
Contents

| | | |
|----------|---|-----------|
| 1 | Introduction | 1 |
| 1.1 | Overall demands | 1 |
| 1.2 | Historic remark | 1 |
| 1.3 | Perspectives | 2 |
| 2 | Thermodynamic Engine Cycles | 3 |
| 2.1 | Introduction to Thermodynamics | 3 |
| 2.1.1 | First Thermodynamic Law | 3 |
| 2.1.2 | Specific Heat Constant | 7 |
| 2.1.3 | State Changes of Ideal Gases | 9 |
| 2.1.4 | Thermodynamic Cycles | 15 |
| 2.2 | Ideal Combustion Engines | 19 |
| 2.2.1 | Spark-ignited (SI) Engine | 20 |
| 2.2.2 | Diesel Engine | 22 |
| 2.2.3 | Seiliger Process | 24 |
| 2.2.4 | Comparison of Different Engine Concepts | 27 |
| 2.3 | Alternative Combustion Engines | 29 |
| 2.3.1 | Gas Turbine | 29 |
| 2.3.2 | Stirling Engine | 34 |
| 2.3.3 | Steam Engine | 37 |
| 2.3.4 | Potential of Different Fuels and Propulsion Systems | 39 |
| 3 | Engine Management Systems | 43 |
| 3.1 | Basic Engine Operation | 43 |
| 3.1.1 | Effective Work | 43 |
| 3.1.2 | Air-Fuel Ratio | 47 |
| 3.1.3 | Engine Concepts | 49 |
| 3.1.4 | Inflammation of Air-Fuel Mixtures | 51 |

| | | |
|----------|--|-----------|
| 3.1.5 | Flame Propagation | 52 |
| 3.1.6 | Energy Conversion | 53 |
| 3.2 | Engine Control | 56 |
| 3.2.1 | Emissions of Internal Combustion Engines | 56 |
| 3.2.2 | Fuel Measurement | 58 |
| 3.2.3 | Intermittent Fuel Injection | 60 |
| 3.2.4 | Injection Time Calculation | 62 |
| 3.2.5 | Air Mass per Combustion Cycle | 63 |
| 3.2.6 | Intake Manifold Dynamics | 65 |
| 3.2.7 | Ignition Angle Control | 68 |
| 3.2.8 | Optimization of Engine Maps | 70 |
| 4 | Diesel Engine Modeling | 75 |
| 4.1 | Four Stroke Cycle Diesel Engine | 76 |
| 4.2 | Charge Exchange | 77 |
| 4.2.1 | Flow into Exhaust Pipes | 77 |
| 4.2.2 | Flow into Combustion Chamber | 78 |
| 4.3 | Air-fuel Ratio | 79 |
| 4.3.1 | Exhaust Stroke | 79 |
| 4.3.2 | Intake Stroke | 80 |
| 4.3.3 | Compression and Combustion | 80 |
| 4.4 | Mass Balance | 81 |
| 4.5 | Fuel Injection | 81 |
| 4.6 | Fuel Evaporation | 83 |
| 4.7 | Cylinder Dynamics | 88 |
| 4.7.1 | Zero-Dimensional Modeling | 88 |
| 4.7.2 | Thermodynamic Equations | 89 |
| 4.7.3 | Energy Balance | 89 |
| 4.7.4 | Volumetric Work | 89 |
| 4.7.5 | Heat Losses | 90 |
| 4.7.6 | Energy Conversion | 91 |
| 4.7.7 | Enthalpy of Mass Flows | 91 |
| 4.7.8 | Internal Energy of the Gas Charge | 92 |
| 4.7.9 | Calculation of State Variables | 92 |
| 4.8 | Fitting of Model Parameters | 93 |
| 4.8.1 | Simulation results | 95 |
| 4.9 | Soot Accrue ment | 97 |
| 5 | Engine Control Systems | 99 |
| 5.1 | Lambda Control | 99 |
| 5.1.1 | Stoichiometric Operation of SI Engines | 99 |
| 5.1.2 | Oxygen Sensor | 104 |
| 5.1.3 | Engine Model for Lambda Control | 105 |
| 5.1.4 | Lambda Control Circuit | 108 |
| 5.1.5 | Measurement Results | 112 |
| 5.1.6 | Adaptive Lambda Control | 113 |
| 5.2 | Idle Speed Control | 120 |
| 5.2.1 | Energy Conversion Model and Torque Balance | 121 |
| 5.2.2 | State Space Control | 123 |

| | | |
|----------|--|------------|
| 5.2.3 | Measurement Results | 127 |
| 5.3 | Knock Control | 128 |
| 5.3.1 | Knocking at SI Engines | 128 |
| 5.3.2 | Knock Sensors | 132 |
| 5.3.3 | Signal Processing | 135 |
| 5.3.4 | Knock Control | 137 |
| 5.3.5 | Adaptive Knock Control | 138 |
| 5.4 | Cylinder Balancing | 142 |
| 5.4.1 | Residues at Stationary Engine Operation | 143 |
| 5.4.2 | Residues at Engine Transients | 144 |
| 5.4.3 | Adaptation of Injection Map | 146 |
| 6 | Diagnosis | 149 |
| 6.1 | Diagnosis of Automotive Engines | 150 |
| 6.1.1 | Why On-Board Diagnosis? | 150 |
| 6.2 | OBDII | 151 |
| 6.2.1 | Main Characteristics | 151 |
| 6.3 | Introduction to Diagnosis | 153 |
| 6.3.1 | Basic Definitions and Concepts | 154 |
| 6.4 | Model Based Diagnosis | 156 |
| 6.4.1 | Some Characteristics of Model Based Diagnosis | 156 |
| 6.5 | Faults | 157 |
| 6.5.1 | Fault Modeling | 159 |
| 6.6 | Principles of Model Based Diagnosis | 159 |
| 6.6.1 | Residual Generator Design | 161 |
| 6.6.2 | Residual Evaluation | 164 |
| 6.6.3 | Examples of model based diagnosis for SI-engines | 166 |
| 6.7 | Application Example - Air Intake System | 167 |
| 6.7.1 | Modeling the Air Intake System | 168 |
| 6.7.2 | Model Identification | 170 |
| 6.7.3 | The Diagnosis System | 172 |
| 6.7.4 | Residual Generation | 172 |
| 6.7.5 | Residual Evaluation | 174 |
| 6.7.6 | Implementation | 175 |
| 6.7.7 | Validation of the Diagnosis System | 175 |
| 6.8 | Misfire Detection | 183 |
| 6.8.1 | Crankshaft Moment of Inertia | 183 |
| 6.8.2 | Crankshaft Torque Balance | 186 |
| 6.8.3 | Transformation into Linear System Representation | 186 |
| 6.8.4 | Kalman Filter Design | 187 |
| 6.8.5 | Results | 189 |
| 6.9 | Engineering of Diagnosis Systems | 191 |
| 7 | Driveline Control | 193 |
| 7.1 | Driveline Modeling | 193 |
| 7.1.1 | Basic Driveline Equations | 194 |
| 7.1.2 | A Basic Complete Model | 197 |
| 7.1.3 | Combining the equations | 199 |
| 7.1.4 | An Illustrative Modeling Example | 199 |

| | | |
|----------|--|------------|
| 7.2 | Modeling of Neutral Gear | 221 |
| 7.2.1 | Stationary Gear-Shift Experiments | 221 |
| 7.2.2 | Dynamical Gear-Shift Experiments | 222 |
| 7.2.3 | A Decoupled Model | 224 |
| 7.3 | Driveline Control | 226 |
| 7.3.1 | Background | 227 |
| 7.3.2 | Field Trials for Problem Demonstration | 228 |
| 7.3.3 | Goals of Driveline Control | 231 |
| 7.3.4 | Comment on Architectures for Driveline Control | 232 |
| 7.3.5 | State-Space Formulation | 233 |
| 7.3.6 | Controller Formulation | 235 |
| 7.3.7 | Some Feedback Properties | 236 |
| 7.3.8 | Driveline Control with LQG/LTR | 238 |
| 7.4 | Driveline Speed Control | 243 |
| 7.4.1 | RQV Control | 245 |
| 7.4.2 | Problem Formulation | 246 |
| 7.4.3 | Speed Control with Active Damping and RQV Behavior | 249 |
| 7.4.4 | Influence from Sensor Location | 252 |
| 7.4.5 | Simulations | 258 |
| 7.4.6 | Speed Controller Experiments | 260 |
| 7.4.7 | Summary | 264 |
| 7.5 | Driveline Control for Gear-Shifting | 264 |
| 7.5.1 | Internal Driveline Torque | 265 |
| 7.5.2 | Transmission-Torque Control Criterion | 270 |
| 7.5.3 | Transmission-Torque Control Design | 275 |
| 7.5.4 | Influence from Sensor Location | 278 |
| 7.5.5 | Simulations | 281 |
| 7.5.6 | Gear-Shift Controller Experiments | 282 |
| 7.6 | Anti-Jerking Control for Passenger Cars | 289 |
| 7.6.1 | Model of the Power train of a Passenger Car | 291 |
| 7.6.2 | Controller Design | 295 |
| 7.6.3 | System Performance | 298 |
| 8 | Vehicle Modelling | 301 |
| 8.1 | Introduction | 301 |
| 8.2 | Co-ordinate Systems | 302 |
| 8.3 | Wheel Model | 304 |
| 8.3.1 | Wheel Ground Contact Point Velocities | 304 |
| 8.3.2 | Wheel Slip and Tire Side Slip Angle | 313 |
| 8.3.3 | Friction Co-efficient Calculation | 319 |
| 8.3.4 | Calculation of Friction Forces | 322 |
| 8.3.5 | Tire Characteristics | 324 |
| 8.3.6 | Definition of the Wheel Radius | 327 |
| 8.4 | The Complete Vehicle Model | 327 |
| 8.4.1 | Chassis Translatory Motion | 328 |
| 8.4.2 | Chassis Rotational Motion | 332 |
| 8.4.3 | Suspension | 334 |
| 8.4.4 | Reduced Nonlinear Two-track Model | 337 |

| | | |
|-----------|---|------------|
| 8.4.5 | Vehicle Stability Analysis | 342 |
| 8.5 | Validation of the Vehicle Model | 344 |
| 8.5.1 | Validation Procedure | 345 |
| 8.5.2 | Validation Results | 347 |
| 9 | Vehicle Parameters and States | 351 |
| 9.1 | Vehicle Velocity Estimation | 351 |
| 9.1.1 | Sensor Data Preprocessing | 352 |
| 9.1.2 | Kalman Filter Approach | 353 |
| 9.1.3 | Short Introduction to Fuzzy Logic | 355 |
| 9.1.4 | Fuzzy Estimator | 356 |
| 9.1.5 | Results of Vehicle Velocity Estimator | 361 |
| 9.2 | Vehicle Yaw Rate Estimation | 364 |
| 9.2.1 | Data Preprocessing | 364 |
| 9.2.2 | Yaw Rate Calculation using the Wheel Speeds | 364 |
| 9.2.3 | Inputs | 365 |
| 9.2.4 | Outputs | 366 |
| 9.2.5 | The Fuzzy System | 367 |
| 9.2.6 | Measurement: Roundabout Traffic on Public Road | 368 |
| 9.3 | Trajectory Reconstruction | 369 |
| 9.3.1 | Vehicle Location | 369 |
| 9.3.2 | Reconstructed Trajectories | 370 |
| 9.3.3 | Robustness Analysis | 371 |
| 9.4 | Identification of Vehicle Parameters | 375 |
| 9.4.1 | Friction Characteristics | 375 |
| 9.4.2 | Mass Moments of Inertia | 379 |
| 9.4.3 | Shock Absorber Characteristics | 385 |
| 9.5 | Approximation of Vehicle Parameters | 387 |
| 9.5.1 | Calculation of Wheel Ground Contact Forces | 388 |
| 9.5.2 | Adaptation of the Tire Side Slip Constants | 391 |
| 9.5.3 | Approximation of Pitch and Roll Angles | 393 |
| 9.5.4 | Approximation of Vehicle Mass | 394 |
| 9.6 | Vehicle Body Side Slip Angle Observer | 396 |
| 9.6.1 | Basic Theory of a Nonlinear Observer | 396 |
| 9.6.2 | Observer Design | 398 |
| 9.6.3 | Validation of Vehicle Body Side Slip Angle Observer | 400 |
| 9.7 | Determination of the Road Gradient | 402 |
| 9.7.1 | Method 1: Acceleration and Wheel Speed Method | 403 |
| 9.7.2 | Method 2: Model based Road Gradient Observation | 404 |
| 10 | Vehicle Control Systems | 409 |
| 10.1 | ABS Control Systems | 409 |
| 10.1.1 | Torque Balance at wheel-road contact | 409 |
| 10.1.2 | Control Cycles of the ABS System | 410 |
| 10.1.3 | ABS Cycle Detection | 412 |
| 10.2 | Control of the Yaw Dynamics | 415 |
| 10.2.1 | Derivation of Simplified Control Law | 416 |
| 10.2.2 | Derivation of Reference Values | 419 |

| | |
|--|------------|
| 11 Road and Driver Models | 425 |
| 11.1 Road Model | 425 |
| 11.1.1 Requirements of the Road Model | 425 |
| 11.1.2 Definition of the Course Path | 426 |
| 11.1.3 Road Surfaces and Wind Strength | 429 |
| 11.2 PID Driver Model | 430 |
| 11.3 Hybrid Driver Model | 432 |
| 11.3.1 Vehicle Control Tasks | 432 |
| 11.3.2 Characteristics of the Human as a Controller | 434 |
| 11.3.3 Information Handling | 437 |
| 11.3.4 Complete Driver Model | 440 |
| 11.3.5 Model of Human Information Acquisition | 441 |
| 11.3.6 Inter-event Arrival and Service Times | 443 |
| 11.3.7 Reference Value Calculation | 445 |
| 11.3.8 Longitudinal and Lateral Control | 451 |
| A Appendix | 465 |
| A.1 Jacobian Matrices/ Nonlinear Two-track Model | 465 |
| A.2 Verification of Observability | 469 |
| A.2.1 Step 1: Taylor expansion with respect to time | 469 |
| A.2.2 Step 2: Linearization around actual point of operation | 470 |
| A.2.3 Proof of observability | 471 |
| A.3 Design of GPC Controllers | 475 |
| A.3.1 The Process Model | 475 |
| A.3.2 Recursion of the Diophantine Equation | 476 |
| A.3.3 The Control Law | 477 |
| A.3.4 Choice of the Controller Parameters | 478 |
| A.4 Driver Model: Constants and Weighting Factors | 479 |
| A.5 Least Squares Parameter Estimation | 480 |
| A.5.1 Parameter Estimation by means of Least Squares Method | 480 |
| A.5.2 Parameter Estimation by means of Recursive Least Squares | 481 |
| A.5.3 Discrete Root Filter Method in Covariant Form | 482 |
| B Nomenclature | 483 |
| B.1 Mathematical Definitions | 483 |
| B.2 Physical variables | 484 |
| B.3 Abbreviations | 496 |
| B.4 Units | 496 |
| Bibliography | 496 |
| Index | 507 |