

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.

**On-line Quality Control and Experimental  
Design Analysis for Plastic Injection  
Moulding**

A Thesis presented in partial fulfilment of the requirements  
for the degree  
of Master of Technology in  
Manufacturing and Industrial Technology at  
Massey University

Tae Eub Kim  
1996

to

**Jung Hun, Hyeon Jin and Hoon Ah**

## **Abstract**

This thesis describes automatic quality data acquisition and experimental design methods for product quality improvement.

The approach used, focuses on the computer based, process and product quality data acquisition from the shop floor. The collected data was then analysed by the 'design of experiments' method, an advanced statistical quality analysis method, to determine which process parameters influence product quality.

Many advanced statistical quality control methods have been developed for maintaining manufacturing product quality. In spite of this development, most manufacturing organisations depend on downstream statistical quality control methods, such as control charts and sampling inspection. These downstream methods, which require more time to collect quality information after the process, cannot always prevent quality problems, or produce prompt quality improvements.

A case study is presented which is concerned with the implementation of an on-line data collection system and the 'design of experiments' methods. A plastic injection moulding machine was used for this project, using an instrumented mould designed for process data collection, together with interfaced dimension and weight measurement instruments.

The results clearly indicate the process parameters which are important to product quality.

By the use of integrated on-line quality data collection systems and 'design of experiments' methods, rapid reaction to process problems, and quality design activities should be able to be easily adopted by manufacturing industries.

## Acknowledgments

The author would like to acknowledge all members of the staff within the Production Technology Department whose assistance has proved invaluable.

Specially to:

Professor Don Barnes, who introduced me the world of 'design of experiments', for his professional knowledge of statistics and its quality methods.

Dr. James Tannock for his help and direction endurance over the last two years. Without his drive and dedication this research would never have been possible.

Dr. Ted Smith for his help to develop mechanical sensing instrumentations and kind advice.

Mr. Merv Foot, who supplied nearly most of the equipment and material for this research, for his expert advice on the machinery.

Also to,

Mr. Len Chisholm, Mr. Leith Baker, and Mr Bruce Rapley for their endless advice and help on mechanical and computational matters.

# CONTENTS

**Title Page**

**Abstract**

**Acknowledgements**

**Contents**

**List of Figures**

**List of Tables**

## **Chapter 1**

<b>Introduction and Overview of Thesis .....</b>	<b>1</b>
1.1 Foreword .....	2
1.2 Objectives of the research work .....	2
1.3 Summary of contents .....	3
1.4 General references.....	3

## **Chapter 2**

<b>Plastic Injection Moulding.....</b>	<b>4</b>
2.1 Introduction to Injection Moulding Machine .....	5
2.1.1 Injection Unit .....	5
2.1.2 Clamping Unit.....	7
2.1.3 Mould .....	7
2.2 Injection Moulding Process .....	8
2.3 Injection Moulding Machine in Department of Production Technology.....	11
2.4 Experimental mould and product design.....	12

## **Chapter 3**

<b>Computer based Process and Product Data Acquisition .....</b>	<b>15</b>
--	-----------

3.1 Introduction.....	16
3.2 Process Data Acquisition .....	17
3.2.1 Injection Pressure.....	17
3.2.2 Injection nozzle temperature.....	22
3.2.2.1 Calibration of the wire thermocouple.....	23
3.2.3 Cavity temperature.....	24
3.2.3.1 Calibration of the melt thermocouple data.....	24
3.3 Product Data Acquisition.....	25
3.3.1 Weight.....	25
3.3.2 Dimensions.....	25

## Chapter 4

<b>Implementation of the Automatic Quality Data Acquisition System (AQDAS).....</b>	<b>27</b>
4.1 Introduction.....	28
4.2 Requirements for AQDAS .....	30
4.3 AQDAS hardware choice.....	31
4.4 AQDAS application design .....	34
4.4.1 Software Development.....	35
4.4.2 Monitoring quality data acquisition.....	39
4.5 Quality data analysis on the supervisory computer.....	41
4.5.1 Process parameters analysis.....	41
4.6 Summary .....	44

## Chapter 5

<b>Designed experiments and results.....</b>	<b>45</b>
5.1 Introduction.....	46
5.2 The experimental design process .....	47
5.3 Plackett-Burman designs.....	50
5.3.1 Introduction .....	50

5.3.2 Conducting the Plackett-Burman design .....	50
5.3.4 Result analysis.....	53
5.4 Factorial two level experimental design .....	55
5.4.1 Introduction .....	55
5.4.2 Conducting two level factorial design .....	56
5.4.3 Centre point shrinkage.....	58
5.4.3.1 Main factor effects for centre point shrinkage .....	59
5.4.3.2 Two factor interactions for centre point shrinkage .....	60
5.4.3.3 Input levels to obtain the lowest centre point shrinkage.....	63
5.4.4 Product length.....	64
5.4.4.1 Main factor effects for product length.....	65
5.4.4.2 Two factor interactions for product length.....	66
5.4.4.3 Input levels to obtain the lowest length shrinkage.....	68
5.4.5 Product weight.....	70
5.4.5.1 Main factor effects for product weight.....	71
5.4.5.2 Two factor interactions for product weight.....	72
5.4.5.3 Best input levels to produce the highest product weight.....	75
5.5 Summary and conclusions .....	76

## Chapter 6

<b>Discussion and Conclusions .....</b>	<b>77</b>
6.1 Introduction.....	78
6.2 On-line quality data acquisition .....	78
6.3 'Design of experiments' for quality improvement.....	79
6.4 Recommendations for further studies .....	80

<b>References.....</b>	<b>83</b>
------------------------	-----------

<b>Appendices.....</b>	<b>85</b>
------------------------	-----------



## List of Figures

2.1	Plastic injection moulding machine	5
2.2	Injection unit	6
2.3	Detail parts of injection unit	7
2.4	Mould and its main features	8
2.5	Injection moulding cycle flow charts	10
2.6	Moulded experimental product	12
2.7	Designed mould cavity and sprue parts	13
2.8	Instrumentations on the mould	14
3.1	Process data acquisition diagram	17
3.2	Pressure pin method (diagram)	19
3.3	Moment formula for strain gauge plate	20
3.4	Wheatstone bridge circuit and mounted strain gauge	21
3.5	Strain gauge calibration graph for resolution 14 bit	22
3.6	Injection nozzle and wire thermocouple location	22
3.7	Wire thermocouple calibration graph for resolution 14 bit	23
3.8	Melt thermocouple calibration data for resolution 14 bit	24
3.9	Product data acquisition diagram	25
3.10	Measuring the product dimensions using the pedal switch	26
4.1	Automatic Quality Data Acquisition System (AQDAS)	29
4.2	Main and unit programs of AQDAS	34
4.3	Menu screen for the AQDAS program	35
4.4	Collected pressure data from one moulding cycle	37
4.5	AQDAS program flow chart	38
4.6	Process quality data (product no. 1-15)	39
4.7	Product quality data (product no. 1-15)	40

4.8	Collected injection pressure	42
4.9	Collected nozzle temperature from 200 and 240 machine settings	43
4.10	Collected cavity melt temperature	43
5.1	Cause and effect diagram for causes of shrinkage in plastic products	49
5.2	Plackett-Burman design in Minitab program	53
5.3	Fractional factorial design in the Minitab program	57
5.4	Significant effects for centre point thickness	58
5.5	Main effects analysis for centre point thickness	59
5.6	Isoplots for centre point thickness	61
5.7	Significant effects for product length	64
5.8	Graphical analysis for product length	65
5.9	Isoplots for product length	67
5.10	Significant effects for product weight	70
5.11	Graphical analysis for product weight	72
5.12	Isoplots for product weight	73

## List of Tables

5.1	Selected 11 input factors and their high (+) and low (-) input levels	49
5.2	Plackett-Burman design for 11 factors with 12 runs	51
5.3	Treatment table for Plackett-Burman design	52
5.4	Input factors and their effects	54
5.5	Significance order for input factors	54
5.6	Six chosen factors and their input levels	56
5.7	Significant effect order and their absolute effect value	58
5.8	Average thickness from different input levels	59
5.9	Main factor effect analysis results for centre point shrinkage	60
5.10	The best input levels for the highest thickness	63
5.11	Significant effect order and their absolute effect value	64
5.12	Average product length from different input levels	65
5.13	Main factor effect analysis results for product length	66
5.14	Input levels for the lowest length shrinkage	69
5.15	Significant effect order and their absolute effect value	71
5.16	Average product weight from different input levels	71
5.17	Main factor effect analysis results for product weight	72
5.18	Input levels for the greatest product weight	75

# Chapter 1

## Introduction and Overview of Thesis

<b>INTRODUCTION AND OVERVIEW OF THESIS.....</b>	<b>1</b>
1.1 FOREWORD.....	2
1.2 OBJECTIVES OF THE RESEARCH WORK.....	2
1.3 SUMMARY OF CONTENTS .....	3
1.4 GENERAL REFERENCES .....	3

---

This chapter describes the object and aims of this research work followed by a summary of each chapter.

## **1.1 Foreword**

This research thesis describes a method of computer based, on-line process and product data collecting to control product quality from the plastic injection moulding machine. The collected quality data is then analysed by the 'design of experiments' method to determine the optimum process input parameters for target quality characteristics.

The on-line quality data collecting method, which is called 'Automatic Quality Data Acquisition System (AQDAS)' in this thesis, were devised and developed to collect the process parameters with special instrumentations, and product quality measurements.

The AQDAS developed through this research, can be applied to a wide range of manufacturing industries with relatively low cost.

## **1.2 Objectives of the research work**

Exhibited dimensional shrinkage on a plastic product is the most difficult product quality problem to control. The reason is that many input parameters affect directly and indirectly the product quality.

The aims of this research are to devise a low cost automatic quality data acquisition system and to determine the optimum level of the input process parameters to achieve target product quality characteristics.

Two main objectives were outlined for this research. They were as follows:

- To devise a computer based, shop floor data collection system for process parameters and product data for a plastic injection moulding machine.

For the process parameters, the three following parameters were chosen to be measured with special instrumentation.

- Injection pressure in the mould cavity,
- Temperature of the polymer when it is injected into the cavity,
- Temperature of the polymer when it is being injected from the nozzle.

For the product parameters, the product dimensions and weight were measured.

- To use the 'design of experiment' methodology used to analyse the resultant data and to use the analysed results to optimise the settings for the injection moulding machine.

### 1.3 Summary of contents

**Chapter 2** describes the main units of the injection moulding machine and the operation of its product moulding process. In addition key features of the plastic injection moulding machine and designed mould which were used for this research project are described.

**Chapter 3** describes instrumentation methods for computer based shop floor quality data acquisition methods which were devised to collect the process and product quality data for the injection moulding machine and its product.

**Chapter 4** describes the implementation of a real time quality data acquisition on the shop floor. The structure of Automatic Quality Data Acquisition System (AQDAS) and its development process was described. The collected process and product data are shown and displayed as graphics.

**Chapter 5** describes the design process of experiments and shows experimental design results for product quality characteristics. Optimum input process parameters were suggested for the designed plastic product.

**Chapter 6** discusses the achievements from the research project and makes recommendations for further studies.

### 1.4 General References

The following general references were used for this project.

Gofton, Peter W. (1986), *Mastering serial communications*, San Francisco, Sybex.

John, Vernon (1992), *Introduction to Engineering Materials*, New York, Industrial Press Inc.

Walton, J. (1991), *Engineering design: from art to practice*, St. Pual, West Publishing Co.

Minitab Reference Manual Release 10 for Windows (1994), USA, Minitab Inc.