Developing a Low Pressure Blow Molding Machine for Demonstration Purposes and Production of Plastic Bottles

A thesis presented in partial fulfillment of the requirements
for the degree of

Master of Engineering
in
Mechatronics

at
Massey University,
Palmerston North, New Zealand

Bruno Hugener
Dipl. Ing. (FH)

in March 2009

Abstract

This thesis presents the research of packaging beer into plastic bottles and the design and manufacture of a low pressure bottle blow moulding machine for demonstration purposes. The machine will be used for the production of plastic bottles suitable for bottling brewed beer at the microbrewery at Massey University Palmerston North.

Premanufactured PET preforms have proven to be the most convenient and promising choice for the fabrication of blown bottles. Basic tests to understand the behaviour of the preforms and the challenges of the blowing process have been carried out. A special focus has been placed on the different circumstances at University in contrast to industrial bottle production in particular the needed air pressure to form the bottles. The following step was to find the ideal method and principle to handle the preforms and to transform them in the desired shape. Finally the design, drawing of the parts and assemblies were carried out with the 3-D CAD software Solidworks.

The designed parts for the bottle blower have been manufactured at the mechanical Workshop at Massey University. To control the bottle blower, the National Instruments USB interface was selected which required the design and manufacture of an additional driver interface card to protect the USB interface and convert the TTL levels into higher voltage. The final assembly and testing of the blower then concluded the practical work for this master project.

A suitable design for the bottle production was found and the assembled Bottle Blower can now be used for the production of PET bottles.

Acknowledgements

I would like to thank all the people who got involved in my project work and in the process of writing up my thesis. Special thanks go to Ralph Ball who supported my ideas and gave me helpful feedback and inputs throughout my time at Massey University. Richard Archer and Huub Bakker supported me especially during my first days back at University and also provided me with brilliant advice during my year of working on the project.

During the Bottle Blowers building and manufacturing Clive Bardell and Stan Hyde did an amazing job producing all the parts needed to actually realize my project. Their effort and knowledge helped me greatly when assembling and putting together all the parts. The time spent in the workshop has always been really enjoyable and friendly due to the welcoming atmosphere.

I would like to thank Mr David Wheller from Visy Plastics for his kind and timely help when I was confronted with problems concerning plastics and preforms. His supply of PET preforms was greatly appreciated.

Furthermore, I would like to thank John Howarth for his fast and precise job on the CNC mill, John Edwards for his time and effort he spent organizing bits and pieces, Bruce Collins for all the support in the wood workshop and electronics, Ken Mercer and Colin Plaw for their expertise and help in Labview and the design of printed circuit boards and finally all the administration staff involved with the School of Engineering and Advanced Technology for their always kind and straightforward help when needed.

My friends and family have supported me from the other side of the world and have provided the necessary energy and motivation to strive in my postgraduate studies so far away from home. Many thanks to all of them for writing me emails, sending delicacies from home and keeping contact with the other end of the planet.

I would like to acknowledge the encouragement and friendship from my flatmates and friends for the great times we spent together. My last and deeply personal thanks goes to Juliane, who made my time in New Zealand a most memorable one.

Palmerston North, March 2009

Table of contents

Table of contents

Table of contents

Table of contents

List of figures

List of figures

List of tables

1 Introduction

Plastic materials and products make up a vast part of our daily life. The introduction of plastics and polymers changed a whole industry forever, especially for the packaging of food and drinks. In 1976, PET for drink containers was introduced in the USA and three years later in Europe (Giles 1999). The characteristics of the material are excellent. For example it is clear, lightweight, unbreakable, does not taint the beverage and has an acceptable shelf life. With these features the new container was accepted by consumers almost overnight.

It has to be said that the main use of PET was mainly for packaging of carbonated softdrinks and mineral water. The packaging of beer into plastic containers has become popular only in the last few years. This was mainly made possible through advancements in barrier properties for the bottles. With these improvements, the packaging of beer into PET containers was only a matter of time and will become even more popular in the near future. As an increase of prices for resources and transportation can be expected in the future, the plastic container will be even more competitive against other packaging such as aluminium and glass containers.

1.1 Research aim

The aim of this postgraduate master project is to develop and design a low pressure bottle blow moulding machine for demonstration purposes and also to produce PET bottles which can be used to bottle beer produced by the micro brewery at Massey University Palmerston North.

1.2 Research objectives

The main objectives of this project are:

- To investigate and find a suitable plastic packaging solution for the beer brewed at Massey University's micro brewery
- To practically test different production methods for blow forming of plastic bottles out of preforms
- To develop and manufacture a blow moulding machine for demonstrating purposes and for the production of plastic bottles

1.3 Research outcomes

- A list of the needed properties of the bottle used for bottling the beer from the Massey University microbrewery
- Contacts with suppliers of plastic preforms which are suitable for the in house production of beer bottles with an acceptable shelf-life
- Methods of blow forming suitable for producing bottles with the resources and possibilities at Massey University
- Design of a bottle blow moulding machine and manufacturing of an operational machine to be able to produce plastic bottles
- Documentation of the design and function of the bottle blow moulding machine for demonstration purposes and production of plastic bottles

1.4 Chapter overview

Chapter 2:

This chapter covers the different plastic materials used for manufacturing of bottles. An in depth view is given to PET preform technology with special emphasis on the multilayer preforms suitable for the packaging of oxygen sensitive drinks. This chapter details the different blow moulding methods, the equipment being used for the producing plastic containers in general and in particular the process of stretch blow moulding widely used for the production of PET bottles for carbonated drinks.

Chapter 3:

The evaluation of a suitable preform is the topic of chapter 3. The contacted companies are presented and the properties of the finished Massey beer bottle are discussed and finalized.

Chapter 4:

The right method and process for blow forming at Massey University are found after several practical tests described in chapter 4. All the equipment and methods used as well as the problems being faced during the process of heating and blowing preforms in a non industrial environment are the focus of this section. The summary of results from the tests finishes this section and leads to the design of the bottle blower in the next section.

Chapter 5:

The process of reaching the ideal functioning and operation of the bottle blow moulding is the central topic of chapter 5. The principles and design features used for the bottle blow moulding machine are described as well as the design and manufacturing of the control system. The description of the function and sequences of the Bottle Blower are detailed at the end of this section.

Chapter 6:

Conclusion, discussion and summarizing the achievements and outcomes of this project are part of the last chapter in the main part of this thesis.

Appendices:

The appendices contain the data and results of the blow forming tests. It contains the detailed contact data of the companies contacted during the project. The attached CD-ROM contains the drawings and 3-D models created with the Solidworks CAD programme and holds the design data produced with the Altium Designer PCB design software.

2 Literature review

Introduction

Nowadays, the use of plastic beverage packaging is widely spread. Especially carbonated softdrinks are preferably packed into plastic bottles. Their versatility, low weight, high strength, easy processing and their good ability to be recycled makes plastic beverage packaging so popular. Nevertheless, plastic and in particular PET is not yet very wide spread for the use for beer bottles. The main reason for this are its lower gas barrier properties and its different feel compared to glass. New techniques including multilayer co-injection moulding of preforms and coating techniques lead to better barrier properties and therefore a growing popularity of PET in the market of beer containers.

2.1 The use of plastic for beer bottles - a brief history

One of the first plastic containers for beer, which appeared on the market in 1971, was the so called Beer Sphere® - a spheric beer container made of plastic. The widely spread stainless steel or aluminium beer kegs often got stolen and made their way to scrap dealers which paid some money in exchange for the empty containers. Johnson Enterprises Inc. (USA), a manufacturer of beer-tapping equipment came up with the idea of a disposable non-deposit pressurized beer container to replace the multi use beer kegs.

To overcome the problems of lower barrier properties of plastic compared to aluminium and stainless steel a shape as close as possible to a sphere seemed to be the solution. A sphere was also the ideal geometry to withstand the pressure of the carbonated beer. With a minimum wall thickness of 2.03mm this high density polyethylene (HDPE) bubble was a lightweight and modern solution. Soon the packing of beer into the Beer Spheres® was a great success although the purchase of the HDPE containers was quite expensive for the breweries.

Moreover, the delivered containers were quite bulky to store. The most often used size was the 330mm Beer Sphere® containing 20 litres of beer. The filled container weighted only 19.05kg compared to a filled metal keg with the same amount of beer, which comes to almost the double of the weight at 38.1kg (Giles, 1999).

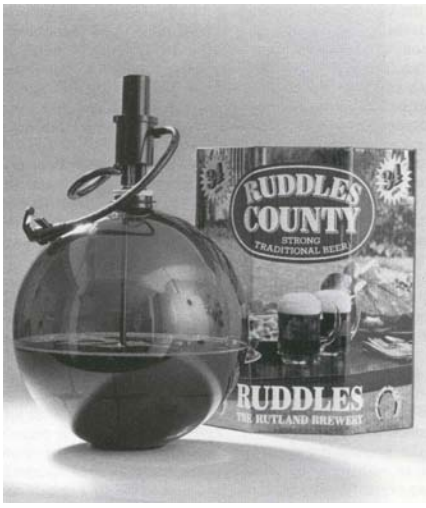


Figure 2-1: 20L Beer Sphere®

The commercialisation of PET bottles for carbonated softdrinks (CSD) also affected the Beer Sphere® as PET showed superior taint and odour characteristics compared to any other resin at that time. To overcome the expensive and bulky purchase of the produced spheres, the breweries started to blow mould the Beer Spheres® in house. Therefore a suitable preform was designed and manufactured at Broadway Companies of Dayton, Ohio, USA. Compared to the bulky spheres the delivery of the preforms was much easier and cheaper. By July 1982 the first Reheat Stretch Blow Moulding machine from Cincinatti-Milacron the RHB-IX was ready for the production of Beer Spheres® at a cycle time of 15 seconds per container. The Beer Spheres® were available in the sizes of 10, 20 and, 30 litres with a maximum shelf life of 6 month for pasteurized beer using approved grades of PET.

In the early 1980's the use of smaller sized PVDC copolymer-coated PET bottles started in the United Kingdom, but it was not very widely spread and brewers in other countries did not use this new material for beer bottles very widely either.

After culminating years of research and testing, it was in October 1998 when Owens Illinois Plastic, now part of Graham Packaging, and the Miller Brewing Company, now part of MillerCoors, introduced the innovative polyethylene terephthalate (PET) container that revolutionized beer packaging. This made life more convenient for American beer consumers. What finally made this breakthrough possible was the development of a proprietary oxygen scavenging barrier material (Sarvey 2008).

2 Literature review

During the period from the late 1990s to the early 2000s around 20 beer brands introduced beer in PET bottles. More and more customers and vendors became aware of the advantages of PET beer bottles. The light weight and the fact that they are unbreakable made these plastic bottles popular especially at venues for sport, parties, concerts etc. Especially at these venues and in the outdoors in general, the consumer prefers a bottle to cups because they eliminate foam and are easier to carry (Packaging-Gateway 2006).

Figure 2-2: 0.5 Litre PET beer bottle of a German brewery

Probably the biggest increase in the use of the PET-beer bottles until now was triggered by the one-way deposit law introduced in Germany in January 2003. By law, every single-use container (eg. cans, bottles for beer, mineral water, and carbonated softdrinks) requires a deposit of approximately NZ$ 0.50. Many of the big vendors of softdrinks, beers and mineral water changed their entire product range to PET containers to simplify the process of bottle return and recycling. This forced many of the beer and CSD manufacturers to rethink the current bottling philosophy. Hence, the introduction of the one-way deposit on drink containers and the fact of constantly improving barrier properties of PET enabled the gainful production of PET beer bottles.

One example of a leading company in packaging beer into PET-bottles is the Holsten Brewery, Hamburg, Germany. In August 2003, Holsten installed a new dedicated line for bottling beer and beer-based mixdrinks. This line is a new dimension in bottling volume with an investment of 7 million Euros. Capable of bottling 36,000 0.5-litre bottles per hour, this line is a top end filling line for PET bottles. This enables an annual output of 500’000 hectolitre of beer and mixed drinks. The bottles are stretch-blow-moulded from preforms provided by Amcor PET Packaging, Belgium (Packaging-Technology, 2008).

2.1.1 Future and advantages of plastic beer bottles

The very high volume market of beer still sold in glass bottles is a target for the next years to come. As pure PET does not have sufficient gas barrier performance, developments in barrier polymers and barrier technology are providing potential solutions for a PET-based structure for bottles, cans and containers to replace glass. In the future new polyesters may be developed which could have the required gas barrier. Issues of cost, recycling and environment will need to be addressed. Various options involving coatings, multilayer structures incorporating high barrier polymers, scavengers and nanocomposites will continue to be tested for oxygen-sensitive products. A solution which meets the requirements of food and beverage manufacturers and consumers is close, but a single polymer material or technology may not satisfy all these requirements (Brooks 2002). With the arising public awareness for environmental issues and recycling, beer bottled in PET will have a bright future ahead.

2.2 Plastics used for bottles

Table 2-1 shows most of the plastics used for containers and barrier layers for the production of containers to pack a huge variety of products. The following sections describe the different materials, what they can be used for and which properties they have (Giles 1999).

PE	Polyethylene	PET	Polyethylene therephthalate
HDPE	High-density Polyethylene	OPET	Oriented PET
MDPE	Medium-density Polyethylene	RPET	Recycled PET
LDPE	Low-density Polyethylene	PVOH	Polyvinyl alcohol
LLPDE	Linear low-density Polyethylene	EVOH	Ethylene vinyl alcohol
PP	Polypropylene	PVDC	Polyvinylidene chloride
OPP	Oriented polypropylene	HNR	High nitrile resin
PVC	Polyvinyl chloride	PAN	Polyacrylonitrile
UPVC	Unplasticised polyvinyl chloride	PEN	Polyethylene naphthalate
PPVC	Plasticised polyvinyl chloride	EVA	Ethylene vinyl acetate
PS	Polystyrene	PVA	Polyvinyl acetate
PC	Polycarbonate		

Table 2-1: Abbreviations of materials used for bottles and barrier layers

2.2.1 Polyethylene (PE)

The different types of polyethylene can be distinguished by their density. The density is controlled by the degree of chain-branching and the crystallinity present in the polymer structure. The barrier properties of PE are comparable with those of polypropylene (PP), i.e. it is a good moisture barrier, but a poor oxygen barrier. HDPE exhibits the highest degree of crystallinity and is therefore the least permeable to moisture. Polyethylene is suitable for rigid and flexible packaging, although it must be combined with an oxygen barrier for certain applications.

2.2.2 Polypropylene (PP)

Polypropylene is highly crystalline, relatively cheap, colourless, odourless, has a high surface hardness and shows better rigidity and temperature resistance than PE. At low temperatures PP, becomes very brittle and can crack easily under impact. By co-polymerising of small amounts of ethylene the impact strength of PP can be improved.

Although it is impermeable to moisture, PP has limited use as monolayer because oxygen can readily permeate through it. For oxygen sensitive products it is used in combination with a good barrier layer such as PVDC or EVOH. (See 2.2.6)

2.2.3 Polyvinyl chloride (PVC)

Two types of polyvinyl chloride are available, unplacticised PVC (UPVC), which is rigid, and plasticised PVC (PPVC), which is flexible. Due to its high viscosity, UPVC can undergo degradation during processing as a result of excessive heating. It can be too brittle for certain applications, but this can be overcome by the inclusion of certain additives.

The continuing controversy concerning the toxic effects of PVC due to its chlorine content and the additives makes PET a more popular choice as a packaging material. PVC is still widely used in packaging, especially for the manufacture of bottles, where UPVC shows better clarity and barrier properties than PE.

2.2.4 Polystyrene (PS)

Polystyrene is mainly found in rigid applications, although not especially for beverage packaging. It is relatively cheap, has a good rigidity and strength, but poor impact resistance causing it to shatter easily. To reduce the problem, additives are available but extremely expensive. Thermoformed cups are often made from PS.

2.2.5 Polyethylene therephthalate (PET)

PET has some excellent properties such as a crystal clear clarity, high strength, toughness, and good shatter resistance. It also has a good strength-to-weight ratio. As a result of this it is under constant development to produce high performance grades that will suit more demanding applications. It is found in combinations with other polymers. A typical PET bottle consists of five layers, i.e. PET ¦ EVOH ¦ PET ¦ EVOH ¦ PET, where EVOH provides the barrier to oxygen. Inclusion of recycled PET into one layer is becoming more and more common practice to reduce the more expensive amount of virgin PET. The main use of PET is for bottling of carbonated soft drinks and mineral water.

2.2.6 Polymers with high barrier properties

- **Polyvinyl alcohol (PVOH)**

PVOH is considered to be the best barrier to gaseous substances. However, due to the presence of hydroxyl groups in the polymer chain, it has a tendency to absorb moisture. This dramatically reduces the barrier performance and as PVOH poses problems during processing, it is not considered a suitable choice for packaging liquid beverages.

- **Ethylene vinyl alcohol (EVOH)**

EVOH is formed by the co-polymerisation of PVOH and ethylene. The addition of ethylene makes the polymer impermeable to both gas and moisture and improves its processability. EVOH is a fairly new barrier material in the packaging industry and has now secured a niche both in the rigid and flexible markets. The ethylene content of EVOH ranges from 18-34% and at lower levels the gas barrier properties are comparable with PVDC, although permeability to moisture vapour increases. EVOH is usually co-extruded as a thin layer in combination with a moisture barrier such as PE. As EVOH can be recycled and incinerated, environmentalists favour EVOH in comparison to PVDC.

- **Polyvinylidene chloride (PVDC)**

Due to the high content of chlorine, PVDC exhibits the greatest barrier properties to both water vapour and gases. Vinylidene chloride is co-polymerised with various polymers at levels of 5-25%. The barrier properties benefit more from lower levels of co-monomers. The co-monomers used include vinyl chloride, methyl acrylate, ethyl methacrylate and butyl acrylate. One major drawback of PVDC is the emission of hydrochloric acid gas when subjected to high temperatures. Hydrochloric acid is highly corrosive and could create dangerous situations during processing. Therefore EVOH is a more favourable solution as a barrier. In packaging PVDC is normally used in very thin layers to reduce costs.

- **Polyamide MXD6**

MXD6 is commercially used nylon. It has better barrier properties than conventional nylon but its performance is still lower than EVOH as an oxygen barrier. It is tough, moisture sensitive and more suited to blending or co-extrusion.

- **High nitrile resins (HNR) or polyacrylonitrile (PAN)**

Acrylonitrile is co-polymerised with methyl acrylate in a ratio of 3:1 to form a high nitrile resin. HNR's are renowned for being impermeable to gaseous products. Moisture does not affect this feature. They can be used as monolayer in some applications, are reasonably priced, have good stiffness and high transparency. In the early 1970's HNR's were targeted as packaging materials for the carbonated drinks market and potentially for the beer market. In 1977, however, they were banned from being used for beverage packaging due to the residual acrylonitrile present in the bottle. The ban only went as far as food contact applications. Eventually, in 1987 the ban was upheld, as irradiation techniques could be used to bind the residual monomer, but by this time PET was firmly established as a carbonated drinks bottle. HNR or PAN are now widely used for food, cosmetic and medical applications.

- **Polyethylene naphthalene (PEN)**

Due to its superior performance as an oxygen barrier and its strength, PEN is being considered as a possible replacement for PET.

2.3 Barrier technologies for plastic bottles

2.3.1 Single layer blended polymer bottle

PET is polymerized from the two monomers PTA (terephtalic acid) and EG (ethylene alcohol), a di-alcohol. Replacing one of these two main ingredients of PET by another monomer new polyesters with different properties can be produced. The main advantage of polymer blends is the fact that preforms can be made on the same injection moulding machines as the pure PET preform. After finishing the bottle by blowing it into its final shape no further processing is needed.

2.3.2 Multilayer bottle from co-injected preform

No single plastic can be considered a perfect barrier material. For example, EVOH and nylon are impermeable to oxygen, whereas water vapour can readily pass through. On the other hand, polyolefin plastics, such as high density polyethylene (HDPE) and PP, form a good barrier to water vapour, but are poor oxygen barriers. For this reason, a multilayer structure is usually the preferred option to combine a barrier to both water vapour and oxygen (Giles 1999).

Three, five or more layers of different materials can be co-injected into preforms with better barrier properties. Barrier materials such as polymers and polyamides (Nylon) have a significant better ability than PET to either block carbon dioxide from leaving the bottle or oxygen permeating into the bottle. As these barrier materials are more expensive than PET, only the minimum required amount of barrier material is placed into the bottle walls. A typical multilayer co-injected preform incorporates PET as the main material, a barrier polymer and an adhesive polymer. It may also include recycled PET to reduce the amount of the more expensive virgin PET.

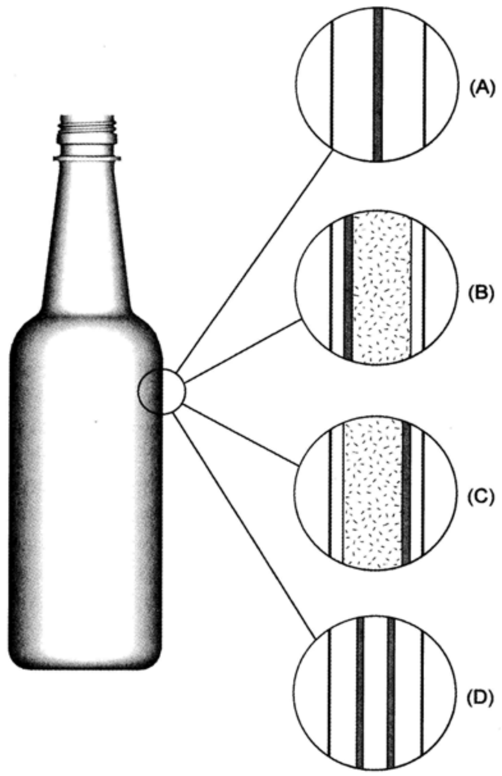


Figure 2-3: Wall sections of a multilayer drink container

A) three-layer wall with centered core

B) four-layer wall of barrier and recycled polyethylene terephthalate (RPET)

C) four-layer wall with barrier towards the outside

D) five-layer wall

2.3.3 Oxygen scavenger layer

A special type of oxygen barrier is an active material called scavenger. These scavenger materials actively absorb remaining oxygen from the headspace of a bottle and trap oxygen coming from the outside of the bottle through the walls before it reaches the oxygen sensitive beverages such as beer, wine, and fruit juice. Most of these scavengers are made of a polyester copolymer containing an iron or cobalt salt which actively binds oxygen. This copolymer is compatible with PET and does not delaminate (Brooks 2002).

2.3.4 Coated single layer bottle

To improve the barrier properties of finished PET-bottles an organic or inorganic coating can be applied to the bottle walls. Two different methods are used to apply the coating: either spraying a liquid organic coating material onto the outside of the bottle or using a plasma or vacuum deposition method for inorganic materials, like carbon or silica, onto either the inside or the outside of the bottle (Brooks 2002).

These internally or externally applied coatings improve the gas barrier properties of pure PET significantly and therefore enable an extended shelf-life compared to uncoated pure PET bottles. The coating of the bottles adds an extra step to the process of bottle making and needs more equipment to apply the coating onto the bottle wall.

2.3.4.1 Organic coatings

External organic coatings such as PVDC and EVOH emulsions have been used for many years. In the 1980's Metal Box developed the PVD coated 2 litre PET bottle for non-premium beers to give a two to three times improvement in shelf-life compared to PET alone (Brooks 2002).

Epoxyamine (called Bairocade by PPG) is another organic coating which gives an excellent gas barrier and is a clear coating suitable for packaging beer. This coating is not affected by humidity. The coating thickness is normally less than 10µm and the gas barrier properties for a coated PET bottle can be up to 20 times better than for a standard uncoated PET bottle.

Dow Chemicals has developed a thermoplastic epoxypolymer barrier, BLOX (blocks oxygen), an amorphous thermoplastic epoxy resin that combines the adhesive and durable properties of epoxies with the flexibility and processability of thermoplastics. This material can be used as a barrier layer in multilayer PET structures and as coating for bottles.

2.3.4.2 Inorganic coatings

The alternative inorganic coatings can be applied to the inside or outside of the PET bottle. The latest developments in plasma coatings use carbon and silica, which are applied in a high vacuum environment.

A process being developed by TetraPak, called Glaskin, plasma coats the inside of PET bottles with SiOx to produce a clear coating of 0.2μm thickness. This coating is said to improve the gas barrier properties at least two fold.

A further plasma deposition process, called ACTIS (amorphous carbon treatment on internal surface), has been developed by Sidel. The amorphous carbon is deposited onto the internal surface with a thickness of 0.1μm, using acetylene gas and microwave energy directed at the bottle. PET bottles can be produced with 30 times better barrier ability to oxygen and 7 times better barrier ability to carbon dioxide. The coating is clear but has a yellow tint, making it suitable for beer packaging. This technology offers one of the best available systems in approaching gas barrier performance and economic costs compared to glass and metal cans (Brooks 2002).

2.3.5 Barrier technologies for closures

In those cases where the closure is made out of plastic, oxygen and CO_2 will also permeate through the closure. In most cases, the loss of carbon dioxide through the closure is very small compared to that through the bottle walls and can be ignored. However, for small bottles and/or larger caps the percentage of carbon dioxide passing through the cap increases. The same applies to oxygen ingress for oxygen sensitive products. In those cases, it may be useful to fit the cap with a gas barrier; the easiest way to achieve this is to fit the cap with a liner of multilayer extruded sheet containing a barrier layer. In the case of oxygen sensitive products, an oxygen scavenger layer may also be included next to the product (Giles 1999).

2.4 Detrimental effects on the beer

- **Oxygen amount**

Beer is especially sensitive to oxygen. The amount of 1-5 ppm of absorbed oxygen already shortens the shelf life of beer (Giles 1999), whereas fruit juice for example tolerates up to 40ppm of oxygen without deteriorating effects.

The oxygen comes from different sources. Bottling the beer is the first occasion where oxygen can enter into the bottle and deteriorate the beer. After bottling, the permeable walls and closure are the next problem area where oxygen can get into the bottle.

- **CO_2 loss**

Another issue faced with beer containers is the loss of carbon dioxide through the bottle walls and closure. This requires high barrier properties of the bottle and the closure. Particularly with beer, these properties cannot be met by pure PET itself. Either barrier layers inside the bottle wall or bottle coating from the outside is needed to meet the high standards required for beer bottles to minimize CO_2 loss. Therefore, oxygen ingress is only part of the permeation design of a beer container. Carbon dioxide egress mainly defines the requirements of the barrier component of the barrier-scavenger unit (Brooks 2002). See chapter 2.5 for more details.

- **UV light radiation**

The influence of UV radiation can also have a damaging influence on the beer. Loss of odour and aroma are the most common effects of UV radiation. Recommendations for storage and transportation as well as coloring of the plastic reduces the detrimental influence of UV radiation significantly.

2.5 Multilayer preform technologies for beer containers

The total package O_2 threshold is typically in the 1-2ppm range and some beers are even below 1ppm. Thus, a beer package requires the use of scavenger components in both the closure and the container.

Oxygen ingress is only one part of the permeation design for a beer container. Carbon dioxide egress defines the requirements of the barrier component of the barrier-scavenger. When using any of the commercially available materials, the thickness of the barrier-scavenger layer is dictated by the requirements to minimize CO_2 egress rather than by the capacity of the O_2 scavenging component. For example, the thickness which would provide 150 days of CO_2 life has enough oxygen scavenging capacity to prevent O_2 ingress for more than 300 days.

The placement of the barrier-scavenger layer in the wall must balance several factors: oxygen desorption, CO_2 ingress vs. relative humidity of the barrier layer and cost. The scavenger layer is effective when located in the center of the wall or when biased toward the inside wall surface of the container. However, the high relative humidity of a layer close to the inside of the container increases the CO_2 permeability of the barrier layer by 50%. Therefore a layer biased towards the inside wall will decrease the CO_2 shelf-life by 14%, or conversely, require a 50% increase (from 5% to 7.5%) in barrier-scavenger volume to maintain the same CO_2 life as does a centrally placed layer. The bias-inside scavenger layer halves the already low O_2 desorption from 0.18ppm to 0.1ppm, but requires a thicker layer to meet the CO_2 shelf-life requirements. The cost of the layer thickness increase to

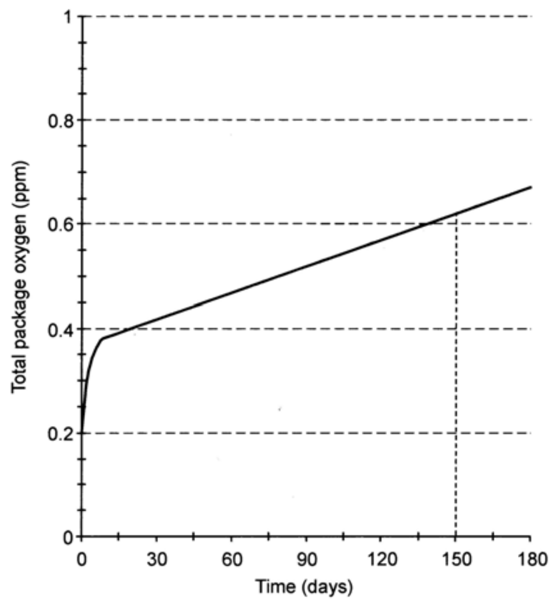


Figure 2-4: Total package oxygen over time for 500ml barrier scavenger container

achieve 0.08ppm desorption decrease adds about 3% to the price of a barrier-scavenger-enhanced bottle. Thus, the ideal structure to optimize the O_2 and CO_2 performance for a product such as beer is the central barrier-scavenger layer. For a typical scavenger-lined closure and 500ml beer bottle with 5% volume of barrier-scavenger centrally placed in the wall, the total package oxygen is plotted in Figure 2.4. The initial oxygen level is the sum of the O_2 entrained in the beer at the time of filling (typically 0.20ppm) and the O_2 desorbed from the PET (0.18ppm) The graph shows the desorption taking place in the first week after filling. For purposes of comparison, the shelf-life expiration time is shown at 150 days (Brooks 2002).

2.6 Overview of blow moulding processes for plastic container manufacturing

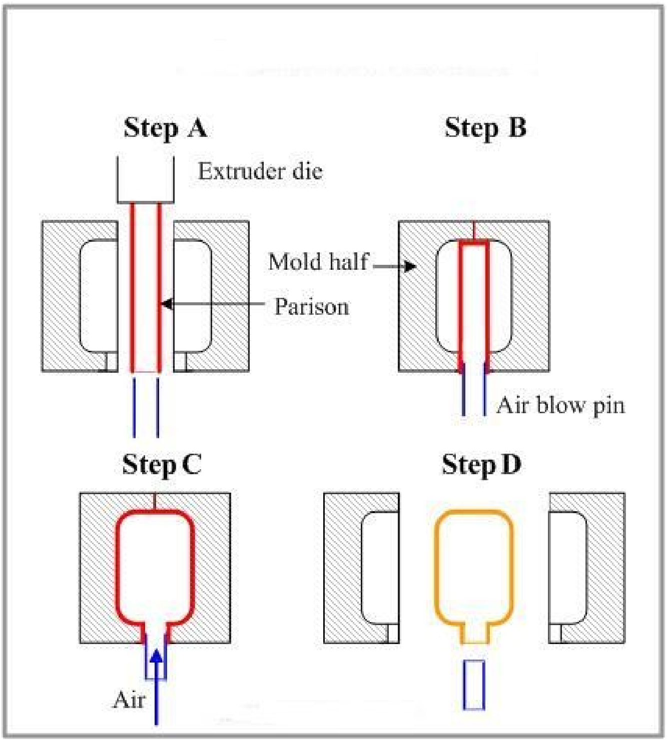
Introduction

Blow moulding is widely used for a big variety of containers and other products with all sorts of applications. Cosmetics jars, rubbish bins, milk bottles, oil cans, bellows, rain water tanks, air ducts, panels and soft drink bottles are just a few products which are produced with one of the specialized types of blow moulding. The following section gives an overview of the different blow moulding techniques and shows advantages and disadvantages and some example products that are made with the described process. A deeper view is given to the process of stretch blow moulding (SBM) which is mainly used for the production of PET-drink bottles.

The process of blow moulding can be divided into three main groups, which are Extrusion Blow Moulding (EBM), Injection Blow Moulding (IBM) and Stretch Blow Moulding (SBM). These three groups are distinguished by their manufacturing steps and equipment.

2.6.1 Extrusion blow moulding

For this type of blow moulding a parison is extruded from a mandrel or die unit. The parison then extends from the die unit until the needed length of the parison is reached. The two halves of the blow mould then enclose the parison into the mould cavity and pinch off the top part of the extruded tube. After pinching the mould is moved to the blowing station. A lance closes the bottom opening of the blow mould and enables pressurization of the inside of the parison. The parison



Equation 2-1: Steps of the extrusion blow moulding (EBM) process

gets blown into the finished shape and remains pressurized for some seconds in the water cooled mould until the plastic has cooled down enough to keep its new shape. The lance is now removed and the bottle is ejected from the mould and the process begins again.

Products: milk bottles, oil cans, automotive gas tanks, rubbish bins, water tanks

Advantages: fairly simple mould manufacturing, easy application of a multilayer die unit, suitable for large product weights, only a few limitations in container shape

Disadvantages: inaccurate neck and thread finishing, flash removing can be necessary, recycling and handling of removed flash needed

2.6.2 Injection blow moulding

Injection moulding is used to produce a molded parison, called a preform, prior to blow moulding it on the same machine. The preform is injection moulded onto a support pin or core. After this step the neck and thread are already finished and do not need any further processing. The outer part of the injection mould is then

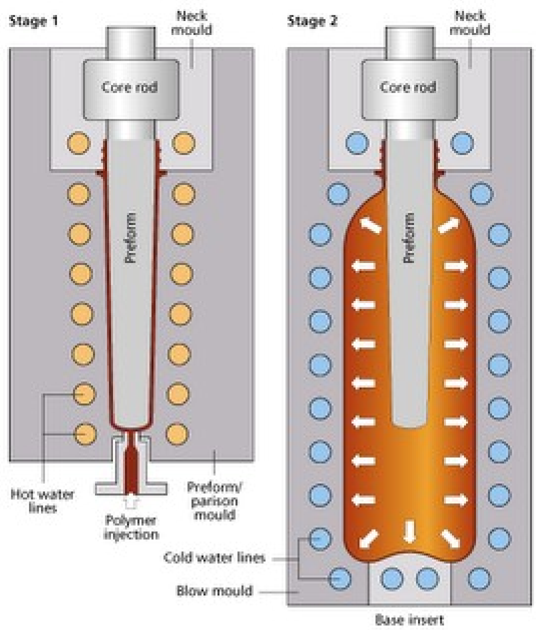


Figure 2-5: Two stages of injection blow moulding (IBM)

opened while the preform still remains on the support core. While the preform is still warm it is moved to the actual blow mould which encloses the preform. Through the support core air is applied to the inside of the preform to bring it into the final shape. After the cooling time has elapsed the blow mould opens and the finished container is ejected from the support pin.

Products: small cosmetics jars, soap bottles, tablet containers

Advantages: controlled and accurate dimensions of neck and thread, compact machine and storage of preforms is not necessary

Disadvantages: not suitable for large container, higher tooling costs, only suitable for nearly rotational symmetric containers

2.6.3 Stretch blow moulding

The process of stretch blow moulding (SBM) is quite similar to injection blow moulding with the main difference that the preforms are stretched in axial direction prior to blowing them into the final shape. This stretching in axial and radial direction during blow forming orients the polymer molecules and enhances impact strength, transparency, surface gloss, gas barrier and stiffness. The four commonly used plastics for this process are polypropylene (PP), polyvinylchloride (PVC), polyethylene therephthalate (PET), and polyacryonitrile (PAN) (Harper 2006). Stretching in axial direction prior to blowing also ensures that the preform is well centered inside the blow mould which enables an even wall thickness of the finished container and allows the production of bigger containers.

There are two different methods of stretch blow moulding: single stage SBM and double stage SBM. In the single stage SBM process the preforms are not cooled down after the injection moulding process, whereas in the double stage SBM process the preforms are cooled down to ambient temperature and then are reheated before blowing them into their final shape.

2.6.3.1 Single stage SBM

This process is executed on a machine similar to the injection blow moulding equipment. The preform is injection moulded inside the injection mould and then stays warm until it reaches the blow mould. The preform is then stretched with a rod in axial direction prior to blowing. The formed bottle cools down inside the mould and is ejected as soon as the plastic is solid.

2.6.3.2 Double stage SBM

The process of double stage stretch blow moulding is described in the following paragraphs. The difference to single stage SBM is the additional reheating step of the premanufactured preforms.

1. Injection moulding of preforms

The monolayer or multilayer preforms are injection moulded on specific injection moulding machines with multi cavity moulds, which can produce up to 96 pieces per shot. Similar to injection blow moulding the thread and the neck of the preforms are finished once they are ejected from the injection mould. The preforms are now stored until they are blown on an independent stretch blow moulding machine. This process also enables producers of bottles to buy in suitable preforms from a supplier as they need them. They simply blow the preforms without maintaining an injection moulding machine and worrying about the tricky process of preform manufacturing.

2. Preform heating

Reheating as the second step in the double stage SBM is often underestimated in its impact on the stretch blow portion of the process.

Process consistency and final container properties are determined by the reheating process of the preform. The goal is to apply a certain amount of heat energy to the preform combined with a temperature profile over the length and the wall thickness of the preform. Whatever is achieved in the reheating stage will only be fine-tuned by the process parameters of the stretch blow stage.

Key objectives:

1) increasing the energy level of the preform to stretch blow moulding temperature range (90-115°C)
2) temperature profiling along the preform axis to support the control of the wall thickness distribution (slight gradients)
3) temperature profiling through sidewall of the preform in order to achieve a higher temperature on the inside of the preform wall than the outside

Theses objectives are normally achieved by an infrared oven in which an array of lamps is adjusted in such a way that the longitudinal axis of the preform is fully covered in ideal conditions according to the preform shape. The preforms are being rotated and moved along this array to ensure a uniform temperature profile along the circumference. In addition to the infrared, convection is used by forced airflow to prevent the preform from getting burnt at the outside and enabling the infrared rays to penetrate the sidewall so that a uniform energy level can be achieved throughout the preform.

After heating, the preform is allowed to ‘equilibrate’ in ambient conditions with natural convection. This eventually causes a temperature gradient from a higher temperature at the inside to a lower temperature at the outside of the preform caused by a higher heat transfer coefficient on the outside than on the inside of the closed tube of the preform body. The larger the overall stretch ratio of the preform, the larger the difference needed between the inside and outside temperatures.

To control the axial temperature profile, either the length of the lamp or the distance to the preform can be varied. The distance of the lamp to the preform is typically accomplished by mechanically adjusting the lamps. The lower lamps are usually as close as possible to the preform as there is little or no neighbouring heatflow from other lamps. Additionally, the preform might have a taper in this section close to the neck with thicker wall dimensions. Heat is required in this section to start the stretch blow process and predetermine the overall material distribution in the bottle.

The middle lamps are usually moved a little further away from the preform. The close array of heating lamps in this section results in higher heat flow than at the ends. The middle lamps have a typical distance of 15-20mm.

Heating and equilibration times may have a considerable impact on the effectiveness of the reheating process. Practical experience shows that times between 15 and 25 seconds are appropriate to reheat preforms to their required temperature range and accomplish the profiling during this time period. Good results have been achieved in conventional high-performance heating systems with equilibration times of 40-60% of the heating times (Brooks 2002).

3. Stretch blow moulding of heated preform

The neck of the preform now acts as a counterpart for the handling tool of the preform in which it is now fed into the single or multi cavity blow mould station.

After placing the preform into the mould four subsequent phases follow:

1) axial pre-stretching
2) Pre-blowing and bubble propagation up to typically 90-95% of the final shape of the container
3) Final blowing to the residual shape of the container
4) Cooling of the stretch blown container in the closed mould

The longer the pre-stretching occurs, the more material will be transfered to the base end of the container. The earlier the pre-blowing starts, the more material will be expanded early enough to be pressed to the chilled walls and keeping it in that very section. A high pressure final blow of up to 40barg is applied to shape the final contour of the container which is then frozen through contact cooling on the wall of the cooled mould. Eventually the pressure is released form the container when the container can maintain its shape and dimensions.

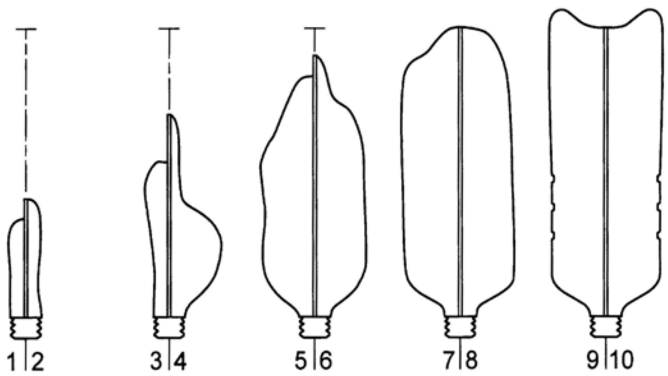


Figure 2-6: Steps of stretch blow moulding

Products: bottles for carbonated beverages, detergent bottles, hotfill containers for pasteurized fruitjuices and milk drinks

Advantages: enhanced physical properties, containers can withstand high pressures, have controlled and accurate dimensions of neck and thread, fine texture details on container surface are possible, clear and glossy surface

Disadvantages: higher machine and tooling costs, more complex process

3 Preform evaluation and bottle characteristics

Introduction

In this chapter the advantages of the buy-in of preforms from an external supplier are discussed. A brief description of some external preform suppliers follows in the next section. Finally, the desired properties of the preform and finished beer bottle are discussed.

3.1 Manufacturing vs. buy-in of preforms

One basic decision to be made was whether it is easier to produce the preforms at Massey University with the existing injection moulding equipment or to buy the preforms from an external supplier. Several reasons speak for the buy-in of preforms:

- The design and manufacturing of a complex mould does not need to be done and therefore saves a lot of time for the project
- Different preforms can be chosen according to the desired properties of the bottle and are not limited to the size of an injection mould designed at Massey University
- Co-injected preforms would not be able to be manufactured on the machinery and equipment at Massey University
- The purchase and storage of one or several resins for the production of preforms is not necessary
- A high and constant quality of the preforms can be assured over a long period of time when buying them from a supplier
- The manufacturing and design of the bought preforms is state of the art and keeps up with the leading technologies and knowhow developed for preforms

Therefore the manufacturing of a injection mould for preforms was not followed any further in this project.

3.2 Suppliers of preforms

The following section shows some of the suppliers of plastic materials and preforms which have been contacted during the evaluation of the preforms. See appendix A for the full list of addresses and contact details of the contacted companies.

3.2.1 Linkplas

This contact was provided by Mr. Tom Robertson, Senior Lecturer at Massey University. The small company located in Auckland, North Harbour, produces injection stretch blow moulded PET containers for food and drinks as well as for personal healthcare and toiletry applications. Linkplas celebrated its 10th anniversary in December 2007 and is still growing fast. In 2008, Linkplas was producing PET products 24 hours, 6 days a week. Linkplas especially focuses on the New Zealand market. One good example of their productrange is a 0.187 litre PET bottle for wine used by Air New Zealand on their long haul flights. With only 34gr per PET-bottle compared to 154gr of the heavy glass equivalent a saving of 120gr is made with each unit. Linkplas is specialised on other markets than the standard CSD bottles.

Linkplas replied the enquiries that they cannot provide preforms for our needs for a standard CSD bottle of 0.5 litres.

3.2.2 HP packaging

Located in Auckland, HP Packaging belongs to AMCOR Ltd., which is one of the biggest producers of PET and a range of general packaging solutions. The person I dealt with was Mr. Jeremy Bardsley Technical Manager of HP Packaging (NZ) Ltd. Again this contact was provided by Tom Robertson.

Unfortunately HP can not provide suitable preforms for beer bottles. Their preforms do not have good enough barrier properties for a extended shelf life. But Jeremy Bardsley could still give some interesting informations about bottle blow moulding techniques and closures.

3.2.3 Visy Plastics Ltd.

Visy is an Australian based company with branches in New Zealand and the USA. Visy employs around 8000 people in the packaging and recycling sector and produces all sorts of packaging materials. The Technical Sales Manager of New Zealand, Mr David Wheller, has got his office in Palmerston North. Visy is also not able to supply suitable preforms for beer bottles. But David Wheller could give further contacts of preform suppliers overseas. Mr. Wheller mentioned that co-injected multilayer barrier preforms are nowhere produced in the pacific area close to New Zealand.

He was able to provide a lot of information about the manufacturing of blow moulding machines and the safety aspects arising with the high pressurized air used in the industrial applications of stretch blow moulding.

For the basic blow tests Mr. Wheller provided 100 pure PET preform with a weight of 29 grams produced from Visy Australia. Those preforms were of great value for the basic testing of the mould, the heating and stretching of the preforms. See chapter 4 for more detailed information about the tests carried out with the wooden blow mould.

3.2.4 Resilux

David Wheller from Visy Plastics Ltd. provided the contact of Resilux NV in Belgium. Resilux is specialised in the production of PET preforms and bottles. It is the only company so far which can supply suitable preforms for the production of beer bottles. To reach the desired barrier properties these preforms are made in multilayer technology to reach the needed shelf life.

Mr Nick Bartlett is Product Manager of Barrier Technologies at Resilux and he answered a lot of questions concerning the processing of preforms and the achievable shelf-life.

3.2.5 TSL plastics

TSL is mainly using single stage machines and therefore cannot offer preforms. Ian Armstrong from TSL also mentioned that they do not manufacture their own closure but instead buy them from an external supplier.

3.2.6 Owens of Illinois

Owens of Illinois is acting as one of the biggest glass and plastic container manufacturers in the United States. Owens of Illinois might be a good supplier of preforms and closures, but has not yet been contacted as Owens of Illinois has sold all its plastic and closures businesses in the Asian Pacific area.

3.3 Suppliers of closures

3.3.1 CSC plastics

CSC as an Auckland based company is a specialist in plastic injection moulding, blow moulding, design and toolmaking. CSC plastics also do not produce closures themselves.

3.4 Conclusion of the preform and closure evaluation

Overall the contacting of all the different companies took quite some time. All the companies listed have been contacted by email once or twice but only a few of them replied on the email enquiries. Where there was no reply on the emails the companies have been contacted by phone which most of the time resulted in better informations and more detailed answers.

It got obvious that the multilayer technology for producing preform with high barrier capabilities is applied nowhere in the pacific area. Resilux, who is based in Belgium (Europe) was one of the only companies which is actually producing preforms in multilayer technology.

Further on, a lot of the smaller New Zealand based companies concentrate on the niche market in New Zealand and therefore have a very specialised product range. Typical for the globalised world a few global players such as Amcor, Owens of Illinois or Visy are capable of producing a big amount of units in order to be competitive and thus make the life for the small players tough.

3.5 Properties of the finished beer bottle

3.5.1 Sizes of commercially sold beer bottles

The following table 3-1 shows a list of different beer brewers and the bottle sizes they use. The list is not complete and should only give an overview of common bottle sizes on the market of PET beer bottles.

Company	Bottle sizes
Heineken	500ml, 660ml, 1000ml
Carlsberg	375ml
Hoslten	375ml
Tucher	375ml
Martens	500ml
San Miguel	1000ml
Bitburger	500ml
Union-Brewery	430ml, 1800ml

Table 3-1: Beer bottle sizes of different breweries

The sizes of the different beer bottles range from 375ml to 1800ml. The smaller sizes up to around 600ml are intended for a single user and are therefore preferably used at events, festivals and in stadiums. In contrast, the bigger bottles are intended for households and occasions where a bottle will be shared between more than one person.

3.5.2 Size and color

The size of the finished bottle will be around 500ml which is a compromise of different influences of bottle making and storing beer. A bigger bottle size is not favorable due to the bigger size of the blow mould and thus increased clamping forces. Bigger bottles are normally left open longer until they are consumed. This leaves the beer longer exposed to atmosphere and makes it dull. Smaller bottle sizes are not suitable in regards of the bottle surface to volume ratio. Small bottles have therefore a reduced shelf life compared to bigger bottles.

To prevent beer from getting deteriorated by UV-rays an amber or green coloured plastic should be used. This also distinguishes the beer from other CSD.

3.5.3 Shape

The shape of the produced bottles can be chosen freely within certain limits. To make sure the bottle can withstand a high pressure which can occur from the second fermentation of the beer after bottling the cross section of the bottle should be close to a circular shape. Special attention should be given to the bottle base. Again the pressure from the inside is the defining parameter for its shape. A petaloid base or concave base (champagne base) is ideal to withstand the inside pressure and enables the bottle to be placed vertically without any additional part added to the base. The actual manufacturing of the wooden mould also has to be taken into consideration when choosing the shape of the bottle.

The bottles produced on the Massey Bottle Blow Moulding Machine shall be different to the existing standard glass and PET bottles. A bottle shaped like a mug or a pint with a relatively big diameter is a good shape to distinguish the Massey Bottle from other beer bottles. In order or keep the axial stretch ratio within the limits the diameter cannot be bigger than the height of the bottle.

3.5.4 Closure

Two different closure systems are readily available for PET bottles. The crown cap as used on most glass beer bottles and the screw on cap mainly used on CSD bottles. Both systems are tamper proof and well established. The screw on cap has the big advantage that no special tools are necessary to apply the cap onto the bottle. Especially for the low numbers of bottles used at Massey an easy and simple closure system is wanted. The screw on cap is therefore used as closure system for the bottles produced on the Massey Bottle Blower.

3.6 Supplied preforms from Visy Plastics Ltd. Australia

The preforms supplied from Visy are designed for the use in blow moulds which create bottles of around 500ml. Figure 3-1 shows the section of one of these preforms. The neck of this preform is a standard PCO1810 neck. It is a single layer pure PET preform which weights 29 grams. The preform has a total length of 108mm and an outer diameter of 23mm with a wall thickness of 3mm.

Figure 3-1: Section of the Visy preform (29gr. pure PET)

3.7 Final shape and dimensions of the bottle

With all the features and properties discussed above, the final shape of the bottle is ideal with a cylindrical body, a conical neck and a champagne base. The Volume of the bottle should be 500ml. The total volume of the bottle needs to be bigger in order to have some air volume at the top of the bottle. Therefore, 50ml were added to the total volume of the bottle which makes a total of 550ml.

According to Mr Nick Bartlett from Resilux, an radial stretch ratio of $\lambda_{rd}=4.0$ and an axial stretch ratio of $\lambda_{ax}=2.0$ is normally applied for this type of preform and the usage of the bottles for CSD, beer or carbonated water. Multiplying the middle diameter of the preform (20mm) with the given stretch ratio of 4.0 gives a diameter of 80mm. Figure 3-2 shows the dimensions of the bottle and the preform and the formulas, which have been used to calculate the stretch ratios.

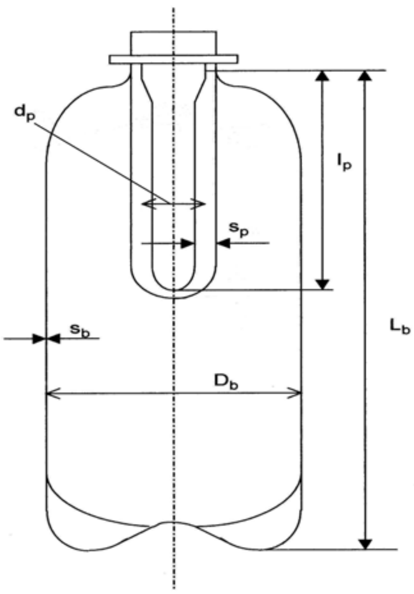


Figure 3-2: Dimensions of preform and bottle to calculate stretch ratios

$$\lambda_{ax}=\frac{L_b}{l_p} \quad (3.1)$$

$$\lambda_{rd}=\frac{D_b}{d_p} \quad (3.2)$$

λ_{ax} = axial stretch ratio

λ_{rd} = radial stretch ratio

L_b = length of blown bottle

l_p =length of preform

D_b = diameter of blown bottle

d_p = middle diameter of preform

With the diameter of the cylindrical part at 80mm it is bigger than a standard 0.5L CSD or beer bottle in order to create the desired mug-style look. The champagne base was estimated with a section cut of a sphere with an outer diameter of 50mm and a height of 10mm to be subtracted from the volume of the cylindrical part of the bottle.

The conical shoulder part then is the connection from the neck diameter of 22mm to the bottle diameter of 80mm. Having set all these dimensions, the height of the neck and the height of the cylindrical part are remaining to adjust the volume of the bottle. The conical neck part was was set to 15mm, which left the cylindrical height at 100mm. Table 3-2 summarizes the dimensions of the bottle which will be produced on the Massey Bottle Blower.

	Diameter	**Height**	**Volume**
Neck cylindrical	22mm	27mm	10ml
Bottle cylindrical	80mm	100mm	502ml
Champagne base	50mm	10mm	-14ml
Neck conical	22 – 80mm	15mm	54ml
Total			**552ml**

Table 3-2: Final dimensions and volume of the bottle

4 Blow forming tests

Introduction

Prior to starting the design of the blow moulding machine a set of basic tests have been carried out with the preforms provided by Visy Australia. The tests are done to find out how how the heating up of the preforms is done best and how the heated preforms behave when forming them with different moulding techniques. In particular the feasibility of forming the preforms with a lower pressure than generally used in industrial machinery. The following section explains the used equipment and after that explains the general setup and parameters. The conclusions at the end of the chapter the directly lead to the design of the Massey Bottle Blower.

4.1 Equipment used for the tests

4.1.1 Heating of preforms

Prior to blow forming the preform needs to be heated up to its glass transition temperature. For pure PET this temperature ranges from 342 – 388K (69 – 115°C). PET will melt at a temperature of 538K (265°C). To get the preform heated up to the glass transition temperature several methods have been tested. The following section describes the equipment that has been used to heat up the preforms.

4.1.1.1 Boiling water

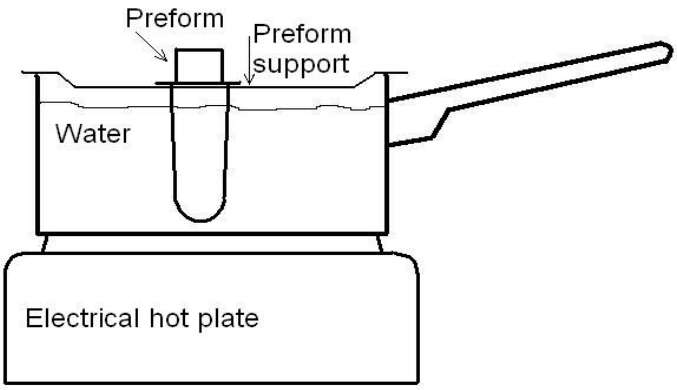


Figure 4-1: Heating of preform immersed in hot water

For many of the tests the heating of the preforms was done with hot water. The used equipment is an electrically heated cooking plate with a pot on top. The preform is kept in place with a clamp and is then immersed into the water hanging upside down. The clamp lies on a frame which keeps the preform at a defined position in the pan. The level of the water inside the pan can then be adjusted to heat up the desired area of the preform. For most of the tests the water level was adjusted to just reach 5mm below the collar of the preform.

4.1.1.2 Aluminium tube with heating tape

This type of preform heater consists of an aluminium tube with an inner diameter 4mm bigger than the outer diameter of the preform. The inner contour of the aluminium tube has a taper at the lower end in order to keep the gap between the tube and the preform equal over the length of the preform. The other end of the tube is cylindrical and hence does not cover the half spherical tip of the preform. On the outside of the aluminium tube an electrically heated tape normally used for pipe trace heating is winded around the whole length of the tube. This tube was then installed on a linear guide to be able to move the hot tube up and down without touching the preform.

To control the temperature of the alloy tube a thermocouple is placed into a small hole in the alloy tube to get an accurate feedback of the actual temperature.

The measured temperature is then fed back into a temperature controller box which controls the power of the heating tape to keep the set temperature constant. See chapter 4.1.1.4 for more details about the heater box and the controller.

Figure 4-2: Aluminium heating tube installed on a linear guides

4.1.1.3 Infrared heating elements

The most common heating method used on commercial equipment is either with ceramic or glass infrared heating elements. Those elements normally stand upright side by side along a conveyor where the preforms pass by and get heated up. The temperature of the elements is kept at fixed level to make sure the preforms always get heated up to the same temperature.

Intensive research on the Internet finally brought up Hislop & Barley in Auckland who distributes all kinds of infrared heating elements. Evan Seaman from Hislop & Barley offered me to do tests at the companies laboratory to find out which wavelength is the most efficient and thus which surface temperature of the elements gives the best heat transfer. For this purpose four of the 29gramms pure PET preforms were sent to Auckland for the tests. Unfortunately these test have never been carried out even after several enquiries by phone at Hislop & Barley.

4 Blow forming tests

In order to be able to make test here at Massey University two of the FSR/2 elements have been ordered. They arrived within two days after ordering and the tests could be done. See chapter 4.2.1 for more details about the method of heating the preforms with the IR-elements.

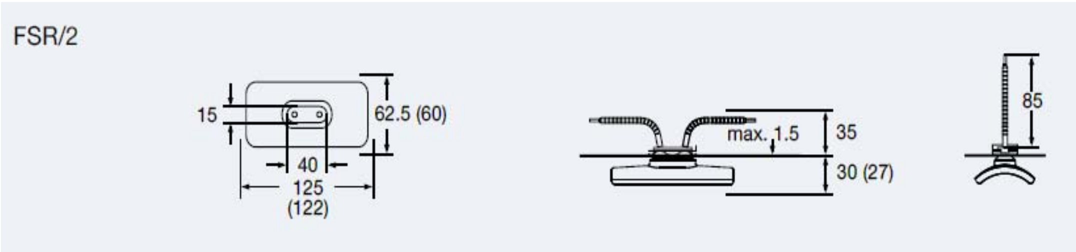


Figure 4-3: Dimensions of Elstein FSR/2 IR-heating element

The control of the temperature of these IR-elements was done with the same heater control box as used for the aluminium tube. The thermocouple used for the feedback of the temperature was placed on the surface of the elements.

4.1.1.4 Heater box and temperature controller

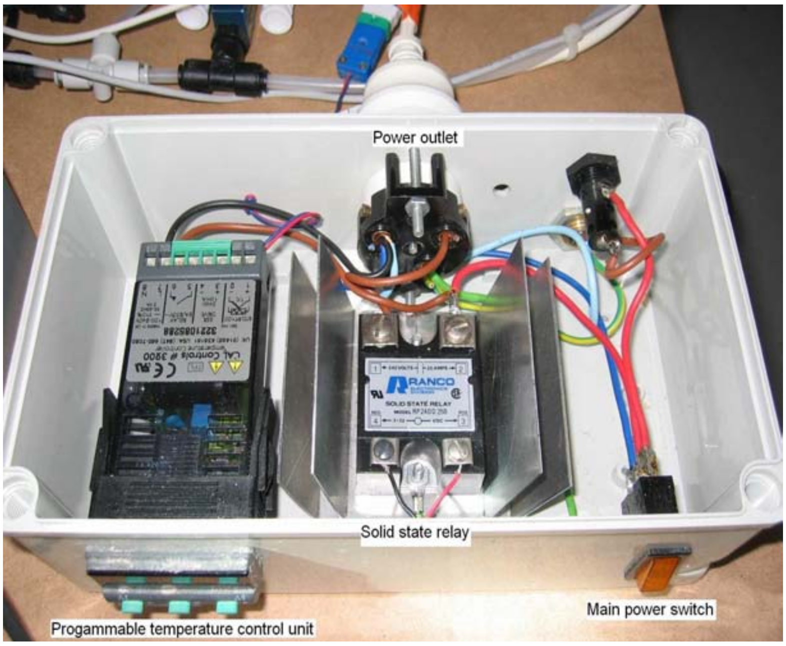


Figure 4-4: Inside of heater control box

The heater control box basically contains a programmable temperature control unit and a solid state relay which switches the power supply to the heating elements. The temperature is controlled by pulse width modulation of the electrical power going to the heating element.

The actual controller is an industrial temperature control module from CAL-Controls. The type used in this application is the CAL 3200 autotune temperature controller. After switching on the controller the actual temperature measured by the thermocouple appears on the display and the controller starts working. The heater box does not need any further manipulation. The controller settings are preset with standard values. However, for best response and controlling of the temperature either autotuning or manual setting of the parameters is necessary. The electronic manual for the temperature controllers of the 3200 and 3300 series is on the CD-Rom attached to this thesis.

4.1.2 Forming of preforms

4.1.2.1 Vacuum forming machine for plastic sheet

For the tests where vacuum is applied to the mould the vacuum forming equipment at the Industrial Engineering Laboratory at the Riddet Building at Massey was used. This machine is equipped which a vacuum pump which is able to create a vacuum of approx. -78kPa. The vacuum pump is connected to a tank which will be evacuated and acts as a reservoir. The valve which is between the tank and the opening of the machine table can then be activated to evacuate the cavity of the mould.

4.1.2.2 Aluminium clamp for free blowing of the preform

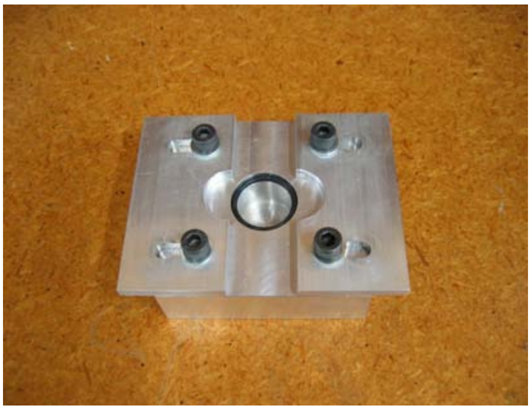


Figure 4-5: Open clamp

Figure 4-6: Closed clamp with preform in place

To make blow tests with heated preforms without mould an aluminium clamp was designed and manufactured. The clamp has got a pocket in the middle of the square base plate where the preform is positioned. To secure the preform, two sliding plates on top of the base plate hold down the collar of the preform into the base plate and apply pressure onto the o-ring to seal the preform against the base plate. A hose connector on the side of the base plate enables the inside of the preform to be pressurized with air.

4.1.2.3 Fabrication and features of the wooden mould

The mould is a stacked MDF wooden block with one vertical parting line which splits the mould into a left and a right half. The size of the mould is 140x140x192mm.

To facilitate the machining of the inner contour of the cavity the mould was split into a lower half which forms the base and the lower cylindrical part of the bottle and into an upper half which contains the upper cylindrical part of the bottle, the tapered shoulder and the neck with the pocket for the preform holder. The upper and lower half are made of stacked and prehollowed MDF plates which then could be machined on a lathe.

After finishing the upper and lower part of the mould the two pieces were glued together to a complete mould. The block was then split with a saw into a right and left half. The inner part of the mould is vented to the bottom side of the mould by a total of 14 holes of 1.5mm and 2mm in diameter where the vacuum can be applied to the cavity. Stripes of foam seal the the split face to ensure that there is no ambient air leaking into the evacuated area of the mould. Due to the fact that MDF is quite porous, the outer faces of the mould had to be coated with a varnish to seal the mould against unwanted leaking of ambient air into the mould cavity when applying the vacuum. During the tests the mould was kept together with two adjustable clamps.

Figure 4-7: Split wooden mould halves with preform in place

The preform holder can be secured with two aluminium L-bars on top of the mould. The two bars slide over the preform holder once it is in place and secure it against lifting off the mould.

The preform is screwed into the round MDF clamp which has a cap of a standard PET bottle to hold the preform. This preform holder seals the top part of the mould and also enables pressurization of the preform. This is achieved with a plastic screw-in fitting for a standard 6mm PVC hose.

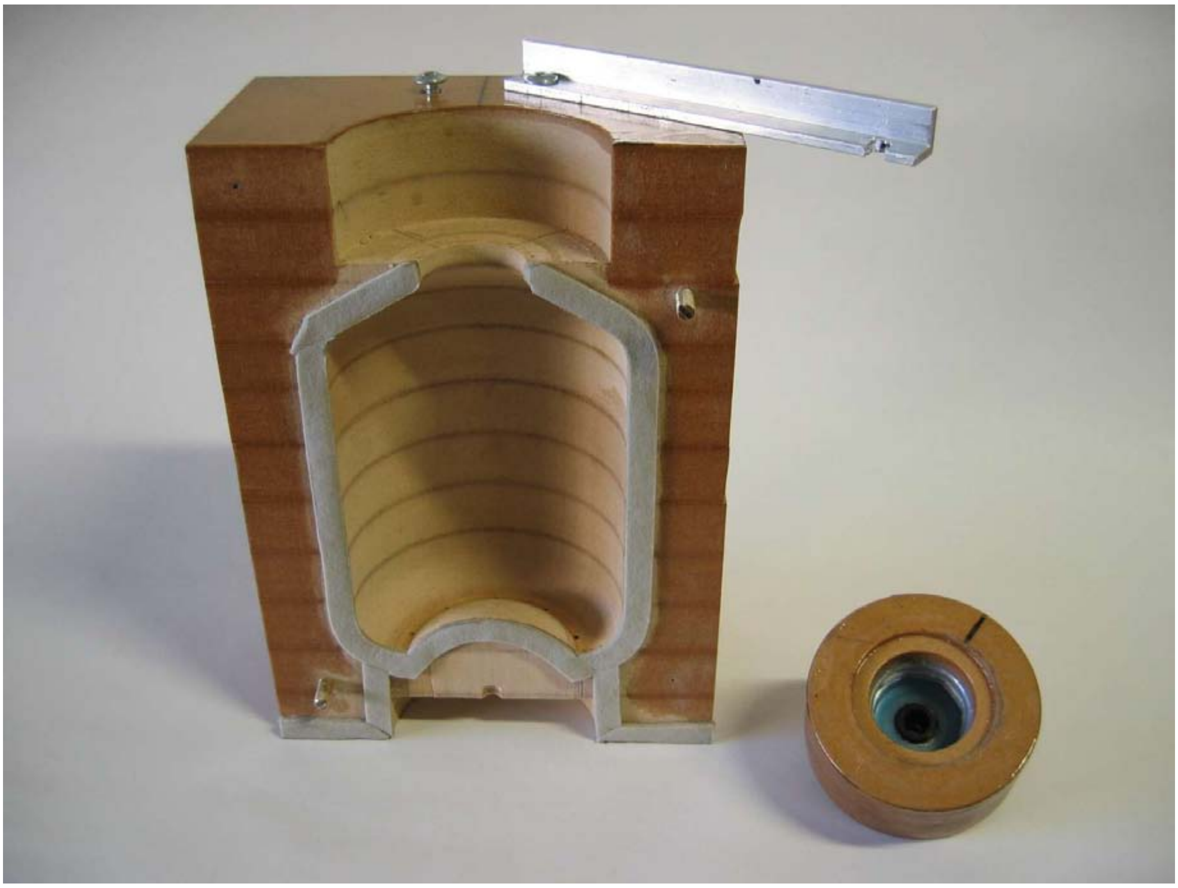


Figure 4-8: Finished wooden mould with seal stripes, center pins and locking bars

4.2 Techniques and methods used for the tests

This section explains the different techniques used for the test with the Visy pure PET preforms. The results of the correspondent tests follow the explanation of each of the test procedures.

4.2.1 Heating of preforms

- **Heating in boiling water**

To estimate the time needed to heat the preforms thoroughly the temperature on the inside wall of the preform has been measured with a thermocouple placed 60mm down from the opening of the preform. The inside wall reaches 93°C after 4 minutes after immersing the preform into 96°C hot water. Figure 4-9 shows the development of the temperature of the inside wall of the preform. For most of the blow tests the heating time of the preforms was therefore chosen with 4 minutes.

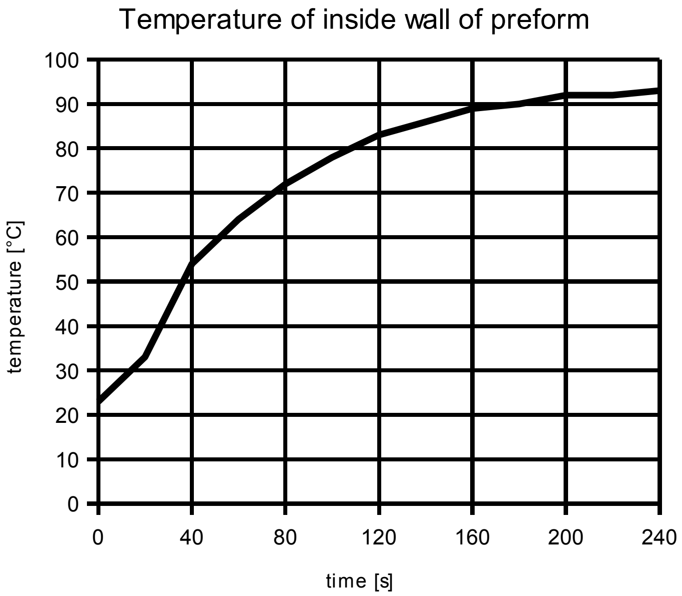


Figure 4-9: Temperature development of preform inside wall during heating in hot water

- **Heating inside hot aluminium tube**

The temperature of the alloy tube was set to 140°C. This is the maximum temperature the heating tape is allowed to be operated at. The heated tube was then slided over the preform. During heating the temperature of the outside wall of the preform was checked every minute with an infrared thermometer with laser targeting. To enable the infrared thermometer to read the actual temperature of the clear glossy preform areas on surface have been coloured black with a permanent marker. It took around ten minutes to reach an outside wall temperature of around 98°C. Due to gravity or uneven heat transfer from the aluminium tube to the preform the preform bended slightly and touched the surface of the alloy tube. In the areas where the preform touched the alloy it immediately crystallised and got white. The crystallisation can not be reversed and makes it impossible to inflate and expand the crystallised area of the preform.

- **Heating with infrared ceramic heating elements**

The two ceramic IR-heating elements are placed left and right of the upright standing preform. The preform is sitting on an turntable which ensures a constant rotation of the preforms and therefore an even temperature profile on the circumference of the preform.

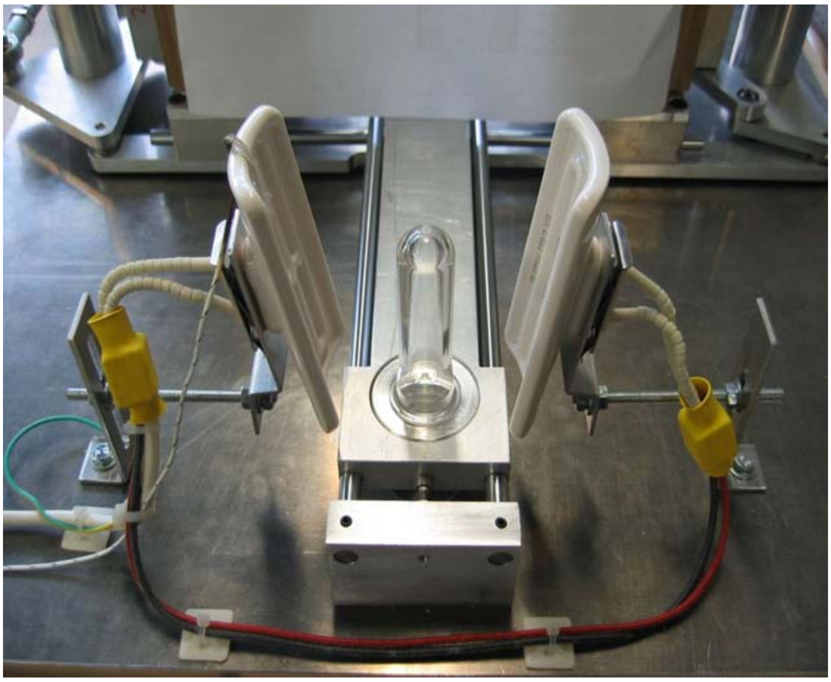


Figure 4-10: Infrared heating elements

Firstly the maximum possible surface temperature of the IR-heating elements was measured. The elements were therefore powered without the control box directly from a 230V plug. The surface temperature reached a maximum of 540°C on the upper half of the element.

To determine the most efficient surface temperature of the heating elements the time was measured until the preform placed between the IR-elements overheats and turns white. With a distance of the lower ends of the IR-Heating elements of 100mm and a surface temperature of 500°C the preforms got overheated after approximately 140 seconds.

4.2.2 Results and conclusions of preform heating methods

- **Boiling water**

This method was used for most of the basic blow tests. This method is simple and can easily be reproduced. A further advantage is the clear border between the heated area of the preform (immersed in water) and the non heated area (above the water). By simply changing the level of water in the pan the border can be changed. What showed to be the biggest disadvantage is the remaining water drops on the outside surface of the preform after heating. The preform had to be gently wiped dry to remove all the water in order to get a smooth bottle surface. See also Chapter 4.2.6 for the influence of remaining water drops on the preform. Further on, the maximum temperature to be reached with this method is limited by the fact that water can not be heated up to more than 100°C at standard atmospheric pressure at sea level.

- **Aluminium tube**

The method of heating the preforms inside a hot aluminium tube was not further looked at as it took too long to heat the preforms and hence reach a reasonable cycle time. Further on, the deflection of the preforms seemed to happen randomly and most likely could not be overcome easily.

- **IR-heating elements**

This method proved to be the most efficient and easy method for heating up of the preforms. Different to the heating in hot water, the preforms need to be rotated during the heating up as the IR-elements do not equally cover the surface of the preform. The positioning of the elements relative to the preform needs to be tested and adjusted for optimum temperature distribution. Tests with the IR-heating elements facing parallel to each other showed that the tip of the preform reached higher temperatures than the lower area close to the neck. Therefore the elements needed to be placed in a diverging position in order to have a bigger distance of the elements to the preform at the upper part of the preform.

4.2.3 Procedure of vacuum forming into wooden mould

This test was carried out with a preform screwed into to the wooden preform holder of the mould and then heated in boiling water. Then the preform was inserted into the wooden mould and the vacuum was applied to the cavity of the mould. The vacuum level at start was at -78kPa and dropped then to -60kPa after 6 seconds and to -20kPa after 60 seconds from start. After 2 minutes the vacuum valve has been closed again.

4.2.4 Results of vacuum forming

The preform remained in the same shape as it was before applying the vacuum to the mould. As later tests will show with positive pressure from the inside the pressure difference between the inside and the outside of the preform need to be much higher than the 0.8bar which can be achieved by applying vacuum to the outside of the preform.

4.2.5 Procedure of blow forming without mould

For this test the preform was installed into the aluminium clamp. The installed preform was then heated in boiling water. The first few preforms were blown with remaining water drops on the outside. For the later tests the water has been dried off gently with a paper towel. The clamp with the preform was then either put upright on a table or hanging down sitting on top of a cardboard box. For both positions a cardboard box was put around the preform to prevent hot plastic pieces flying around and causing burns in case the preform would burst.

With the pressure control valve on the air supply the pressure was increased gradually until the preform began to expand. The amount of air blown into the preform was controlled by hand with the ball valve on the air supply line. The preforms were blown to a size of around 0.5litres. When this size was reached the valve was shut. The pressure inside the blown preform was maintained until the preform was cold and solid. The remaining air inside the blown container was released to atmosphere through the second valve between the supply line and the clamp.

4.2.6 Results of blow forming without mould

These tests showed interesting results which explain some typical behaviour of the preforms.

The minimal required pressure to inflate the heated preforms is at around 4.1barg. The highest pressure is needed right at the start when the preform has its lowest volume with the thickest walls. As soon as a small bubble has formed the necessary pressure to inflate the preform is lower.

Tests #2 and #3 showed clearly the effect of remaining water drops on the preform. On all the spots where there was water remaining the wall thickness of the blown container was substantially thicker than on the dry areas and they showed lumps and streaks on the surface. The water drops cooled down the preform surface to a temperature where the stretching of the plastic needs more force and therefore the wall remains thicker than on the areas where there were no water drops. See appendix B for further details and data about the tests.

The effects of cumulated heat in the alloy clamp from the previous heating and blowing tests was clearly visible on container #3. The elevated temperature of the aluminium clamp created a higher temperature in the area close to the neck of the preform. This higher temperature distorted the collar and neck and allowed the preform to be inflated to its biggest diameter right after the neck.

Containers #4 and #5 proved that drying off the water drops create a smooth and even wall of the blown container. The aluminium clamp has been cooled to room temperature beforehand which leaves the neck and collar undistorted.

4.2.7 Procedure of blow moulding into wooden mould with pressurized air and vacuum

The preform is screwed into the wooden clamp which also holds the fitting for the connection of the plastic hose to inflate the preform. For the tests with the wooden mould the preforms have been heated in boiling water for most of the trials. The water has been wiped of gently with a paper towel before inserting the clamp with the preform into the closed mould. Immediately after placing the preform in to the mould and securing the clamp in place the vacuum and/or the pressure to the preform were applied. For the different trials the sequence of applying pressure and vacuum has been changed to see the influence of vacuum and pressure to the finished bottles. Test without applying vacuum to the mould cavity have been carried out as well. After the inflation of the preform the pressure was maintained for approximately one minute to enable the PET to cool down. The pressure was then released from the container into atmosphere and the mould was opened.

During the test the following adaptations have been made to the process:

- A pipe which is reaching from the wooden clamp to the tip of the preform to guide the air. The pipe has an outer diameter of 8mm and an inner diameter of 5mm. The idea of the extended tube is to create an air jet to stretch and force the hot preform in vertical direction.
- An aluminium rod is used instead of the wooden clamp which is inserted into the hot preform which stretches the preform to the full length to the bottom of the mould. An O-ring then seals the rod against the neck of the preform and enables the inflation of the preform through the holes in the alloy rod.

4.2.8 Results of blow moulding into wooden mould with pressurized air and vacuum

The comparison of the bottles from test #6 and #7 show the effect of the increase of the pressure from 5barg (#6) to 6barg (#7). The shape of bottle 7 is closer to the desired outcome than bottle 6. Also the difference of the brimfull volume shows the better forming of bottle 7.

For the tests #7 to #13 the inflating pressure was 6 barg. The variation of the sequence of applying pressure or vacuum first did not make any obvious difference to the shape of the blown bottles. What can be seen on all the bottles is that the sprue of the preform never lines up with the center at the base of the mould. Also the orientation of the deflection of the sprue was distributed randomly around the base of the mould. The distance of the sprue to the center of the mould varied between 8mm to 26mm. All the bottles are not completely formed and always lean to the opposite side of where the sprue got deflected when putting them upright on an even surface.

The only preform heated inside the alloy tube was #14. What can be seen on this bottle is the effect of the crystallisation during heating where the preform touched the aluminium tube. This white patch of crystallised PET became completely solid and could not be stretched or blown at all. On this sample the deflection of the sprue is even bigger than on the other samples. Further on, a circular area around the sprue of around 35mm remained thicker. This was most likely caused by the lower temperature of the half spherical tip of the preform. This lower temperature was caused by the bigger air gap of the tip of the preform to the hot aluminium tube which made the heat transfer less efficient.

The samples #15 to #18 and #23 to #26 were made with increased pressure up to 8.5 barg. Again the existence of vacuum on the outside of the preform did not make a noticeable difference to the shape of the containers. The sprue was deflected from the center of the mould similar to the tests carried out earlier on. What could be measured was the slightly higher brimful volume of some of the bottles compared to the previous tests.

For the tests #23 to #26 the focus was on the heating of the preforms in boiling water. The water level inside the pan was altered and the preform was rotated during heating up. What could be seen is that the water level has an impact on the forming of the neck. Similar to the free blow tests, a distorted neck and collar could be seen with a higher water level.

An air jet was used for the bottles #19 to #22. This modification also did not have the desired effect on the shape of the bottles. The shape and volume was again the same as in the tests #15 to #18. What could be seen is a thicker wall at the area where the tip of the air pipe ended up close to the half spherical end of the preform. The concentrated airflow out of the pipe cooled down the area on the preform which made the PET less stretchable and therefore remained thicker.

The final tests (#27 and #28) were made with an alloy rod which was inserted into the preform prior to blowing. This stretching aligned the sprue almost perfect to the base of the mould. This resulted in completely blown upright standing bottles with a nicely formed champagne base. The cold aluminium rod formed a lump of unformed PET at the base of the preform on bottle #27. For the next test the rod has been heated in hot water as well which formed out the base correctly with no remaining lump.

Figure 4-11: Mould half with blown bottle and aluminium rod in place

4.2.9 Pressure testing of blown bottle

To ensure that the bottles can withstand the pressure created from an eventual second fermentation inside the bottle a pressure test has been carried with the bottles. The bottles have been tested for their burst pressure. The bottles have been filled with water and then pressurized until they failed.

The bottles are placed into the aluminium clamp used for free blow forming tests (Chapter 4.1.2.2). To create the pressure a small bore hand pump with a pressure gauge was used. The tested bottles could withstand a pressure of at least 8.5barg. The expected pressure during the second fermentation is approximately 3barg so the bottle can withstand almost three times the pressure occurring during a second fermentation inside the bottle. Figure 4-12 shows the champagne base were the bottles failed.

Figure 4-12: Detail of a bottle after burst pressure testing

4.3 Discussion and conclusions of the tests

The first step of the blow moulding process, the heating of the preforms, has been done either with the preform immersed in water, covered with an aluminium pipe or in between two infrared heating elements. It became clear that the heating of the preforms is best done with infrared heating elements. It is the easiest to control of the three methods and the preform stays dry. What needs to be ensured is that the preform is rotated during the heating up. The positioning of the IR-elements relative to the preform is important in order to get a uniform temperature profile over the length of the preform.

The second step of the blow moulding process the actual forming of the preform was done in four different ways:

- Forming without mould
- Forming inside the mould with vacuum applied to the outside

- Forming inside the mould with pressure from the inside and vacuum applied to the outside

- Forming inside the mould only with pressure from the inside

The tests without mould showed a minimum pressure required to inflate a hot preform of around 4.1barg. Using only vacuum on the outside of the preform proved to be unable to form the preform. The testing even showed that the presence of vacuum on the outside of the preform does not have a significant influence on the forming of the preforms. To overcome the deflection of the tip of the preform the only solution was a rod inserted into the preform before blowing. The fact that a pressure of 4.1barg is already sufficient to inflate the preform greatly reduces the necessary precautions when dealing with air at pressure above 8 barg and proves that blowing bottles with a low pressure is possible. The low pressure used for forming had the effect that miniature faults and surface features of the mould do not get transferred onto the finished bottle. This on the other hand makes it impossible to create fine design features on the outside of the bottle wall.

This leads to the final conclusion after the tests that the blow forming is done best with the preforms heated between IR-elements and the blowing then is assisted with a stretching rod and then pressurization of the preform is done from the inside without the presence of vacuum on the outside of the preform.

5 Design of bottle blow moulding machine

Introduction

With all the experience and results from the basic blow forming test discussed in Chapter 4.3 the actual design of the Massey Bottle Blower could be started. This chapter covers all the aspects of the design and manufacture of the bottle blower.

5.1 Basic principle and function

The principle of the Massey Bottle Blower is basically the second step of the commercially widely used double stage stretch blow moulding process. The bought in preforms need to be heated up to the desired temperature they then will be moved to the blow mould and get inflated to their final shape. The finished bottle will then be ejected and stored until filling.

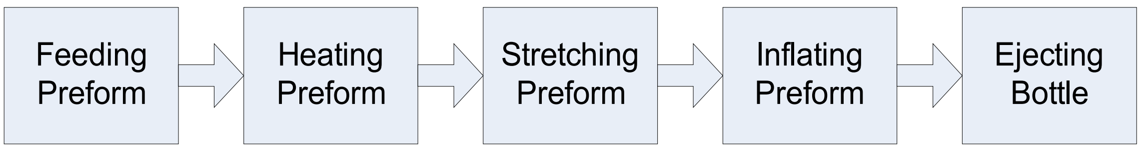


Figure 5-1: Basic function of the Massey Bottle Blower

This figure pictures the above described steps which will be executed by the bottle blower.

5.2 Design necessities

The design necessities are a summary of the results from the basic blow tests. Additional requisites are the logical consequence of set features that the Massey Bottle Blow Moulder should have e.g. the capability of blowing different bottle shapes with different moulds. The following list shows all the wanted features of the Massey Bottle Blow Moulder which had to be considered during the design phase of the Blower. More details on the separate necessities can be found in the following section where the design is described more detailed.

- A toggle mechanism for the opening and closing of the mould halves which reduces the holding forces during the blowing of the bottles to a minimum.
- The pivot points of the toggle mechanism shall be at a fixed position in order to have a rigid setup which can withstand the occurring forces.
- A central support for the sliding mould brackets to have a rigid support for the guide rods.
- At least two heating stations are necessary in order to have a reasonably low cycle time.
- The undercut of the champagne base requires the movement of the core relative to the blow mould.
- The infrared heating elements need to be positioned at a diverging distance at the top of the elements in order to have an even temperature profile of the preform.

5.3 Mechanical Design

The process of finding the right mechanical principles to create all the wanted functions of the bottle blower took several iterations until the final design was found and the 3-dimensional model could be made with the Solidworks CAD software. The use of Solidworks with the ability to create a complete assembly of the whole machine was a great help in order to avoid conflicting parts and dimensions. Further on, the data of the 3-D model was processed to manufacture parts on the CNC mill which reduced the amount of time to write machine programme code remarkably. This chapter will describe all the mechanical functions in detail and explain why the used principles have been chosen.

5.3.1 General layout

For easy operation the Bottle Blower is installed on a skid which carries the Bottle Blower on top and leaves enough space underneath for the controls and pneumatic equipment. The mould split is vertical so that the mould halves slide parallel to the baseplate. The baseplate also holds all the bearings and guides and is therefore the main part which holds all the assemblies in correct place to each other and distributes the forces between them.

The stretch pin moves up and down on a slide from underneath the baseplate. Therefore the preform will stand upright with the neck pointing down towards to the skid.

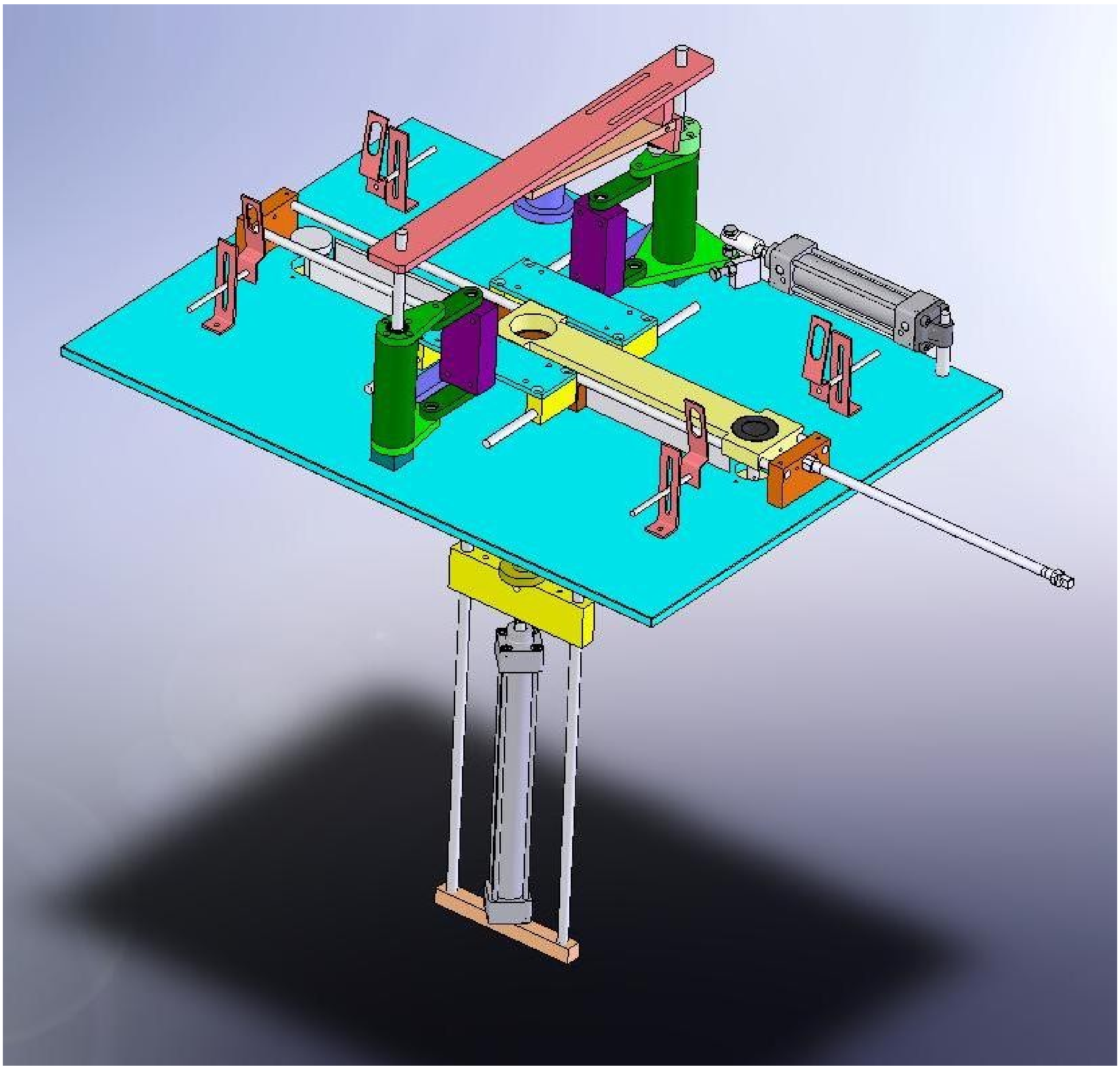


Figure 5-2: 3-D assembly of the Massey Bottle Blower without blow mould and heating elements

As the heating of the preforms will take a considerable amount of the cycle time, two independent heater stations are designed to have always one preform heated up while the blowing of another preform is in progress. The two heating stations are placed on each side of the mould. The two holes in the slide which move the preforms back and forth line up with the mould center in the middle and one of the heating stations. By simply moving the preform slide back and forth the heated preform is fed to the blow mould and at the same time the finished bottle gets removed from the mould.

5.3.2 Skid and baseplate

The baseplate is an aluminium plate 800 x 600 mm and 15 mm thick. This is the main support and fixation for all the other components of the blower. Aluminium was chosen because of its light weight and its ability to be machined easily. The baseplate is placed on two hammerlock shelves which are connected together at their longer side. The top of the shelves is covered with two MDF boards on which the aluminium baseplate is fixed.

5.3.3 Preform handling

To ease the handling and movement of the preforms, an aluminium ring is used to hold the preform. The neck of the preform is put into the ring manually before feeding it into the heater station The ring stays on the preform until the bottle is finished. The ring and the preform always stays at the same horizontal position during the whole process. The movement of the preform is done with a slide which holds two of the aluminium rings on either side and moves it over sliding tracks from the heating stations to the mould and back. The linear movement of the slide is maintained by two cylindrical rods with a diameter of

Figure 5-3: Preform placed into aluminium ring

10mm on each side of the slide. To ensure that the slide stops at the exact position adjustable stop screws are installed on end of the slide.

The slide is moved by a pneumatic cylinder with the cylinder rod directly attached to the slide. As the performs with ring weighs not more than approx. 100 grams the force of the pistons just needs to be big enough to operate the slide and slide the aluminium ring over the tracks. Given the distance of 300mm from the heater station to the centre of the mould the stroke of the cylinder needs to be 300mm at least. A double acting cylinder from SMC pneumatics with 10mm bore and 300+1 mm stroke was chosen for this task. The rod diameter is 4 mm. See parts list in the appendix for more details about the used parts.

5.3.4 Preform heating

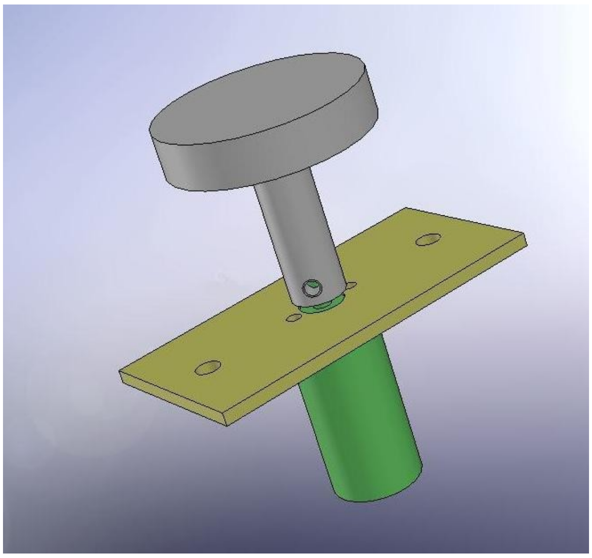


Figure 5-4: DC-gearhead motor with attached turntable

To ensure an even temperature profile on the circumference of the preform it needs to be rotated during the heating phase. This is achieved with a gear head motor which drives a turntable like platform where the preform with the aluminium ring is placed. The surface of the turntable is on the same horizontal level as the track where the aluminium ring then slides back and forth to and from the mould. To ensure that the aluminium ring with the preform rotates freely the whole in the preform slide has a slightly bigger diameter than the ring. The turntables do not need to be stopped before the movement of the preforms.

The upper end of the IR-heating elements is tilted back to to even out the temperature difference caused by thermal convection of the hot air moving upwards on the surface of the elements. (Figure 4-10) The IR-heating elements are kept in place with two aluminum sheet metal mounts and can be fully adjusted in height and distance relative to the preform with threaded rods and nuts. This allows maximum freedom in adjusting the position of the IR-elements position to achieve the best possible heating up and establish an even temperature profile.

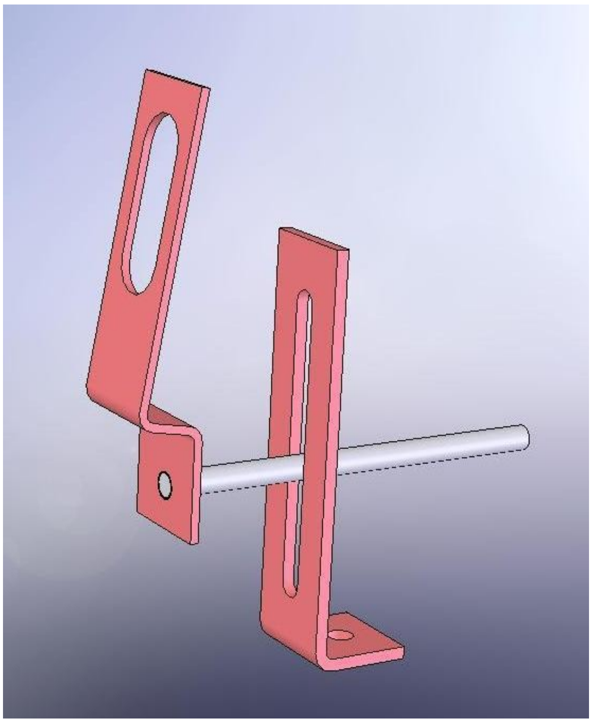


Figure 5-5: Heater support assembly

5.3.5 Mould support, movement and core lifting

To ensure linear movement of the two mould halves during opening and closing of the mould two cylindrical rods of 10mm diameter hold a carriage onto which the mould halves are attached to. The carriage directly slides on the two rods with no further bearings. The two rods are fixed in the centrally placed block between the two guide rods of the preform slide.

The actual opening and closing movement of the two mould halves is carried out by a toggle on each side of the mould. A toggle has the big advantage of locking itself when fully stretched, thus leaving no clamping force to the pneumatic cylinder when the mould is closed. The clamping force is transferred into the levers and fixed axes of the toggle. To ensure a rigid and stable toggle the two axes are not adjustable in distance. This means than in case of a different mould size needs to be installed the distance between the end block of the toggle needs to be adjusted with shims. All the connections of the plates, levers and connecting rods are realised with single row ball bearing to minimize wear and friction of the mechanism.

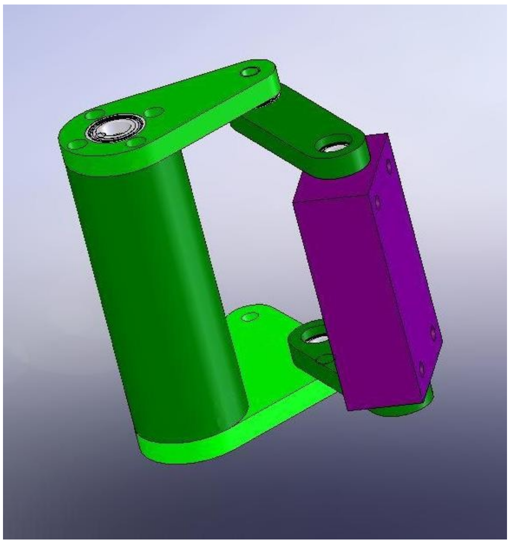


Figure 5-6: 3-D model of the left toggle lever assembly

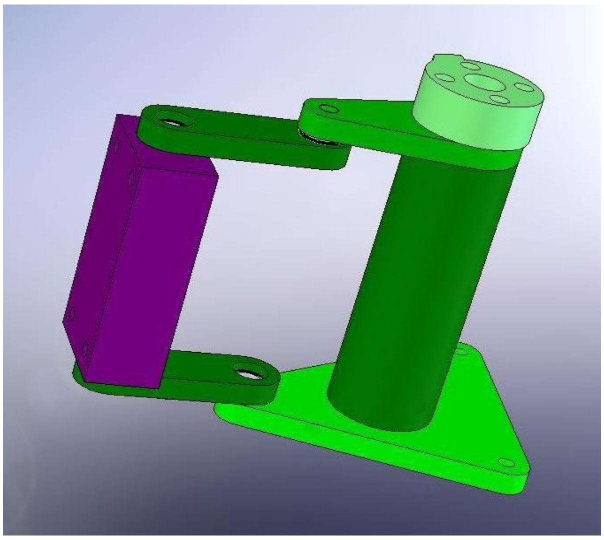


Figure 5-7: 3-D model of the right toggle lever assembly

The pneumatic cylinder of the toggle mechanism rotates the plate on the bottom of the right hand toggle around the axis on the far side of the baseplate. The force gets conveyed to the opposite side of the toggle mechanism via a connecting rod which lies just above the base plate. The torque from the two plates on either side of the mould are transferred to the top lever through a pipe on either side rotating the upper lever of the toggle. A block attached to the end of the toggle levers then directs the force in to the mould halves.

The driving double acting pneumatic cylinder for the toggle is from SMC pneumatics with a bore of 32 mm and a stroke of 100 mm the rod has a diameter of 12mm.

5.3.6 Core lifting

As the bottle is designed with a champagne base to withstand the pressure from the inside, the mould contains an undercut which requires the lifting of the core prior to removing the finished bottle from the mould. A lever which is positioned on top of the mould holds the core of the mould in place when the mould is closed. During opening of the mould a cam sitting on top of one the rotating toggle levers lift the core up from the base of the finished bottle. When the two mould halves are closing again, the lever drops down by gravity and core is placed into the right position again. As soon as the mould is closed the core is positively fitted between the two mould halves during inflating of the hot preform.

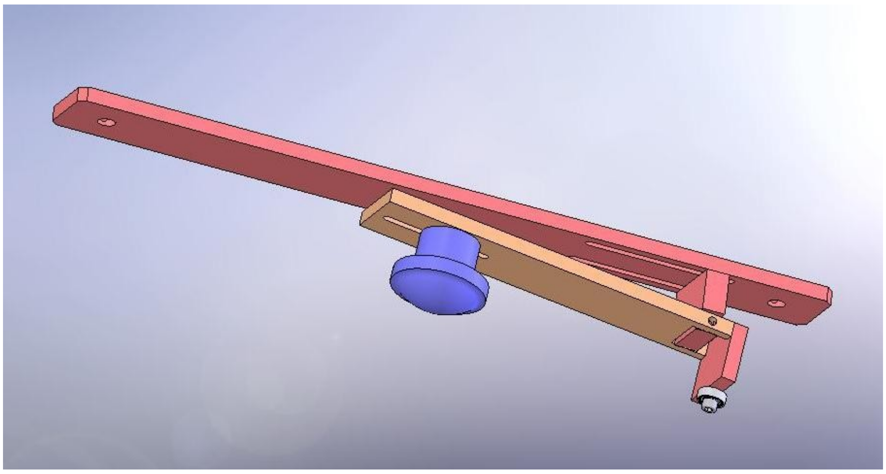


Figure 5-8: Leverage designed to lift the core out of the blow mould

5.3.7 Preform stretching

Stretching of the preform is necessary to keep the tip of the preform centered inside the mould and to get a uniform distribution of the material. As soon as the preform is placed in the center and the mould is closed the stretch pin extends from underneath the base plate and stretches the hot preform to almost the full length of the finished bottle. The fully extended stretch pin fits into the neck of the preform and is sealed airtight with an O-Ring. The holes in the stretch pin allow then the inflation of the preform.

The stretch pin is mounted on a slide which is guided by two vertical guide rods. These guide rods are attached to the baseplate and hold the support for the pneumatic cylinder on the bottom end. The double acting cylinder from SMC with a bore of 32mm and a stroke of 250mm then drives the slide with the mounted stretch pin up and down. The air to inflate the preform is fed into the slide and gets then passed through a hole into the stretch pin. With two stop screws on top of the slide the position of the fully extended blow pin can be adjusted.

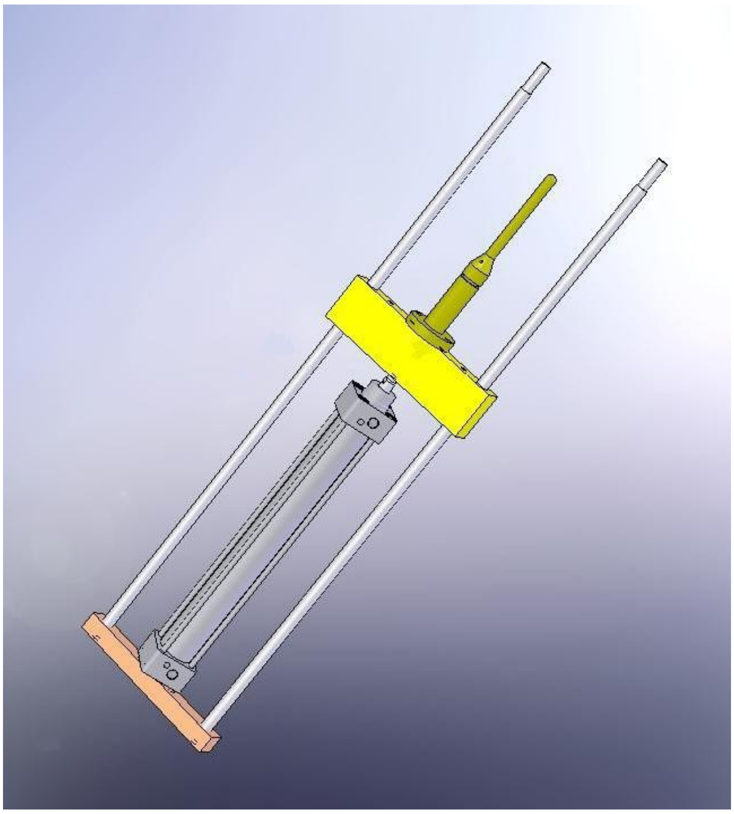


Figure 5-9: 3-D model of the stretch pin assembly

5.4 Electrical Design

5.4.1 Infrared heating system

Two Elstein IR-heating elements of the type FSR/2 with a power of 375 Watts are installed at each of two heating stations. All the four installed elements are connected in parallel to the heater control box described in Chapter 4.1.1.4. The four elements are of the same type so the surface temperature of only one of the elements is measured with a K type thermocouple and fed back into the controller. The heater control box is powered by single phase 230 Volts from the main power supply.

The controller of the heater has been auto tuned according to the operating instructions of the controller. See Table 5-1 for the settings that have been found and programmed with the autotune function.

Setting	**Value**	**Unit**
Proportional band	28	-
Integral time	0.7	min
Derivative time	3	sec
Derivative approach	1.5	-
Cycle time	2.9	sec
Temperature setpoint	500	°C
Sensor Type	K	-

Table 5-1: CAL 3200 Heater controller settings

5.4.2 Actuators and Sensors

All of the solenoid valves for the control of the pneumatic cylinders are operated with 24 Volts DC. The solenoids get their power directly from the interface driver card. Chapter 5.4.4 describes the interface in detail.

The gearhead motors which rotate the turntables require 12 Volts DC. These motors had to be wired in parallel to ensure that each motor gets the same voltage in order to have them rotating at the same speed. Therefore the motors are driven from a 12V voltage regulator (IC7812) . Which is again directly fed from the Interface driver card.

All the limit switches at the cylinders are reed contact switches which are activated by the magnet mounted on the piston of the pneumatic cylinders. The interface driver card feeds the limits switches with 24VDC which switches the inputs of the USB interface when the switch is activated.

For the 24VDC power a 24VDC/50 Watts (230V/50Hz) switch mode power supply is installed.

5.4.3 Control system for the bottle blower

To control and operate the Massey Bottle Blower a suitable and convenient control system had to be chosen. The main task of the control system for the Bottle Blower are:

- reading digital inputs signals
- carrying out logic operations
- delaying and timing signals
- writing digital output signal

Functions such as PID-controller, analog signal operations or analog mathematic calculations are not needed for the control of the Bottle Blower. The following three different systems are able to do the above listed tasks and already existing at Massey University:

- Programmable logic controller
- Micro controller with driver card
- National Instruments USB interface with driver card

Out of these three possibilities the National Instruments USB interface has been chosen mainly because I did not had any experience with this device and also wanted to learn more about LabView which is used for operating the USB interface. Further on, the use of the LabView Interface made the design of a interface driver card necessary which was something new too. This gave me the possibility to learn more about Altium Designer for the drawing and design of printed circuit boards (PCB). The design of a interface driver card also required calculations and design of basic electronic circuits.

5.4.4 LabView USB interface and design interface driver card

To be able to drive solenoid valves with the National Instruments (NI) USB interface an interface driver card is necessary. The NI USB interface is not capable of driving solenoids directly. Further on, the input signals needed to the galvanically isolated from the interface to prevent it from damage. The following sections describe the NI USB interface in more detail and design of the interface driver card.

5.4.4.1 Features of National Instruments USB Interface

Figure 5-10: National Instruments USB interface 6501

The National Instruments USB-6501 is a portable digital input/output device, providing reliable data acquisition and control at a low price. With plug-and-play USB connectivity, the NI USB-6501 is simple enough for home / academic applications, but robust and versatile enough for laboratory / industrial applications (NI website).

The device has got 24 programmable Input/Output channels. Each of the channels can either be assigned as an input or output Channel. The NI interface is powered from the USB power supply of the connected computer. See table 5-2 for a list of the technical data off the USB-6501 interface.

Number of Channels	24 DIO
Timing	Software
Logic Levels	TTL
Maximum Input Range	0..5 V
Maximum Output Range	0..5 V
Input Current Flow	Sinking, Sourcing
Programmable Input Filters	No
Output Current Flow	Sinking, Sourcing
Current Drive (Channel/Total)	8.5 mA/65 mA

Table 5-2: Part of the technical data of the NI USB-6501 Interface

5.4.4.2 Design of printed circuit board

The USB interface has a total of 24 input/output channels. The total of 24 channels has been divided into 7 output signals and 12 input signals. Main reason for this is the price and availability of integrated circuits (IC) for the board.

- **Input circuit**

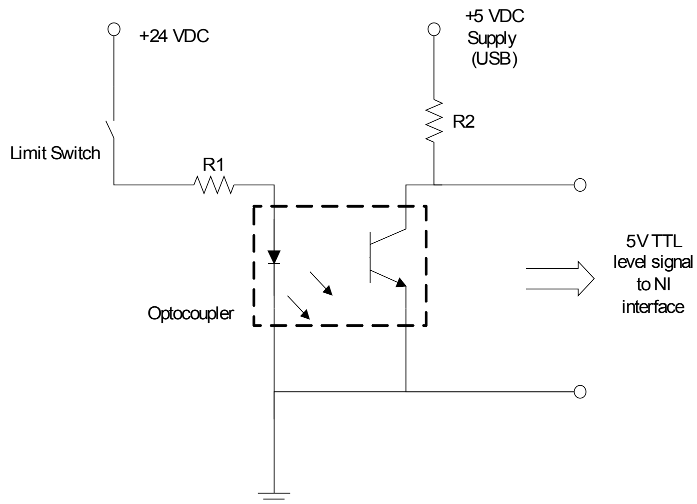


Figure 5-11: Schematic of a single input circuit with galvanic separation

The input circuit consists of an optocoupler and two resistors to limit the current of the optocouplers circuits. Figure 5-11 shows the schematic of one of the 12 input circuits.

As soon as the limit switch is closed the 24VDC get fed into the IR-diode of the optocoupler. With R1 at 4.7kΩ the current through the diode is limited to approximately 5mA. Once the diode inside the optocoupler is ON the photosensitive transistor becomes conductive and connects the 5VDC to ground. Resistor R2 has been dimensioned for a current through the collector emitter path of the transistor of 2mA which is obtained with a resistance of 2.5kΩ. Hence a closed limit switch results in a LOW TTL signal and therefore to a boolean 0 signal in the software. The signal then can be inverted in the LabView programme.

- **Output circuit**

The output circuit of the interface driver card is amplifying the TTL signal from the NI USB interface to be able to directly energize the coil of a solenoid valve. The integrated circuit 7-channel Darlington array has the freewheeling diode already built in which simplifies the output circuit. Figure 5-12 displays the schematic diagram of one output circuit on the interface card.

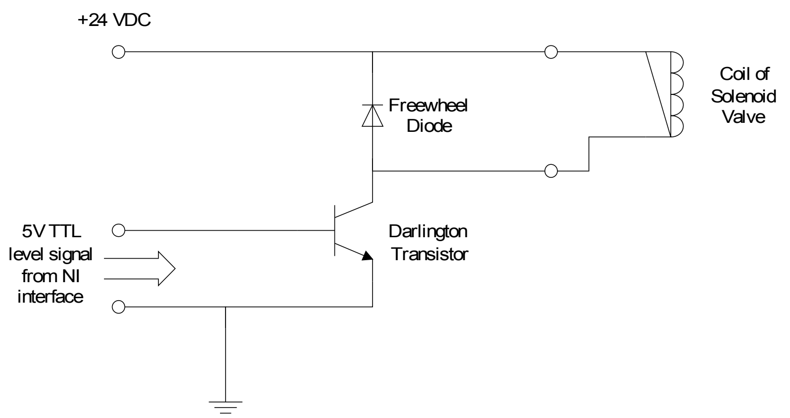


Figure 5-12: Schematic of a single output circuit with Darlington transistor

The TTL signal from the NI USB interface is directly fed into the Darlington transistor array. As soon as the TTL signal is high the transistor becomes conductive and the current flows through the coil which activates the solenoid valve. If the TTL signal goes back to 0 volts again the transistor isolates the solenoid from ground and the residual energy stored in the coil gets dissipated over the freewheel diode inside the transistor array.

- **Printed circuit board of the interface driver card**

On the printed circuit board (PCB) there are now three 4-channel optocouplers K847PH and one Darlington transistor array IC ULN2003A. Additional to these IC's there are three decoupling capacitors and one diode to prevent damage to the interface card case of wrong polarity of the 24VDC power supply. Twelve of the resistors are of SMD type, mounted on the track side of the PCB where as the other twelve wired resistors are placed on the part side of the PCB. The NI USB interface gets directly plugged onto the 34-pin header on the interface driver card. Wire screw terminals then allow the connection of all the cables of the limit switches, solenoid valves and gearhead motors. All the parts could be fitted onto a 100mm by 150mm single layer board. Figure 5-13 shows the finished PCB viewing onto the track side. The figure 5-14 shows the schematic diagram of the PCB interface card.

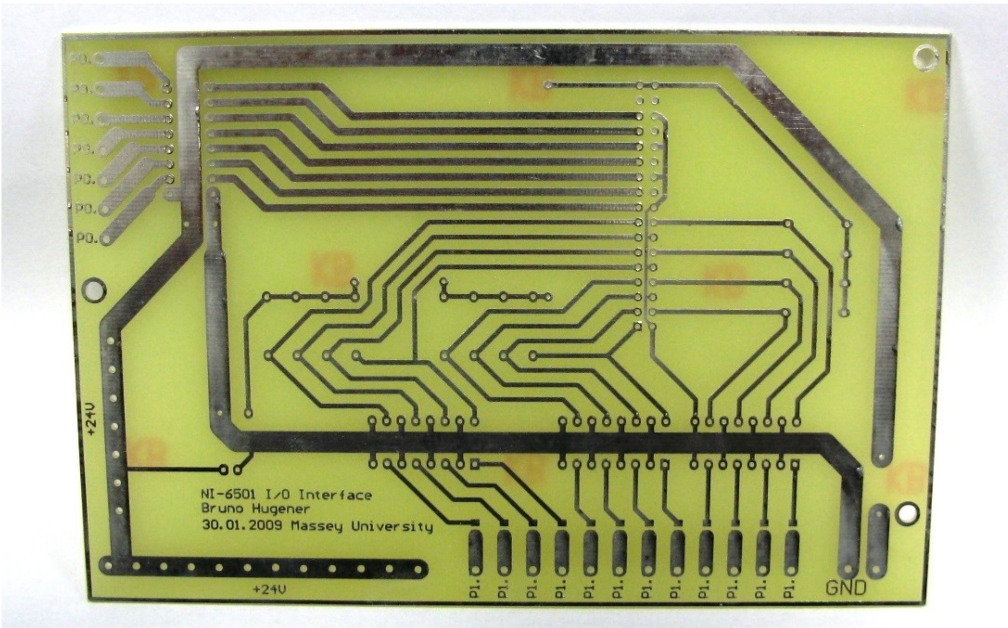


Figure 5-13: Track side of the interface driver card circuit board

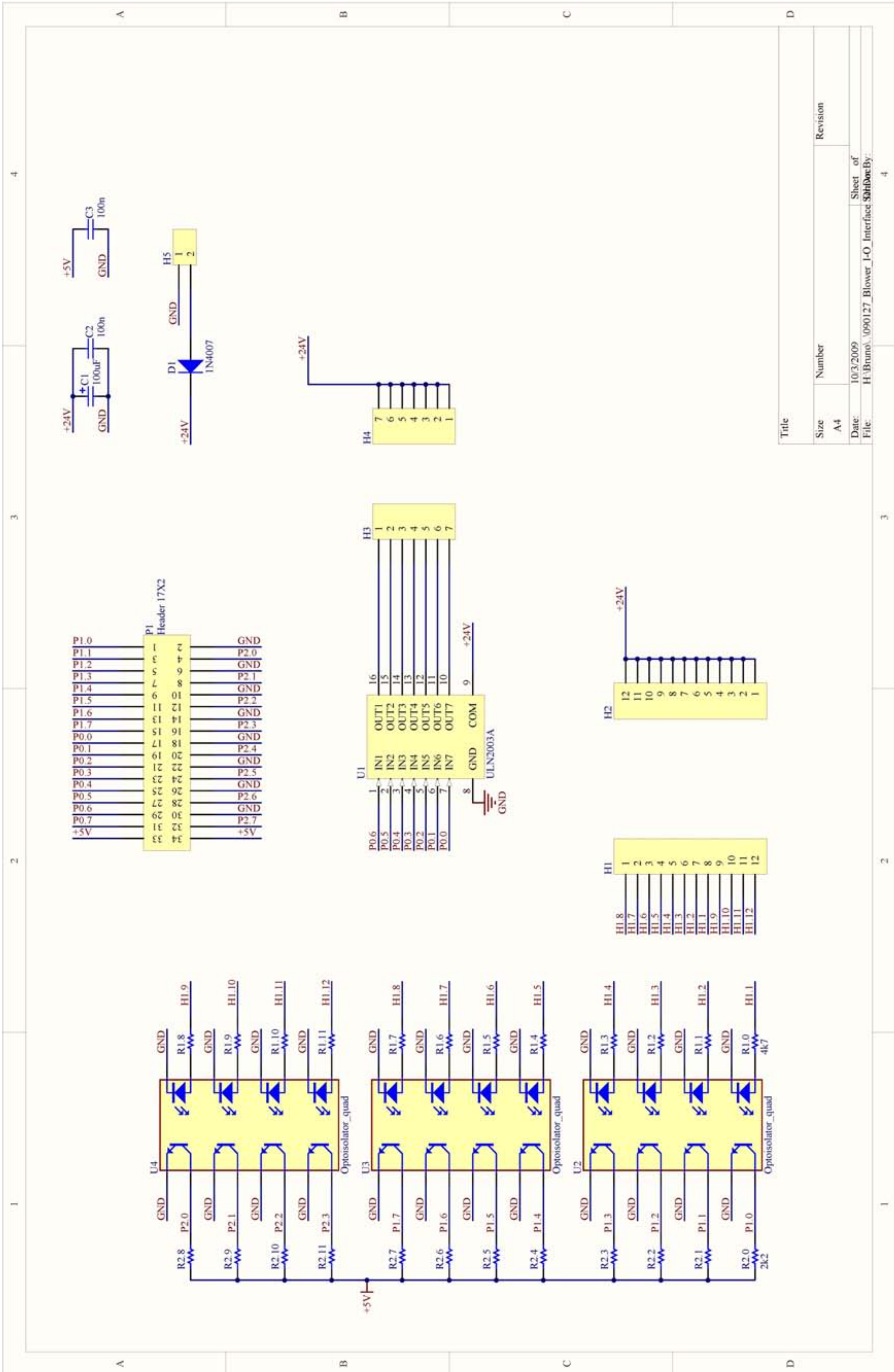


Figure 5-14: Schematic of the Interface Card for the NI-6501 USB I/O device

5.4.4.3 Assembly and testing of the Interface driver card

The PCB was produced by a private company outside of Massey University from the data out of the Altium Designer software. All the tracks were already presoldered which made the remaining assembling of the parts easy. The IC's are soldered directly onto the PCB without sockets in order to have a short thermal path to conduct eventual loss heat away from the IC and into the copper tracks.

The interface driver card was tested with the LabView test programme which is a basic testing panel to assign the output channels and read the input channels. For the test all the solenoids have been connected to the PCB and where switch on at the same time. Concerns of possible overheating of the Darlington array IC under full load proved to be insignificant. All the channels were working correctly and could be switched flawlessly.

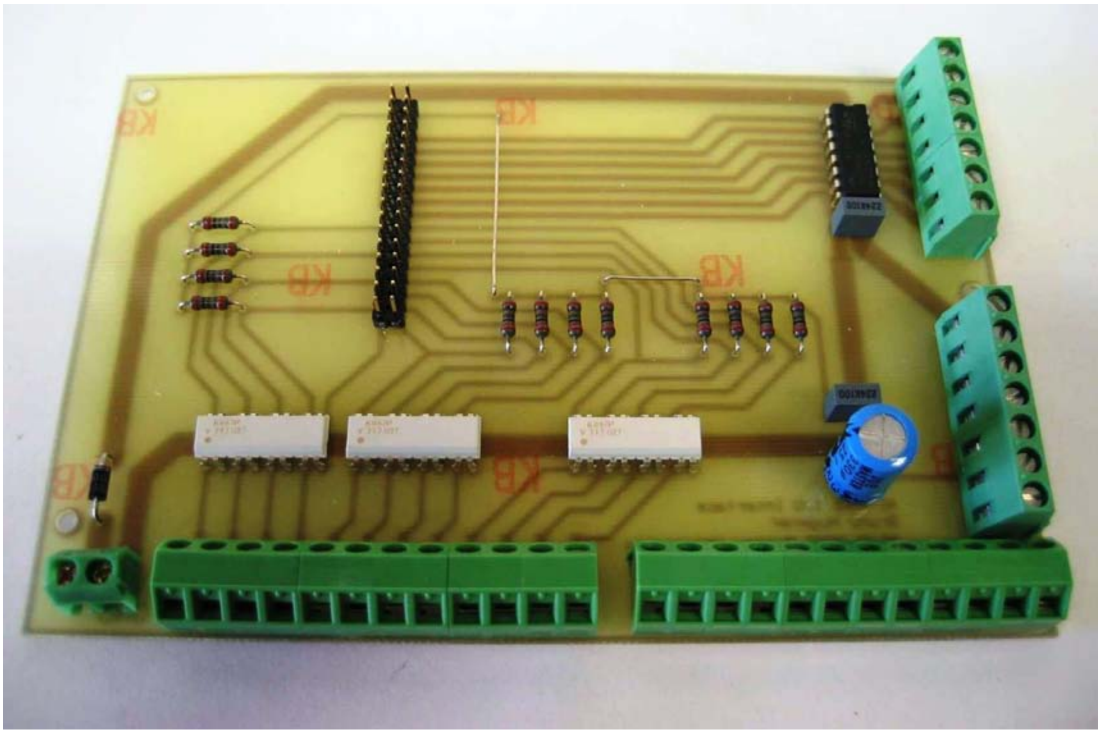


Figure 5-15: Assembled interface driver card without NI-6501 USB interface

5.5 Pneumatic Design

All of the mechanical movements are powered by pneumatic cylinders. The air supply is split in to two different systems where one is driving all the pneumatic cylinder and the other supply is used to inflate the preform. The air supply for the inflation of the preforms needs to be cleaned more thoroughly than the air which operates the cylinders. The next sections explain all the details of the air system of the Massey Bottle Blower.

5.5.1 Air schematic

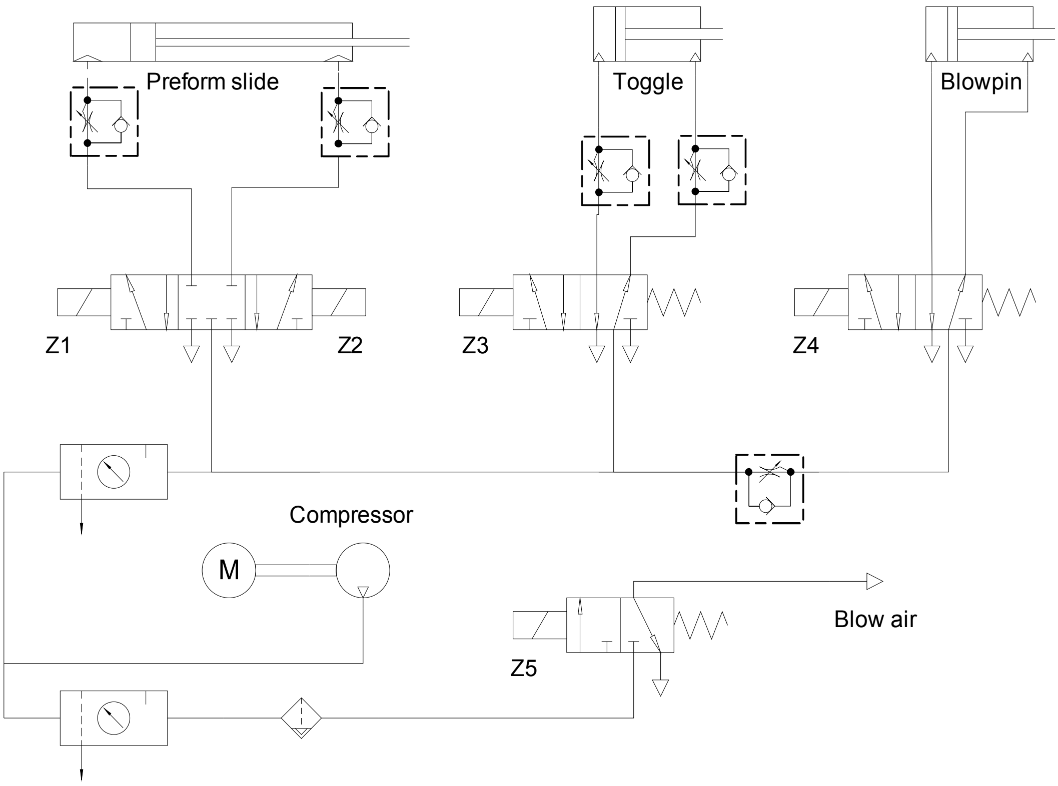


Figure 5-16: Schematic of the Massey Bottle Blower air system

Either a movable compressor or the building air supply system can be used to feed the pneumatic system. The air for all the pneumatic cylinders gets treated with a combined filter, pressure control and water separator unit. The air which is used to inflate the preform has an additional micro mist separator with a nominal filtering rating of 0.01µm. The two separate pressure control units allow the independent setting of the inflating pressure and the pressure fed to the pneumatic cylinders. All the part lists and details of the used components can be found in the appendix.

5.5.1.1 Preform slide

In order to be able to stop the preform slide in an intermediate position the double acting cylinder is controlled with a 3/5 way valve with two coils. The speed of the slide can be adjusted independently with meter-in speed controllers on each side of the cylinder. 4Mm PVC hose is big enough for the small bore cylinder used for the preform slide. This is the only valve directly placed inside the plastic control box together with the NI USB interface and the interface driver card. The feedback of the end position of the piston is done with reed contact limit switches on either end on the outside of the cylinder.

5.5.1.2 Toggle mechanism

The operation of the toggle mechanism is done with a double acting cylinder with pneumatic cushions built-in for soft stopping of the movement. As the operation does not require stopping of the movement at intermediate positions a 2/5 way valve is used for the controlling of the air to and from the cylinder. The speed of the cylinder can be controlled independently for each direction with meter-in speed controllers in line with the air supply hose to the cylinder. The mechanical end position of the toggle is detected with reed contact limit switches mounted on the cylinder.

5.5.1.3 Blow pin

To move the blow pin up and down a double acting cylinder is used. The only difference to the setup of the toggle cylinder is that there is only one speed controller placed in the feed line of the 2/5 way valve. Again the mechanical end positions of the piston are detected with reed contact limit switches.

5.5.1.4 Inflating air into preform

The air to inflate the hot preform is controlled with a basic 2/3 valve. The air gets filtered before it reaches the preform to make sure it contains no dirt or moisture which would end up in the blown bottle. After turning off the blow air the remaining pressure inside the bottle is released through the valve and is muffled by a silencer.

5.6 Manufacturing and assembling of Bottle Blower

All the parts which are not standard industrial items were manufactured at the mechanical workshop at Massey University, Palmerston North. Some of the parts which included more complicated geometries have been manufactured on the CNC mill. The Solidworks 3-D CAD data was used to directly programme the mill. This saved a lot of time and the created parts are exactly as designed. Threading was not done on the mill but afterwards by hand with taps in the mechanical workshop.

All the standard construction items have been bought from Palmerston North companies and shops. See the appendix for contact details.

The assembling of the Bottle Blower was started with the skid. The wooden boards on top of the skid needed to be cut out to access the base plate from underneath for attaching the stretch pin guide rods and the gear head motors. Once the baseplate was in place all the other components where placed onto the plate and aligned to be in correct position to each other. Next step was the installation of the pneumatic cylinders. Having all the mechanical parts in placed and aligned the mould halves could be adapted to fit onto the carriage. The distance between the two end blocks of the toggle needed to be adjusted with shims to have the correct tension once the mould halves are closed. The core of the mould was then installed and the levers adjusted to position the core perfectly centered between the two mould halves.

The pneumatic lines and valves have been installed after all the mechanical items where in place. The limit switches, cables and infrared heating elements where the last parts to be installed onto the baseplate and the lower shelf on the skid. The cabling of the IR-elements was carried out by Bruce Collins as he is certified to do electrical work which involves cabling and testing of 230 Volt installations. After the complete connection of all the cables Bruce tested the whole installation for insulation resistance and any unsafe parts.

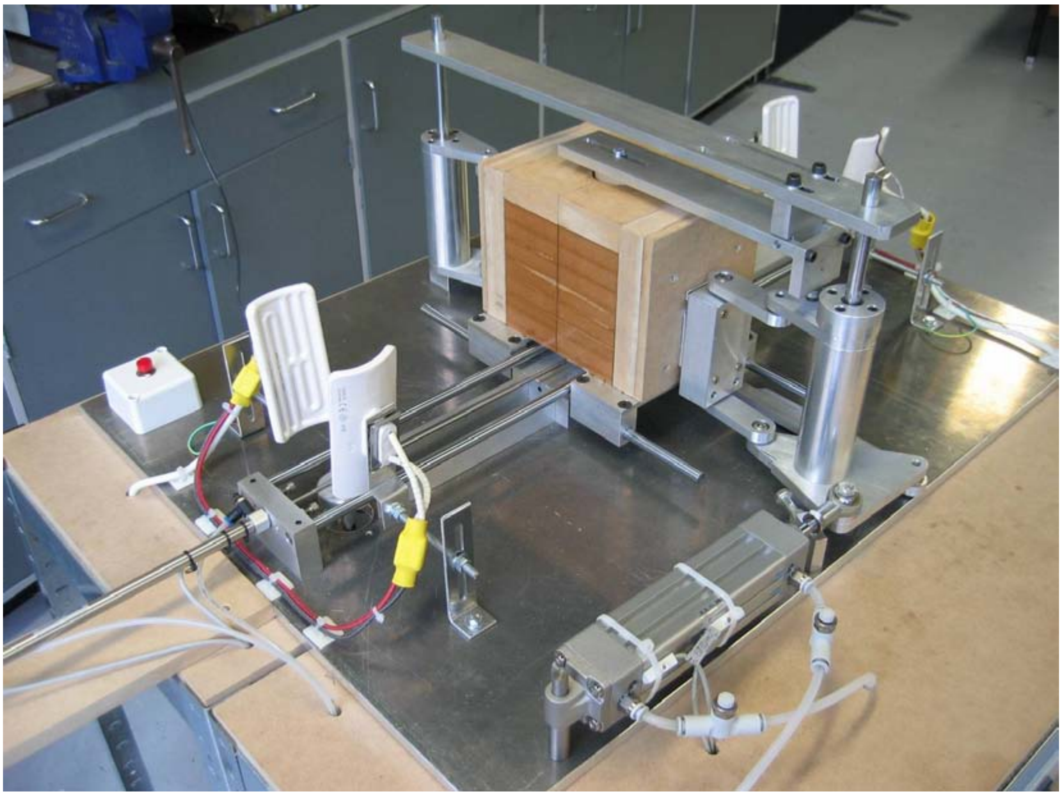


Figure 5-17: Assembled Massey Bottle Blower

5.7 Function and operation of Bottle Blower

The Blowing process starts with a manual operation of putting a cold preform into an aluminium ring and then placing it into the heater station where the slide is placed at. The preform then rotates and gets heated up for a specified time. When the preform is heated up the slide moves the hot preform between the two mould halves. The mould then closes and the blow pin extends to stretch the preform before blowing. As soon as the the blow pin is fully extended the blow air is turned on and the preform gets inflated to its final shape. During the time when a preform gets stretch and inflated and cold preform can already be placed on the opposite heater station to get heated up simultaneously.

The pressure to inflate the bottle normally needs to be applied for around 10 seconds until the plastic has cooled down enough to keep its shape. After that, the air from inside of the bottle gets released and the blow pin moves down again. Now the mould is opened and the finished bottle can be removed as soon as the other preform is heated up and the slide is moved to the intermediate position.

The now hot preform from the other heating station gets moved between the mould halves and the process starts again.

5.7.1 Sequence diagram

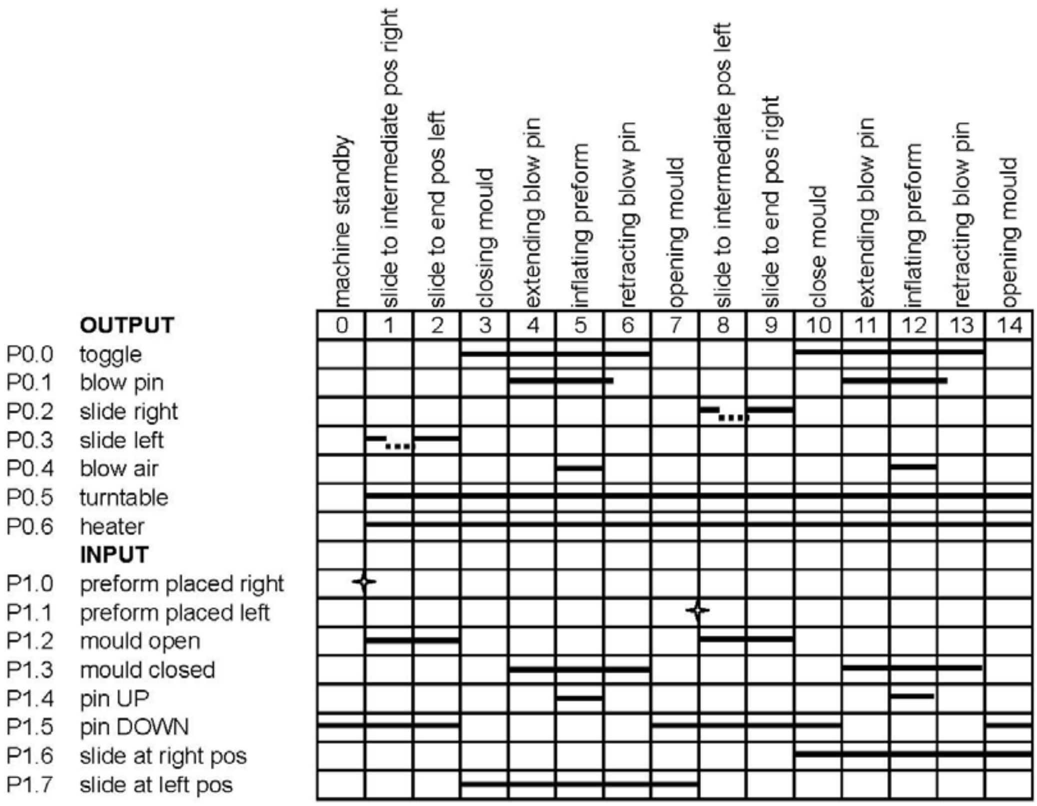


Figure 5-18: Sequence diagram of Bottle Blower

Figure 5-18 shows the sequence diagram of the Bottle Blower. Each horizontal line represents an input or output signal. Where as the vertical columns stand for the different sequence that follow each other in the same order all the time. A black line then indicates if the input or output is active. A dashed line indicates a time delay within the sequence step. The star at sequence one and eight is the start for one part sequence which starts with heating up of the preform and all the subsequent steps to finish one bottle. After this part of the sequence is finished the process is idling and can be started again by placing a preform onto the heater station.

5.7.2 LabView programme

The LabView programme software version 8.6 and the additional driver for the NI USB-6501 Interface are needed to run the written programme for the Bottle Blower. LabView is running on a standard desktop PC with 2.4GHz Pentium processor and 512MB RAM the operating system is Windows XP Professional with Service Pack 2 installed. To start the LabView programme the running of the LabView Measurement & Automation Manager is necessary in order to be able to communicate with the USB interface.

The LabView programme consists of three main parts. The first part is the acquisition of all the input states. They are read from the USB interface and can then be used in LabView. In order to have only one input block (DAQmx) all the inputs are read and then written into a Byte. The single bits which are later used for the logical operations are then separated in the next step.

These single bits now can be used for the logical operations and timing of the process. All the output bits from the logical connection now get put together into a Byte again and are sent to the Output block. The signal from the output block then sends the data to the USB interface and controls the attached devices. All these operations are executed in a loop which is timed to be started every 50ms which is a reasonably short time and loads the CPU only a few percent of its maximal capacity.

Two programmes are written to control the bottle blower. The first one is a basic manual control with only limited interlocks and no timing at all. Where as the second programme is used for the operation of the Bottle Blower and also involves timing of the heating and interlocks the outputs if the state of the Bottle Blower is not OK to operate the solenoids. Both of the programmes do not need to be run continuously as the timed loop repeats itself. Is the programme run in continuous mode the CPU is running at 100%. This does not speed up the process but loads the CPU unnecessarily. See the next two subsections and the appendix D for more detailed information about the two programmes written in LabView.

5.7.2.1 Manual control

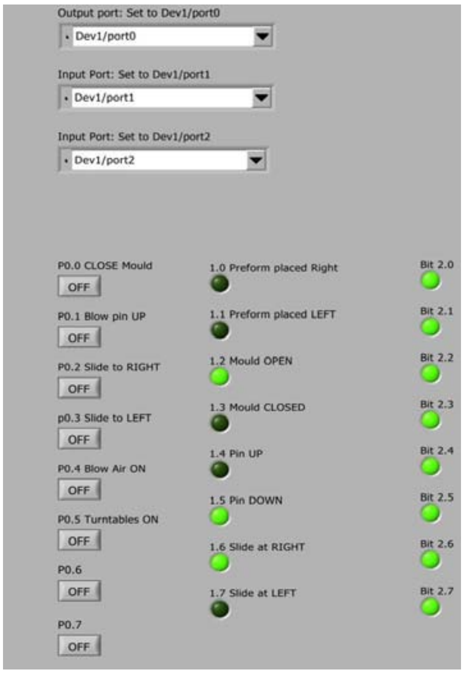


Figure 5-19: LabView faceplate of the manual control programme in running condition

Figure 5-19 shows the user interface of the manual control programme. This programme is a basic tool to operate and adjust the bottle blower e.g. to check the operation of limit switches or adjust the end stop of the levers. This face plate shows all the input and output channels of the interface card that are available although the operation of the bottle blower only needs a part of these channels. Some interlocks are in place e.g. the slide can only be operated when the mould is open. But no timing functions are present in this basic programme.

5.7.2.2 Operation programme

This programme shows the necessary indications for the operation of the Bottle Blower and has more detailed description of the different buttons and indicators.

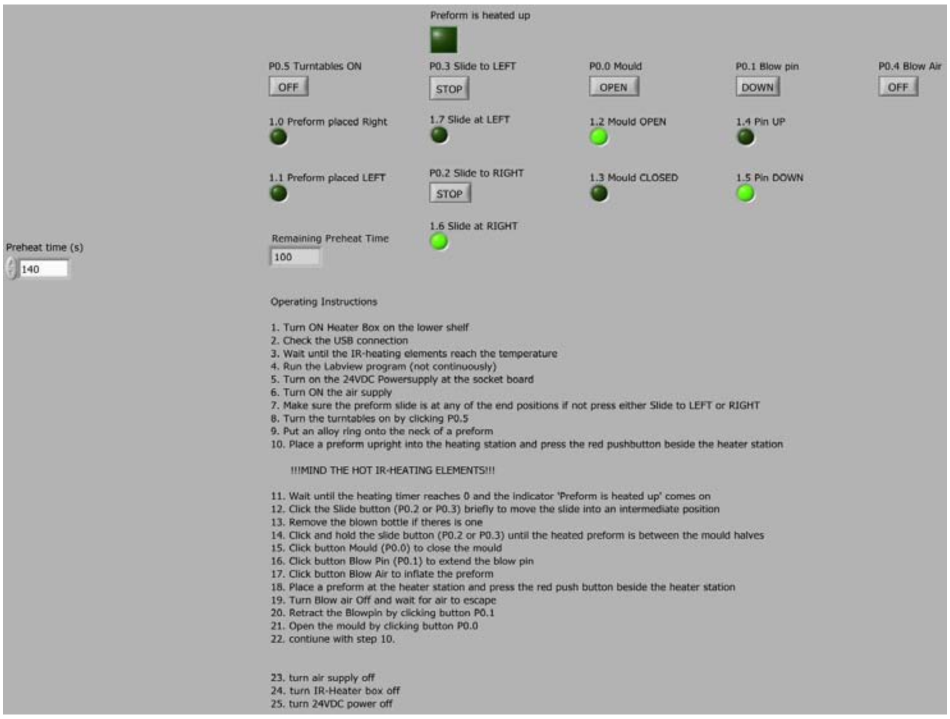


Figure 5-20: LabView faceplate of the operation programme in runnning condition

The operating instructions are directly visible on the faceplate. This programme is timing the heating of the preforms so that the operator does not need to worry about the heating time. As soon as the preform is heated up and indicator goes on and the operation can be continued by the operator. See appendix D for more details and the printout of the programme windows.

6 Conclusion

The study of commercially used blow moulding methods made clear that the best results for a plastic bottle produced at Massey University can be achieved with the use of premanufactured preforms. Contacting of different companies working in the area of plastic packaging for drinks showed that preforms in multilayer technology, needed for extended shelf-life, are not available in the asian-pacific area. The Australia based company Visy Plastics provided single layer pure PET preforms, which have been used to try out different heating methods and to carry out blow forming tests.

The testing showed that the best and easiest way of heating is with infrared heating elements. Nevertheless, for most of the testing the heating of the preforms was done in hot water. This allowed a constant heating process minimising variance that may result from the heating of the preforms.

The testing showed that a pressure of 4.1 barg applied to the inside of the preform is already sufficient to inflate the preform and to form a container. This fact allowed a much simpler design of the Massey Bottle Blower as the necessary pressure for inflating the preform is much lower than the 40 barg used in industrial applications. Further on, symmetrical forming of the preforms was not successful until the hot preforms were stretched with a rod prior to inflation. This stretching is necessary in order to achieve an even distribution of PET across the bottle wall. The use of vacuum applied to the outside of the preform did not make a noticeable difference to the shape of the blown bottle. The use of wood (MDF) as material for the blow mould proved to be an efficient and convenient choice. The results obtained from these tests provided the information and data necessary to start designing the Massey Bottle Blower.

The final layout of the Massey Bottle Blower consists of two infrared heating stations and one blow mould placed in between the two heating stations. The preforms and the finished bottles are moved back and forth horizontally between the heater station and the mould. The 3-D model and drawings were made with the 3-D CAD software Solidworks.

The manufacturing of the parts and the assembling was done at the Massey University mechanical workshop. Minor modifications and changes of some parts where necessary but no major faults in the design did appear which would have required a redesign. The wooden mould used for the basic testing was adapted for the use on the Massey Bottle Blower.

The National Instruments (NI) software LabView was used to control the Bottle Blower together with the NI USB interface to control the actuators and read the process signals. The use of the NI USB interface required the design of an interface driver card. This card was designed especially for the use with the Massey Bottle Blower. The Altium Designer software was used to create the schematic and the layout of the printed circuit board.

The production of PET bottles with the Massey Bottle Blower works well, but still needs some actions from the operator. With the small amount of time left at the end of the project, the LabView programme could not be improved to a completely self operating system. It also became clear that LabView, and in particular the use of the USB interface, is not the ideal solution for the automation of the Massey Bottle Blower. A sometimes failing USB connection after the start of LabView could not be sorted out completely. Furthermore, the fact that the USB interface cannot store programme code, a computer needs to be running continuously to control the outputs of the USB interface.

6.1 Recommendations

To further improve the operation of the Bottle Blow Moulder a feeding system for the cold preforms could be added to get rid of the manual steps of placing a preform into the heater station.

The choice for LabView was mainly made because I have not had much experience with LabView so far and wanted to learn more about this software. It showed that LabView is not the ideal solution for the task of automating a process like that one. A simple programmable logic controller (PLC) would be much more reliable and would make programming and running the process easier than with LabView.

Additional automation of the process would require more input and output channels which is exceeding the capacity of the existing USB interface and the interface driver card what again would favour a PLC.

To further improve the cycle time additional heater stations could be added to the Bottle Blow Moulder. A horizontal rotating table would enable the use of more heating stations. The preforms will then get heated up in steps passing through the heaters until reaching the blow mould. A rotating table would be a continuous movement as opposed to the slide where the process is intermittent. Another possible way to shorten the heating time of the preforms could be achieved with more heating elements at the heater stations.

Storing the preform in an oven with controlled air temperature before heating and blowing them could also improve the cycle time. The preforms then would already have an elevated temperature and the heating to the final temperature would take less time.

Bibliography

Brooks, D. W. and G. A. Giles (2002). PET packaging technology, Sheffield Academic Press Ltd. Sheffield, UK.

Cross, N. (2008). Engineering Design Methods, John Wiley & Sons, Chichester, UK.

Dieter, G. E. and L. C. Schmidt (2009). Engineering Design, McGraw-Hill, New York, USA.

DuBois, J. H. and W. I. Pribble (1987). Plastics mold engineering handbook, Chapman & Hall, New York.

Esposito, A. (2000). Fluid power with applications, Prentice-Hall, Inc. New Jersey, USA.

Foodproductiondaily. (2003). "PET beer 'en masse'." from http://www.foodproductiondaily.com/news/ng.asp?id=30574-pet-beer-en.

Foodproductiondaily.com. (2004). "AMCOR heralds beer bottle revolution." from http://www.foodproductiondaily.com/Packaging/Amcor-heralds-PET-beer-bottle-revolution.

Giles, G. A. (1999). Handbook of beverage packaging, CRC Press LLC, Boca Raton, USA.

Harper, C. A. (2006). Handbook of plastic processes, John Wiley & Sons, Hoboken, New Jersey.

Hurst, K. (1999). Engineering Design Principles, John Wiley & Sons, New York, USA.

Kokernak, R. P. (1999). Fluid power technology, Prentice-Hall, Inc. New Jersey, USA.

Lewis, J. P. (2002). Fundamentals of project management, Amacom, New York.

Mills, N. J. (2005). Plastics microstructure and applications, Elsevier, London, UK.

Montgomery, D. C. (1996). Introduction to statistical quality control, John Wiley & Sons, New York.

Osswald, T. A. and E. Bauer (2006). International plastics handbook: the resource for plastics engineers, Carl Hanser Verlag, Munich, Germany.

Packaging-Gateway. (2006). "Beer in PET bottles - alternative packaging." from http://www.packaging-gateway.com/features/feature79/.

Packaging-Technology. (2008). "Holsten Brauerei PET line for bottled beer." from http://www.packaging-technology.com/projects/holsten/.

Risch, S. (2000). Food packaging, Testing methods and applications, American Chemical Society, Washington DC, USA.

Robertson, G. L. (2006). Food packaging principles and practice, CRC Press Taylor & Francis Group, Boca Raton, FL, USA.

Sarvey, D. C. (2008) PET beer bottle celebrates 10 years of market success. Volume, DOI:

Steele, R. (2004). Understanding and measuring the shelf-life of food, CRC Press, New York, USA.

Tannahill, E. (1973). Food in history, Eyre Methuen, London, UK.

Ulrich, K. T. and S. D. Eppinger (2008). Product design and development, Mc Graw-Hill, New York, USA.

Appendices

Appendix A

Appendix A contains all the details of the companies that have been contacted during the evaluation of a suitable preform as well as the other companies I was working with.

Preform manufacturers:

Company:	Resilux
Contact:	Nick Bartlett
City:	Belgium
E-Mail:	nick.bartlett@resilux.com
Web:	www.resilux.com
Phone:	+32 936 57428

Company:	Husky
Contact:	David Armstrong
City:	Bella Vista, NSW, AUS
E-Mail:	darmstrong@husky.ca
Web:	www.husky.ca
Phone:	+61 2 9898 9911

Company:	Owens of Illinois New Zealand Plant
Contact:	
City:	Penrose, Auckland
E-Mail:	
Web:	www.o-i.com
Phone:	+64 9 976-7100

Company:	TSL Plastics Ltd
Contact:	Ian Armstrong
City:	Auckland
E-Mail:	ian.armstrong@petbottles.co.nz
Web:	www.petbottles.co.nz
Phone:	+64 9 274 6498

Company:	Visypak - PET Ltd
Contact:	Tony Forrest
City:	Auckland
E-Mail:	tony.forrest@visy.com.au
Web:	www.visy.com.au
Phone:	+64 9 573-3530

Company:	Visypak Palmerston Nth Sales
Contact:	David Wheller
City:	Palmerston North
E-Mail:	david.wheller@visy.com.au
Web:	www.visy.com.au
Phone:	+64 6 353 8007

Company:	Linkplas
Contact:	Julie Windybank
City:	Auckland
E-Mail:	pet@linkplas.com
Web:	www.linkplas.com
Phone:	

Company:	Amcor Flexibles Australasia
Contact:	Chris Houston
City:	Auckland
E-Mail:	chris.houston@amcor.com.au
Web:	www.amcor.com.au
Phone:	+64 9 979 1000

Company:	HP Packaging, Jeremy Bardsley
Contact:	Jeremy Bardsley
City:	Auckland
E-Mail:	jeremy.bardsley@hppackaging.co.nz
Web:	
Phone:	+64 9 415 6130

Company:	ALTO (Vertex-pacific)
Contact:	
City:	Auckland
E-Mail:	enquiries@alto.co.nz
Web:	www.vertex-pacific.co.nz
Phone:	+64 4 567 7155

Closure manufacturers:

Company: Aotea Plastics Industries Ltd
Contact:
City: Christchurch
E-Mail: iain@aoteaplas.co.nz
Web: www.aoteaplas.co.nz
Phone: +64 3 384 4123

Company: Axiam Plastics Ltd
Contact:
City: Wanganui
E-Mail: k.jones@axiam.co.nz
Web: www.axiam.co.nz
Phone: +64 6 343-9009

Company: CSC Plastics Ltd
Contact:
City: Auckland
E-Mail: chris@cscplastics.co.nz
Web: www.cscplastics.co.nz
Phone: 09 427 8445

Company: Gale Plastics Ltd
Contact:
City: Auckland
E-Mail: galeplastics@xtra.co.nz
Web:
Phone: +64 9 579 2567

Company: Koves Plastic Industries Ltd
Contact:
City: Auckland
E-Mail: koves@koves.co.nz
Web: www.koves.co.nz
Phone: +64 9 634 4410

Company: Optoplast (NZ) Ltd
Contact:
City: Wellington
E-Mail: optoplast@optoplast.co.nz
Web: www.optoplast.co.nz
Phone: +64 4 388 8396

Company: Petersens Plastics
Contact:
City: Auckland
E-Mail: info@petersens.co.nz
Web: www.petersens.co.nz
Phone: +64 9 827 3796

Company: Portola Packaging (ANZ)
Contact: Mark Sargent
City: Auckland
E-Mail: mbryce@portpack.com
Web: www.portpack.com
Phone: +64 09 444 0888

Company: Premier Plastics Ltd
Contact: Andrea Kennedy
City: Auckland
E-Mail: sales@premierplastics.co.nz
Web: www.premierplastics.co.nz
Phone: +64 9 849 5480

Suppliers of general parts for the Bottle Blower:

Company: Hislop & Barley
Contact: Evan Seaman
City: Auckland
E-Mail: evans@hibar.co.nz
Web: www.hibar.co.nz
Phone: +64 9 625 4292

Company: SMC Pneumatics
Contact: Kevin Buckley
City: Palmerston North
E-Mail: kbuc@smc.co.nz
Web: www.smc.co.nz
Phone: +64 6 357-6724

Company: Steelmasters
City: Palmerston North
Web: www.steelmasters.co.nz
Phone: +64 6 356-5635

Company: SKF
City: Palmerston North
Web: www.skf.co.nz
Phone: +64 6 356-9145

Appendix B

The following pages list all the details to the tests carried out and show the pictures of the results of the basic blow tests.

#	heating time	press barg	vacuum kPa	position	mould	volume brimfull	clamp	deflctn	angle CW	comments
1	5 min. (1)	4.3	n.a.	upright	no	50ml	Alloy, cold			pressure applied and on all times
2	5 min. (1)	5.0	n.a.	upright	no	600ml	alloy, warm			2 'stage' blowing, waterdrops remaind on preform before blowing
3	4 min. (1)	5.0	n.a.	upright	no	480ml	alloy, hot			1 blowing, higher waterlevel in water pot, hot aluminium clamp, waterdrops on pref.
4	4 min. (1)	5.0	n.a.	hanging	no	760ml	alloy, cold			plastic window on cardboard box, waterdrops dryed off before blowing
5	4 min. (1)	6.0	n.a.	hanging	no	730ml	alloy, cold			waterdrops dryed off, "controlled" inflation, on/off/on/off
6	4 min. (1)	5.0	on, -78kPa	hanging	yes, MDF	450ml	wood	23mm		waterdrops dryed off, 1st vacuum applied to mould, 2nd pressure to preform
7	4 min. (1)	6.0	on, -78kPa	hanging	yes, MDF	480ml	wood	13mm	120°	waterdrops dryed off, 1st vauum applied 2nd pressure to preform, vac con til cold
8	4 min. (1)	6.0	none	hanging	yes, MDF	490ml	wood	8mm	320°	waterdrops dryed off, pressure applied and on alltimes until cold
9	4 min. (1)	6.0	on, -78kPa	hanging	yes, MDF	480ml	wood	20mm	75°	Waterdrops dryed off, 1st pressure applied, then vacuum
10	6 min. (1)	6.0	on, -78kPa	hanging	yes, MDF	470ml	wood	19mm	350°	Waterdrops dryed off, 1st vacuum applied, then pressure
11	6 min. (1)	6.0	on, -78kPa	hanging	yes, MDF	465ml	wood	26mm	5°	waterdrops dryed off, 1st pressure, then vacuum
12	4 min. (1)	6.0	on, -78kPa	hanging	yes, MDF	470ml	wood	21mm	95°	waterdrops dryed off, 1st pressure, then vacuum, bigger vacuum holes in base
13	4 min. (1)	6.0	on, -78kPa	hanging	yes, MDF	475ml	wood	16mm	0°	waterdrops dryed off, 1, vacuum, then pressure, holes 2mm in base, indexing
14	10 min. (2)	8.0	on, -78kPa	hanging	yes, MDF	455ml	wood	51mm	190°	dry heating, 1st vacuum, then pressure, holes 2mm, alloy bars across clamp
15	4 min. (1)	7.0	on, -78kPa	hanging	yes, MDF	485ml	wood	11mm	110°	water dryed off, 1st vacuum, then pressure, slow reacting pressure control valve
16	4 min. (1)	8.0	on, -78kPa	hanging	yes, MDF	480ml	wood	20mm	0°	water dryed off, 1st vacuum, then pressure
17	4 min. (1)	8.5	on, -78kPa	hanging	yes, MDF	485ml	wood	27mm	280°	water dryed off, 1st pressure, then vacuum
18	4 min. (1)	8.5	none	hanging	yes, MDF	490ml	wood	10mm	200°	water dryed off, only pressure 8.5 bar, not really better forming than with 6 bar
19	4 min. (1)	8.5	none	hanging	yes, MDF	470ml	wood	31mm	225°	water dryed off, 'airjet' fitted to clamp to create a jet, fairly thick base
20	4 min. (1)	8.5	none	hanging	yes, MDF	475ml	wood	21mm	10°	water dryed off, 'airjet'
21	4 min. (1)	8.5	none	hanging	yes, MDF	470ml	wood	22mm	195°	water dryed off, 'airjet'
22	4 min. (1)	8.5	none	hanging	yes, MDF	480ml	wood	27mm	100°	water dryed off, 'airjet', heavy boiling water, less deflection
23	4 min. (1)	8.5	none	hanging	yes, MDF	490ml	wood	20mm	185°	water dryed off, no airjet, 5mm lower water level, no vac, preform rotated in water
24	4 min. (1)	8.5	none	hanging	yes, MDF	485ml	wood	25mm	100°	water dryed off, no airjet, high waterlevel, 2mm from neck, preform rotated in water
25	4 min. (1)	8.5	none	hanging	yes, MDF	485ml	wood	31mm	320°	no airjet, wet, preform rotated in water, quickly moved and blown
26	4 min. (1)	8.5	none	hanging	yes, MDF	500ml	wood	6mm	180°	same as 25
27	4 min. (1)	8.5	none	hanging	yes, MDF	480ml	wood	0mm	n.a.	water dryed off, use of alloy rod to stretch preform before blowing, Rod was cold
28	4 min. (1)	8.5	none	hanging	yes, MDF	500ml	wood	0mm	n.a.	water dryed off, alloy rod, heated rod in water as well, nicely centred

1 in boiling water
2 alloy tube with heating tape, controlled tube temp to 140°C, 2mm air gap

The numbers on the pictures correspond to the list above in the appendix and to the numbers mentioned in Chapter 4.2


7
9
10
11
12
13
14
14


15


16


17


19


19


20


21


22


23
24
25
26
27
27
28
28

Appendix C

This section contains all the part lists of the bottle blower. This includes all the manufactured parts as well as the standard parts purchased from external companies.

Bottle Blower Parts List, standard mechanical parts

Item	Name	Mat	Pcs	Dim	Remarks
101	O-ring		1	D12x2	
102	Countersunk screw, allen key	ST	8	M6x15	
103	Set screw	ST	2/4/2	M5x5	
104	Hex screw	ST	3	M5x30	
105	Nut	ST	3	M5	
106	Head Screw, allen key	ST	8	M4x25	
107	Set screw	ST	2	M5x10	
108	Head Screw, allen key	ST	4	M8x20	
109	Roller ball bearing 698ZZ	ST	2/8	8x19x6	
110	Washer	ST	2/8/2/3/2	d8x2	
111	Head Screw, allen key	ST	4/4/4	M4x12	
112	Head Screw, allen key	ST	2/2/2	M8x16	
113	Roller ball bearing 6901ZZ	ST	1/1/2	12x24x6	
114	Head Screw, allen key	ST	1	M8x40	
115	Nut	ST	2	M8	
116	Head Screw, allen key	ST	4	M4x35	
117	Head Screw, allen key	ST	2	M5x20	
118	Head Screw, allen key	ST	1/4	M6x15	
119	Roller ball bearing 626ZZ	ST	1	6x19x6	
120	Head Screw, allen key	ST	2	M6x20	
121	Washer	ST	2/4	M6	
122	Set screw	ST	2	M6x10	
123	Hex Screw	ST	2	M8x25	
124	Flathead screw, slot	ST	4	M2.5x8	
125	Hex screw	ST	4	M5x12	
126	Set screw	ST	4	M4x5	
127	Nut	ST	16	M6	
128					
129					
130					

Bottle Blower Parts List, machined parts

Item	Name	Mat	Pcs	Raw dim	Remarks
1	Top plate	AL	1	10x50x540	nalco 804760
2	Top hinge	AL	1	16x40x50	plate
3	Top lever lifter	AL	1	10x50x40	nalco 804760
4	Top lever	AL	1	10x50x250	nalco 804760
5	Top cam	AL	1	ø50x20	
6	Pivot top lever	AL	2	10x50x93	nalco 804760
7	Lever right	AL	1	10x125x140	plate
8	Lever left	AL	1	10x91x93	plate
9	End lever	AL	4	10x25x85	Ullrich UA1153
10	Connecting rod	AL	1	10x25x505	Ullrich UA1153
11	Toggle end block	AL	2	50.8x50.8x101	nalco 804742
12	Torsion pipe	AL	2	ø44.8x129	Ullrich UA2995
13	IR-heater support	AL	4	2x25x120	sheet
14	IR-heater stand	AL	4	3x25x130	sheet
15	Bracket D12	AL	2	31.8x31.8x20	nalco 803556
16	Supportblock slide M12	AL	1	20x50x80	nalco 804761
17	Supportblock slide M5	AL	1	20x50x80	nalco 804761
18	Center piece	AL	1	76.2x38.1x180	nalco 804658
19	Tracks for preform right	AL	2	6x38x200	nalco 803508
20	Tracks for preform left	AL	2	6x38x200	nalco 803508
21	Slide new	AL	1	20x78x370	plate
22	Mould support block	AL	4	31.8x31.8x60	nalco 803556
23	Mould support plate	AL	2	6x60x180	nalco 803529
24	Preform holder	AL	4	ø50.0x21	
25	Bearing toggle piston	ST	1	ø14x86	
26	Slide blowpin base	AL	1	19.1x19.1x180	nalco 803680
27	Slide for blowpin	AL	1	20x50x180	nalco 804761
28	Guide 10mm-long	ST	2	ø10x740	
29	Guide 10mm-short	ST	2	ø10x360	
30	Slide Blowp Guiderod D12	ST	2	ø12x710	
31	Guide 12mm-300	ST	2	ø12x300	
32	Toplever_axis	ST	1	ø6x50	
33	Rod M6-100mm	ST	4	M6x100	
34	Toggle Stop	AL	1	31.8x31.8x10	nalco 803556
35	Base plate	AL	1	12..16x600x800	plate
36	DC_mot_hub	AL	2	ø50x46	
37	DC_mot_mount	AL	2	3x40x80	sheet
38					
39					
40					

Bottle Blower Parts List, pneumatic parts

Item	Name	Mat	Pcs	Dim	Remarks
201	Cylinder blow piston		1	CP95SDB32-250	smc
202	Cylinder toggle mechanism		1	CP95SDB32-100	smc
203	Cylinder preform slide		1	CD85N10-300-B	smc
204	Single knuckles for 202	ST	1	I-032B (M10/d8)	smc
205	Blow air valve		1	2/3 way valve 2nd hand	
206	Toggle valve		1	2/5 way valve 2nd hand	
207	Blow piston valve		1	2/5 way valve 2nd hand	
208	Slide Valve		1	3/5 way valve 2nd hand	
209	Micro mist separator		1	AFD20-02-C	smc
210	Air filter pressure control unit		2	2nd hand	
211	Speed controller meter in		2	AS1211F-M5-04	smc
212	Silencer 1/8		2	AN103-01	smc
213	Silencer 1/4		2	AN203-02	smc
214	Straight connector 4mm M5		2	KQ2H04-M5-X2	smc
215	Straight connector M6x1/8		4	KQ2H06-01S-X2	smc
216	Straight connector M6x1/4		4	KQ2H06-02S-X2	smc
217	T-Connector 6mm/4mm		1	KQ2T06-04	smc
218	Elbow connector 6mmx1/4		1	KQ2L06-02S-X2	smc
219	Speed controller inline 6mm		2	AS2051f-06	smc
220	Speedcontroller inline 1/4		1	2nd hand	
221					
222					
223					
224					
225					
226					
227					
228					
229					
230					

Bottle Blower Parts List, electric parts

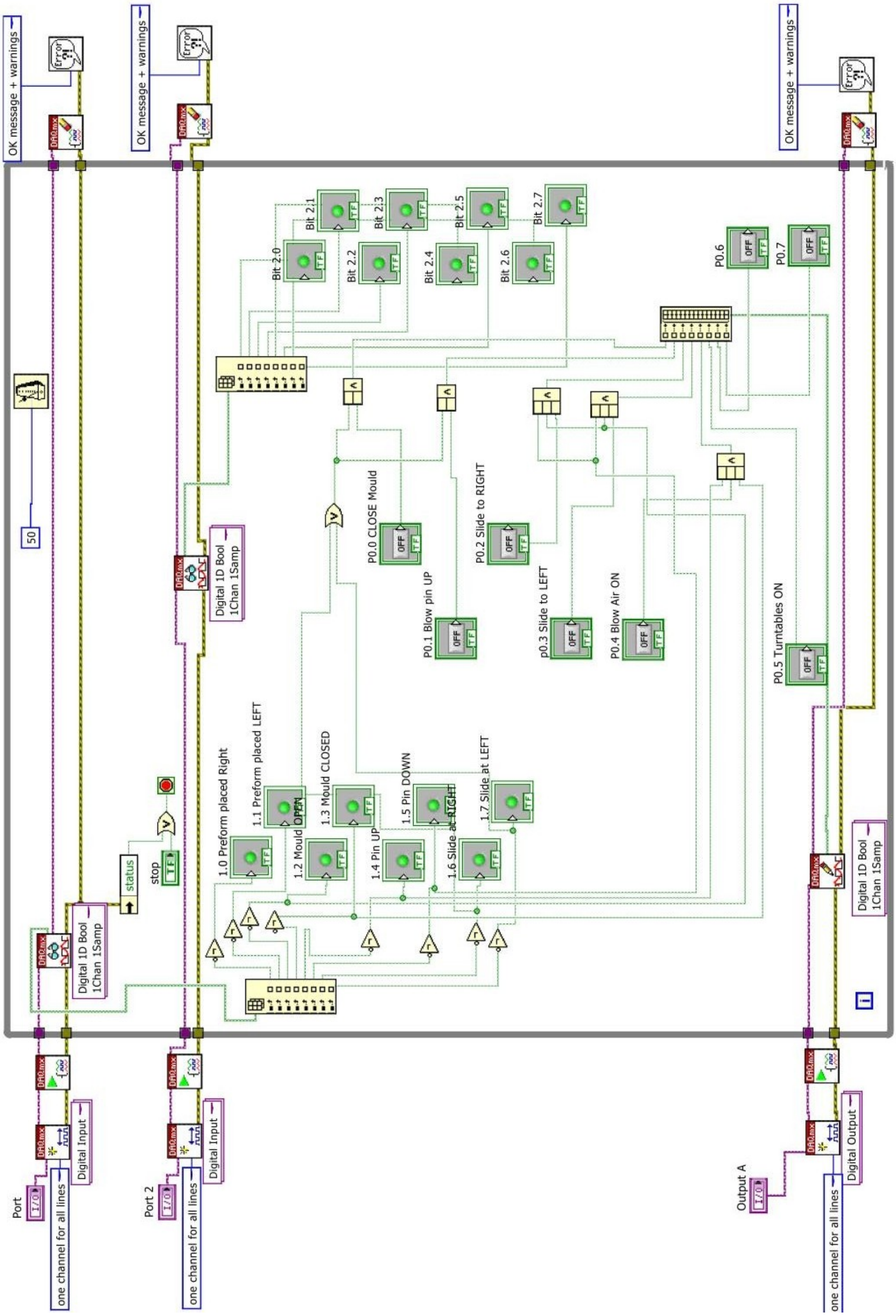
Item	Name	Mat	Pcs	Type	Remarks
301	Darlington Array		1	ULN 2003 A	farnell
302	4 Channel optocoupler		3	K847PH	farnell
303	Diode		1	1N4005	farnell
304	Capacitor unipolar 0.1uF/50V		2	0.1uF/50V	farnell
305	Capacitor bipolar		1	470uF/25V	farnell
306	Resistor wire 500mW		12	2.2 kOhms	farnell
307	Resistor SMD		12	4.7 kOhms	farnell
308	Pin header 17x2		1	34 pole	farnell
309	Screw terminal		1	2 pole	farnell
310	Screw terminal		2	7 pole	farnell
311	Screw terminal		2	12 pole	farnell
312	DC gearhhead motor 12V		2	YG-2732	Jaycar
313	Switchmode Powersupply		1	24V 50Watts	sicom.co.nz
314	Plug connector		2	SY100-30-4A	smc
315					
316					
317					
318					
319					
320					

Appendix D

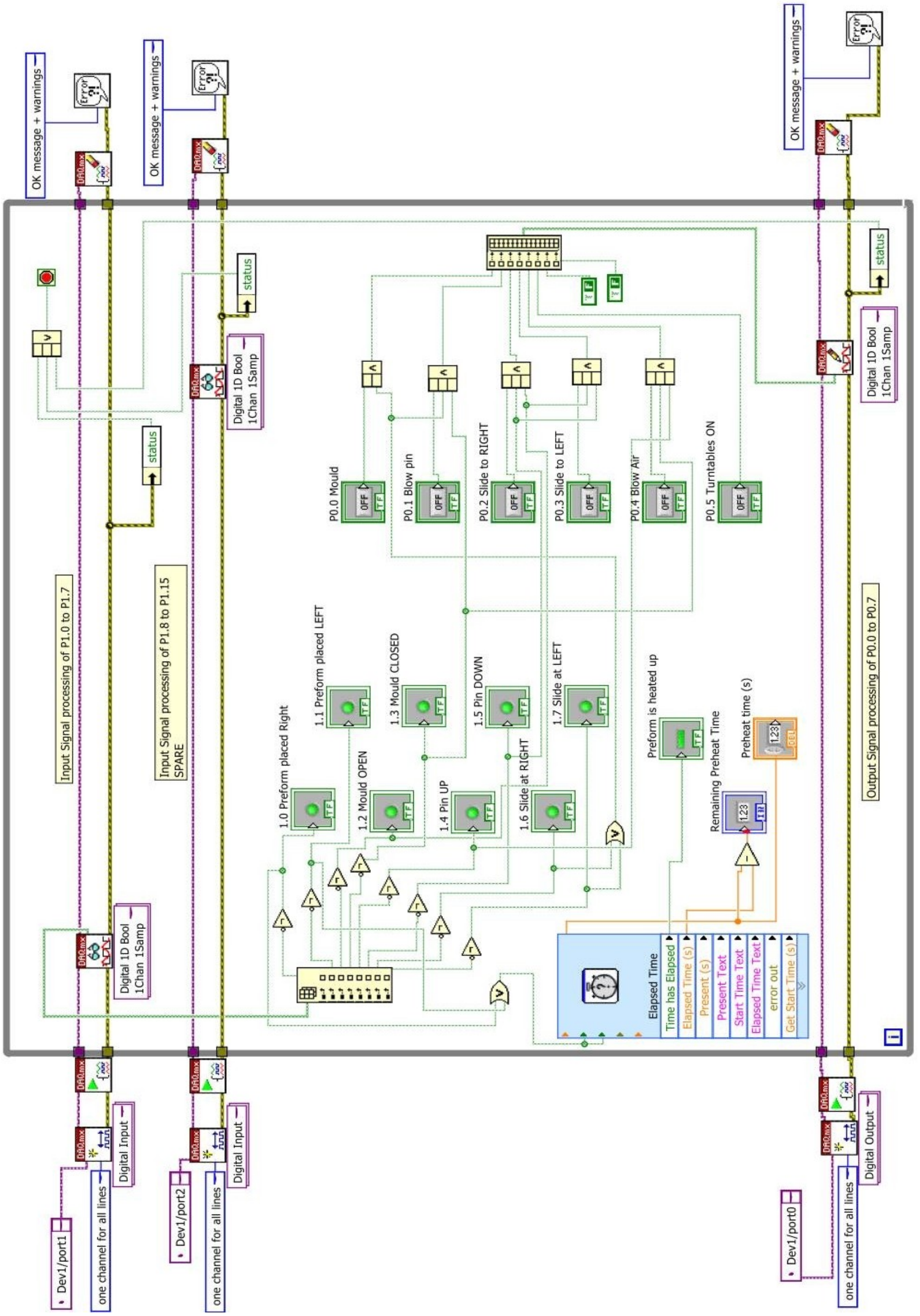
The following printouts show the two LabView programmes written for the control and operation of the Bottle Blow Moulder.

The first figure shows the programme to control the basic functions of the Blower, for troubleshooting and testing. The second figure shows the programme of the manual operation programme of the Bottle Blower.

Both programmes are stored on the Thesis CD-ROM an can be opened and modified from there on. They are programmed in LabView Version 8.6.



Printout of the basic manual control programme of the Bottle Blower



Printout of the manual operation programme of the Bottle Blower for the bottle production.

Appendix E

The following data are stored on the Thesis CD-ROM which is attached to this document.

- Electronic version of this thesis
- Solidworks 3-D model and drawings
- Altium Designer printed circuit project files
- LabView programme files
- Manuals
- Data sheets
- Part lists

Thesis CD-ROM