

Contents

| | | |
|----------|---|-----------|
| 1 | Introduction | 1 |
| 1.1 | The Engineering Designer | 1 |
| 1.1.1 | Tasks and Activities | 1 |
| 1.1.2 | Position of the Design Process within a Company | 6 |
| 1.1.3 | Trends | 6 |
| 1.2 | Necessity for Systematic Design | 9 |
| 1.2.1 | Requirements and the Need for Systematic Design | 9 |
| 1.2.2 | Historical Background | 10 |
| 1.2.3 | Current Methods | 14 |
| 1.2.4 | Aims and Objectives of this Book | 19 |
| 2 | Fundamentals | 27 |
| 2.1 | Fundamentals of Technical Systems | 27 |
| 2.1.1 | Systems, Plant, Equipment, Machines, Assemblies and Components | 27 |
| 2.1.2 | Conversion of Energy, Material and Signals | 29 |
| 2.1.3 | Functional Interrelationship | 31 |
| 2.1.4 | Working Interrelationship | 38 |
| 2.1.5 | Constructional Interrelationship..... | 42 |
| 2.1.6 | System Interrelationship..... | 42 |
| 2.1.7 | Systematic Guideline | 43 |
| 2.2 | Fundamentals of the Systematic Approach | 45 |
| 2.2.1 | Problem Solving Process..... | 45 |
| 2.2.2 | Characteristics of Good Problem Solvers..... | 49 |
| 2.2.3 | Problem Solving as Information Processing | 51 |
| 2.2.4 | General Working Methodology | 53 |
| 2.2.5 | Generally Applicable Methods | 58 |
| 2.2.6 | Role of Computer Support | 62 |
| 3 | Product Planning, Solution Finding and Evaluation | 63 |
| 3.1 | Product Planning..... | 63 |
| 3.1.1 | Degree of Novelty of a Product | 64 |

| | | |
|----------|--|------------|
| 3.1.2 | Product Life Cycle | 64 |
| 3.1.3 | Company Goals and Their Effect..... | 65 |
| 3.1.4 | Product Planning | 66 |
| 3.2 | Solution Finding Methods | 77 |
| 3.2.1 | Conventional Methods | 78 |
| 3.2.2 | Intuitive Methods..... | 82 |
| 3.2.3 | Discursive Methods | 89 |
| 3.2.4 | Methods for Combining Solutions | 103 |
| 3.3 | Selection and Evaluation Methods | 106 |
| 3.3.1 | Selecting Solution Variants..... | 106 |
| 3.3.2 | Evaluating Solution Variants | 109 |
| 4 | Product Development Process | 125 |
| 4.1 | General Problem Solving Process | 125 |
| 4.2 | Flow of Work During the Process of Designing | 128 |
| 4.2.1 | Activity Planning | 128 |
| 4.2.2 | Timing and Scheduling | 134 |
| 4.2.3 | Planning Project and Product Costs | 136 |
| 4.3 | Effective Organisation Structures..... | 138 |
| 4.3.1 | Interdisciplinary Cooperation | 138 |
| 4.3.2 | Leadership and Team Behaviour | 141 |
| 5 | Task Clarification | 145 |
| 5.1 | Importance of Task Clarification | 145 |
| 5.2 | Setting Up a Requirements List (Design Specification) | 146 |
| 5.2.1 | Contents | 146 |
| 5.2.2 | Format | 147 |
| 5.2.3 | Identifying the Requirements | 149 |
| 5.2.4 | Refining and Extending the Requirements | 151 |
| 5.2.5 | Compiling the Requirements List | 152 |
| 5.2.6 | Examples | 153 |
| 5.3 | Using Requirements Lists..... | 153 |
| 5.3.1 | Updating | 153 |
| 5.3.2 | Partial Requirements Lists | 156 |
| 5.3.3 | Further Uses | 157 |
| 5.4 | Practical Application of Requirements Lists | 157 |
| 6 | Conceptual Design | 159 |
| 6.1 | Steps of Conceptual Design | 159 |
| 6.2 | Abstracting to Identify the Essential Problems | 161 |
| 6.2.1 | Aim of Abstraction | 161 |
| 6.2.2 | Broadening the Problem Formulation | 162 |
| 6.2.3 | Identifying the Essential Problems from the Requirements List | 164 |
| 6.3 | Establishing Function Structures | 169 |

| | | |
|--------|--|-----|
| 6.3.1 | Overall Function | 169 |
| 6.3.2 | Breaking a Function Down into Subfunctions .. | 170 |
| 6.3.3 | Practical Applications of Function Structures .. | 178 |
| 6.4 | Developing Working Structures | 181 |
| 6.4.1 | Searching for Working Principles | 181 |
| 6.4.2 | Combining Working Principles | 184 |
| 6.4.3 | Selecting Working Structures | 186 |
| 6.4.4 | Practical Application of Working Structures .. | 186 |
| 6.5 | Developing Concepts | 190 |
| 6.5.1 | Firming Up into Principle Solution Variants .. | 190 |
| 6.5.2 | Evaluating Principle Solution Variants | 192 |
| 6.5.3 | Practical Application of Developing Concepts .. | 198 |
| 6.6 | Examples of Conceptual Design | 199 |
| 6.6.1 | One-Handed Household Water Mixing Tap | 199 |
| 6.6.2 | Impulse-Loading Test Rig | 210 |
| 7 | Embodiment Design | 227 |
| 7.1 | Steps of Embodiment Design | 227 |
| 7.2 | Checklist for Embodiment Design | 233 |
| 7.3 | Basic Rules of Embodiment Design | 234 |
| 7.3.1 | Clarity | 235 |
| 7.3.2 | Simplicity | 242 |
| 7.3.3 | Safety | 247 |
| 7.4 | Principles of Embodiment Design | 268 |
| 7.4.1 | Principles of Force Transmission | 269 |
| 7.4.2 | Principle of the Division of Tasks | 281 |
| 7.4.3 | Principle of Self-Help | 290 |
| 7.4.4 | Principles of Stability and Bi-Stability | 301 |
| 7.4.5 | Principles for Fault-Free Design | 305 |
| 7.5 | Guidelines for Embodiment Design | 308 |
| 7.5.1 | General Considerations | 308 |
| 7.5.2 | Design to Allow for Expansion | 309 |
| 7.5.3 | Design to Allow for Creep and Relaxation | 321 |
| 7.5.4 | Design Against Corrosion | 328 |
| 7.5.5 | Design to Minimise Wear | 340 |
| 7.5.6 | Design for Ergonomics | 341 |
| 7.5.7 | Design for Aesthetics | 348 |
| 7.5.8 | Design for Production | 355 |
| 7.5.9 | Design for Assembly | 375 |
| 7.5.10 | Design for Maintenance | 385 |
| 7.5.11 | Design for Recycling | 388 |
| 7.5.12 | Design for Minimum Risk | 402 |
| 7.5.13 | Design to Standards | 410 |
| 7.6 | Evaluating Embodiment Designs | 416 |
| 7.7 | Example of Embodiment Design | 417 |
| 7.8 | Detail Design | 436 |

| | |
|---|-----|
| 8 Mechanical Connections, Mechatronics and Adaptronics | 439 |
| 8.1 Mechanical Connections | 439 |
| 8.1.1 Generic Functions and General Behaviour | 440 |
| 8.1.2 Material Connections | 440 |
| 8.1.3 Form Connections | 441 |
| 8.1.4 Force Connections | 443 |
| 8.1.5 Applications | 447 |
| 8.2 Mechatronics | 448 |
| 8.2.1 General Architecture and Terminology | 448 |
| 8.2.2 Goals and Limitations | 450 |
| 8.2.3 Development of Mechatronic Solutions | 450 |
| 8.2.4 Examples | 451 |
| 8.3 Adaptronics | 458 |
| 8.3.1 Fundamentals and Terminology | 458 |
| 8.3.2 Goals and Limitations | 459 |
| 8.3.3 Development of Adaptronic Solutions | 460 |
| 8.3.4 Examples | 461 |
| 9 Size Ranges and Modular Products | 465 |
| 9.1 Size Ranges | 465 |
| 9.1.1 Similarity Laws | 466 |
| 9.1.2 Decimal-Geometric Preferred Number Series .. | 469 |
| 9.1.3 Representation and Selection of Step Sizes | 472 |
| 9.1.4 Geometrically Similar Size Ranges | 476 |
| 9.1.5 Semi-Similar Size Ranges | 481 |
| 9.1.6 Development of Size Ranges..... | 493 |
| 9.2 Modular Products | 495 |
| 9.2.1 Modular Product Systematics | 496 |
| 9.2.2 Modular Product Development | 499 |
| 9.2.3 Advantages and Limitations of Modular Systems | 508 |
| 9.2.4 Examples | 510 |
| 9.3 Recent Rationalisation Approaches | 514 |
| 9.3.1 Modularisation and Product Architecture..... | 514 |
| 9.3.2 Platform Construction | 515 |
| 10 Design for Quality | 517 |
| 10.1 Applying a Systematic Approach | 517 |
| 10.2 Faults and Disturbing Factors | 521 |
| 10.3 Fault-Tree Analysis | 522 |
| 10.4 Failure Mode and Effect Analysis (FMEA) | 529 |
| 10.5 Quality Function Deployment (QFD) | 531 |

| | |
|---|-----|
| 11 Design for Minimum Cost | 535 |
| 11.1 Cost Factors | 535 |
| 11.2 Fundamentals of Cost Calculations | 537 |
| 11.3 Methods for Estimating Costs | 539 |
| 11.3.1 Comparing with Relative Costs | 539 |
| 11.3.2 Estimating Using Share of Material Costs | 544 |
| 11.3.3 Estimating Using Regression Analysis | 545 |
| 11.3.4 Extrapolating Using Similarity Relations | 547 |
| 11.3.5 Cost Structures | 558 |
| 11.4 Target Costing | 560 |
| 11.5 Rules for Minimising Costs | 561 |
| 12 Summary | 563 |
| 12.1 The Systematic Approach | 563 |
| 12.2 Experiences of Applying the Systematic Approach in Practice | 567 |
| References | 571 |
| English Bibliography | 603 |
| Index | 609 |