) (\text{Length of Slide})
\]

\[
\text{Required Stroke Length} = 766 - \left(\frac{1}{2}\right) 487.5 = 522.25 \text{mm}
\]

A chosen stroke length of 550mm was chosen to accommodate any extra movement required for the drive.

Moment Calculation

Moment calculations were performed to determine if the DGEA drive slide is able to support the necessary swab attachment mass. Using the product manual, provided in Figure Q-6 are permissible forces and torques this drive can withstand. It was found the moment that would have the worst impact on the drive would be the mass of the swab when the drive is in its most extended position moment \( M_y \). The moment \( M_z \) would only be affected if the system was knocked by an operator—this was therefore neglected from the calculations. Moment \( M_x \) would be the affected by the motor placed on the drive.
Figure Q-6: Permissible forces and torques the DGEA drive can withstand (Festo 2013).

My moment (Static)

\[ F = 10\, \text{kg} \times 9.81\, \text{m/s}^2 = 98.1\, \text{N} \]

\[ My = F \times d \]

\[ My = 98.1 \times 0.029375 \times 0.79375 \, (1/2\, \text{of carriage + stroke length}) \]

\[ My = 77\, \text{Nm} \]

The worst case moment for My is when the drive is in its most extended position.

The 25 size DGEA is able to support a moment of 230Nm and is therefore sufficiently strong.

Mx moment (Static)

The worst case moment for Mx is when the motor is attached. The approximate weight of the motor is 3kg.

\[ F = 3\, \text{kg} \times 9.81\, \text{m/s}^2 = 29.43\, \text{N} \]

\[ Mx = F \times d \, (0.029\, \text{mm}) \]

\[ Mx = 29.43 \times 0.029 = 0.85\, \text{Nm} \]
The DGEA drive size 25 is able to support a moment of 0.85Nm so this size is sufficient.

**Weight Calculation**

The approximated weights for the components were selected using the product manual for the DGEA-25. The total weight for the DGEA drive type including the swab attachment would be approximated using the equation below:

\[
\text{Weight} = \text{swab attachment} + \text{drive} + \text{motor} = 10 + 7.5 + 3 = 21.5\text{kg}
\]

**Vertical Drive**

To determine a suitable stroke length for the EGC-120 electrical drive, using the 3D CAD model developed of the IS machine (see Figure Q-4), measurements were taken to determine the vertical height necessary to reach into the blank moulds. This measurement is approximately 920mm. Incorporating the carriage component design, the available height for when the drive is positioned onto the edge of the carriage is 563mm see Figure Q-4. Before the stroke could be calculated it was necessary to select a suitable slide for the drive to be able to accommodate the environmental elements of the IS machine. The guide selected is the GQ extended and protected guide. Shown in Figure Q-7, demonstrates the dimensions of the EGC-120 drive selected. To calculate the stroke it is necessary to determine the length of the guide on the drive which is 335mm (L10).
Figure Q-7: Selected dimensions of EGC-120 drive (Festo 2013).

**Stroke Calculation**

The required length determined for the drive is 946mm, necessary to reach into the blank moulds.

**Moment Calculations**

Moment calculations were performed to determine if the EGC-120 drive slide is able to support the necessary horizontal drive and swab attachment mass. Provided in Q-8 are the permissible forces and torques this drive can withstand. The moment that would have the worst impact on the drive would be the mass of the horizontal drive, when the horizontal drive is in its most extended position, moment Mz. The moment My and Mx would only be affected if the system was knocked by an operator these were therefore neglected from the calculations.
Figure Q-8: Permissible forces and torques the EGC-120 drive can operate in (Festo 2013).

**Mz moment (Static)**

![Diagram of horizontal drive](image)

The worst case static moment is when the horizontal drive is in its most extended position. The approximate mass of the horizontal drive is 21.5 kg. This is the mass of the whole drive but was taken as being at the end of the drive as this would provide the worst case scenario.

\[
F = 21.5 \text{ kg} \times 9.81 \text{ m/s}^2 = 210.915 \text{ N}
\]

\[
M_z = F \times d
\]

\[
M_z = 210.915 \times 0.79375 \text{ (1/2 of carriage + stroke length)}
\]

\[
M_z = 167.41 \text{ Nm}
\]

Therefore the 120 EGC size is suitable for a Mz of 680 Nm with the extended slide. This moment would be counteracted with the positioning of a motor as demonstrated in drawing.
Swab Holder Development

Provided in Figure Q-9 below are the different concepts assessed to be able to hold the swab on the swab attachment. The most suitable design developed was to have holder consist of one component with a key hole design to insert the swab into place and have it locked. This simplified design eliminates the time required for the operator to insert the swab and no required tightness of doing up a thread is required. This design is also suitable for wear. Thread and ball bearing operations were discussed but these were eliminated as they had the potential to wear over time. A prototype would have to be produced to verify the functionality of the swab holder design.

![Swab Holder Concepts](image)

Figure Q-9: Swab holder concepts developed.

Connector Plate Design

A connector plate was designed to enable the attachment for the horizontal drive to the vertical drive. The dimensions for the plate were designed using the guide dimensions of each of horizontal and vertical drive provided in each of the product manuals.
Components Chosen and Estimated Mass of Bespoke System

Provided in Table Q-1, is the estimated mass of the bespoke system. These values were calculated using the product manual guides provided in further in the this Appendix and the estimated swab attachment mass of 10kg.

Table Q.1: Estimated mass for bespoke System

<table>
<thead>
<tr>
<th>Component Chosen</th>
<th>Weight Approximate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toothed b. axis EGC-120-946-TB-GQ</td>
<td>26.69kg</td>
</tr>
<tr>
<td>Servo motor EMMS-AS-100-S-HS-RSB</td>
<td>3kg</td>
</tr>
<tr>
<td>Cantilever axis DGEA-25-550-ZR</td>
<td>7.5kg</td>
</tr>
<tr>
<td>EMMS-AS-70-S-LS-RS</td>
<td>3kg</td>
</tr>
<tr>
<td>Swab Attachment</td>
<td>10kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>50kg</strong></td>
</tr>
</tbody>
</table>

Bolt Calculations

Provided below is the necessary bolt calculations performed to confirm the bolt selection for the connecting the electric two drives of the bespoke system. Festo components are designed to fit M6 bolts. The calculations below confirm this selection.
Bolts Connecting to Horizontal Drive

Figure Q-11 and Q012 indicates the bolts locations to attach to the horizontal drive. From left to right is bolts A, B, top to bottom bolts C, D. Calculations were performed using (Shigley 2008, p. 425)

Assumptions
Assume swab Attachment, total weight is 10kg

Assume Motor mass is 3kg

Mass of the drive horizontal excluding attachments is 7kg

Assume worst case resultant force of combined masses is 21.5kg x 9.81 = 210.9N

Therefore now calculating the total moment around the bolts;

\[ \therefore \text{Moment} = F \times d \]

\[ \therefore \text{Moment} = 210N \times 0.794 = 167.467Nm \]

Vertical Shear Force;

\[ \therefore \text{Each bolt withstands a vertical shear force of; } \]

\[ F_{\text{shear}} = \frac{F_r}{4} \]

\[ F_{\text{shear}} = \frac{210}{4} = 52.5N \text{ per bolt} \]

Distance from centroid to center of each bolt is;

\[ r = \sqrt{10^2 + 20^2} = 22.36mm \]

Secondary shear forces are on the bolts are;

all four are equal as each bolt is the same distance from the centroid

\[ F'' = \frac{Mr}{4r^2} = \frac{167.46 \times \frac{22.36mm}{4 \times 22.36^2mm}} = 1872N \]

Using a scaled diagram and adding the resultant forces of each of the bolts this came to;
Figure Q-13: Resultant force diagram for forces exerted on bolts.

Using a scaled diagram (Figure Q-13 not to scale) and adding the resultant forces of each of the bolts this came to approximately;

\[ F_A = F_C = 1900 \text{N} \]
\[ F_B = F_D = 1700 \text{N} \]

Bolts A and C will hold the largest shear load

Shear Area; is As

Smallest diameter where the greatest shear force occurs for an M6 bolt is;

20.1mm\(^2\) (Shigley 2008,p.425)

Therefore the maximum shear stress in each bolt is;

\[ \tau = \frac{F}{A_s} = \frac{1900}{20.1 \text{mm}^2} = 94.53 \text{MPa} \]

Bearing Stress per bolt;

\[ \sigma = \frac{F}{(td)} = \frac{1900}{(10 \text{mm} \times 6 \text{mm})} = 31.66 \text{MPa} \]
Therefore selection M6 bolts of a grade 12.9 have a minimum tensile stress of $1220 \times 10^6$Pa (Shigley 2008,p.425) which is more than adequate for the connection of the two drives.

**Bolts Connecting to Vertical Drive**

Assume swab Attachment, total weight is 10kg

Motor mass is 3kg

Mass of the drive horizontal excluding attachments is 7kg

Assume worst case resultant force above of $21.5 \times 9.81 = 210.9$N

**Therefore now calculating the total moment around the bolts;**

\[
\therefore \text{Moment} = F \times d
\]

\[
\therefore \text{Moment} = 210 \times 0.794 = 167.467 \text{Nm}
\]

**Vertical Shear Force:**
Each bolt withstands a vertical shear force of;

\[ F'_{\text{shear}} = \frac{F_r}{4} \]

\[ F'_{\text{shear}} = \frac{210}{4} = 52.5 \text{N per bolt} \]

Distance from centroid to centre of each bolt is;

\[ r = \sqrt{10^2 + 40^2} = 41.23 \text{mm} \]

Secondary shear forces are on the bolts are;

all four are equal as each bolt is the same distance from the centroid

\[ F'' = \frac{Mr}{4r^2} = \frac{167.46 \times 41.23 \text{mm}}{4 \times 41.23^2 \text{mm}} = 1015 \text{N} \]

Figure Q-15: Resultant force diagram for forces exerted on bolts.

Using a scaled diagram Figure L-16 (not to scale) and adding the resultant forces of each of the bolts this came to approximately;

\[ F_A = F_C = 1015 \text{N} \]

\[ F_B = F_D = 900 \text{N} \]

Bolts A and C will hold the largest shear load
Shear Area; is As

Smallest diameter where the greatest shear force occurs for an M6 bolt is;

20.1mm² (Shigley 2008,p.425)

Therefore the maximum shear stress in each bolt is;

\[ \tau = \frac{F}{A_s} = \frac{1015}{20.1mm^2} = 50.49\text{MPa} \]

Bearing Stress per bolt;

\[ \sigma = \frac{F}{(td)} = \frac{1015}{10\text{mm} \times 6\text{mm}} = 16.92\text{MPa} \]

Therefore selection M6 bolts of a grade 12.9 have a minimum tensile stress of 1220 x 10⁶Pa which is more than adequate for the connection of the two drives.

Figure Q-16: Connector plate depicting secondary bolt connections onto vertical drive.
Assume swab Attachment, total weight is 10kg

Motor mass is 3kg

Mass of the drive horizontal excluding attachments is 7kg

Assume worst case resultant force above of 21.5kg x 9.81= 210.9N

Therefore now calculating the total moment around the bolts;

\[ \therefore \text{Moment} = F \times d \]

\[ \therefore \text{Moment} = 210\text{N} \times 0.794 = 167.467\text{Nm} \]

Vertical Shear Force:

Each bolt withstands a vertical shear force of;

\[ F'_{\text{shear}} = F_r / 4 \]

\[ F'_{\text{shear}} = 210 / 4 = 52.5\text{N per bolt} \]

Distance from centroid to center of each bolt is;

\[ r = \sqrt{10^2 + 80^2} = 80.62\text{mm} \]

Secondary shear forces are on the bolts are;

all four are equal as each bolt is the same distance from the centroid

\[ F'' = \frac{Mr}{4r^2} = \frac{167.46 \times 80.62\text{mm}}{4 \times 80.62^2\text{mm}} = 520\text{N} \]
Using a scaled diagram and adding the resultant forces of each of the bolts this came to;

\[ F_A = F_C = 520\, \text{N} \]
\[ F_B = F_D = 400\, \text{N} \]

Bolts A and C will hold the largest shear load

Shear Area; is \( A_s \)

Smallest diameter where the greatest shear force occurs for an M6 bolt is;

20.1mm² (Shigley 2008, p. 425)

Therefore the maximum shear stress in each bolt is;

\[ \tau = \frac{F}{A_s} = \frac{520}{20.1\, \text{mm}^2} = 25.87\, \text{MPa} \]

Bearing Stress per bolt;

\[ \sigma = \frac{F}{(td)} = \frac{520}{(10\, \text{mm} \times 6\, \text{mm})} = 8.62\, \text{MPa} \]
Therefore selection M6 bolts of a grade 12.9 have a minimum tensile stress of $1220 \times 10^6$ Pa which is more than adequate for the connection of the two drives.

**Profile and Foot Mount Selection**

The use of profile mount and a foot mount were selected to hold up the bespoke system for the EGC-120 onto the carriage component concept. Details of these are provided in the product manual guide for the EGC-120. These are designed to hold M8 bolts which can withstand a shear stress of up to 1220MPa for grade 12.9 (Shigley 2008,p.425). The plate thickness for the carriage component was chosen to be 6mm so the force at which these bolts would exposed to is;

Bearing Stress per bolt;

$$\sigma = \frac{F}{(td)} = \frac{F}{(6\text{mm} \times 8\text{mm})} = 1220\text{MPa}$$

$$F = 57,000N$$

The total mass of the bespoke system is approximately 50kg, these bolts are adequate to support the mass of the bespoke system.
Deflection Calculations

To determine if deflection would impact on the drives, using Finite Element Analysis in SolidWorks 2012 a simplified model of the bespoke system was constructed. Because of the complexity of the Festo components it would be difficult to accurately determine the stress and deflection, therefore the drives were constructed as rectangular tubes to match the dimensions of the drive and estimated material properties applied to them, which closely represented the material of the drives. The material of the drives was approximated to be an aluminium material Aluminium alloy 6061. The material chosen for the carriage comprised of carbon steel. The components were fixed at the required ends and an approximated force was applied at the end of the drive which represented the swab attachment. The swab attachment has an estimated mass of approximately 10kg. The mesh chosen for this FEA analysis was fine curvature based to reduce large changes in the mesh sizes from being adjacent to one another which can result in large singularities this was due to sharp corners (Kurowski 2012).

The first analysis conducted was the effect of the swab attachment located at the end of the horizontal drive in its most extended position (static). A force of 100N was approximated for this the swab attachment and applied at the end of the drive. It was identified that the stress on the simplified structure was minimal as evidently seen in Figure Q-18 a stress of Only singularities were identified and therefore these could be neglected. Evidently the deflection was also minimal whereby the maximum deflection was 0.5mm as provided in Figure Q-19.
Figure Q-18: FEA for simplified bespoke system.
The second analysis undertaken was looking at when the system shifted across to another IS section specifically for the vertical drive. The force estimated is 450N representing the total mass of the both the electrical drives and swab attachment representing the worst case scenario. Evidently in Figure Q-20 we can see that is there is minimal stresses applied to the system whereby the maximum force applied is 30.8MPa. As shown in Figure Q-21 the main stress applied to the carriage were where singularity points were identified. The deflection was also analysed it was shown the deflection created would be 0.3mm (see Figure Q-22).
Figure Q-20: FEA for simplified bespoke system.

Figure Q-21: Stress on carriage component.
The third analysis undertaken was looking at when the system shifted across to another IS section specifically for the horizontal drive. The force chosen was 200N representing the total mass of horizontal drive approximated to 20kg; this would represent the worst case scenario. Evidently in Figure Q-23 we can see that there is minimal stresses applied to the system whereby the maximum force applied is 18MPa. As shown in Figure Q-23 the main stress applied was to the carriage of the system whereby singularity points were identified. The deflection was also analysed it was shown the deflection created would be 0.8mm (see Figure Q-24).
Figure Q-23: Stress on bespoke system.
Figure Q-24: Deflection analysis on bespoke system.
Timing Calculations

Once the drives were selected it was essential to calculate the timing to confirm these drives were able to perform the swabbing task. Festo has available software Festo *positioning drives* to calculate the potential timing a drive as able to perform a stroke. A report is produced from the Festo positioning drive software for each of the timing scenarios assessed, this is provided further in this Appendix.

**Vertical Drive**

Inputting the necessary stroke data, mass requirements and time requirements a timing positioning graph was produced this is provided in Figure Q-25. The maximum acceleration the EGC-120 is able to perform is $50 \text{m/s}^2$. The acceleration in the software was able to be changed for different values providing different timing outputs. The higher the acceleration the higher the percentage of usage of the motor, slide and drive this would therefore decrease the service life. It was found with an acceleration of $8 \text{m/s}^2$ provided a time of 0.825 seconds including dwell time.

<table>
<thead>
<tr>
<th>Table Q.2: Data input for timing calculations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
</tr>
<tr>
<td>Stroke Length</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Orientation</td>
</tr>
</tbody>
</table>

Q-27
Figure Q-25: Acceleration time profile indicating timing results of simulation (Festo 2013).

Horizontal Drive

Figure Q-26: Bespoke system in stationary position.

Inputting the necessary stroke data, mass requirements and time requirements a timing positioning graph was produced this is provided in Figure Q-27. The required stroke to move the swabs to above the mould using the CAD model from the stationary position was
approximately 350mm. 400mm was inputted at the moving stroke to compensate. The maximum acceleration the DGEA is able to perform is 50m/s². The acceleration in the software was able to be changed for different values providing different timing outputs. The higher the acceleration the higher the percentage of usage of the motor, slide and drive this would therefore decrease the service life. It was found with an acceleration of 5m/s² provided a time of 0.825 seconds including dwell time.

Table Q.3: Data for horizontal drive timing calculations.

<table>
<thead>
<tr>
<th>Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke Length</td>
<td>400mm</td>
</tr>
<tr>
<td>Mass</td>
<td>10kg</td>
</tr>
<tr>
<td>Orientation</td>
<td>Horizontal</td>
</tr>
</tbody>
</table>

Figure Q-27: Acceleration time profile indicating timing results of simulation (Festo 2013)
Figure Q-28: Position 1 side view, system in stationary position.

Figure Q-29: Position 2 side view. Swabs above moulds ready to lubricate.
Motor and Controller Selection

The motor and controller selection was made using the Festo positioning drives software. Additionally, the positioning of the motors were selected using both the EGC and DGEA product manual guides. Positioning of these motors are provided in the drawings for the bespoke system Appendix U.

Table Q.4: Motor and controller selection for the bespoke system.

<table>
<thead>
<tr>
<th>Drive Type</th>
<th>Motor</th>
<th>Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGEA-25 (Horizontal drive)</td>
<td>Servo motor EMMS-AS-70-S-LS-RS</td>
<td>Motor control. CMMP-AS-C5-3A-M3</td>
</tr>
</tbody>
</table>
Rack and Pinion Selection

To enable the bespoke system to travel across each of the IS machines, a rack and pinion concept was developed. It was possible to replace the bar on the beam of the IS machine as indicated in with a rack to allow the system to travel along.

Given

<table>
<thead>
<tr>
<th>Operation Type</th>
<th>Travelling Across</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass to be Moved</td>
<td>50kg</td>
</tr>
<tr>
<td>Speed</td>
<td>1m/s</td>
</tr>
<tr>
<td>Acceleration Time</td>
<td>1 second</td>
</tr>
<tr>
<td>Acceleration Due to Gravity (g)</td>
<td>9.81 m/s²</td>
</tr>
<tr>
<td>Coefficient of Friction (μ)</td>
<td>0.1</td>
</tr>
<tr>
<td>Load Factor (KA)</td>
<td>1.5</td>
</tr>
<tr>
<td>Life-Time Factor (fₙ)</td>
<td>1.05</td>
</tr>
<tr>
<td>Safety Coefficient (Sₙ)</td>
<td>1.2</td>
</tr>
<tr>
<td>Linear Load Distribution Factor (LKHₙ)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Calculation Process Results

\[ a = \frac{v}{t} = \frac{1 \text{m/s}}{1 \text{s}} = 1 \text{m/s}^2 \]

\[ Fu = mg + ma \]

\[ Fu = 50 \times 9.81 \times 0.1 + 50 \times 1 = 99.5 \text{N} \]

Assumed feed force: rack C₄₅, ind. hardened, straight tooth, module 3, pinion 16MnCr₅, case hardened, 20 teeth, page ZB-40 with \( F_{\text{utab}} = 11.5 \text{ kN} \) provided in Appendix

\[ Fu_{\text{zul./per.}} = F_{\text{utab}/K_A \times S_b \times f_n \times L_{khb}} \]

\[ Fu_{\text{zul./per.}} = 11.5 / 1.5 \times 1.2 \times 1.05 \times 1.5 \]

\[ Fu_{\text{zul./per.}} = 4.06 \text{kN} \]

Therefore checking condition;

\[ Fu_{\text{zul./per.}} > Fu ; 4.05 \text{kN} > 99.5 \text{N} = > \text{fulfilled} \]

Therefore a suitable rack and pinion is the;
Motor Selection

Provided below is a calculation to determine the motor speed necessary to transport the bespoke system.

Assume motor can operate at 80RPM

Number of teeth on pinion selected: 20 teeth

Pitch of pinion teeth selected is 6mm (Atlanta 2013).

Therefore;

\[ \text{RPM} \times 20 \text{ teeth} = 1600 \]

\[ \therefore \text{Distance Travelled} = 1600 \times 6\text{mm} = 9600\text{mm per minute} \]

A suitable motor selection is the Festo EMMS-AS-70-S-LS-RS.
Appendix R-COTS System

This appendix illustrates a selection images from the COTS system investigation.

Figure R-1: Robot dimensions (ABB, 2013)
Figure R-2: Rail and carriage concept for robot. (RASM 2013)

Table R.1: Data measurements necessary for robot simulation.

<table>
<thead>
<tr>
<th>Bottle Type (Long or short)</th>
<th>Bottle Type</th>
<th>Hook Hinge Height (mm)</th>
<th>Swab Height (mm)</th>
<th>Total Length of Blank (mm)</th>
<th>Height Available between deflector (mm)</th>
<th>Approximate Timing for Moulds open (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>AG-071</td>
<td>54.1</td>
<td>272.5</td>
<td>287.9</td>
<td>360.6</td>
<td>2</td>
</tr>
<tr>
<td>Long</td>
<td>AG-020</td>
<td>46.8</td>
<td>259.25</td>
<td>299</td>
<td>367.9</td>
<td>2</td>
</tr>
<tr>
<td>Long</td>
<td>AG-007</td>
<td>22.2</td>
<td>208.25</td>
<td>256.5</td>
<td>392.5</td>
<td>1.88</td>
</tr>
<tr>
<td>Long</td>
<td>AG-045</td>
<td>19.2</td>
<td>211.915</td>
<td>253</td>
<td>395.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Short</td>
<td>AG-124</td>
<td>128</td>
<td>190</td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
Figure R-3: Robot Simulation (Boyer 2013)

R-4: Concept end attachment. (Boyer 2013)
Figure R-5: Position of blank mould halves
Appendix S- Safety Questionnaire

Presented in this appendix is the safety questionnaires undertaken for both the bespoke and COTS system with necessary assumptions. Both questionnaires presented were identical for the bespoke and COTS system. Overall similar guarding is required for both to ensure they run in a safe operation.

Assumptions

- The both systems would be able to move and be controlled with the use of controllers for each of the motors to move the system to a required position. Without a person present when the system is in operation.

- All controllers would be away from device and operated at a distance from the moving equipment.

- All electrical cables and attachments would be ensured to meet the Australian safety standards for both cable covers and cable positioning.

- An operator would only be present near the system when it was not in operation to replace the swabs as required or for maintenance operations.

- The Independent section machine would match the category of safety if a new robotic device was introduced.

Safety Questionnaire for Bespoke System (Australian Standards 2013)

Are there hazards present?
Yes, both mechanical and thermal hazards.

Is access required during use?
Yes, for the replacement of brushes

Can access to the danger zone be totally prohibited?
No, continuous maintenance is needed to ensure the IS machines run smoothly

Is access required only for setting process correction or maintenance?
Yes, replenishment of brushes and maintenance operations performed on the IS machine.

**Is access required more than once a shift?**
Yes, for the replenishment of brushes and lubricant

**Does opening the guard cause no hazard to cease before access?**
Yes

Suitable Guarding is movable guard with interlocking device and a control guard

---

**Safety Questionnaire for COTS System (Australian Standards 2013)**

**Are there hazards present?**
Yes, both mechanical and thermal hazards

**Is access required during use?**
Yes, for the replacement of brushes

**Can access to the danger zone be totally prohibited?**
No

**Is access required only for setting process correction or maintenance?**
Yes

**Is access required more than once a shift?**
Yes, for the replenishment of brushes and lubricant

**Does opening the guard cause no hazard to cease before access?**
Yes

Suitable Guarding is movable guard with interlocking device and a control guard
Appendix T-Cost Analysis

Presented in this appendix is the costs research undertaken for the project. This includes a calculation performed by Kalatzis 2010, it provides a cost benefit analysis for removing the swab cycle from production. Additionally included is the cost breakdown quote for the estimated cost of the COTS system provided by RASM and a list of components which were provided to Festo for a total cost estimate of $20,665.00.

Cost Analysis-Removing Swab Cycle

AMCOR produces bottles 24 hours a day, a single machine cycle takes 6.6 seconds and on average the machines are swabbed every 15 minutes. Thus the loss of production time due to swabbing cycles during a day for a single section is:

4 (swabs per hour) x 24 = 96

96 cycles x 6.6 seconds = 633.6 seconds per day = 0.176 hours per day

So for a whole year:

688.5 x 365 = 231264 seconds per year = 64.24 hours per year

Thus if the IS machines are in constant operation for a year 64.24 hours are spend on swab cycles. In reality the IS machine will not be in constant operation for an entire year as down time is required for job changes and maintenance.

231264 seconds per year/6.6 seconds per cycle = 35040 cycles per year

Now two bottles are made every cycle.

35040 x 2 = 70080 bottles

Thus if the swab cycle is eliminated 70080 additional bottles may be manufactured each year by a single section, each machine has 16 sections and furnaces G1 and G2 have two machines each, thus there are a total of 64 sections in operation.

70080 x 64 = 4485120 bottles
Thus furnaces G1 and G2 would be capable of producing an additional 4485120 bottles per year if the swab cycle was eliminated. It can be conservatively assumed that at least 30% of these bottles would be of suitable quality to supply to a customer. An average price per bottle is 38 cents.

4485120 bottles x 30% x $0.38 = $511 303.68

Thus the elimination of the swab cycle alone would produce an additional $500 000 per year across four IS machines.

**Cost Estimate for COTS System**

Table T.1: Cost estimate breakdown for design and implementation of COTS system

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation and Research</td>
<td>$5000.00</td>
</tr>
<tr>
<td>Machine Safety and Risk Assessment</td>
<td>$2500.00</td>
</tr>
<tr>
<td>Electrical Design and Drawings</td>
<td>$7500.00</td>
</tr>
<tr>
<td>Mechanical Design and Drawings</td>
<td>10,000.00</td>
</tr>
<tr>
<td>Electrical Components and Cabinet Build</td>
<td>5000.00</td>
</tr>
<tr>
<td>Pneumatic Components and Cabinet Build</td>
<td>5000.00</td>
</tr>
<tr>
<td>Safety System Components</td>
<td>10,000.00</td>
</tr>
<tr>
<td>Robot Purchase</td>
<td>45,000.00</td>
</tr>
<tr>
<td>Mechanical Components and Fabrication</td>
<td>10,000.00</td>
</tr>
<tr>
<td>Electrical Wiring and Materials</td>
<td>2500.00</td>
</tr>
<tr>
<td>Pneumatic Assembly and Materials</td>
<td>2500.00</td>
</tr>
<tr>
<td>Mechanical Assembly and Materials</td>
<td>7500.00</td>
</tr>
<tr>
<td>Machine Programming</td>
<td>10,000</td>
</tr>
<tr>
<td>Initial Set-up and Testing (Before Delivery)</td>
<td>2500</td>
</tr>
<tr>
<td>Machine Commissioning (Before Delivery)</td>
<td>2500</td>
</tr>
<tr>
<td>Delivery of Machine to Site</td>
<td>2500</td>
</tr>
<tr>
<td>Site Installation and Materials</td>
<td>5000.0</td>
</tr>
<tr>
<td>Site Commissioning</td>
<td>5000</td>
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<tr>
<td>Site Travel Expenses</td>
<td>5000</td>
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<tr>
<td>Project Management</td>
<td>15000</td>
</tr>
<tr>
<td>Documentation Manuals</td>
<td>5000</td>
</tr>
</tbody>
</table>
### Component Breakdown for Bespoke System

Table T-2 shows the components selected for the bespoke system. This was provided to Festo and a cost estimate was produced $20,665.00 excluding GST.

Table T.2: Table of supplied components for Festo for cost estimate (Monk 2013).

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Quantity</th>
<th>Article designation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>556815</td>
<td>1</td>
<td>Toothed b. axis EGC-120-946-TB-GQ</td>
<td>EGC-120-946-TB-GQ</td>
</tr>
<tr>
<td>552194</td>
<td>1</td>
<td>Gear unit EMGA-80-P-G3-SAS-100</td>
<td>EMGA-80-P-G3-SAS-100</td>
</tr>
<tr>
<td>550124</td>
<td>1</td>
<td>Servo motor EMMS-AS-100-S-HS-RSB</td>
<td>EMMS-AS-100-S-HS-RSB</td>
</tr>
<tr>
<td>558323</td>
<td>1</td>
<td>Foot mounting HPE-120</td>
<td>HPE-120</td>
</tr>
<tr>
<td>558044</td>
<td>2</td>
<td>Profile mounting. MUE-120/185</td>
<td>MUE-120/185</td>
</tr>
<tr>
<td>195612</td>
<td>1</td>
<td>Cantilever axis DGEA-25-550-ZR</td>
<td>DGEA-25-550-ZR</td>
</tr>
<tr>
<td>550114</td>
<td>1</td>
<td>Servo motor EMMS-AS-70-S-LS-RS</td>
<td>EMMS-AS-70-S-LS-RS</td>
</tr>
<tr>
<td>550311</td>
<td>2</td>
<td>Motor cable NEBM-M23G6-E-10-N-LE7</td>
<td>NEBM-M23G6-E-10-N-LE7</td>
</tr>
<tr>
<td>550319</td>
<td>2</td>
<td>Encoder cable NEBM-M12W8-E-10-N-S1G15</td>
<td>NEBM-M12W8-E-10-N-S1G15</td>
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<tr>
<td>1501326</td>
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<tr>
<td>Code</td>
<td>Quantity</td>
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<tr>
<td>1501330</td>
<td>2</td>
<td>Safety module CAMC-G-S1</td>
<td>CAMC-G-S1</td>
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<tr>
<td>552254</td>
<td>2</td>
<td>Control cable NEBC-S1G25-K-2.5N-LE26</td>
<td>NEBC-S1G25-K-2.5N-LE26</td>
</tr>
</tbody>
</table>
Appendix V Project Costs

All project funding is provided by Amcor Glass, provided below are expenses incurred to date for the project:

- $6,886.00 for the initial investigation of the COTS system in conjunction with RASM. The official quote for this has been provided in this Appendix.

- $1013.36 for the manufacture of the new swab design. Six brushes were manufactured. The official quote for this has been provided in this Appendix.

- $6,050 for the robot simulation performed by Liquid Robotics the official quote for this is been provided in this Appendix.

- Also, approximately 600 hours have been logged by the author during this project. At $26 an hour this would have cost AMCOR an additional $15,600.

- The Thus the total project cost would have been $29,551.