

Contents

Foreword xv

Preface xvii

About the Companion Website xix

Part I Fundamentals of Process Planning 1

1 Introduction to Process Planning 3

1.1 Introduction 3

1.2 Process Planning Within Product Development Cycle 3

1.3 Process-Planning Levels of Detail and Activities 6

1.3.1 Interpretation of Product Design Data and Manufacturability 7

1.3.2 Bill of Materials Analysis and Make-or-Buy Decision 8

1.3.3 Manufacturing Process Evaluation and Selection 8

1.3.4 Selection of Machines and Equipment 8

1.3.5 Machining Sequence and Tolerance Charting 8

1.3.6 Selection of Operation and Process Parameters 9

1.3.7 Tooling Design 9

1.3.8 Time and Cost Estimation 9

1.3.9 Documentation and Communication 9

1.3.10 Selection of Quality Assurance Methods 10

1.4 Technical Data Required for Process Planning 10

1.5 Process-Planning Methods 11

1.5.1 Manual Planning Methods 11

1.5.2 Computer-Aided Process Planning 11

1.5.2.1 Variant Approach 12

1.5.2.2 Generative Approach 15

Questions and Exercises 17

References 17

2 Product Data and Manufacturability 19

2.1 Introduction 19

2.2 Product Data 20

2.2.1 Product Structure and Bill of Materials 20

2.2.2 3D Models and Engineering Drawings 22

2.2.3 Dimensional and Geometric Tolerances 24

2.2.3.1	Dimensional Tolerances	24
2.2.3.2	Geometric Tolerances	25
2.2.3.3	Datum Features and Datum Reference Frames	25
2.2.4	Traditional Tolerancing Versus GPS/Geometric Dimensioning and Tolerancing (GD&T)	28
2.2.5	General Tolerances	31
2.2.5.1	Dimensional and Geometrical Tolerances for Machined Parts	31
2.2.5.2	Dimensional and Geometrical Tolerances for Metal Casting Parts	31
2.2.5.3	General Tolerance Indication in Engineering Drawings	33
2.2.6	Surface Roughness and Surface Treatments	36
2.3	Manufacturability	39
2.3.1	Machining Parts	40
2.3.2	Metal Casting Parts	41
	Questions and Exercises	42
	References	43
3	Selection of Manufacturing Processes	45
3.1	Introduction	45
3.2	Materials in Manufacturing	45
3.3	Manufacturing Processes	47
3.3.1	Casting and Molding Processes	48
3.3.1.1	General Characteristics of Casting and Molding Processes	48
3.3.2	Forming Processes	50
3.3.2.1	General Characteristics of Bulk Forming	53
3.3.3	Powder Metallurgy Processes	53
3.3.4	Machining Processes	55
3.3.4.1	General Characteristics of Machining Processes	56
3.3.5	Surface Processes	56
3.4	Manufacturing Process Selection	56
3.4.1	Factors in Process Selection	56
3.4.2	Process Selection Method	60
3.4.2.1	Drawing Interpretation	61
3.4.2.2	Material and Process Compatibility	62
3.4.2.3	Geometry and Process Compatibility	62
3.4.2.4	Manufacturing Processes Technically Feasible	62
3.4.2.5	Manufacturing Processes Economically Feasible	62
3.4.2.6	Identifying a Process	66
3.4.3	Practical Example	68
3.5	Use of Software for Process Selection	75
	Questions and Exercises	77
	References	79

4	Process-Planning Documentation	81
4.1	Introduction	81
4.2	Process Flow Charts	81
4.3	Assembly Charts and Operation Process Charts	82
4.4	Routing Sheets	83
4.5	Operations Lists	84
4.6	Tooling List	86
4.7	CNC Programs	86
4.8	Work Instructions Sheet	87
4.9	Inspection Sheets and Reports	87
	Questions and Exercises	88
	References	91

Part II Process Planning in Casting 93

5	Fundamentals of Casting	95
5.1	Introduction	95
5.2	Sand Casting	95
5.3	Heating the Metal	97
5.4	Pouring the Molten Metal	97
5.4.1	Flow Velocity and Reynolds Number	97
5.4.2	Filling Time	100
5.4.3	Ceramic Filters	101
5.5	Solidification and Cooling	101
5.5.1	Solidification Time	101
5.5.2	Shrinkage	102
5.5.3	Directional Solidification	103
5.6	Casting Quality	104
5.7	Cleaning Operations	105
	Questions and Exercises	105
	References	106

6	Process Planning in Sand Casting	109
6.1	Introduction	109
6.2	Mold-Making Guidelines	110
6.2.1	Part Orientation Rules	110
6.2.2	Parting Plane Rules	110
6.2.3	Gating System	110
6.2.3.1	Sprue Rules	110
6.2.3.2	Runner Rules	111
6.2.3.3	Gate Rules	112
6.2.3.4	Steps for Gating System Design	113
6.2.3.5	Practical Example	114
6.2.4	Riser's Rules	115
6.2.4.1	Practical Example	118
6.3	Pattern Fabrication Guidelines	120
6.3.1	Geometry Simplification	121

6.3.2	Shrinkage Allowance	122
6.3.3	Machining Allowance	124
6.3.4	Draft	124
6.3.5	Fillets and Radii	124
6.3.6	Parting Line	125
6.3.7	Core Prints and Chaplets	126
6.3.8	Opening Forces on Molds	128
6.3.9	Practical Example	129
6.4	Core and Core Box Fabrication	131
6.5	Casting Simulation	132
6.6	Melting and Casting	132
6.7	Knockout, Fettling, and Finishing	134
6.7.1	Knockout	134
6.7.2	Fettling	134
6.7.3	Finishing	135
6.8	Inspection	135
6.9	Operations List in Sand Casting	135
	Questions and Exercises	136
	References	137

Part III Process Planning in Machining 139

7	Definition and Selection of Workholding Systems	141
7.1	Introduction	141
7.2	Principles of Workholding	142
7.2.1	Locating and Clamping Principles	142
7.2.1.1	Forms of Location	142
7.2.1.2	Locating from External Surfaces	143
7.2.1.3	Locating from Internal Surfaces	145
7.2.1.4	Analyzing Machining Forces	145
7.2.2	Locating Guidelines	146
7.2.2.1	Positioning Locators	146
7.2.2.2	Avoiding Over-Constrained Workpieces	147
7.2.2.3	Designing Foolproofing Layouts	148
7.2.2.4	Evaluating Locating Accuracy	148
7.2.3	Clamping Guidelines	149
7.2.3.1	Positioning Clamps	150
7.2.3.2	Avoiding Workpiece Deformation	150
7.2.3.3	Evaluation of Clamping Force Requirement	151
7.2.4	Basic Steps for Workholding/Fixturing Design	155
7.3	Types of Workholding Systems	155
7.3.1	Permanent Fixturing	155
7.3.2	Modular Fixtures	156
7.3.3	General-Purpose Workholders	156
7.3.4	Workholding System Selection	157
7.4	Permanent and Modular Fixtures	158
7.4.1	Basic Fixture Elements	158

7.4.2	Fixturing Examples	162
7.5	General Purpose of Workholding Devices for Turning	162
7.5.1	Chucks and Plates	163
7.5.1.1	Three-Jaw Self-Centering Chucks	163
7.5.1.2	Four-Jaw Independent Chucks	163
7.5.1.3	Magnetic Chucks	163
7.5.1.4	Face Plates	163
7.5.2	Collets and Mandrels	164
7.5.3	Devices for Holding between Centers	164
7.5.4	Rests	165
7.6	General Purpose of Workholding Devices for Milling	167
7.6.1	Vices	167
7.6.2	Work Directly Mounted on Table	167
7.6.3	Rotary Tables and Magnetic Plates	170
7.7	Workholding Drawing Representation	171
	Questions and Exercises	175
	References	178
8	Geometry Analysis and Machining Operations Sequence	179
8.1	Introduction	179
8.2	Definition of Terms	179
8.3	Geometry Analysis	181
8.4	Machining Volumes	182
8.4.1	Determination of Machining Volumes, Features, and Tool Approach Directions (TADs)	182
8.4.2	Linking Machining Features and Potential Machining Operations	183
8.5	Definition and Sequence of Machining Operations	186
8.5.1	Grouping Features According to Tool Approach Direction (TAD)	186
8.5.2	Precedence Constraints	186
8.5.3	Feature–Datum Interactions. Critical Extrinsic Relationships	189
8.5.4	Machining Sequence Diagram	190
8.6	Definition of Locating Surfaces and Workholding	191
8.7	Practical Example	192
	Questions and Exercises	204
	References	207
9	Machine Tool/Cutting Tool Selection	209
9.1	Introduction	209
9.2	Machine Tool Selection	209
9.2.1	Factors in Machine Tool Selection	209
9.2.2	Machine Tool Selection Method	211
9.2.3	Practical Example	211
9.3	Cutting Tool Selection	212
9.3.1	Factors in Cutting Tool Selection	212
9.3.2	Cutting Tools and Selection Recommendations	214
9.3.2.1	Cutting Tools in Turning	214
9.3.2.2	Turning Holders and Cutting Inserts	215
9.3.2.3	Cutting Tools in Milling	222

9.3.2.4	Milling Holders and Cutting Inserts	226	
9.3.2.5	Cutting Tools in Drilling	226	
9.3.2.6	Cutting Tools in Reaming and Boring	232	
9.3.2.7	Cutting Tools in Threading	233	
9.3.3	Practical Example	234	
9.4	Example Data: Shop-Floor Tool Tables	236	
	Questions and Exercises	241	
	References	242	
10	Process Parameter Selection	243	
10.1	Introduction	243	
10.2	Methodology	243	
10.2.1	Stepwise Procedure	243	
10.2.2	General Constraints	247	
10.2.2.1	Constraints on Cutting Speed	247	
10.2.2.2	Constraints on Feed Rate	247	
10.2.2.3	Constraints on Depth of Cut	250	
10.2.2.4	Constraints on Cutting Forces and Power Consumption	251	
10.2.3	Cutting Force and Power Calculation	252	
10.3	Specific Guidelines for Turning	255	
10.4	Specific Guidelines in Milling	255	
10.5	Specific Guidelines in Drilling	258	
10.6	Use of Cutting Fluids	259	
10.7	Practical Example	261	
	Questions and Exercises	266	
	References	268	
11	Geometric Validation: Tolerance Charting	269	
11.1	Introduction	269	
11.2	Definition of Terms	270	
11.3	Steps for Tolerance Charting	271	
11.3.1	Step 1: Create the Rooted Tree and Start Chart Preparation	273	
11.3.2	Step 2: Write Design Dimensions, Process Tolerances, and Raw Surface Tolerances	274	
11.3.3	Step 3: Define a Surface Reference and Write the Stock Removal Set Table	275	
11.3.4	Step 4: Calculate the Resultant Dimensions and Verify	276	
11.3.5	Step 5: Calculate the Stock Removal and Verify	276	
11.3.6	Step 6: Calculate Working Dimensions	277	
11.3.7	Adding Fixturing Tolerances	278	
	Questions and Exercises	279	
	References	281	
12	CNC Programming	283	
12.1	Introduction	283	
12.2	CNC Machine Tools	283	
12.2.1	Nomenclature of Machine Tool Axes	283	
12.2.2	Coordinate Systems in Machine Tools: Reference Systems	284	

12.3	Programming CNC Machine Tools	286
12.3.1	Manual Programming	286
12.3.2	Computer-Aided Programming	286
12.3.3	Conversational Programming	288
12.4	Basic Concepts of CNC Programming. G-Code	288
12.4.1	Program Structure	289
12.4.2	List of Preparatory Functions	289
12.4.3	Programming Modes	289
12.4.3.1	Measurement Units. G20/G21 or G70/G71	289
12.4.3.2	Absolute and Incremental Programming: G90/G91	289
12.4.4	Changes in Reference Systems	290
12.4.5	Programming of Movements	290
12.4.5.1	Rapid Movement: G00	290
12.4.5.2	Linear Interpolation: G01	291
12.4.5.3	Circular Interpolation: G02/G03	291
12.4.6	Programming of Cutting and Feed Speeds	293
12.4.6.1	Feed Speed (F): G94/G95	293
12.4.6.2	Spindle Speed (S). G96/G97	293
12.4.6.3	Formulae	293
12.4.7	Cutting Tool Change	294
12.4.8	Tool Offsets	294
12.4.9	Radius Compensations (G40, G41, and G42)	295
12.4.9.1	Compensation in Turning	295
12.4.9.2	Compensation in Milling	295
12.4.10	Length Compensations (G43, G44, and G49)	297
12.4.11	Auxiliary Functions	298
12.5	CNC Canned Cycles	298
12.5.1	G81 Turning Canned Cycle with Straight Sections	299
12.5.2	G87. Rectangular Pocket Canned Cycle	299
12.6	Machining Methods/Cutting Strategies	301
12.6.1	Milling	301
12.6.2	Turning	304
12.6.3	Drilling	304
12.6.4	Threading	305
	Questions and Exercises	307
	References	310

Part IV Process Planning in Inspection and Costing 311

13	Inspection Process Planning	313
13.1	Introduction	313
13.2	Inspection Plans for Product and Process Validation	313
13.2.1	Product Validation. First Article Inspection (FAI)	314
13.2.2	Process Validation. Process Capability Studies	316
13.3	Inspection Plans in Production	318

13.3.1	Statistical Process Control	318
13.3.2	Inspection Sampling for Reception/Shipment. Acceptance Sampling	319
13.3.2.1	Operating Characteristic Curve	321
13.3.2.2	Acceptance Quality Level	321
13.3.2.3	Lot Tolerance Percent Defective	322
13.3.2.4	Consumer's and Producer's Risk	322
13.3.2.5	Determining the Sampling Plan	322
13.4	Features to be Inspected	326
13.5	Selection of Measurement Instruments for Inspection	326
13.6	Example Data: Measurement Instrument Specifications	328
	Questions and Exercises	329
	References	331
14	Product Cost Estimation	333
14.1	Introduction	333
14.2	Elements of Costs	334
14.3	Make-or-Buy Decision	335
14.4	Pricing	337
14.5	Sand-Casting Cost Estimation (C_{tsc})	338
14.5.1	Tooling Cost (C_{tooling})	339
14.5.1.1	Mold Sand and Core Sand Cost ($C_{\text{msd}}, C_{\text{csd}}$)	339
14.5.1.2	Pattern and Core Box Cost ($C_{\text{pm}}, C_{\text{box}}$)	340
14.5.2	Processing Cost (C_{proc})	341
14.5.2.1	Cost of Producing Cores (C_{core})	342
14.5.2.2	Cost of Producing Molds (C_{mp})	342
14.5.2.3	Cost of Cleaning Castings (C_{cl})	342
14.5.3	Metal Cost (C_{mat})	343
14.5.3.1	Cost of Raw Material (C_{rm})	343
14.5.3.2	Cost of Melting Energy (C_{en})	343
14.5.3.3	Cost of Equipment (C_{fk})	344
14.5.3.4	Cost of Labor (C_{lk})	344
14.5.4	Practical Example	345
14.6	Machining Cost Estimation (C_{tmach})	349
14.6.1	Material Cost (C_{mat})	349
14.6.2	Setup Cost (C_{setup})	349
14.6.3	Nonproductive Cost ($C_{\text{non-pr}}$)	350
14.6.3.1	Machine Loading and Unloading ($C_{\text{ld-uld}}$)	350
14.6.3.2	Handling between Machines (C_{hn})	351
14.6.3.3	Nonmachining Movements ($C_{\text{non-mach}}$)	351
14.6.4	Machining Cost (C_{mach})	352
14.6.5	Tooling Costs (C_{tooling})	352
14.6.5.1	Cutting Tool Costs ($C_{\text{cutting-tools}}$)	353
14.6.5.2	Fixturing Cost ($C_{\text{fixturing}}$)	355
14.6.6	Practical Example	355
14.7	3D Printing Cost Estimation (C_{3Dpr})	358
14.7.1	Material Cost (C_{mat})	358
14.7.2	Operating Cost (C_{op})	359

14.7.2.1	Cost of manpower (C_{man})	359
14.7.2.2	Electricity Cost (C_{elec})	360
14.7.2.3	Cost of the equipment (C_{eq})	360
14.7.3	Postprocessing Cost (C_{post})	360
14.7.4	Practical Example	361
14.8	Computer-Aided Cost Estimators	362
14.9	Web-Based Tools for Cost Estimation	362
14.10	Product Costing Sheets	364
14.11	Data of Interest: Wage Statistics for Primary Metal Manufacturing Industries	364
	Questions and Exercises	366
	References	368

Appendix 1: ISO Dimensional Tolerances 369

Appendix 2: Cutting Data 381

Appendix 3: AQL Tables 403

Index 405