## **Table of contents**

- Chapter 1 Introduction (p. 1)
- 1.1 Historical Development of the Assembly Process (p. 2)
- 1.2 Choice of Assembly Method (p. 6)
- 1.3 Social Effects of Automation (p. 10)
- References (p. 15)
- Chapter 2 Automatic Assembly Transfer Systems (p. 17)
- 2.1 Continuous Transfer (p. 17)
- 2.2 Intermittent Transfer (p. 17)
- 2.3 Indexing Mechanisms (p. 23)
- 2.4 Operator-Paced Free-Transfer Machine (p. 27)
- References (p. 28)
- Chapter 3 Automatic Feeding and Orienting Vibratory Feeders (p. 29)
- 3.1 Mechanics of Vibratory Conveying (p. 29)
- 3.2 Effect of Frequency (p. 34)
- 3.3 Effect of Track Acceleration (p. 34)
- 3.4 Effect of Vibration Angle (p. 35)
- 3.5 Effect of Track Angle (p. 35)
- 3.6 Effect of Coefficient of Friction (p. 37)
- 3.7 Estimating the Mean Conveying Velocity (p. 38)
- 3.8 Load Sensitivity (p. 42)
- 3.9 Solutions to Load Sensitivity (p. 44)
- 3.10 Spiral Elevators (p. 46)
- 3.11 Balanced Feeders (p. 47)
- 3.12 Orientation of Parts (p. 47)
- 3.13 Typical Orienting System (p. 48)
- 3.14 Effect of Active Orienting Devices on Feed Rate (p. 54)
- 3.15 Analysis of Orienting Systems (p. 55)
- 3.15.1 Orienting System (p. 57)
- 3.15.2 Method of System Analysis (p. 58)
- **3.15.3 Optimization** (p. 61)
- 3.16 Performance of an Orienting Device (p. 63)
- **3.16.1 Analysis** (p. 63)
- 3.17 Natural Resting Aspects of Parts for Automatic Handling (p. 69)
- **3.17.1 Assumptions** (p. 70)
- 3.17.2 Analysis for Soft Surfaces (p. 71)
- 3.17.3 Analysis for Hard Surfaces (p. 77)
- 3.17.4 Analysis for Cylinders and Prisms with Displaced Centers of Mass (p. 78)
- 3.17.5 Summary of Results (p. 78)
- 3.18 Analysis of a Typical Orienting System (p. 78)
- 3.18.1 Design of Orienting Devices (p. 85)
- 3.19 Out-of-Bowl Tooling (p. 87)
- References (p. 89)
- Chapter 4 Automatic Feeding and Orienting Mechanical Feeders (p. 91)

- 4.1 Reciprocating-Tube Hopper Feeder (p. 92)
- 4.1.1 General Features (p. 94)
- 4.1.2 Specific Applications (p. 94)
- 4.2 Centerboard Hopper Feeder (p. 94)
- 4.2.1 Maximum Track Inclination (p. 94)
- 4.2.2 Load Sensitivity and Efficiency (p. 99)
- 4.3 Reciprocating-Fork Hopper Feeder (p. 100)
- 4.4 External Gate Hopper Feeder (p. 102)
- 4.4.1 Feed Rate (p. 102)
- 4.4.2 Load Sensitivity and Efficiency (p. 106)
- 4.5 Rotary-Disk Feeder (p. 108)
- 4.5.1 Indexing Rotary-Disk Feeder (p. 108)
- 4.5.2 Rotary-Disk Feeder with Continuous Drive (p. 109)
- 4.5.3 Load Sensitivity and Efficiency (p. 110)
- 4.6 Centrifugal Hopper Feeder (p. 110)
- 4.6.1 Feed Rate (p. 111)
- 4.6.2 Efficiency (p. 114)
- 4.7 Stationary-Hook Hopper Feeder (p. 115)
- 4.7.1 Design of the Hook (p. 115)
- 4.7.2 Feed Rate (p. 118)
- 4.8 Bladed-Wheel Hopper Feeder (p. 119)
- 4.9 Tumbling-Barrel Hopper Feeder (p. 119)
- 4.9.1 Feed Rate (p. 121)
- 4.10 Rotary-Centerboard Hopper Feeder (p. 124)
- 4.11 Magnetic-Disk Feeder (p. 124)
- 4.12 Elevating Hopper Feeder (p. 125)
- 4.13 Magnetic Elevating Hopper Feeder (p. 126)
- 4.14 Magazines (p. 126)
- References (p. 130)
- Chapter 5 Feed Tracks, Escapements, Parts-Placement Mechanisms, and Robots (p. 131)
- 5.1 Gravity Feed Tracks (p. 131)
- 5.1.1 Analysis of Horizontal-Delivery Feed Track (p. 132)
- **5.1.2 Example** (p. 137)
- 5.1.3 On/Off Sensors (p. 139)
- 5.1.3.1 Theory (p. 140)
- **5.1.4 Feed Track Section** (p. 143)
- 5.1.5 Design of Gravity Feed Tracks for Headed Parts (p. 146)
- **5.1.5.1 Analysis** (p. 146)
- 5.1.5.2 Results (p. 153)
- 5.1.5.3 Procedure for Use of Figure 5.17 to Figure 5.20 (p. 158)
- 5.2 Powered Feed Tracks (p. 158)
- 5.2.1 Example (p. 160)
- 5.3 Escapements (p. 161)
- 5.3.1 Ratchet Escapements (p. 162)
- **5.3.2 Slide Escapements** (p. 164)

- **5.3.3 Drum Escapements** (p. 165)
- 5.3.4 Gate Escapements (p. 167)
- 5.3.5 Jaw Escapements (p. 167)
- 5.4 Parts-Placing Mechanisms (p. 168)
- **5.5 Assembly Robots** (p. 171)
- 5.5.1 Terminology (p. 171)
- 5.5.2 Advantages of Robot Assembly (p. 172)
- **5.5.3 Magazines** (p. 174)
- 5.5.4 Types of Magazine Systems (p. 175)
- 5.5.5 Automatic Feeders for Robot Assembly (p. 175)
- 5.5.6 Economics of Part Presentation (p. 178)
- 5.5.7 Design of Robot Assembly Systems (p. 182)
- References (p. 186)
- Chapter 6 Performance and Economics of Assembly Systems (p. 187)
- 6.1 Indexing Machines (p. 187)
- 6.1.1 Effect of Parts Quality on Downtime (p. 187)
- 6.1.2 Effects of Parts Quality on Production Time (p. 188)
- 6.1.3 Effect of Parts Quality on the Cost of Assembly (p. 190)
- 6.2 Free-Transfer Machines (p. 195)
- 6.2.1 Performance of a Free-Transfer Machine (p. 196)
- 6.2.2 Average Production Time for a Free-Transfer Machine (p. 200)
- 6.2.3 Number of Personnel Needed for Fault Correction (p. 200)
- 6.3 Basis for Economic Comparisons of Automation Equipment (p. 201)
- 6.3.1 Basic Cost Equations (p. 202)
- 6.4 Comparison of Indexing and Free-Transfer Machines (p. 204)
- **6.4.1 Indexing Machine** (p. 204)
- 6.4.2 Free-Transfer Machine (p. 205)
- 6.4.3 Effect of Production Volume (p. 205)
- 6.5 Economics of Robot Assembly (p. 207)
- 6.5.1 Parts Presentation (p. 208)
- 6.5.2 Profile of Typical Candidate Assembly (p. 211)
- 6.5.3 Single-Station Systems (p. 212)
- 6.5.3.1 Equipment Costs (p. 212)
- 6.5.3.2 Personnel Costs (p. 213)
- 6.5.3.3 Parts Quality (p. 213)
- 6.5.3.4 Basic Cost Equation (p. 214)
- 6.5.4 Multistation Transfer Systems (p. 215)
- 6.5.4.1 Equipment Costs (p. 215)
- 6.5.4.2 Cost Equation (p. 216)
- References (p. 217)
- Chapter 7 Design for Manual Assembly (p. 219)
- **7.1 Introduction** (p. 219)
- 7.2 Where Design for Assembly Fits in the Design Process (p. 219)
- 7.3 General Design Guidelines for Manual Assembly (p. 221)
- 7.3.1 Design Guidelines for Part Handling (p. 221)
- 7.3.2 Design Guidelines for Insertion and Fastening (p. 222)

- 7.4 Development of a Systematic DFA Analysis Method (p. 227)
- **7.5 DFA Index** (p. 229)
- 7.6 Classification System for Manual Handling (p. 230)
- 7.7 Classification System for Manual Insertion and Fastening (p. 233)
- 7.8 Effect of Part Symmetry on Handling Time (p. 236)
- 7.9 Effect of Part Thickness and Size on Handling Time (p. 237)
- 7.10 Effect of Weight on Handling Time (p. 239)
- 7.11 Parts Requiring Two Hands for Manipulation (p. 240)
- 7.12 Effects of Combinations of Factors (p. 240)
- 7.13 Threaded Fasteners (p. 240)
- 7.14 Effects of Holding Down (p. 242)
- 7.15 Problems with Manual Assembly Time Standards (p. 242)
- 7.16 Application of the DFA Method (p. 244)
- 7.16.1 Results of the Analysis (p. 248)
- 7.17 Further General Design Guidelines (p. 251)
- References (p. 254)
- Chapter 8 Product Design for High-Speed Automatic Assembly and Robot Assembly (p. 257)
- 8.1 Introduction (p. 257)
- 8.2 Design of Parts for High-Speed Feeding and Orienting (p. 258)
- 8.3 Example (p. 263)
- 8.4 Additional Feeding Difficulties (p. 265)
- 8.5 High-Speed Automatic Insertion (p. 266)
- 8.6 Example (p. 269)
- 8.7 Analysis of an Assembly (p. 271)
- 8.8 General Rules for Product Design for Automation (p. 272)
- 8.9 Design of Parts for Feeding and Orienting (p. 276)
- 8.10 Summary of Design Rules for High-Speed Automatic Assembly (p. 280)
- 8.10.1 Rules for Product Design (p. 280)
- 8.10.2 Rules for the Design of Parts (p. 280)
- 8.11 Product Design for Robot Assembly (p. 281)
- 8.11.1 Summary of Design Rules for Robot Assembly (p. 287)
- References (p. 289)
- Chapter 9 Printed-Circuit-Board Assembly (p. 291)
- **9.1 Introduction** (p. 291)
- 9.2 Terminology (p. 291)
- 9.3 Assembly Process for PCBs (p. 292)
- **9.4 SMD Technology** (p. 301)
- 9.5 Estimation of PCB Assembly Costs (p. 302)
- 9.6 Worksheet and Database for PCB Assembly Cost Analysis (p. 303)
- **9.6.1 Instructions** (p. 303)
- 9.7 PCB Assembly Equations and Data for Total Operation Cost (p. 305)
- **9.7.1 Manual** (p. 306)
- 9.7.2 Autoinsertion Machine (p. 306)
- 9.7.3 Robot Insertion Machine (p. 306)
- **9.8 Glossary of Terms** (p. 308)

- References (p. 310)
- Chapter 10 Feasibility Study for Assembly Automation (p. 311)
- 10.1 Machine Design Factors to Reduce Machine Downtime Due to Defective Parts (p. 312)
- **10.2 Feasibility Study** (p. 313)
- 10.2.1 Precedence Diagrams (p. 314)
- 10.2.2 Manual Assembly of Plug (p. 317)
- **10.2.3 Quality Levels of Parts** (p. 318)
- 10.2.4 Parts Feeding and Assembly (p. 319)
- 10.2.5 Special-Purpose Machine Layout and Performance (p. 321)
- 10.2.5.1 Indexing Machine (p. 321)
- 10.2.5.2 Free-Transfer Machine (p. 324)
- 10.2.6 Robot Assembly of the Power Plug (p. 326)
- References (p. 332)
- **Problems** (p. 333)
- Appendix A Simple Method for the Determination of the Coefficient of Dynamic Friction (p. 363)
- **A.1 The Method** (p. 363)
- **A.2 Analysis** (p. 365)
- A.3 Precision of the Method (p. 366)
- **A.4 Discussion** (p. 366)
- **Reference** (p. 368)
- Appendix B Out-of-Phase Vibratory Conveyors (p. 369)
- B.1 Out-of-Phase Conveying (p. 370)
- **B.2 Practical Applications** (p. 372)
- **Reference** (p. 373)
- Appendix C Laboratory Experiments (p. 375)
- C.1 Performance of a Vibratory-Bowl Feeder (p. 375)
- **C.1.1 Objectives** (p. 375)
- **C.1.2 Equipment** (p. 375)
- **C.1.3 Procedure** (p. 375)
- **C.1.4 Theory** (p. 376)
- C.1.5 Presentation of Results (p. 378)
- C.2 Performance of a Horizontal-Delivery Gravity Feed Track (p. 379)
- C.2.1 Objectives (p. 379)
- C.2.2 Equipment (Objective 1) (p. 379)
- C.2.3 Theory (Objective 1) (p. 380)
- C.2.4 Procedure (Objective 1) (p. 381)
- C.2.5 Results (Objective 1) (p. 381)
- C.2.6 Equipment (Objective 2) (p. 381)
- C.2.7 Theory (Objective 2) (p. 382)
- C.2.8 Procedure (Objective 2) (p. 382)
- C.2.9 Results (Objective 2) (p. 383)
- C.2.10 Conclusions (p. 383)
- Appendix D Feeding and Orienting Techniques for Small Parts (p. 385)
- **D.1 Coding System** (p. 385)

- D.1.1 Introduction to the Coding System (p. 386)
- D.1.2 Coding Examples (p. 390)
- D.1.3 Sample Parts for Practice (p. 392)
- D.1.4 Analysis of the Coding of the Sample Parts (p. 393)
- D.1.5 Coding System for Small Parts (p. 395)
- D.2 Feeding and Orienting Techniques (p. 408)
- D.3 Orienting Devices for Vibratory-Bowl Feeders (p. 474)
- **D.4 Nonvibratory Feeders** (p. 492)
- Nomenclature (p. 501)
- Index (p. 507)