Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
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,
Acknowledgements

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

Abstract..............................................................................................................................................ii

Acknowledgements............................................................................................................................iii

Table of contents.................................................................................................................................v

List of figures.........................................................................................................................................ix

List of tables.........................................................................................................................................xi

1 Introduction.......................................................................................................................................1
   1.1 Research aim...............................................................................................................................1
   1.2 Research objectives....................................................................................................................2
   1.3 Research outcomes....................................................................................................................2
   1.4 Chapter overview......................................................................................................................2

2 Literature review..............................................................................................................................4
   2.1 The use of plastic for beer bottles - a brief history.................................................................4
      2.1.1 Future and advantages of plastic beer bottles.................................................................7
   2.2 Plastics used for bottles............................................................................................................7
      2.2.1 Polyethylene (PE)............................................................................................................8
      2.2.2 Polypropylene (PP).........................................................................................................8
      2.2.3 Polyvinyl chloride (PVC)................................................................................................9
      2.2.4 Polystyrene (PS).............................................................................................................9
      2.2.5 Polyethylene terephthalate (PET)....................................................................................9
      2.2.6 Polymers with high barrier properties.............................................................................10
   2.3 Barrier technologies for plastic bottles....................................................................................11
      2.3.1 Single layer blended polymer bottle................................................................................11
      2.3.2 Multilayer bottle from co-injected preform.....................................................................12
      2.3.3 Oxygen scavenger layer..................................................................................................13
      2.3.4 Coated single layer bottle................................................................................................14
         2.3.4.1 Organic coatings.......................................................................................................14
         2.3.4.2 Inorganic coatings....................................................................................................15
      2.3.5 Barrier technologies for closures......................................................................................15
   2.4 Detrimental effects on the beer...............................................................................................16
Table of contents

2.5 Multilayer preform technologies for beer containers................................. 16
2.6 Overview of blow moulding processes for plastic container manufacturing 18
  2.6.1 Extrusion blow moulding................................................................. 19
  2.6.2 Injection blow moulding................................................................. 20
  2.6.3 Stretch blow moulding................................................................. 21
    2.6.3.1 Single stage SBM................................................................. 21
    2.6.3.2 Double stage SBM................................................................. 21

3 Preform evaluation and bottle characteristics.............................................. 25
  3.1 Manufacturing vs. buy-in of preforms.................................................. 25
  3.2 Suppliers of preforms........................................................................ 26
    3.2.1 Linkplas....................................................................................... 26
    3.2.2 HP packaging............................................................................. 26
    3.2.3 Visy Plastics Ltd........................................................................ 27
    3.2.4 Resilux......................................................................................... 27
    3.2.5 TSL plastics................................................................................ 28
    3.2.6 Owens of Illinois......................................................................... 28
  3.3 Suppliers of closures.......................................................................... 28
    3.3.1 CSC plastics................................................................................ 28
  3.4 Conclusion of the preform and closure evaluation................................... 28
  3.5 Properties of the finished beer bottle.................................................. 29
    3.5.1 Sizes of commercially sold beer bottles........................................ 29
    3.5.2 Size and color............................................................................. 30
    3.5.3 Shape......................................................................................... 30
    3.5.4 Closure....................................................................................... 31
  3.6 Supplied preforms from Visy Plastics Ltd. Australia.............................. 31
  3.7 Final shape and dimensions of the bottle............................................. 32

4 Blow forming tests....................................................................................... 34
  4.1 Equipment used for the tests............................................................... 34
    4.1.1 Heating of preforms..................................................................... 34
      4.1.1.1 Boiling water........................................................................ 35
      4.1.1.2 Aluminium tube with heating tape........................................ 35
      4.1.1.3 Infrared heating elements...................................................... 36
    4.1.2 Forming of preforms............................................................... 38
      4.1.2.1 Vacuum forming machine for plastic sheet............................ 38
      4.1.2.2 Aluminium clamp for free blowing of the preform.................. 39
      4.1.2.3 Fabrication and features of the wooden mould...................... 39
  4.2 Techniques and methods used for the tests....................................... 41
Table of contents

5.7.1 Sequence diagram.................................................................73
5.7.2 LabView programme.............................................................74
  5.7.2.1 Manual control.................................................................75
  5.7.2.2 Operation programme.....................................................76

6 Conclusion....................................................................................77
  6.1 Recommendations....................................................................78

Bibliography......................................................................................I

Appendices.........................................................................................III
  Appendix A...................................................................................IV
  Appendix B...................................................................................VIII
  Appendix C..................................................................................XIV
  Appendix D...............................................................................XVIII
  Appendix E...............................................................................XXI
List of figures

Figure 2-1: 20L Beer Sphere®.................................................................5
Figure 2-2: 0.5 Litre PET beer bottle of a German brewery.......................6
Figure 2-3: Wall sections of a multilayer drink container..........................13
Figure 2-4: Total package oxygen over time for 500ml barrier scavenger container ...........................................................................................................17
Figure 2-5: Two stages of injection blow moulding (IBM)..........................20
Figure 2-6: Steps of stretch blow moulding..............................................24
Figure 3-1: Section of the Visy preform (29gr. pure PET).........................31
Figure 3-2: Dimensions of preform and bottle to calculate stretch ratios ......32
Figure 4-1: Heating of preform immersed in hot water...............................35
Figure 4-2: Aluminium heating tube installed on a linear guides................36
Figure 4-3: Dimensions of Elstein FSR/2 IR-heating element....................37
Figure 4-4: Inside of heater control box.....................................................37
Figure 4-5: Open clamp............................................................................39
Figure 4-6: Closed clamp with preform in place.......................................39
Figure 4-7: Split wooden mould halves with preform in place..................40
Figure 4-8: Finished wooden mould with seal stripes, center pins and locking bars ..............................................................................................................41
Figure 4-9: Temperature development of preform inside wall during heating in hot water........................................................................................................42
Figure 4-10: Infrared heating elements........................................................43
Figure 4-11: Mould half with blown bottle and aluminium rod in place.........49
Figure 4-12: Detail of a bottle after burst pressure testing..........................50
Figure 5-1: Basic function of the Massey Bottle Blower...............................52
Figure 5-2: 3-D assembly of the Massey Bottle Blower without blow mould and heating elements............................................................................................................54
Figure 5-3: Preform placed into aluminium ring..........................................55
Figure 5-4: DC-gearhead motor with attached turntable............................56
List of figures

Figure 5-5: Heater support assembly ............................................................... 57
Figure 5-6: 3-D model of the left toggle lever assembly .............................. 58
Figure 5-7: 3-D model of the right toggle lever assembly ......................... 58
Figure 5-8: Leverage designed to lift the core out of the blow mould ........ 59
Figure 5-9: 3-D model of the stretch pin assembly ....................................... 60
Figure 5-10: National Instruments USB interface 6501 ............................ 63
Figure 5-11: Schematic of a single input circuit with galvanic separation .... 64
Figure 5-12: Schematic of a single output circuit with Darlington transistor .. 65
Figure 5-13: Track side of the interface driver card circuit board ............... 66
Figure 5-14: Schematic of the Interface Card for the NI-6501 USB I/O device .. 67
Figure 5-15: Assembled interface driver card without NI-6501 USB interface .. 68
Figure 5-16: Schematic of the Massey Bottle Blower air system .................. 69
Figure 5-17: Assembled Massey Bottle Blower ............................................ 72
Figure 5-18: Sequence diagram of Bottle Blower ....................................... 73
Figure 5-19: LabView faceplate of the manual control programme in running condition ............................................................................. 75
Figure 5-20: LabView faceplate of the operation programme in running condition ............................................................................. 76
List of tables

Table 2-1: Abbreviations of materials used for bottles and barrier layers .................8
Table 3-1: Beer bottle sizes of different breweries ..................................................29
Table 3-2: Final dimensions and volume of the bottle ..............................................33
Table 5-1: CAL 3200 Heater controller settings .....................................................61
Table 5-2: Part of the technical data of the NI USB-6501 Interface ..........................64