

Optimization of Screw Cap Process for E & J Gallo Winery

By

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Executive Summary

This project takes a microscopic look at all raw material, machinery, and practices that effect the screw cap process of wine products in order to highlight and eliminate the causes of defects. The approach for this project involves the analysis of process capability for raw material to achieve its required dimensions. This project also displays methods of attaining appropriate machinery settings, and provides a basis for operating standards. Many quality engineering applications are used throughout this study, revealing the decision process for analyzing said applications.

The studies in this project found uncontrolled dimensions in the suppliers' caps and bottles and a present need for adjusted operational standards and machinery settings. A variance of nearly 21% was witnessed during operator setup on the machinery and a method for operator improvement was implemented. This project provides methods to eliminate defects in order to better meet Six Sigma quality standards.

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Introduction

This project takes a microscopic look at the process of screw cap bottling of wine products. This undertaking sheds light on various, commonly found issues throughout the joining of cap to bottle. Recently E&J Gallo winery has experienced many screw cap issues such as cut caps, broken and/or collapsed bridges, and other various defects.

These issues can be attributed to many different sources: caps, glass bottles, the capper, or a combination of the aforementioned sources. E&J Gallo aspires to determine a specific setting on the capper that will suit all screw cap products among all bottling lines with the capability of applying said caps. This project aims to ensure that all cap measurements, glass bottle measurements, and capper settings will produce a quality product, free from defects.

To resolve capping issues, many studies must first be conducted. One must take a precise look at the materials (caps and bottles) to ensure all measurements meet the necessary specifications. If they are not, corrective actions must be taken to obtain materials that are suitable for the capping process. Once all material issues are solved, capper operator ability must be analyzed. A statistical test must be conducted to ensure that capper setup by a trained operator is repeatable and reproducible. If the setup procedure is not concluded to be repeatable and reproducible, a new method for setup must be established to guarantee proper capper setup.

Subsequent to the operator capability study, a new study must be conducted to determine the proper settings and tolerances that are suitable for the capper to produce a flawless product. Once ideal settings and tolerances are established, these settings must be studied to determine whether they will fit a large array of various caps and bottles designed for screw cap application.

Upon completion of this study, E&J Gallo will be tendered a document and analysis recommending changes to materials, setup procedures and techniques, and capper settings. Plans for an operator training routine will also be developed. Lastly, a report analyzing common defects and usual solutions will be delivered.

Project Objectives

As previously stated, this project aims to optimize the screw cap process at E & J Gallo Winery. Because many defects have been witnessed, this project aims to highlight all potential causes of these defects. All sources that factor into the screw capping process will be critically analyzed to determine if any process outliers exist.

This project will peer into all raw material characteristics, machinery, supplementary sub assemblies, and line operators that can have an impact in the screw capping process. The ultimate goal of this project is to determine all causes of defects, and recommend appropriate methods of correction. To do this, samples of caps and bottles will be taken and each dimension will be measured to see if it meets the specified standards and tolerance. Next, an assessment of capper settings will be conducted to determine if the current running settings are appropriate. Finally, a study measuring the repeatability of the capper setup is to be conducted.

Findings of this project will be taken to management for their consideration. This project will conclude with a detailed explanation of each cause of defect, and a recommendation on how to correct the situation. A defect-free process is extremely difficult to create, but by eliminating all causes of defects, the process will be much closer to perfection aside from natural variation.

Background

Before the technicalities of this project are discussed, one must first understand the materials and machinery involved and all significant measurements and attributes of each. The key materials involved in the screw cap process are aluminum caps and glass bottles. The piece of machinery that mates the screw caps to the bottle is a Zalkin Capper.

Screw Cap Functionality

Screw caps must be strong and enduring enough to last for decades, and easy enough to be quickly and effortlessly removed. The screw cap must present the liner in a correct position for sealing. It must also mold to the bottle while holding the liner in place. Finally the cap must provide threads that enfold the bottle while providing adequate space for removal.

The standard cap that is studied in this project is 30 millimeters in diameter and 60 millimeters in height (30x60). The cap must seal at three different places: cap liner to bottle top, cap sides to bottle thread, and cap skirt to the bottle tuck (normally referred to as the “pilfer”).

The caps used in this project consist of 8011 Aluminum Alloy, and range from 0.20 to 0.23 millimeters in thickness. Prior to bottling, the caps are typically stored in a warehouse that ranges in temperature from 32° F to 104°F with humidity ranging from 30% to 75%.

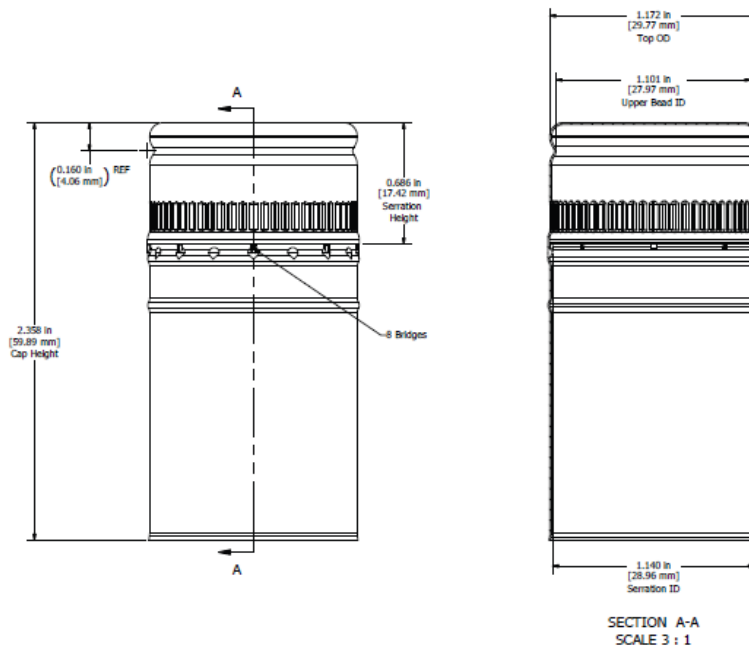


Figure 1: Cap Measurement Locations

Screw Cap Liner

A cap liner is a non-permeable entity that functions to prevent liquid leakage and oxygen ingress. The presence of the liner adds a complicated part into the capping process. An average liner is about 2 millimeters thick and must be compressed to about half its original size to ensure a proper seal with the bottle. Characteristics of density largely come into play when compressibility is concerned. If the liner is not dense enough, it may be more prone to permeation. Needless to say, the liner plays a vital role in bottling.

Bottle

If the bottle is not made within an extremely detailed specification, it would be nearly impossible to create a quality product. Flaws in caps are rare and can easily be corrected however bottles leave much room for imperfections. Flaws found in bottles are extremely complex to fix. The screw cap process needs a bottle of a higher quality standard than a typical cork mouth bottle.

Screw cap and cork mouth bottles only differ from the neck area to the top (or the upper quarter of the bottle). Both bottles are made under a complex process. A blob of a molten combination of sand and glass is continuously pushed out of a furnace onto a slide. This blob follows a path into a mold. Once in the mold, the blobs of the molten mixture are hydraulically secured. Air is then pumped into the mold to expand the glass to the walls of the mold. Another clamp then comes down and shapes the neck in specified detail. The bottle's shape is finalized and then released from the mold, allowed to cool and then pushed onto a conveyor belt with the other bottles. Each bottle is sprayed with a coating before it comes to rest in storage.

Many significant measurements on the bottles come into play when aiming for a flawless product. This project focuses on two specific bottle shapes: 7345 and 7255 (See Appendices 5 and 6). This project closely scrutinizes measurements in the bottles that are likely to cause common defects if they are out of the predetermined tolerance range. The three main defects that occur in the caps are collapsed bridges, broken bridges, and cut caps. Each defect can be attributed to specific measurements in the glass. Collapsed bridges can be caused by inaccuracies in the K Dimension, Neck Taper, or Bottle Height (See Appendix B). Broken bridges can be attributed to inaccuracies in the K Dimension, Neck Taper, T Dimension, or E Dimension (See Appendix B). Cut caps can be caused by many different sources, primarily by inaccuracies in the A1 Dimension, N Dimension, D Dimension, D Angle, and Bottle Height (See Appendix B). If any of the aforementioned dimensions are found to be out of their appropriate tolerance range, then recommendations seeking correction will aptly be made.

Another significant aspect of the bottle is the thread. Thread commonly varies in location, protrusion, and roundness. Proper thread structure is crucial for accurate cap location and functionality. Bottle thread inconsistency cannot be tolerated during the bottling process due to its

critical impact. In addition the rim above the thread is significant in providing an area for the liner to rest and cause a sufficient seal along the bottle's surface.

Bead angle is vital in preventing the entire cap from slipping off breaking any bridges upon removal. The bead is located just below the thread. Typically cap manufacturers aim for a tucked angle to be anywhere from 12° to 15° . Anything more than 12° to 15° may lead to loose caps. If the cap is not secured tightly enough at this position many other issues may occur as well. On the other hand, if the cap is secured too tightly at this position, cuts in the cap may appear during application.

The neck diameter of the bottle must be extremely precise to allow the cap to sit at an appropriate height on the bottle. The neck diameter is measured at 60 millimeters from the top of the bottle. It should be about the same diameter as the cap inner diameter. If it is too large, the cap may sit too high on the bottle for accurate application. If it is too small however, the cap may sit askew on top of the bottle and may be subjected to a misaligned finish.

Lastly, bottle concentricity and height must be carefully controlled to ensure that the cap meets the bottle at the desired location. Concentricity correlates with the vertical digression or perpendicularity of the bottle. If a bottle does not sit straight, there may be cuts in the sleeve and improper liner seals. Height is not likely to cause a huge issue unless it is grossly out of control. Typically the capper can adjust to accommodate different heights to a certain extent.

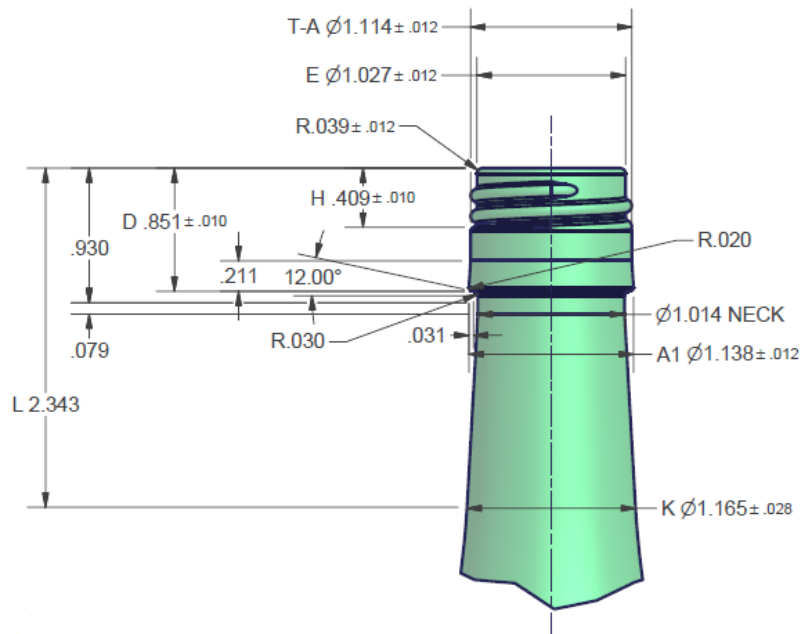


Figure 2: Locations of Bottle Measurements

Capping Process

The critical last step of capping is the application of the cap to the bottle. Once the cap is aligned on top of the bottle, a capper head grasps the bottle head and completes a four-step process. First, the liner is compressed to the bottle surface by a pressure block. Second, the pressure block continues to travel down the bottle, drawing the outer edge closer to the bottle (known as the redraw). Next, a set of rollers spin down the side of the bottle, forming the aluminum sides in between the threads of the bottle. Lastly, another set of rollers create a tuck underneath the thread of the bottle to prepare the bottom skirt for eventual removal. This is commonly referred to as the pilfer.

The amount the liner is compressed to the top surface is mainly attributed to the head pressure setting. An average liner is about 2 millimeters thick and should be compressed to about 1 millimeter. The manufacturer of the capper used by Gallo (Zalkin) suggests a head pressure setting of 160 ± 20 kilograms.

While the pressure block is compressing the liner and inducing a reform, the thread and tuck rollers are forming the aluminum side of the cap to the appropriate bottle positions. This is accomplished by a spinning motion around the cap. It is vital to set the roller pressure to a setting that will provide a strong seal, but not too strong as to damage the cap. If the pressure is too high, consumers may have difficulty removing the caps from the bottle and cuts may occur on the surface of the cap. On the other hand, if the pressure is too low, the cap may not form a secure seal to the bottle. Heights of the rollers should be carefully aligned to the bottle as well. If a roller is misaligned the effectiveness and integrity of the cap may be completely void. Zalkin recommends a thread roller pressure setting of 11 to 12 kilograms and a tuck roller setting of 7 to 10 kilograms.

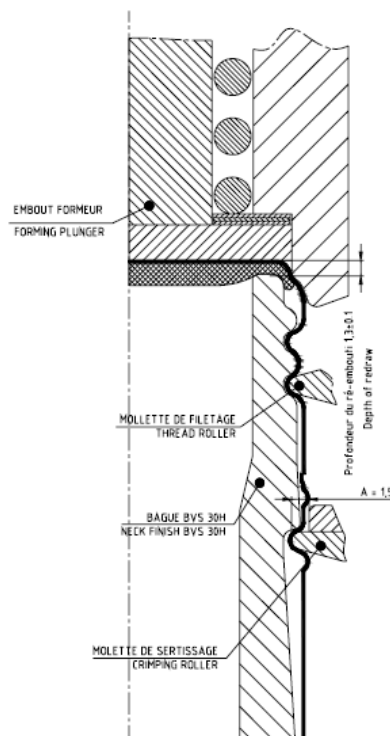


Figure 3: A Zoomed in View of the Capping Process

Another main aspect of capping is the line speed. The appropriate line speed is dependent upon the amount of capper heads present. The rotary capper used by Gallo contains 10 heads.

Zalkin suggests a speed of 1500 caps per head per hour. If the speed is too high, defects are likely to occur.

Overview of Theoretical and Experimental Literature

For this portion of the project, research was primarily divided between text references. Valuable information can be attained in numerous texts. One such text is entirely focused on the process of screw capping, as it covers the process from top to bottom. This project has also been influenced by the many studies of statistical quality control in a manufacturing setting.

Additional research will be conducted in literature measuring statistical quality control impact on industrial costs and economics associated with engineering change orders along with inventory control systems. These sources may highlight barriers hindering a most effective solution. Furthermore, focus will be spent on facets of Manufacturing Organizations because of its significance to the manufacturing field.

Screw Capping Process

The screw capping process is discussed in more detail in the 'Background' section of this report. Screw caps must be strong and enduring enough to last for decades, and easy enough to be quickly and effortlessly removed. The critical step of capping is the application of the cap to the bottle. When the cap is positioned on top of the bottle, a capper head seizes the bottle head and follows a four-step process. The liner is compressed to the bottle surface by a pressure block then the pressure block continues to travel down the bottle, forming the upper edge of the cap to the bottle. Next, a set of rollers rotate down the side of the bottle, forming the aluminum sides in between the threads of the bottle. Lastly, another set of rollers create a tuck underneath the thread of the bottle to prepare the bottom skirt for eventual removal.

As the pressure block is compressing the liner and causing a reform, the thread and tuck rollers are forming the aluminum side of the cap to the appropriate bottle positions. This is accomplished by a spinning motion around the cap. It is vital to set the roller pressure to a setting that will provide a strong seal, but not too strong as to damage the cap. If the pressure is too high, consumers may have difficulty removing the caps from the bottle and cuts may occur on the surface of the cap. On the other hand, if the pressure is too low, the cap may not form a secure seal to the bottle. Heights of the rollers should be carefully aligned to the bottle as well. If a roller is misaligned the effectiveness and integrity of the cap may be completely void.

To effectively troubleshoot the screw capping process, a detailed understanding of the process itself is crucial. Not only did this project set out to maximize the process efficiency, it seeks to work in conjunction with capper operators and stakeholders in this project.

Quality Engineering

A diverse amount of statistical quality practices are witnessed among manufacturing environments. Recently, a surging trend called Six-Sigma has entered into the manufacturing world. Six-Sigma is a business management strategy developed in 1986 by Motorola. It aims to improve the quality of process outputs by detecting and eliminating the sources of the defects and reducing process variation. Under six-sigma quality, the probability that any specific process output unit is non-defective is 0.9999998, or equivalent to 0.2 defective parts per million. However, if a process reaches the six-sigma quality level, a process mean can witness disturbances that could potentially shift it 1.5 standard deviations off target. Assuming the aforementioned scenario is true, a six-sigma process would produce 3.4 defective parts per million produced (Montgomery, 2009). These are the quality standards used by E&J Gallo Winery.

This project uses a five step problem solving process known as Define, Measure, Analyze, Improve, and Control (DMAIC). The DMAIC process methodologies were heavily influence by statistician, Charles Deming's Plan-Do-Check-Act cycle. DMAIC utilizes control charts, designed experiments, process capability analysis, and many other statistical tools.

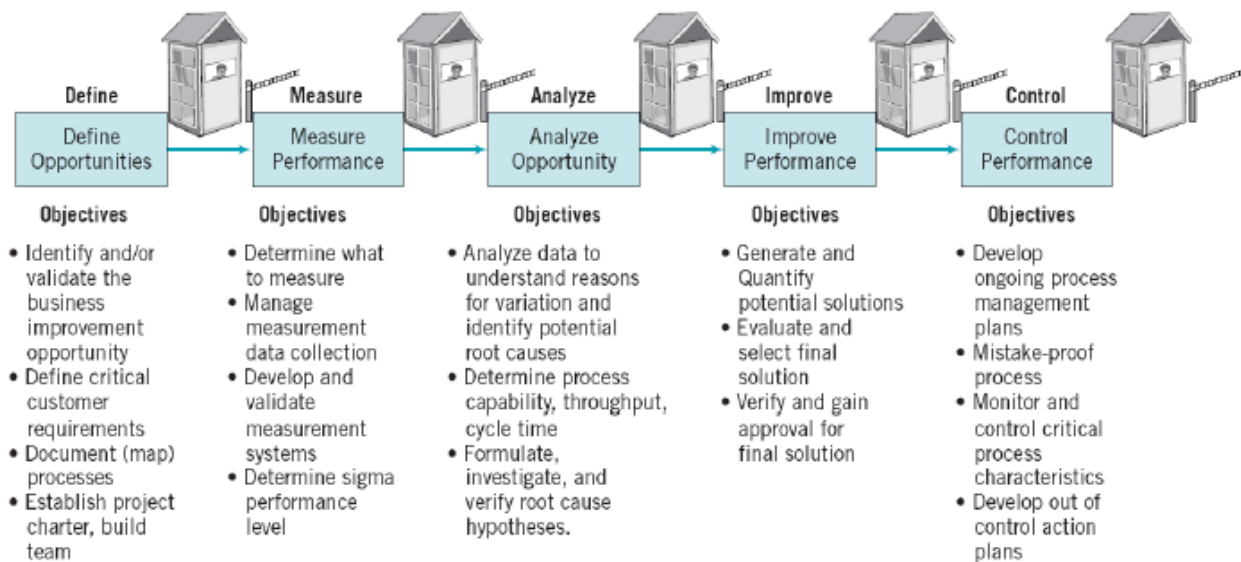


Figure 4: The DMAIC Process

To understand the current performance of the capping process, a sampling of finished output was conducted. Sampling is the procedure involving the selection of a group of individual observations within a population of individuals with the goal to reveal data about the population as a whole. It is generally used to make a statistical assumption of the population.

In this project, the understanding of the quality of a population was done through a Two Sample T-Test. A Two Sample T-Test statistically compares the responses between two populations. The null hypothesis states that the two population means are equal to each other, whereas the alternative hypothesis states otherwise. This is a focus of concern for this project because two types of material sources that are assumed functionally identical are compared to determine if they are interchangeable in the capping process.

Each sample measurement is also compared to its control chart, to determine whether or not the output is statistically in control according to its control limits. This project intends to remove all assignable variability from the screw cap process, or variability caused by a change in the process by operators, defective raw material, environment, machinery, or other assignable causes.

An analysis of process capability (C_p) for each measurement can determine whether or not a dimension of a cap or bottle is in its required functional range. A process capability determines the ability of the process to produce output within its specification limits. A process capability index (C_{pk}) is also analyzed to view how capable the process is of producing the process target within the specification limits.

The last statistical tool used in the project is a Gage R&R. A Gage R&R is a test that reveals the repeatability and reproducibility (R&R) of a process. One is able to determine the percentage of variation that is caused by a particular measurement system. A Gage R&R study also reveals measurements within and between operators as well as evaluates the reliability of the measurement device. Traditionally 10% variation is acceptable, 10-30% variation is marginable based on the environment, and variation greater than 30% must be corrected (Harding & Ketron, 2009).

Engineering for statistical quality plays a crucial role in this project. A true sense of understanding of the process at hand would be impossible without the use of statistical quality control.

Engineering Economic Analysis

Engineering economic analysis focuses on costs, revenues, and benefits that occur under different scenarios. Engineering economics is the division of economics that deals with solving complex problems which are a mixture of economic, political, and humanistic elements (Newman

and Eschenbach 2009). Possible benefits in this project come from many vast sources. If the variation in the process of screw capping is greatly reduced, significant savings will be found in wasted material reductions, operational efficiency, and customer satisfaction.

The most apparent savings possibility in this project will be that of lowering the process's scrap rate. Fixed costs are constant or unchanging regardless of the level of output or activity. Variable costs are costs that depend on the level of output. A marginal cost is the variable cost for one additional unit, while the average cost is the total cost divided by the number of units (Newman and Eschenbach 2009). This project aims to reduce the average cost by ultimately seeking out the lowest possible variable cost while still meeting the customer's demand.

An opportunity cost is associated with using a resource in one activity instead of another. E & J Gallo Winery could have accepted the current running performance of their screw capping process; however it was determined to be financially justified to use resources to reduce process variation and waste. Financial savings will be witness through the limitation of nonrecurring costs of operational output defects. Nonrecurring costs are one-of-a-kind expenses that occur at irregular intervals and this are sometimes difficult to plan for or anticipate from a budgeting perspective (Newman and Eschenbach 2009).

The engineering economic literature also touches on ethics in engineering. Ethics in this situation pertain to how data was collected and how honestly the decision-making process was performed. An engineering change can have many effects on a company's well being, both good and bad. A new technique can revolutionize a manufacturing process, but if it is not carefully and effectively intertwined with the employees of the company, detrimental results can be found in the workplace overall demeanor. The overall goal of this project is to ultimately alleviate operational issues in the screw capping process, and in doing so, positively effect all those involved with it.

Manufacturing Organizations

A large part of this project deals with interacting with and alongside other company members. These members include bottling line operators, quality assurance members, engineering staff, as well as management. It is vital to work alongside every member to ensure a common goal and to prevent the disruption of standard practices. Team members must agree on strategic and tactical decisions to successfully accomplish the goal at hand. Strategic decisions are defined as decisions that set the direction for the entire company (Reid and Sanders, 2009). These decisions are generally broad in scope and long-term in nature. Tactical decisions are those that are generally short term and specific in nature (Reid and Sanders, 2009). Typically, these are bound by the strategic decisions.

When conducting experiments that include human subjects, it is always essential to follow a strict code of ethics. It is essential for each subject to be knowledgeable of the study's purposes, as well as consenting to the study's requirements. Understanding testing guidelines for using humans as test subjects is important to the effectiveness of the study.

Design and Methods

The design section of this project aims to define the problem at hand, objective, existing condition of the problem, alternatives, and the determined path for a solution. The design section will also contain practices of quality engineering and its constraints. This section is extremely significant to the report because it takes the reader through the thought process of tackling various issues that were witnessed in the capping process due to its intricacy. Methods of testing are also discussed in this section. A deeper understanding of the testing design and practices will be had when the thought process and experimental procedure are viewed in the same context.

Objective

E & J Gallo Winery has experienced many screw cap issues such as cut caps, broken and/or collapsed bridges, and other various defects. The objective of this project is to highlight the causes of these defects from a material standpoint as well as an organizational standpoint. This project aims to ensure that all cap measurements, glass bottle measurements, and capper settings will produce a quality product, free from defects. Most importantly this project will shed light into why such problems occur and how they can be prevented in the future.

Before concluding a final solution to screw cap defects, many steps must first be taken. Firstly, all materials (caps and glass bottles) must be scrutinized and deemed suitable for application. The caps and bottles must contain precise correlating dimensions in order to be effectively formed to one another. Once it is known that the cap and bottle specifications correctly correlate to each other, samples of the caps and bottles must be taken to determine the variation and process capability of each dimension. Next, the machine center that joins a cap to a bottle (capper) must be carefully set to ensure a proper finish. Lastly, any outside forces that may have an impact on this

process, such as upstream subassemblies and line speed, must be identified and deemed appropriate for the process as a whole.

Material Dimensions and Correlation

Before sample measurements of caps and bottles are taken to ensure accuracy, the technical drawings of the associated caps and bottles must be analyzed to verify that the dimensions are appropriate for application. Once the specifications are accepted, a Failure Mode and Effects Analysis (FMEA) is to be conducted on caps, bottles, and the capper. An FMEA document highlights all possible causes of defects, moreover emphasizing their severity to the process, probability of occurring, and likelihood of detection. The document will then weigh the effect of each defect and rank it based on its impact to the process as a whole.

Caps

Two different suppliers' caps are used in this study, G3 30x60 caps and Erben 30x60 caps. The dimensions of these caps vary slightly, but are still appropriate for application to the bottles (See Appendices C & D). The potential dimensions of each cap that may cause defects of concern are: inner diameter of cap bottom, inner diameter at cap serration, serration height, cap height, bridge width, serration cut quality, hardness, liner thickness, liner density, specification differences by suppliers, and material tensile strength.

Samples of each cap were taken, and each dimension was measured to see how it compares to the specified dimension. Each measured dimension was compared to the specified dimension through a Two-Sample T-Test and its desired confidence interval. A process capability (C_p) of each measurement was also conducted to determine the ability of the process to produce output within its specification limits. Lastly, the process capability index (C_{pk}) was analyzed to view how capable the process is of producing the process target within the specification limits.

Bottles

The method of analyzing the bottle dimensions is extremely similar to the method of analyzing the caps. Two different bottles are used in the screw cap process, 7255-Series and 7345-Series (See Appendices C & D). The bottles' dimensions greatly vary, as they are suited for different types of wine, however they both have appropriate dimensions to interact with a cap. The potential dimensions of each bottle that may cause defects of concern are: K dimension, neck taper angle, bottle height, angle of bottle skew, A1 dimension, N dimension, A1-N, D dimension, radius at D, D angle, A-1 ovality, T dimension, and E dimension.

Samples of each bottle were taken, and each dimension was measured to see how it compares to the specified dimension. Similar to caps, each measured dimension was compared to the specified dimension through a Two-Sample T-Test and its desired confidence interval. Lastly, a process capability and the corresponding process capability index of each measurement were recorded.

Capper Settings

Assuming all dimensions of the caps and bottles are appropriate, much variation can be had due to the settings on the capper. To produce a quality cap to bottle seal, the capper must be closely aligned to the caps and bottles, and must maintained frequently. Each capper can have up to ten rolling heads that apply the cap to the bottle. The correct measurements the capper must contain are: thread and pilfer roller height, thread and pilfer roller pressure, clean pilfer rollers, overall capper height, head pressure, and an aligned pressure block.

The user manual from the capper provided suitable ranges for each capper setting; however there is room for variation based on the dimensions of the caps and bottles. In the case of this project, the capper manufacturer suggestions were deemed to be broad, thus a more detailed experiment had to be conducted to develop appropriate ranges of each capper setting when dealing with the previously mentioned caps and bottles.

A test using each cap-bottle combination (Erben Cap with 7255 Bottle, Erben Cap with 7345 Bottle, G3 Cap with 7255 Bottle, and G3 Cap with 7345 Bottle) was conducted on the capper to develop suitable ranges for each setting. All of the capper settings were dialed in to the current running settings except for one setting that was set below its recommended range. Three of each bottle combinations were sent through the capping process with the belief that the lowered setting would cause a defect. This experiment was repeated over and over again, each time raising the lowered setting until it was above the maximum recommended setting. Ultimately a range was determined for this particular setting that displayed the lowest acceptable setting to the highest acceptable setting that did not create a defect. A different range was computed for each cap-bottle combination then each range was overlapped to determine an overall suitable range.

For example, the capper manufacturer's recommended range for the pilfer roller height is .841" to .861" from the top of the bottle. The height was then set to .835" and each cap-bottle combination was sent through the capping process, revealing defects. It was now known that if the pilfer roller height was set to .835", defects on all combinations would occur. The height was then raised from .835" to .837" and the test was repeated. The pilfer roller was altered by increments of .002" increments until the height reached .867". It was determined that the appropriate range for the pilfer roller height for the Erben Cap- 7255 Bottle combination was .843" to .865", but this was not the range for all of the combinations. Finally, each range was overlapped to determine the setting that would work for all combinations; in this case, .845" to .859" was deemed to be the suitable range for all combinations.

This test was repeated with each previously noted capper setting, and a list of ranges was determined. After this testing was completed, some concern over how some settings affect others was brought up. A new test was conducted using all of the newly developed ranges. For example, the pilfer roller height was set to maximum acceptable setting, while the head pressure was set to its

lowest acceptable setting. This test was repeated over and over again using variation of the pilfer roller height, thread roller height, pilfer roller pressure, thread roller pressure, and head pressure. After this testing was completed, no additional findings were made. The capper settings from the previous test were not altered by the second test.

Capper Setup Consistency

Appropriate capper settings for all of the cap-bottle combinations were determined, but how robust was the setup process? An operator could be ordered to set the capper to the specified settings, but the process of dialing in one capper roller head to the proposed settings is extremely fastidious, let alone ten capper roller heads. It was determined that a test measuring the repeatability of the capper setup must be conducted.

The goal of this experiment was to determine whether or not operators are able to accurately reproduce desired set up measurements on a capper roller head. Specifically, the test encompassed side pressure settings. Essentially, if side pressure is set to a specific weight unbeknownst to the operator, by the use of a spring scale, what reading will the operator conclude for that specific weight? This test will measure the deviation in the average users' measurements.

Capper Setup Background Understanding:

To adjust the pressure setting, one must first loosen the lock nut (●). Once this is done, the pressure screw (● ●) must be turned clockwise to increase pressure or counterclockwise to decrease pressure (see Figure 5).

Method:

- **Task:** The subject will use a spring scale to

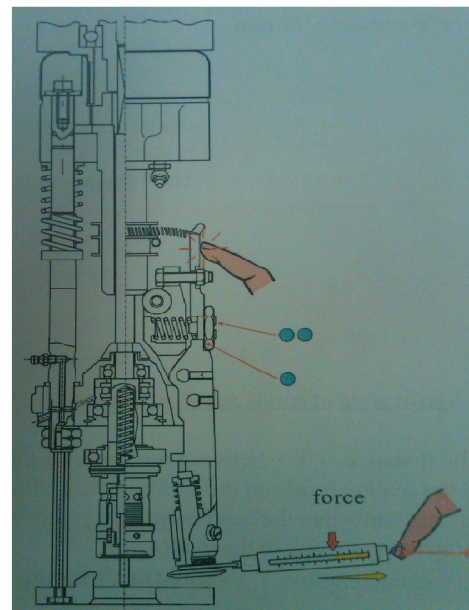


Figure 5: Side Pressure Setting

measure the force applied by a pressure roller. Keeping the spring scale in a horizontal position, the subject will place their left hand on the roller and use their right hand to pull the spring scale. Once the subject feels the roller subdue to the spring scale force, the measured force will be recorded. This same measurement will be conducted in trials of 3, at 10 different pressure settings.

- **Test Subjects:** Maintenance members, or anyone who would normally adjust pressure settings on a capper.

Variables:

- **Control Variables:**
 - Consistent body position will be maintained during measurement.
 - Subjects will stand upright and place their left hand on the roller.
 - With their right hand, subject will pull the spring scale until the roller's position is altered.
 - Subjects are not to look at the scale in order to prevent biases.
- **Dependent Variable:**
 - The recorded force on the spring scale once the roller's position is altered.
- **Independent Variable:**
 - Pre-test Pressure Setting
 - 12-30 pounds in 10 equal intervals

Capper Setup Analysis

The test measured the variation among four capper operators. The results were determined through the use of a Gage R&R study. This type of study reveals the repeatability and reproducibility of the setup process. Moreover, one is able to determine the measurements within and between

operators as well as evaluate the reliability of the measurement device. Traditionally 10% variation is acceptable, 10-30% variation is marginable based on the environment, and variation greater than 30% must be corrected.

Other Sources of Variation

Many other causes of defects in the manufacturing process can easily arise. Cap defects can result from running the machinery too fast, warehouse storage policies, pressures and viscosity of the wine, as well as upstream or downstream subassemblies. None of these aforementioned sources were concluded to have an effect in the capping process.

Design Summary

The greatest challenge of this project was to identify the great number of sources that may cause a defect. Numerous studies can be had, and much focus can be costly spent elsewhere. This project took a bottom to top look of the entire process of screw capping. The main focus of this study was to identify the causes of the defects and prevent them in hope of consistently creating a quality product and ultimately satisfying the customers' expectations.

Results and Discussion

This section will provide an in depth look at the findings of the project testing. Segments will cover raw material functionality, cap settings, and cap setup procedures. This section will discuss what the results reveal about the process and future possibilities of further testing.

Raw Material Results

As previously discussed in the “Design” section, the technical drawings of the associated caps and bottles must be analyzed to verify that the dimensions are appropriate for application (See Appendix B). Comparing these drawings to the manufacturer’s requirements, everything seems to line up appropriately. The two types of caps and bottles do vary slightly, but should still provide the basis for a quality product. The next step of testing involves ensuring that sample measurements of cap and bottle dimensions are statistically identical to the provided drawing dimensions.

Caps

Two different suppliers’ caps are used in this study, G3 30x60 caps and Erben 30x60 caps. As previously stated, there are many cap dimensions that, if not in control, can cause major defects to the process output products. These highlighted dimensions are: inner diameter of cap bottom, inner diameter at cap serration, serration height, cap height, bridge width, serration cut quality, hardness, liner thickness, liner density, specification differences by suppliers, and material tensile strength.

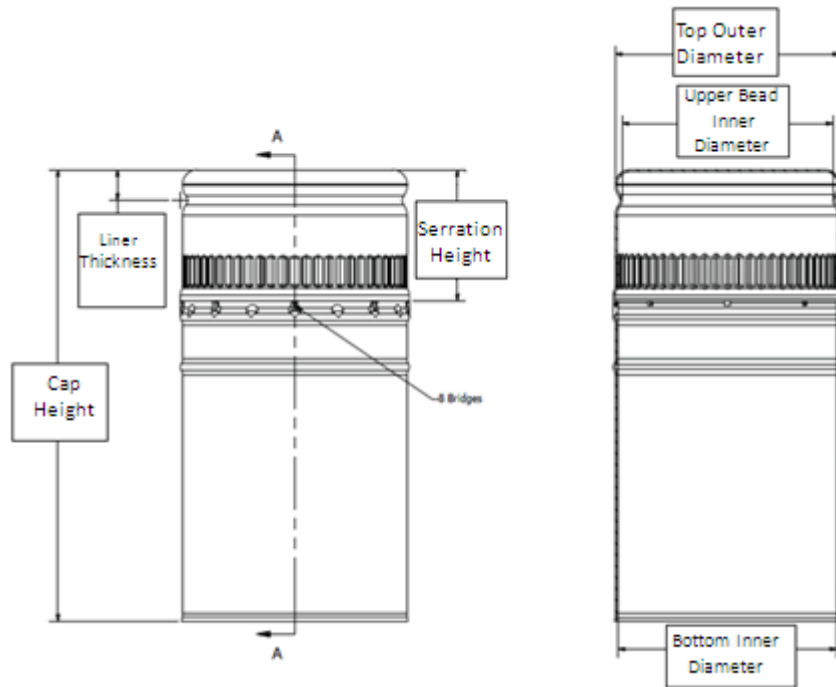


Figure 6: Locations of Cap Dimensions

The first measurement was done on the bottom inner diameter of the caps. The bottom inner diameter of the cap must be strictly controlled to guarantee that the cap will sit at the proper height on the bottle. If the bottom inner diameter is too narrow, the cap will sit too high on the bottle, which could cause many defects during application. If it is too wide, the cap may be too loose along the side of the bottle, which could cause a skewed finish during application.

The G3 and Erben cap drawings suggest that the bottom inner diameter should be 29.2 ± 0.1 millimeters and 29.3 ± 0.1 millimeters, respectively. After taking thirty sample measurements of each cap, the average G3 diameter was 29.41 millimeters and the average Erben diameter was 29.53 millimeters. The process capability values were in suitable ranges, however both process capability index values were below suitable values. Both cap measurements are outside of the process's control limits and must be corrected by both cap suppliers.

The next measurement was on the cap height. The height of the cap has similar process effects as the cap bottom inner diameter. It must be strictly controlled to guarantee that the cap will sit at the proper height on the bottle.

The G3 and Erben cap drawings suggest that the cap heights should be 59.97 ± 0.36 millimeters and 60 ± 0.2 millimeters, respectively. After taking thirty sample measurements of each cap, the average G3 cap height was 60.18 millimeters and the average Erben cap height was 60.02 millimeters. All measurements fell within process control limits. The Erben caps revealed a process capability value of only 0.97, suggesting a wider variation of the measured value within its control limits. The G3 process capability was within a suitable range. Through statistical analysis, the cap heights were not determined to be a cause of concern.

The subsequent measurement was done on the quality of each cap's serration. The cap serration is a cut around the cap that separates the top of the cap from the bottom. A uniform cut is made around the cap, leaving small sections of material, or bridges, as the connectors from the top of the cap to the bottom. If a serration is of poor quality, the upper portion of the cap will either be too difficult or too easily removed from the bottom portion. The results of these measurements are binomial, either satisfactory quality or unsatisfactory quality. All of the sampled caps were found to meet satisfactory quality standards.

The next measurement was done on the cap serration height. If the serration is at the wrong location of a cap, pilfer and thread rollers may elongate or compress the serration bridges. The G3 and Erben cap drawings suggest that the serration heights from the top of the cap should be 17.4 ± 0.2 millimeters and 18.0 ± 0.2 millimeters, respectively. After taking thirty sample measurements of each cap, the average G3 serration height was 17.53 millimeters and the average Erben serration height was 18.22 millimeters. The G3 serration height met its specifications and revealed a process

capability of 1.40. The Erben serration height straddled its upper control limit, and only showed a process capability of 1.09. The Erben serration height is out of control, thus corrective action is needed from the supplier.

Bridge width on each cap was the next focus. Each cap generally has around twenty to thirty bridges. As previously stated, a bridge is the small piece of material connecting the bottom of the cap to the top. If a bridge is not an appropriate size, the cap will either be too difficultly or too easily removed from the bottom portion. The G3 and Erben cap drawings suggest that the bridge width should be 1.4 ± 0.1 millimeters for both. After taking thirty sample measurements of each cap, the average G3 bridge width was 1.35 millimeters and the average Erben bridge width was 1.37 millimeters. All measurements were within the process control limits. Neither cap's bridge width revealed any cause for concern.

The thickness of the liner was the next measurement. A cap liner is a non-permeable entity that functions to prevent liquid leakage and oxygen ingress. The thickness of the liner is generally compressed to half its original height. If the liner is too thick, the cap will not be compressed to a low enough level and the cap pilfer and threads may be applied at incorrect positions. If the liner is not thick enough, the cap may be compressed to far, or the liner may be pierced which may cause leakage. The G3 and Erben cap drawings suggest that the liner thickness should be 2.0 ± 0.2 millimeters for both. After taking thirty sample measurements of each cap, the average G3 liner thickness was 1.97 millimeters and the average Erben liner thickness was 2.05 millimeters. Both processes displayed high process capability values. Both liners are statistically in control and do not require corrective action.

The last cap measurement was the material compression strength. The compression strength is vital because cases of wine are stacked on top of one another in a warehouse. Each cap must be

able to withstand a decent amount of force before collapsing under pressure. Each specification sheet requires that the cap must be able to withstand 50 pounds of vertical force. After taking thirty sample measurements of each cap, the average G3 compressive strength was 72.73 pounds and the average Erben compressive strength was 107.95 pounds. Both processes displayed high process capability values. Both caps perform far greater than their requirements and do not require corrective action.

Cap measurements for the most part were in control, however a few blaring issues were revealed. Both caps' bottom inner diameters did not meet their specification standards and need to be corrected by the cap suppliers. The Erben cap serration height was also out of control. From a cap standpoint, these two issues may be the largest contributing factors to defects.

Bottles

Flaws in caps are rare and can easily be corrected however bottles leave much room for imperfections. Flaws found in bottles are extremely complex to fix. The screw cap process needs a bottle of a higher quality standard than a typical cork mouth bottle. Two different bottles are used in the screw cap process, 7255-Series and 7345-Series (See Appendices E & F). The bottles' dimensions greatly vary, as they are suited for different types of wine, however they both have appropriate dimensions to interact with a cap.

The three main defects that are occurring in the caps are collapsed bridges, broken bridges, and cut caps. Each defect can be attributed to specific measurements in the glass. Collapsed bridges can be caused by inaccuracies in the K Dimension, Neck Taper, or Bottle Height (See Appendix B). Broken bridges can be attributed to inaccuracies in the K Dimension, Neck Taper, T Dimension, or E Dimension (See Appendix B). Cut caps can be caused by many different sources, primarily by inaccuracies in the A1 Dimension, N Dimension, D Dimension, D Angle, and Bottle Height (See

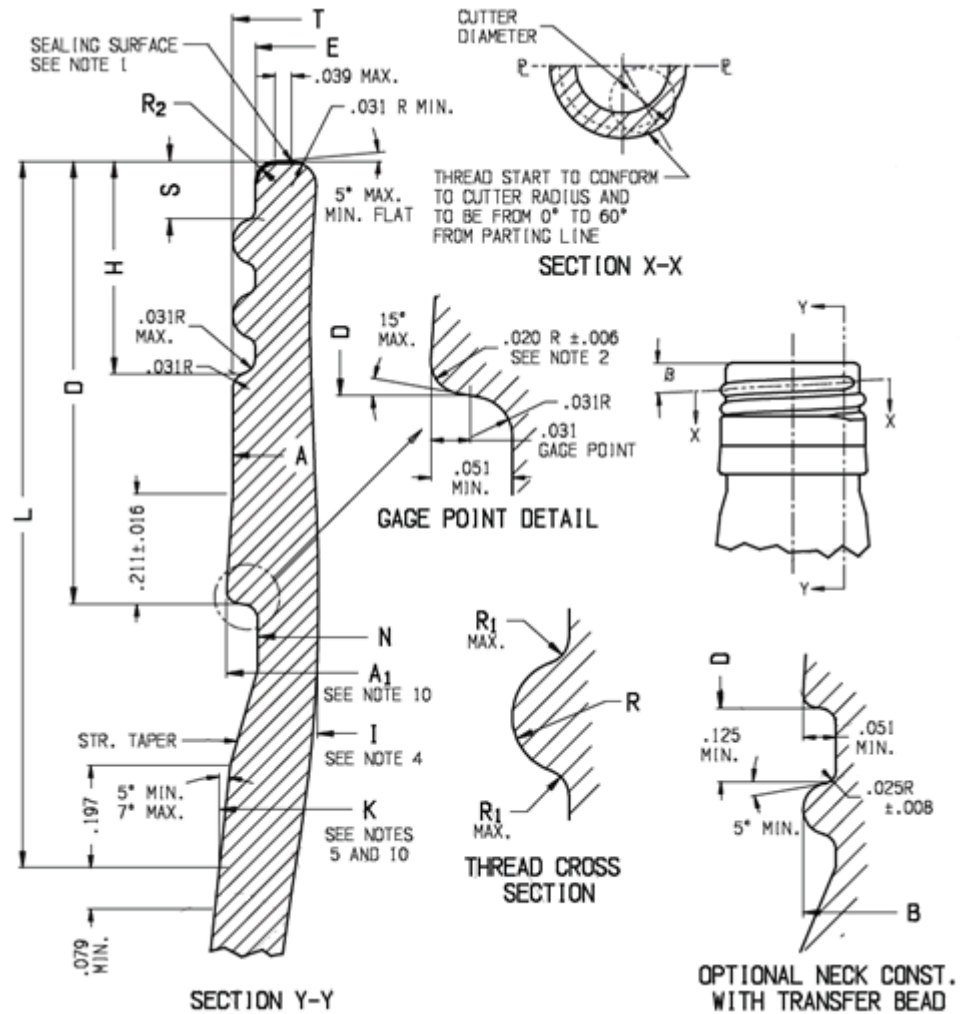


Figure 7: Locations of Bottle Measurements

The first measurement was done on the K dimension of the bottle. An out of control K dimension could be a leading factor in broken or collapsed bridges. The 7255 and 7345 bottle drawings suggest that the diameter at the K dimension should be $1.165 \pm .028$ inches for both bottles. After taking thirty sample measurements of each bottle, the average 7255 K dimension was 1.174 inches and the average 7345 K dimension was 1.164 inches. Both bottles met their specifications

however the 7255 K dimension only revealed a process capability of 0.88. Most samples of the 7255 bottle were above the target goal, but still within the process control limits. The 7345 bottle provided a process capability 1.77 and was very much in control. Neither K dimension needs corrective action, however the 7255 bottle should continue to be monitored.

The next measurement was done on the neck taper angle. An out of control neck taper angle could be a leading factor in broken bridges. Neither bottle drawing provides defined specifications for a neck taper angle, however the capper manufacturer suggests an angle between 5° to 7°. After testing thirty samples of each bottle, the 7255 bottle had an average neck taper angle of 3.6 ° and the 7345 bottle had an average of 4.1 °. Neither measurement had significant process capability values; therefore it is essential that corrective action be taken.

Bottle height was the following measurement. An incorrect bottle height could be a leading cause for collapsed bridges. The 7255 and 7345 bottle drawings suggest that the bottle heights should be $11.875 \pm .062$ inches for both bottles. After taking thirty sample measurements of each bottle, the average 7255 height was 11.868 inches and the average 7345 height was 11.860 inches. All measurements were within the specification limits and both processes provided an extremely high process capability value. No corrective action is needed for bottle heights.

The next measurement was done on the A-1 dimension. A poor A-1 dimension could be a leading factor for cuts in the cap. The 7255 and 7345 bottle drawings suggest that the A-1 dimensions should be $1.138 \pm .012$ inches for both bottles. After taking thirty sample measurements of each bottle, the average 7255 A-1 dimension was 1.131 inches and the average 7345 A-1 dimension was 1.133 inches. The A-1 process is out of control. Neither A-1 dimension matched its specifications, therefore corrective action is needed.

D dimension was the next measurement. An uncontrolled D dimension may cause cuts in the cap. The 7255 and 7345 bottle drawings suggest that the D dimensions should be $0.851 \pm .010$ inches for both bottles. After taking thirty sample measurements of each bottle, the average 7255 D dimension was .853 inches and the average 7345 D dimension was .855 inches. All measurements on the 7255 bottle were within the specification limits and the process provided an extremely high process capability value. A few measurements on the 7345 bottle were out of control, and there appeared to be a heightened shift in the mean. Corrective action is needed for the D dimension in the 7345 bottle only.

The next measurement was done on the D angle. An uncontrolled D angle could be a cause for cuts in the cap. The 7255 and 7345 bottle drawings suggest that the D angle should be a maximum of 15° for both bottles. After taking thirty sample measurements of each bottle, the average 7255 D angle was 15.3° and the average 7345 D angle was 13.0° . Neither bottle contained a high process capability value and many measurements fell outside of the specification limits, therefore corrective action is needed.

Another dimension that could cause defects is the T dimension. An uncontrolled T dimension may be another factor in broken bridges. The 7255 and 7345 bottle drawings suggest that the T dimensions should be $1.114 \pm .012$ inches for both bottles. After taking thirty sample measurements of each bottle, the average T dimension was 1.110 inches for both bottles. Both sets of measurements had high process capability values, suggesting that the T dimension is in control and does not require further action.

The final glass measurement was done on the E dimension. The 7255 and 7345 bottle drawings suggest that the E dimensions should be $1.028 \pm .012$ inches for both bottles. After taking thirty sample measurements of each bottle, the average E dimension was 1.025 inches for both

bottles. All measurements were within the specification limits and both processes provided an extremely high process capability value. No corrective action is needed for the E dimension.

There were quite a few uncontrolled dimensions in the bottles. Much corrective action is required by the bottle supplier. The dimensions that need to be amended are the neck taper angles in both bottles, A-1 dimension in both bottles, D dimension in the 7345 bottle, and the D angle in both bottles. These solutions can be accomplished by the purchasing of new bottle molds by the glass manufacturer.

Results of Capper Settings

The next phase of testing was on the settings of the capper. This testing was accomplished using caps and bottles in their current, uncorrected state. If corrections are made in the cap and bottle dimensions, these results of this test should be recalculated using the new materials. Different capper settings can cause a great deal of variation in the process. The correct measurements the capper must contain are: thread and pilfer roller height, thread and pilfer roller pressure, clean pilfer rollers, overall capper height, head pressure, and an aligned pressure block.

The user manual from the capper manufacturer (Zalkin) provided suitable ranges for each capper setting, however each setting's range was extremely broad. A test using each cap-bottle combination (Erben Cap with 7255 Bottle, Erben Cap with 7345 Bottle, G3 Cap with 7255 Bottle, and G3 Cap with 7345 Bottle) was conducted on the capper to develop suitable ranges for each setting.

All of the capper settings were dialed in to the current running settings except for one setting that was set below its recommended range. Three of each cap-bottle combination was sent through the capping process with the belief that the lowered setting would cause a defect. This experiment was repeated over and over again, each time raising the lowered setting until it was above the

maximum recommended setting. Ultimately a range was determined for this particular setting that displayed the lowest acceptable setting to the highest acceptable setting that did not create a defect. A different range was computed for each cap-bottle combination, and then each range was overlapped to determine an overall suitable range.

The first test was done on the pilfer roller height. The purpose of the pilfer is to prepare the bottom skirt of the cap for eventual removal. If the pilfer indentation is at an incorrect location, the cap may not be secured to the bottle and cuts in the cap may appear. The Zalkin user manual's recommended range for the pilfer roller height is .841" to .861" from the top of the bottle. After testing was completed, it was determined that the appropriate range was .843" to .865" for the Erben Cap- 7255 Bottle combination, .845" to .865" for the Erben Cap-7345 Bottle combination, .843" to .859" for the G3 Cap-7255 Bottle combination, and .843" to .859" for the G3 Cap- 7345 Bottle combination. The suitable range for all combinations was deemed to be .845" to .859".

The next test was done on the thread roller height. Thread structure is crucial for accurate cap location, functionality, and eventual cap removal. The Zalkin user manual's recommended range for the thread roller height is .399" to .419" from the top of the bottle. After testing was completed, it was determined that the appropriate range was .397" to .417" for the Erben Cap- 7255 Bottle combination, .399" to .417" for the Erben Cap-7345 Bottle combination, .405" to .419" for the G3 Cap-7255 Bottle combination, and .405" to .417" for the G3 Cap- 7345 Bottle combination. The suitable range for all combinations was deemed to be .405" to .417".

Pilfer roller pressure was tested next. The pressure on the pilfer determines how strongly the cap material hugs the bottle at the pilfer tuck. The Zalkin user manual's recommended range for the pilfer roller pressure is 7 to 10 kilograms. After testing was completed, it was determined that the appropriate range was 7 to 10 kilograms for the Erben Cap- 7255 Bottle combination and the Erben Cap-7345 Bottle combination, 7 to 11 kilograms for the G3 Cap-7255 Bottle combination, and 7 to

12 kilograms for the G3 Cap- 7345 Bottle combination. The suitable range for all combinations was deemed to be 7 to 10 kilograms, same as the manufacturer's recommendation.

Thread roller pressure was the next phase of testing. The pressure on the thread determines how strongly the cap material hugs the bottle at the thread locations. The Zalkin user manual's recommended range for the thread roller pressure is 11 to 12 kilograms. After testing was completed, it was determined that the appropriate range was 7 to 10 kilograms for the Erben Cap-7255 Bottle combination, 8 to 10 kilograms for Erben Cap-7345 Bottle combination, 11 to 13 kilograms for the G3 Cap-7255 Bottle combination, and 10 to 13 kilograms for the G3 Cap- 7345 Bottle combination. There was not a range that would suit all combinations, thus the thread pressure must be set between 8 and 10 kilograms for Erben caps and 11 to 13 kilograms for G3 caps.

The last measurement was done on the head pressure. The strength of head pressure determines how much of a redraw is present and how much the liner is compressed. If it is too high, the liner may be pierced and leakage can occur. On the other hand, if it is too low, the liner may not be compressed enough to prevent leakage through the top of the bottle. The Zalkin user manual's recommended range for the head pressure is 140 to 180 kilograms. After testing was completed, it was determined that the appropriate range was 145 to 185 kilograms for the Erben Cap- 7255 Bottle combination and Erben Cap-7345 Bottle combination, and 150 to 175 kilograms for the G3 Cap-7255 Bottle combination and the G3 Cap- 7345 Bottle combination. The suitable range for all combinations was decided to be 150 to 175 kilograms.

According to the results of the test, each setting except for the thread roller pressure contains a range suitable for all cap-bottle combinations. These settings do slightly vary from the current running settings and can prevent possible future defects if implemented. One of the greatest discoveries is the fact that the Erben caps cannot handle as much thread pressure as the G3 caps require.

Capper Setup Consistency Results

The purpose of the next phase of testing was to determine whether or not operators are able to accurately reproduce desired set up measurements on a capper roller head. The capper involved in this project contains ten cappers heads. Essentially the capper is capable of capping ten bottles in one rotation. When operators are performing the task of calibrating the capper settings, it can often be extremely timely and require great attention to detail. Because the only setting that must be changed repeatedly is the thread roller pressure, a test was devised to measure operators' deviation when adjusting this setting.

It was determined that the best method for analyzing accuracy of measurement was through a Gage R&R. A Gage R&R is a test that reveals the repeatability and reproducibility (R&R) of a process. One is able to determine the percentage of variation that is caused by a particular measurement system. The data points are the gauge readings by each operator at each pressure setting. A total of four operators participated in the test.



Figure 8: Operator Measuring Roller Pressure

This test required operators to use a spring scale to measure the force applied by the roller. Once the operator felt the roller subdue to the spring scale force, the measured force was be recorded. This

same measurement was conducted in trials of 3, at 10 different pressure settings. The pressure settings ranged from 12 pounds to 30 pounds in increments of 2 pounds. The operators are not knowledgeable of the pressure setting during a given trial run. This test measures the difference of the operator's pressure reading from the preset pressure setting.

From listening to the operators, two of them appeared to be quite experienced with this type of measurement, whereas the other two were novice. The results revealed a variance of 20.99% among all operators accuracy to determine the correct setting. The experienced operators varied by only 18.32% as opposed to the novice operators who varied by 28.17%. Using general guidelines for interpreting Gage R&R variance, 20.99% would be classified as marginally acceptable based on the setting.

Viewing the results of the test, three options for correction were apparent. One could accept the 20.99% variance and allow time for a learning curve to take place, a training regimen could be created to help operators practice their skill, or the measuring system must mechanically corrected. Because the process could allow a small amount of variation, management took to the idea of creating a training regimen for the operators to practice their accuracy.

Summary of Results

Overall, the results made more issues apparent than previously anticipated. To reach Six-Sigma standards, extreme measures must be taken. The design theory held well and provided much information into potential causes of defects. It is crucial for management to correct the outlying issues and repeat the testing to ensure a more stable process. Because many issues were highlighted, the future should hold some positive changes in the quality of screw cap products. Similar testing should be done on all screw cap products to prevent any further or similar defects.

Conclusion

This project set out to optimize the screw capping process for E&J Gallo Winery. Many issues were witnessed such as cuts in the caps, broken bridges, and collapsed bridges. A wide variety of factors can cause major defects in the screw capping process. Uncontrolled raw material dimensions, improper capper settings, and an inexperienced work force among other issues can have a detrimental effect on the quality of finished process outputs.

Many notable potential causes of defects were uncovered in this project:

- Uncontrolled dimensions in the raw material were discovered
- More appropriate setting ranges were determined for the capper
- There was a variation of nearly 21% in capper setup procedures

Analysis of cap dimensional analysis revealed two blaring issues. Both caps' bottom inner diameters did not meet their specification standards and needed correction, and Erben cap serration height was out of control. Both cap suppliers have altered their process since news of these issues arose.

The defects found in the glass were more prevalent. The dimensions that need to be corrected are the neck taper angles in both bottles, A-1 dimension in both bottles, D dimension in the 7345 bottle, and the D angle in both bottles. Since news of these issues, new glass molds have been made by the bottle manufacturer in hopes of correcting these dimensions.

Appropriate capper settings were determined for each cap-bottle combination. The process of calibrating these settings by operators witnessed a variance of 20.99%. Through implementation

of a bi-monthly training regimen, it is believed that each operator will be more apt to apply the correct setting to the machinery.

It is difficult to predict if all screw cap defects will be eliminated based on this study, but many potential causes have been brought to attention. Based on the experimental results, insight in the screw capping process has been vastly heightened. By taking action to eliminate all causes of defects, fewer problems should arise in the future.

The objective of this project was to optimize the screw capping process. If all of the tests lead to the elimination of defect-causing attributes, it appears that the process is well on its way to meeting Six-Sigma quality levels. It is hoped that this project will serve as a foundation for others to continue seeking ultimate quality levels.

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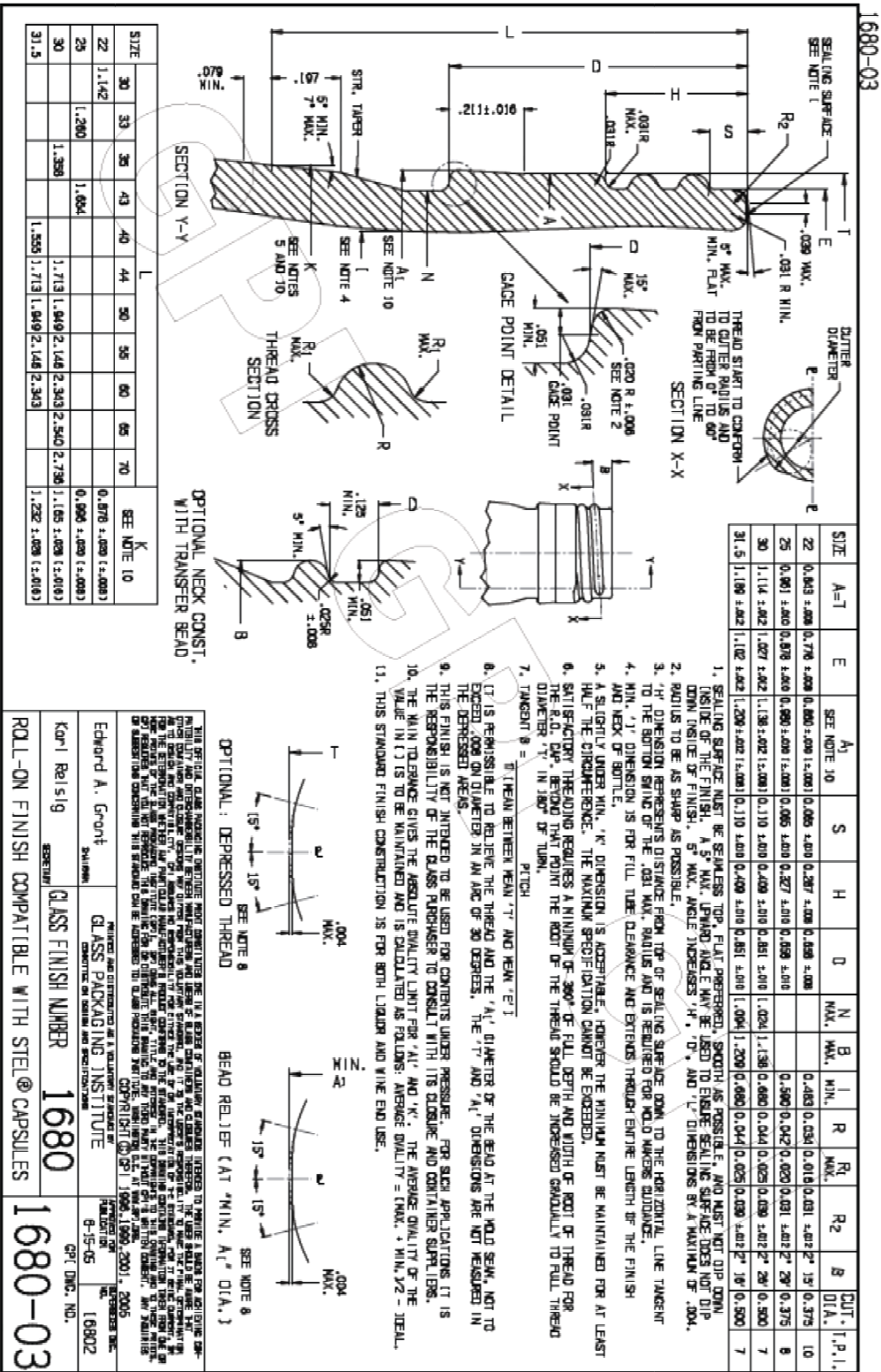
Appendix

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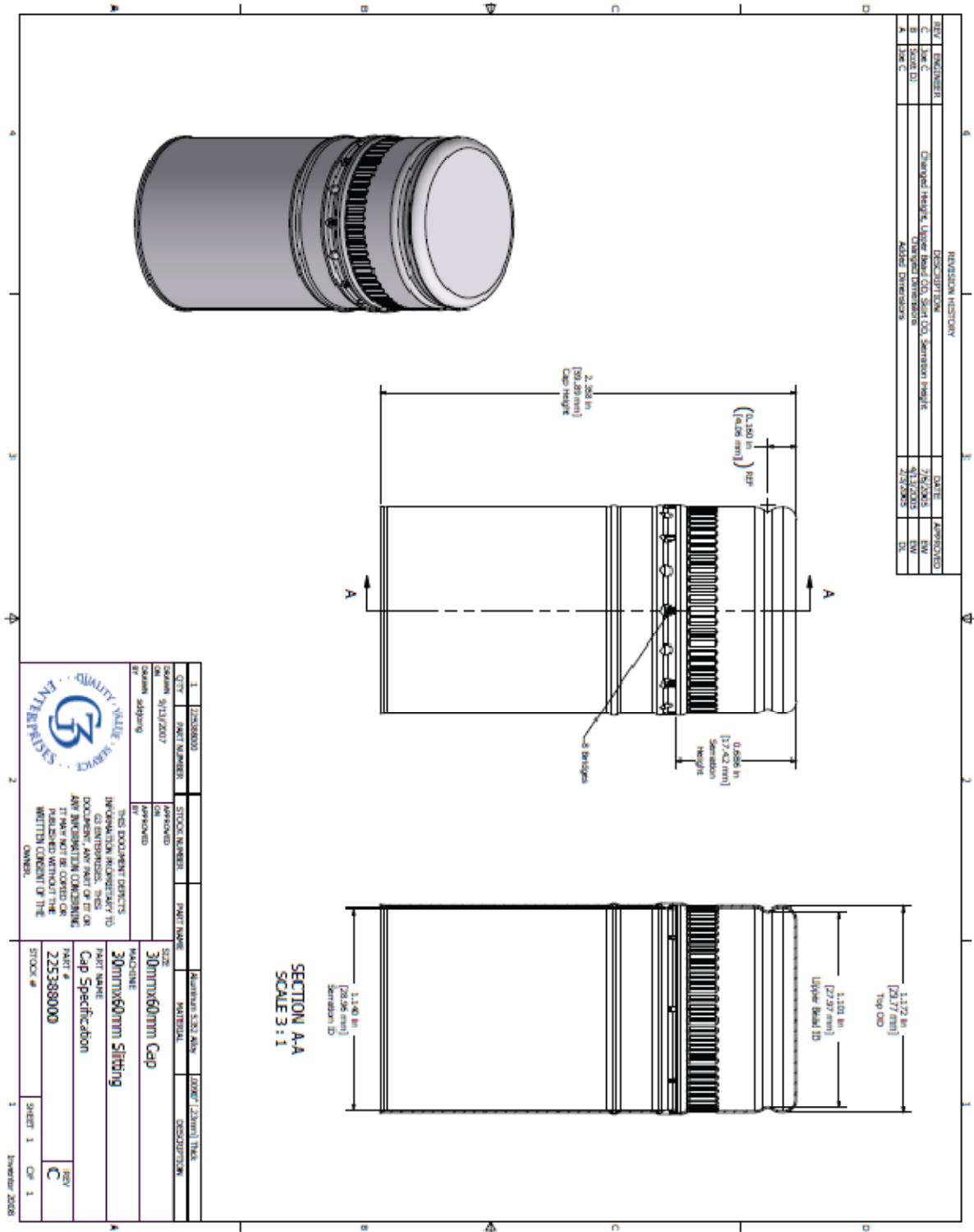
Appendix A- Project Schedule

<i>ID</i>	<i>Task Name</i>	<i>Start</i>	<i>Finish</i>	<i>Duration</i>
1	Project Proposal	10/4/2010	10/8/2010	5d
2	Analysis of Problem	10/11/2010	10/15/2010	5d
3	Status Report	10/18/2010	10/19/2010	2d
4	Background Research	10/18/2010	10/27/2010	8d
5	Material Definition	11/1/2010	11/5/2010	5d
6	Literature Review	1/10/2011	1/28/2011	15d
7	Introduction and Background	11/15/2010	11/19/2010	5d
8	R&R Test Planning	11/22/2010	11/26/2010	5d
9	R&R Test Execution	11/29/2010	12/3/2010	5d
10	Result Analysis	12/6/2010	12/10/2010	5d
11	Measuring Technique Design	1/28/2011	2/9/2011	9d
12	Project Status Report	1/25/2011	1/26/2011	2d
13	Further Testing	12/27/2010	12/31/2010	5d
14	Testing Analysis	1/4/2011	1/10/2011	5d
15	Report Writing	12/13/2010	2/18/2011	49d
16	Edit Report	2/21/2011	3/2/2011	8d
17	Final Presentation	3/9/2011	3/9/2011	1d

Appendix B- Glass Requirements



Appendix C- G3 Cap Drawing



Appendix D- Erben Cap Drawing

USED FOR: WINE

TECHNICAL DRAWINGS (tolerance $\pm 0,20$ mm)

CAPSULE

RIMMING PITCH 1,5

Ø28,80

60,00

LITHOGRAPHIC AREA

N. 8 BRIDGES DIM. 1,0

LINER

26,60

2,00

DENSITY: 0,35 g/cm³

BOTTLENECK

Ø28,30

Ø19,50

21,40

Ø28,00

Ø26,00

59,00

Ø29,60

GENERAL FEATURES					
BOX		PALLET			
Quantity per box	1300	Pallet type	wood EUR 800x1200		
Box dimensions	575 x 375 x 420	Nr of boxes per pallet	20		
Box type	triple wave carton	External wrapping	extensible film		
Internal packaging	transparent plastic bag	Product identification	label on box		
PRINTING FEATURES					
	APPLICABLE	DIMENSIONS			
Top litho printing	YES	Ø 28,5			
Side litho printing	YES	develop.=94 H=14,0			
Side offset printing (marks / logos)	YES	develop.=94 H=60,0			
Top punching	NO				
Side embossing-shaving	NO				
OPTIONS					
* Pallet type can also be EUR 1000x1200 (25 boxes)					

ASSEMBLED PRODUCT

Ø28,30

Ø19,50

21,40

Ø28,00

Ø26,00

59,00

Ø29,60

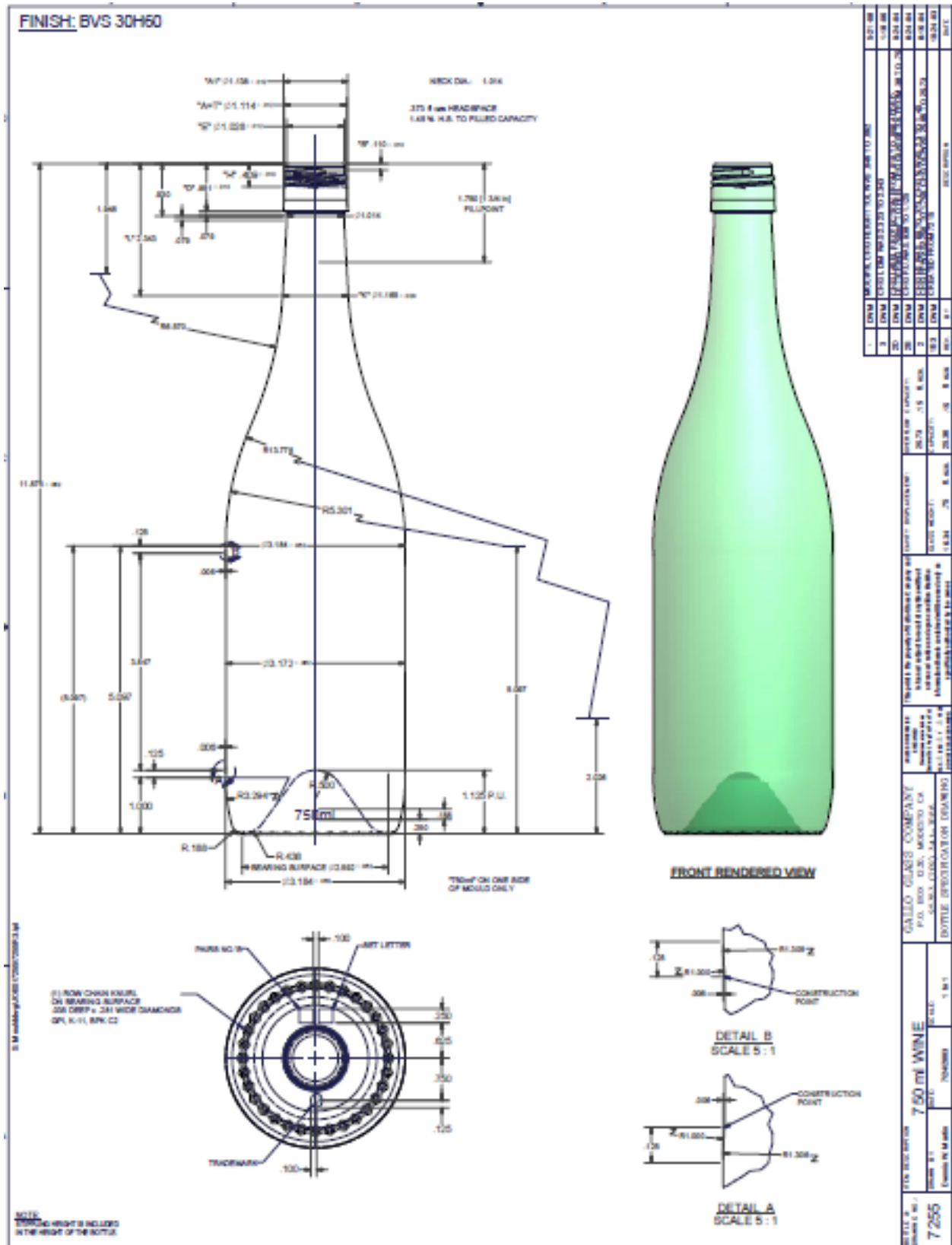
WEIGHT OF THE COMPLETE CAPSULE: 4,8 g

MATERIALS USED					
ALUMINIUM		LINERS		LACQUERS AND INKS	
Physical state:	H14	SARANEX		Internal varnish:	normal internal doré
Specific weight Kg/dm ³	2,7			External varnish:	flexing vinyllic/acrylic varnish
Tensile stress at break RmN/mm	110/150				polyester lacquer/vinyllic varnish
Tensile stress at yield Rp02	90/130			Inks:	polyester

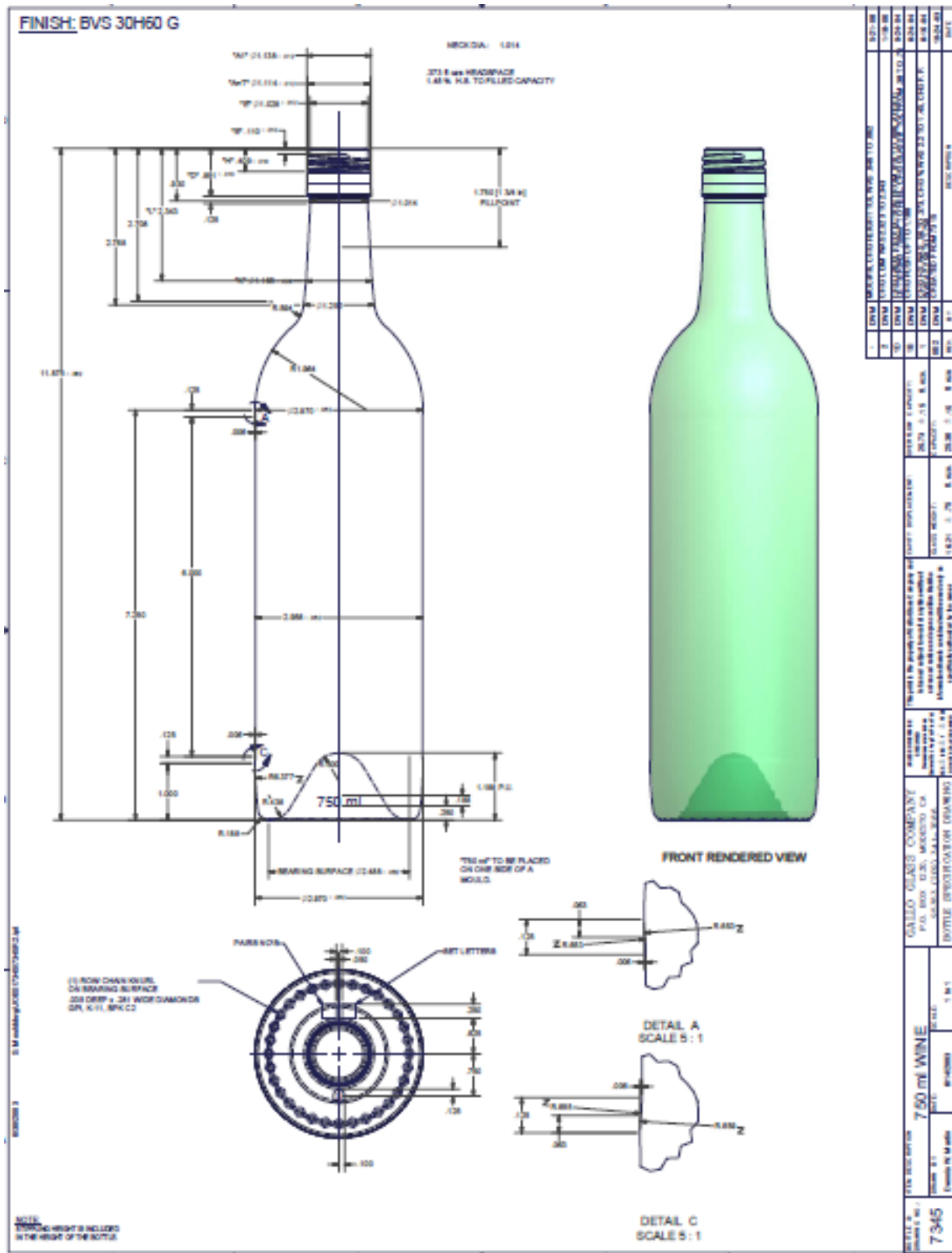
SUITABILITY: all materials used by Astro Srl to produce its capsules and inserts are suitable to contact with food/drinks and comply with the following laws concerning packaging in contact with foods for human consumption:

- Italian Law D.M. 21/3/73 and following updates;
- European Union Laws CE 853/11 CE 1831 CE 1831 20/10/2006 REG 1831/2003

Appendix E- 7255 Bottle Drawing



Appendix F- 7345 Bottle Drawing



Appendix G- Gage R&R Output for All Operators

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	1.8385	6.19
Repeatability	0.6047	2.04
Reproducibility	1.2338	4.15
Operator	0.9441	3.18
Operator*Setting	0.2897	0.98
Part-To-Part	27.8674	93.81
Total Variation	29.7058	100.00

Lower process tolerance limit = 0

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	1.35591	8.1354	24.88	20.99
Repeatability	0.77762	4.6657	14.27	12.04
Reproducibility	1.11076	6.6646	20.38	17.19
Operator	0.97167	5.8300	17.83	15.04
Operator*Setting	0.53820	3.2292	9.87	8.33
Part-To-Part	5.27895	31.6737	96.86	81.71
Total Variation	5.45031	32.7018	100.00	84.36

Number of Distinct Categories = 5

Appendix H- Gage R&R Output for Experienced Operators

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	1.3816	4.55
Repeatability	0.2740	0.90
Reproducibility	1.1076	3.65
Operator	0.7233	2.38
Operator*Setting	0.3843	1.27
Part-To-Part	28.9591	95.45
Total Variation	30.3407	100.00

Lower process tolerance limit = 0

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	1.17541	7.0525	21.34	18.32
Repeatability	0.52341	3.1405	9.50	8.16
Reproducibility	1.05244	6.3147	19.11	16.41
Operator	0.85047	5.1028	15.44	13.26
Operator*Setting	0.61995	3.7197	11.25	9.66
Part-To-Part	5.38137	32.2882	97.70	83.88
Total Variation	5.50824	33.0494	100.00	85.86

Number of Distinct Categories = 6

Appendix I- Gage R&R Output for Novice Operators

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	3.3576	11.20
Repeatability	0.9354	3.12
Reproducibility	2.4222	8.08
Operator	2.0691	6.90
Operator*Setting	0.3532	1.18
Part-To-Part	26.6174	88.80
Total Variation	29.9751	100.00

Lower process tolerance limit = 0

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	1.83239	10.9943	33.47	28.17
Repeatability	0.96717	5.8030	17.67	14.87
Reproducibility	1.55635	9.3381	28.43	23.92
Operator	1.43842	8.6305	26.27	22.11
Operator*Setting	0.59428	3.5657	10.85	9.13
Part-To-Part	5.15921	30.9553	94.23	79.30
Total Variation	5.47495	32.8497	100.00	84.16

Number of Distinct Categories = 3