

HANSER

Chris Rauwendaal

SPC

Statistical Process Control in Injection Molding and Extrusion

ISBN-10: 3-446-40785-5

ISBN-13: 978-3-446-40785-5

Table of Contents

For further information and order see
<http://www.hanser.de/978-3-446-40785-5>
or contact your bookseller.

Contents

1 Injection Molding Technology	1
1.1 The Main Components of an Injection Molding Machine.....	1
1.1.1 The Injection Molding Cycle	2
1.1.1.1 Characteristics of the Injection Molding Process	4
1.1.2 The Plasticating Unit	5
1.1.2.1 The Extruder Screw	5
1.1.2.2 Nonreturn or Check Valves	6
1.1.2.3 The Extruder Barrel	8
1.1.2.4 The Nozzle of the Plasticating Unit	8
1.1.2.5 The Feed Hopper and Feed Opening.....	10
1.1.2.6 The Extruder Drive	10
1.2 The Clamping Unit	11
1.2.1 Mechanical Clamping Systems	12
1.2.2 Hydraulic Clamping Systems.....	13
1.2.3 Hydromechanical Clamping Systems.....	14
1.3 The Mold	14
1.3.1 The Sprue	15
1.3.2 The Runner System.....	16
1.3.2.1 Cold Runner Systems	16
1.3.2.2 Balancing the Runner System.....	18
1.3.2.3 Cold Slug Traps	19
1.3.2.4 Gates	19
1.3.2.5 Hot Runner Systems	20
1.3.3 Flow into the Mold	22
1.3.3.1 Venting	24
1.3.3.2 Weld Lines	25
1.3.3.3 Mold Filling Analysis	26
2 Extrusion Technology	27
2.1 Introduction	27
2.2 The Functions of an Extruder	29
2.2.1 Conveying	29
2.2.2 Heating and Melting	32
2.2.3 Mixing	34
2.2.3.1 Distributive Mixing	36
2.2.3.2 Dispersive Mixing	36
2.2.4 Die Forming.....	37
2.2.4.1 Guidelines for Shapes	39

2.2.4.2	Guidelines for Die Design	39
2.2.5	Devolatilization or Degassing	40
2.3	Efficient Extrusion	41
2.3.1	Efficient Machine Design	41
2.3.1.1	The Extruder Screw	42
2.3.1.2	The Extruder Barrel	43
2.3.1.3	The Feed Hopper and Throat.....	44
2.3.1.4	The Extruder Drive	46
2.3.1.5	Instrumentation and Control	46
2.3.2	Efficient Process Operation	47
2.3.2.1	Feed Stock Consistency	47
2.3.2.2	Temperatures	48
2.3.2.3	Screen Pack	49
2.3.2.4	Feeding	50
2.3.2.5	Gear Pumps	51
3	Plastics and Plastics Properties Important in Injection Molding and Extrusion	53
3.1	Thermoplastics and Thermosets	53
3.2	Amorphous and Semicrystalline Plastics	53
3.3	Liquid Crystalline Plastics	54
3.4	Elastomers	55
3.5	Flow Behavior of Plastics	55
3.5.1	The Melt Index Test	56
3.5.2	Spiral Length Tester	57
3.5.3	The Effect of Shearing.....	57
3.5.3.1	Shear Thinning or Pseudoplastic Behavior	58
3.5.3.2	Effect of Temperature on Viscosity	59
3.5.3.3	Effect of Pressure on Viscosity	59
3.5.4	Flow Properties for Injection Molding	59
3.5.5	Viscous Heat Generation	60
3.6	Thermal Properties	60
3.6.1	Thermal Conductivity	61
3.6.2	Specific Heat and Enthalpy	61
3.6.3	Thermal Stability and Induction Time	62
3.6.4	Density	62
4	Introduction to Statistical Process Control	65
4.1	Introduction	65
4.2	Implementing Statistical Process Control	68
4.3	Basic Statistical Concepts	73
4.3.1	Causes of Variability	73
4.3.2	Basic Statistical Terms	75

4.3.3	Mean, Median, and Mode	75
4.3.4	Range, Variance, and Standard Deviation	76
4.3.5	Plotting Distribution Patterns	78
4.3.6	Characteristics of a Frequency Distribution.....	82
4.3.7	Different Distribution Patterns	83
4.3.8	The Central Limit Theorem.....	84
5	Data Collection, Data Analysis, and Problem Solving	87
5.1	Attributes Data Versus Variables Data	87
5.2	Important Aspects of Data Collection.....	87
5.3	Diagrams for Problem Solving.....	88
5.3.1	Cause Listing Diagram	88
5.3.2	Variation Analysis Diagram	89
5.3.3	Process Analysis Diagram	90
5.4	Pareto Diagrams	91
5.5	Histograms	93
5.6	Scatter Diagrams and Correlation Tables	93
5.7	Recording Data	95
5.7.1	Check Sheets	95
5.7.2	Portable Data Collectors/Machine Analyzers.....	97
5.7.3	Fixed Station Data Acquisition Systems	98
5.8	Sampling	101
6	Measurement	103
6.1	Introduction	103
6.2	Basic Concepts	104
6.3	Measurement Error	106
6.4	Quantifying Measurement Variation	107
6.4.1	Short Method for Gage R&R	109
6.4.2	Long Method for Gage R&R	110
6.4.3	Gage Accuracy	113
6.4.4	Gage Stability	113
6.4.5	Gage Linearity	114
6.4.5.1	Guidelines	114
6.5	Graphical Method for Measurement Analysis	114
6.5.1	Traditional Gage R&R Method	115
6.5.2	Graphical Approach to Gage R&R	116
6.5.3	Differences Between Operators	118
6.5.3.1	Measurement Error and Product Variation	118
6.6	Measurements in Injection Molding	120
6.6.1	Important Process Parameters	120
6.6.1.1	Product Characteristics	121

6.6.1.2	Pressure	121
6.6.1.3	Temperature	124
6.6.1.4	Screw Speed	126
6.7	Measurements in Extrusion	126
6.7.1	Important Process Parameters	126
6.7.1.1	Extrudate Dimensions	127
6.7.1.2	Pressure	127
6.7.1.3	Screw and Take-Up Speed	129
7	Control Charts	131
7.1	Introduction	131
7.2	Control Charts for Variables Data	131
7.2.1	The \bar{x} and R Chart	132
7.3	Interpretation of \bar{x} and R Charts	137
7.4	Control Charts for Attributes Data	140
7.4.1	Creating and Analyzing Attributes Control Charts	141
7.4.2	The p Chart	141
7.4.3	The np Chart	144
7.4.4	The c Chart	146
7.4.5	The u Chart	147
8	Process Capability and Special SPC Techniques for Molding and Extrusion	151
8.1	Introduction	151
8.2	Capability Indices	152
8.2.1	Process Capability Shortcut with Precontrol	154
8.3	Tests for Normality	155
8.3.1	Graphical Methods	155
8.3.2	Statistical Calculations	157
8.4	Capability Measures for Non-Normal Distributions	159
8.5	Special SPC Techniques for Injection Molding	161
8.5.1	Family Processes	161
8.5.1.1	Median/Individual Measurement Control Charts	162
8.5.1.2	Group Charting	164
8.5.2	Grading Machine Capability	165
8.6	Example of SPC in Extrusion	167
8.6.1	Introduction	167
8.6.2	Specific Example Overview	168
8.6.3	Low Cost Portable SPC Package	169
8.6.4	The Extrusion Line	170
8.6.5	Extrusion Line Changes, General	171
8.6.6	Extrusion Line Changes, Details	172
8.6.7	Conclusions	173

9 Other Tools to Improve Process Control	175
9.1 Introduction	175
9.2 Design of Experiments (DOE)	176
9.3 The Shainin Methodology	177
9.3.1 Tools to Generate Clues	179
9.3.1.1 Multi-Vari Charts	179
9.3.1.2 Components Search	180
9.3.1.3 Paired Comparisons	182
9.3.1.4 Variables Search	182
9.3.2 Factorial Designs	184
9.3.2.1 Interaction	185
9.3.2.2 Two-Level Factorial Design with K Factors	187
9.3.3 The B Versus C Analysis	188
9.3.4 Scatter Plots to Determine Appropriate Tolerances	192
9.4 Precontrol	194
9.4.1 Comparing Precontrol to Control Charts	196
References	199
Appendix I, List of Polymer Acronyms	203
Appendix II, Nomenclature	213
Appendix III, SPC/DOE Software	215
Appendix IV, Expressions for the Normal Distribution Curve and z-Table	223
Appendix V, Glossary	227
Appendix VI, Monitoring Systems for Injection Molding	235
Appendix VII, Conversion Constants	237
Appendix VIII, List of Acronyms	241
Appendix IX, Proposed New Terminology	243
Subject Index	245