1 Historical Review

2 Definition and Classification of Reciprocating Piston Engines
   2.1 Definitions
   2.2 Potentials for Classification
      2.2.1 Combustion Processes
      2.2.2 Fuel
      2.2.3 Working Cycles
      2.2.4 Mixture Generation
      2.2.5 Gas Exchange Control
      2.2.6 Supercharging
      2.2.7 Configuration
      2.2.8 Ignition
      2.2.9 Cooling
      2.2.10 Load Adjustment
      2.2.11 Applications
      2.2.12 Speed and Output Graduations

3 Characteristics
   3.1 Piston Displacement and Bore-to-Stroke Ratio
   3.2 Compression Ratio
   3.3 Rotational Speed and Piston Speed
   3.4 Torque and Power
   3.5 Fuel Consumption
   3.6 Gas Work and Mean Pressure
   3.7 Efficiency
   3.8 Air Throughput and Cylinder Charge
   3.9 Air-Fuel Ratio

4 Maps
   4.1 Consumption Maps
   4.2 Emission Maps
   4.3 Ignition and Injection Maps
   4.4 Exhaust Gas Temperature Maps

5 Thermodynamic Fundamentals
   5.1 Cyclical Processes
   5.2 Comparative Processes
      5.2.1 Simple Model Processes
         5.2.1.1 Constant Volume Cycle
         5.2.1.2 Constant Pressure Cycle
         5.2.1.3 Seiliger Process
         5.2.1.4 Comparison of the Cyclical Processes
      5.2.2 Energy Losses

5.3 Open Comparative Processes
   5.3.1 Work Cycle of the Perfect Engine
      5.3.1.1 Elements of Calculation
      5.3.1.2 Work of the Perfect Engine
      5.3.1.3 Effectiveness of the Perfect Engine
      5.3.1.4 Exergy Loss in the Perfect Cycle
   5.3.2 Approximation of the Real Working Cycle
      5.3.2.1 Models to Determine Combustion Behavior

5.4 Efficiency

5.5 Energy Balance in the Engine
   5.5.1 Balance Equation

6 Crank Gears
   6.1 Crankshaft Drive
      6.1.1 Design and Function
      6.1.2 Forces Acting on the Crankshaft Drive
      6.1.3 Tangential Force Characteristic and Average Tangential Force
      6.1.4 Inertial Forces
         6.1.4.1 Inertial Forces in Single-Cylinder Crank Gears
         6.1.4.2 Inertial Forces in a Two-Cylinder V Crank Gear
         6.1.4.3 Inertial Forces and Inertial Torque in Multicylinder Crank Gears
         6.1.4.4 Example
      6.1.5 Mass Balancing
         6.1.5.1 Balancing Single-Cylinder Crank Gears
         6.1.5.2 Balancing Multicylinder Crank Gears
      6.1.6 Internal Torque
      6.1.7 Throw and Firing Sequences

6.2 Rotational Oscillations
   6.2.1 Fundamentals
   6.2.2 Reduction of the Machine System
   6.2.3 Natural Frequencies and Modes of Natural Vibration
   6.2.4 Exciter Forces and Exciter Work
   6.2.5 Measures to Reduce Crankshaft Excursions
   6.2.6 Two-Mass Flywheels
7 Engine Components

7.1 Pistons / Wristpins / Wristpin Circlips

7.1.1 Pistons

7.1.1.1 Requirements and Functions
7.1.1.2 Engineering Designs
7.1.1.3 Offsetting the Boss Bore
7.1.1.4 Installation Play and Running Play
7.1.1.5 Piston Masses
7.1.1.6 Operating Temperatures
7.1.1.7 Piston Cooling
7.1.1.8 Piston Designs
7.1.1.9 Piston Manufacture
7.1.1.10 Protection of Running Surfaces/Surfaces
7.1.1.11 Piston Materials

7.1.2 Wristpins

7.1.2.1 Functions
7.1.2.2 Designs
7.1.2.3 Requirements and Dimensioning
7.1.2.4 Materials

7.1.3 Wristpin Snap Rings

7.2 Connecting Rod

7.2.1 Design of the Connecting Rod
7.2.2 Loading
7.2.3 Conrod Bolts
7.2.4 Design
7.2.4.1 Conrod Ratio
7.2.5 Conrod Manufacture
7.2.5.1 Manufacturing the Blank
7.2.5.2 Machining
7.2.6 Conrod Materials

7.3 Piston Rings

7.3.1 Embodiments
7.3.1.1 Compression Rings
7.3.1.2 Oil Control Rings
7.3.2 Ring Combinations
7.3.3 Characterizing Features
7.3.4 Manufacturing
7.3.4.1 Shaping
7.3.4.2 Wear-Protection Layers
7.3.4.3 Surface Treatments
7.3.4.4 Contact Surface Shapes for Piston Rings
7.3.4.5 Materials for Piston Rings
7.3.5 Loading, Damage, Wear, Friction

7.4 Engine Block

7.4.1 Assignments and Functions
7.4.2 Engine Block Design
7.4.2.1 Types of Engine Blocks
7.4.3 Optimizing Acoustic Properties
7.4.4 Minimizing Engine Block Mass
7.4.5 Casting Processes for Engine Blocks

7.5 Cylinders

7.5.1 Cylinder Designs
7.5.1.1 Monolithic Design
7.5.1.2 Insertion Technique
7.5.1.3 Bonding Technology
7.5.2 Machining Cylinder Running Surfaces
7.5.3 Cylinder Cooling
7.5.3.1 Water Cooling
7.5.3.2 Air Cooling

7.6 Oil Pan
7.6.1 Oil Pan Design

7.7 Crankcase Venting

7.7.1 Conventional Crankcase Ventilation
7.7.2 Positive Crankcase Ventilation (PVC) System
7.7.3 Vacuum-Regulated Crankcase Ventilation

7.8 Cylinder Head

7.8.1 Basic Design for the Cylinder Head
7.8.1.1 Layout of the Basic Geometry
7.8.1.2 Determining the Manufacturing Processes
7.8.1.3 Layout of the Gas Exchange Components
7.8.1.4 Variable Valve Control
7.8.2 Cylinder Head Engineering
7.8.2.1 Laying out the Rough Dimensions
7.8.2.2 Combustion Chamber and Port Design
7.8.2.3 Valve Train Design
7.8.2.4 Cooling Concepts
7.8.2.5 Lubricating Oil Management
7.8.2.6 Engineering Design Details
7.8.2.7 Engineering in Construction Steps
7.8.2.8 Using CAD in Engineering
7.8.2.9 Computer-Assisted Design
7.8.3 Casting Process
7.8.3.1 Sand Casting
7.8.3.2 Die Casting
7.8.3.3 Lost-Foam Process (Full Mold Process)
7.8.3.4 Pressure Die-Casting Process
7.8.4 Model and Mold Construction
7.8.5 Machining and Quality Assurance
7.8.5.1 Mass-Production Manufacture
7.8.5.2 Prototype Manufacturing
7.8.5.3 Quality Assurance for Cylinder Heads
7.8.6 Shapes Implemented for Cylinder Heads
7.8.6.1 Cylinder Heads for Gasoline Engines
7.8.6.2 Cylinder Heads for Diesel Engines
7.8.6.3 Special Cylinder Head Designs
7.8.7 Perspectives in Cylinder Head Technology
7.9 Crankshafts
7.9.1 Function in the Vehicle
7.9.1.1 The Crankshaft in the Reciprocating Piston Engine
7.9.1.2 Requirements
7.9.2 Manufacturing and Properties
7.9.2.1 Process and Materials
7.9.2.2 Materials Properties for Crankshafts
7.9.3 Lightweight Engineering and Future Trends
7.9.3.1 Hollow Cast Crankshafts
7.9.3.2 ADI Austempered Ductile Iron
7.9.3.3 Increasing Component Strength through Postcasting Treatment
7.10 Valve Train Components
7.10.1 Valve Train
7.10.1.1 Direct Drive Valve Trains
7.10.1.2 Indirect Drive Valve Trains
7.10.1.3 Hydraulic Valve Play Compensation
7.10.1.4 Mechanical Valve Play Adjustment
7.10.1.5 Future Trends
7.10.2 Belt Tensioning Systems, Idler and Deflection Pulleys
7.10.2.1 Introduction
7.10.2.2 Automatic Belt Tensioning System for Synchronous Belt Drives
7.10.2.3 Idler and Deflection Pulleys for Synchronous Belt Drives
7.10.2.4 Prospects for the Future
7.10.3 Chain Tensioning and Guide Systems
7.10.3.1 Introduction
7.10.3.2 Chain Tensioning Element
7.10.3.3 Tensioning and Guide Rails
7.11 Valves
7.11.1 Functions and Explanation of Terms and Concepts
7.11.2 Types of Valves and Manufacturing Techniques
7.11.2.1 Monometallic Valves
7.11.2.2 Bimetallic Valves
7.11.2.3 Hollow Valve
7.11.3 Embodiments
7.11.3.1 Valve Head
7.11.3.2 Valve Seat
7.11.3.3 Valve Stem
7.11.4 Valve Materials
7.11.4.1 Heat Treatment
7.11.4.2 Surface Finishing
7.11.5 Special Valve Designs
7.11.5.1 Exhaust Control Valves
7.11.6 Valve Keepers
7.11.6.1 Tasks and Functioning
7.11.6.2 Manufacturing Techniques
7.11.7 Valve Rotation Devices
7.11.7.1 Function
7.11.7.2 Designs and Functioning
7.12 Valve Springs
7.13 Valve Seat Inserts
7.13.1 Introduction
7.13.2 Demands Made on Valve Seat Inserts
7.13.2.1 Loading on Valve Seat Inserts
7.13.2.2 Materials and Their Properties
7.13.2.3 Geometry and Tolerances
7.13.2.4 Cylinder Head Geometry and Assembly
7.14 Valve Guides
7.14.1 Requirements for Valve Guides
7.14.1.1 Loading on Valve Guides
7.14.2 Materials and Properties
7.14.2.1 Materials
7.14.2.2 Materials Properties
7.14.3 Geometry of the Valve Guide
7.14.4 Installing in the Cylinder Head
7.15 Oil Pump
7.15.1 Overview of Oil Pump Systems
7.15.1.1 Internal Gear Pump
7.15.1.2 External Gear Pump
7.15.1.3 Vane Pumps
7.15.1.4 Benefits and Drawbacks of Individual Pump Systems
7.15.2 Regulation Principles
7.15.2.1 Direct Regulation
7.15.2.2 Indirect Regulation
7.15.2.3 Regulation in the Clean Oil Stream
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.15.2.4</td>
<td>Two-Stage or Multistage Regulation</td>
</tr>
<tr>
<td>7.15.2.5</td>
<td>Two-Stage Regulation Pump</td>
</tr>
<tr>
<td>7.15.2.6</td>
<td>Regulated Internal Gear Pump</td>
</tr>
<tr>
<td>7.15.2.7</td>
<td>Regulated External Gear Pump</td>
</tr>
<tr>
<td>7.15.2.8</td>
<td>Regulated Vane Pump</td>
</tr>
<tr>
<td>7.15.3</td>
<td>Engineering Basics</td>
</tr>
<tr>
<td>7.15.3.1</td>
<td>Crankshaft Pump</td>
</tr>
<tr>
<td>7.15.3.2</td>
<td>Sump Pump</td>
</tr>
<tr>
<td>7.15.3.3</td>
<td>Key Oil Pump Values Taken from Practice</td>
</tr>
<tr>
<td>7.15.3.4</td>
<td>Comparison between Crankshaft and Sump Pumps</td>
</tr>
<tr>
<td>7.15.3.5</td>
<td>Cavitation and Noise Emissions</td>
</tr>
<tr>
<td>7.15.4</td>
<td>Calculation</td>
</tr>
<tr>
<td>7.15.4.1</td>
<td>Numerical Simulation of Flow — CFD</td>
</tr>
<tr>
<td>7.15.4.2</td>
<td>One-Dimensional Simulation of Flow Grids</td>
</tr>
<tr>
<td>7.15.5</td>
<td>Reduction of Mass</td>
</tr>
<tr>
<td>7.15.6</td>
<td>Factors Influencing Camshaft Loading</td>
</tr>
<tr>
<td>7.16</td>
<td>Camshaft</td>
</tr>
<tr>
<td>7.16.1</td>
<td>Camshaft Functions</td>
</tr>
<tr>
<td>7.16.2</td>
<td>Valve Train Configurations</td>
</tr>
<tr>
<td>7.16.3</td>
<td>Structure of a Camshaft</td>
</tr>
<tr>
<td>7.16.4</td>
<td>Technologies and Materials</td>
</tr>
<tr>
<td>7.16.4.1</td>
<td>Cast Camshaft</td>
</tr>
<tr>
<td>7.16.4.2</td>
<td>Assembled Camshaft</td>
</tr>
<tr>
<td>7.16.4.3</td>
<td>Steel Camshaft</td>
</tr>
<tr>
<td>7.16.4.4</td>
<td>Materials Properties and Recommended Matches</td>
</tr>
<tr>
<td>7.16.5</td>
<td>Thermodynamics in Air Intake Systems</td>
</tr>
<tr>
<td>7.16.6</td>
<td>Acoustics</td>
</tr>
<tr>
<td>7.17</td>
<td>Chain Drive</td>
</tr>
<tr>
<td>7.17.1</td>
<td>Chain Designs</td>
</tr>
<tr>
<td>7.17.2</td>
<td>Typical Chain Values</td>
</tr>
<tr>
<td>7.17.3</td>
<td>Sprockets</td>
</tr>
<tr>
<td>7.17.4</td>
<td>Chain Guide Elements</td>
</tr>
<tr>
<td>7.18</td>
<td>Belt Drives</td>
</tr>
<tr>
<td>7.18.1</td>
<td>Belt Drives Used to Drive Camshafts</td>
</tr>
<tr>
<td>7.18.1.1</td>
<td>Synchronous Belt Drive</td>
</tr>
<tr>
<td>7.18.1.2</td>
<td>Synchronous Belt Drive System</td>
</tr>
<tr>
<td>7.18.1.3</td>
<td>Synchronous Belt Dynamics</td>
</tr>
<tr>
<td>7.18.1.4</td>
<td>Application Examples</td>
</tr>
<tr>
<td>7.18.2</td>
<td>Toothed V-Belt Drive to Power Auxiliary Units</td>
</tr>
<tr>
<td>7.18.2.1</td>
<td>Micro-V® Drive Belts</td>
</tr>
<tr>
<td>7.18.2.2</td>
<td>Auxiliary Component Drive System</td>
</tr>
<tr>
<td>7.18.2.3</td>
<td>Application Examples</td>
</tr>
<tr>
<td>7.19</td>
<td>Bearings in Internal Combustion Engines</td>
</tr>
<tr>
<td>7.19.1</td>
<td>Fundamentals</td>
</tr>
<tr>
<td>7.19.1.1</td>
<td>Radial Bearing</td>
</tr>
<tr>
<td>7.19.1.2</td>
<td>Axial Bearing</td>
</tr>
<tr>
<td>7.19.2</td>
<td>Calculating and Dimensioning Engine Bearings</td>
</tr>
<tr>
<td>7.19.2.1</td>
<td>Loading</td>
</tr>
<tr>
<td>7.19.2.2</td>
<td>Bearing Journal Displacement Path</td>
</tr>
<tr>
<td>7.19.2.3</td>
<td>Elastohydrodynamic Calculation</td>
</tr>
<tr>
<td>7.19.2.4</td>
<td>Major Dimensions: Diameter, Width</td>
</tr>
<tr>
<td>7.19.2.5</td>
<td>Oil Feed Geometry</td>
</tr>
<tr>
<td>7.19.2.6</td>
<td>Precision Dimensions</td>
</tr>
<tr>
<td>7.19.3</td>
<td>Bearing Materials</td>
</tr>
<tr>
<td>7.19.3.1</td>
<td>Bearing Metals</td>
</tr>
<tr>
<td>7.19.3.2</td>
<td>Overlays</td>
</tr>
<tr>
<td>7.19.4</td>
<td>Types of Bearings — Structure, Load-Bearing Capacity, Use</td>
</tr>
<tr>
<td>7.19.4.1</td>
<td>Solid Bearings</td>
</tr>
<tr>
<td>7.19.4.2</td>
<td>Two-Material Bearing</td>
</tr>
<tr>
<td>7.19.4.3</td>
<td>Three-Material Bearing</td>
</tr>
<tr>
<td>7.19.4.4</td>
<td>Miba™ Grooved Bearings</td>
</tr>
<tr>
<td>7.19.4.5</td>
<td>Sputter Bearing</td>
</tr>
<tr>
<td>7.19.5</td>
<td>Bearing Failure</td>
</tr>
<tr>
<td>7.19.5.1</td>
<td>Progress of Damage</td>
</tr>
<tr>
<td>7.19.5.2</td>
<td>Types of Bearing Damage</td>
</tr>
<tr>
<td>7.19.6</td>
<td>Prospects for the Future</td>
</tr>
<tr>
<td>7.20</td>
<td>Intake Systems</td>
</tr>
<tr>
<td>7.20.1</td>
<td>Thermodynamics in Air Intake Systems</td>
</tr>
<tr>
<td>7.20.2</td>
<td>Acoustics</td>
</tr>
<tr>
<td>7.21</td>
<td>Sealing Systems</td>
</tr>
<tr>
<td>7.21.1</td>
<td>Cylinder Head Sealing Systems</td>
</tr>
<tr>
<td>7.21.1.1</td>
<td>Ferrolastic Elastomer Head Gaskets</td>
</tr>
<tr>
<td>7.21.1.2</td>
<td>Metal-Elastomer Head Gaskets</td>
</tr>
<tr>
<td>7.21.1.3</td>
<td>Metaloflex® Layered Metal Head Gaskets</td>
</tr>
<tr>
<td>7.21.1.4</td>
<td>Prospects for the Future</td>
</tr>
<tr>
<td>7.21.2</td>
<td>Special Seals</td>
</tr>
<tr>
<td>7.21.2.1</td>
<td>Functional Description of the Flat Seal</td>
</tr>
<tr>
<td>7.21.2.2</td>
<td>Elastomer Seals</td>
</tr>
<tr>
<td>7.21.2.3</td>
<td>Metal-Elastomer Seals</td>
</tr>
<tr>
<td>7.21.2.4</td>
<td>Special Metaloseal® Gaskets</td>
</tr>
<tr>
<td>7.21.2.5</td>
<td>Prospects for the Future</td>
</tr>
<tr>
<td>7.21.3</td>
<td>Elastomer Sealing Systems</td>
</tr>
<tr>
<td>7.21.3.1</td>
<td>Elastomer Seals</td>
</tr>
<tr>
<td>7.21.3.2</td>
<td>Metal-Elastomer Gaskets</td>
</tr>
</tbody>
</table>
10.4.3.1 Mechanical Systems
10.4.3.2 Hydraulically Actuated Systems
10.4.3.3 Electromechanical Systems
10.5 Pulse Charges and Load Control of Reciprocating Piston Engines Using an Air Stroke Valve
10.5.1 Introduction
10.5.2 Design and Operation of the Air Stroke Valve
10.5.3 Options for Influencing the Charge Cycle
10.5.3.1 Dynamic Supercharging in Induction Engines (Pulse Charge)
10.5.3.2 Supporting and Recharging Supercharged Engines
10.5.3.3 Throttle-Free Load Control
10.5.3.4 EGR Control
10.5.3.5 Hot Charging
10.5.3.6 Cold Charging Supercharged Engines
10.5.3.7 Cylinder Shutoff
10.5.4 Prototype for Engine Tests
10.5.4.1 Parameters and Design
10.5.4.2 Implemented Prototype
10.5.5 Demonstration of Function in Single-Cylinder Engines
10.5.5.1 Increasing Air Expenditure by Dynamic Supercharging
10.5.5.2 Increasing Torque by Dynamic Supercharging
10.5.5.3 Required Air Stroke Valve Operating Times in Dynamic Supercharging
10.5.5.4 Hot Charging
10.5.6 Summary and Outlook

11 Supercharging of Internal Combustion Engine
11.1 Mechanical Supercharging
11.2 Exhaust Gas Turbocharging
11.3 Intercooling
11.4 Interaction of Engine and Compressor
11.4.1 Four-Stroke Engine in the Compressor Map
11.4.2 Mechanical Supercharging
11.4.3 Exhaust Gas Turbocharging
11.5 Dynamic Behavior
11.6 Additional Measures for Supercharged Internal Combustion Engines
11.6.1 SI Engines
11.6.2 Diesel Engines

12 Mixture Formation and Related Systems
12.1 Internal Mixture Formation
12.2 External Mixture Formation

12.3 Mixture Formation using Carburetors
12.3.1 Mode of Operation of the Carburetor
12.3.2 Designs
12.3.2.1 Number of Intake Air Ducts
12.3.2.2 Position of the Intake Air Duct
12.3.2.3 Designs for Special Applications
12.3.3 Important Auxiliary Systems on Carburetors
12.3.4 Electronically Controlled Carburetors
12.3.5 Constant Vacuum Carburetor
12.3.6 Operating Behavior
12.3.7 Lambda Closed-Loop Control

13 Ignition
13.1 Spark-Ignition Engine
13.1.1 Introduction to Ignition
13.1.2 Requirements of the Ignition System
13.1.3 Minimum Ignition Energy
13.1.4 Fundamentals of Spark Ignition
13.1.4.1 Phases of the Spark
13.1.4.2 Energy Transmission Efficiency
13.1.5 Coil Ignition System (Inductive)
13.1.6 Other Ignition Systems
13.1.7 Summary and Outlook
13.2 Spark Plugs
- 13.2.1 Demands on Spark Plugs
- 13.2.2 Design
- 13.2.3 Heat Range
- 13.2.4 Required Voltage for Ignition
- 13.2.5 Ignition Characteristic (and Mixture Ignition)
- 13.2.6 Wear
- 13.2.7 Application

13.3 Diesel Engines
- 13.3.1 Autoignition and Combustion
- 13.3.2 Diesel Engine Cold Starts
  - 13.3.2.1 Important Influential Parameters
  - 13.3.2.2 Start Evaluation Criteria
- 13.3.3 Components for Supporting Cold Starts
  - 13.3.3.1 Glow Plug Systems
  - 13.3.3.2 Heating Flange
- 13.3.4 Outlook
  - 13.3.4.1 Combined Systems
  - 13.3.4.2 Measurement of Ionic Current
  - 13.3.4.3 Regulated Glow Plug Systems

13.4 Ignition
- 13.4.1 Ignition Principle
- 13.4.2 Ignition Timing
- 13.4.3 Ignition Quality

13.5 Knock
- 13.5.1 Knock Detection
- 13.5.2 Knock Mitigation

13.6 Emissions
- 13.6.1 Emission Standards
- 13.6.2 Emission Control Systems

13.7 Fuel Systems
- 13.7.1 Fuel Supply
- 13.7.2 Fuel Delivery
- 13.7.3 Fuel Injection

13.8 Mechanics
- 13.8.1 Crankshaft
- 13.8.2 Piston
- 13.8.3 Connecting Rod

13.9 Torque Generation
- 13.9.1 Torque Calculation
- 13.9.2 Torque Generation

13.10 Cooling Systems
- 13.10.1 Coolant System
- 13.10.2 Oil System

13.11 Lubrication Systems
- 13.11.1 Engine Oil
- 13.11.2 Oil Supply System

13.12 Lubrication Elements
- 13.12.1 Oil Pump
- 13.12.2 Oil Filter

13.13 Maintenance and Repair
- 13.13.1 Preventive Maintenance
- 13.13.2 Repair Techniques

13.14 Safety
- 13.14.1 Safety Measures
- 13.14.2 Accident Prevention

13.15 Research and Development
- 13.15.1 New Engine Technologies
- 13.15.2 Test and Development Methods

14 Combustion
- 14.1 Principles
  - 14.1.1 Fuels
  - 14.1.2 Oxidation of Hydrocarbons
- 14.2 Combustion in SI Engines
  - 14.2.1 Mixture Formation
    - 14.2.1.1 Intake Manifold Injection
    - 14.2.1.2 Direct Injection
  - 14.2.2 Ignition
  - 14.2.3 Combustion Process
    - 14.2.3.1 Flame Propagation
    - 14.2.3.2 Mean Pressure and Fuel Consumption
    - 14.2.3.3 Cyclic Fluctuations
    - 14.2.3.4 Engine Knock
- 14.3 Combustion in Diesel Engines
  - 14.3.1 Mixture Formation
    - 14.3.1.1 Phenomenology
    - 14.3.1.2 Fuel Jet Propagation
  - 14.3.2 Autoignition
  - 14.3.3 Combustion Process
    - 14.3.3.1 Phenomenological Description
    - 14.3.3.2 Equivalent Combustion Curves
- 14.4 Heat Transfer
  - 14.4.1 Heat Transfer Model
  - 14.4.2 Determination of Heat Transfer Coefficients

15 Combustion Systems
- 15.1 Combustion Systems for Diesel Engines
  - 15.1.1 Diesel Combustion
  - 15.1.2 Diesel Four-Stroke Combustion Systems
    - 15.1.2.1 Methods using Indirect Fuel Injection (IDI)
    - 15.1.2.2 Direct Fuel Injection Method (DI)
    - 15.1.2.3 Comparison of Combustion Systems
    - 15.1.2.4 Special Methods and Features
- 15.2 Spark-Injection Engines
  - 15.2.1 Combustion Processes in Port Fuel Injection (PFI) Engines
  - 15.2.2 Combustion Process of Direct Injection Spark Ignition (DISI) Engines
- 15.3 Two-Stroke Diesel Engines
- 15.4 Two-Stroke SI Engines

16 Electronics and Mechanics for Engine Management and Transmission Shift Control
- 16.1 Environmental Demands
- 16.2 Stand-Alone Products (Separate Devices)
- 16.3 Connecting Approaches
- 16.4 Integrated Products (MTM = Mechatronic Transmission Module)
- 16.5 Electronic Design, Structures, and Components
  - 16.5.1 Basic Structure
  - 16.5.2 Electronic Components
    - 16.5.2.1 IC Knocking Input Filter Component
    - 16.5.2.2 Driver Stage Component
    - 16.5.2.3 Microcontroller
    - 16.5.2.4 Voltage Regulator
- 16.6 Electronics in the Electronic Control Unit
  - 16.6.1 General Description
  - 16.6.2 Signal Conditioning
  - 16.6.3 Signal Evaluation
  - 16.6.4 Signal Output
  - 16.6.5 Power Supply
  - 16.6.6 CAN Bus Interface
  - 16.6.7 Electronics for Transmission ECUs
- 16.7 Software Structures
  - 16.7.1 Task of the Software In Controlling Engines
  - 16.7.2 Demands on the Software
  - 16.7.3 The Layer Approach to Software
  - 16.7.4 The Software Development Process
- 16.8 Torque-Based Functional Structure for Engine Management
  - 16.8.1 Model-Based Functions Using the Example of Intake Manifold Charging
- 16.9 Functions
16.9.1 λ Regulation
16.9.2 Antijerk Function
16.9.3 Throttle Valve Control
16.9.4 Knocking Control
16.9.5 “On-Board” Diagnosis (OBD)
  16.9.5.1 Self-Diagnosis Tasks
  16.9.5.2 Monitoring the Catalytic Converter
16.9.6 Safety Approaches

17 The Powertrain
17.1 Powertrain Architecture
17.2 The Motor-Vehicle’s Longitudinal Dynamics
17.3 Transmission Types
17.4 Power Level and Signal Processing Level
17.5 Transmission Management
  17.5.1 Functions
    17.5.1.1 Overview
    17.5.1.2 Driving or Gearshift Strategy
    17.5.1.3 Automatic Transmissions with Planetary Gears and Torque Converter
    17.5.1.4 Automated Stick-Shift Transmissions
    17.5.1.5 Continuously Variable Transmissions (CVT)
17.6 Integrated Powertrain Management (IPM®)
17.7 The Integrated Starter-Motor/Alternator (ISG)
  17.7.1 ISG: A System Overview
    17.7.1.1 Torque Structure in a Motor Vehicle
    17.7.1.2 Starter-Motor/Alternator Structure
    17.7.1.3 Description of the Starter-Motor/Alternator’s Most Important Modes of Use
17.7.2 Converters (Powertrain Management and Voltage Converters)
  17.7.2.1 Requirements Made on the Electronics from a System Viewpoint
  17.7.2.2 Function Groups and Design Criteria
  17.7.2.3 Cooling
  17.7.2.4 Classification of the Converter’s Power Electronics
  17.7.2.5 DC/DC Converters
17.7.3 Electrical Machine
  17.7.3.1 Design Criteria
  17.7.3.2 Simulation Tools
  17.7.3.3 Thermal Simulation
  17.7.3.4 Mechanical Strengths
  17.7.3.5 Requirements Made on the Electrical Machine
17.7.4 Series Development

18 Sensors
18.1 Temperature Sensors
18.2 Knock Sensors
18.3 Exhaust Gas Sensors
  18.3.1 Lambda Sensors
  18.3.2 NO Sensors
18.4 Pressure Sensors
  18.4.1 Normal Pressure Sensors
    18.4.1.1 Piezoresistive Measurement Principle
    18.4.1.2 Capacitive Measurement Principle
  18.4.2 Medium Pressure Sensors
  18.4.3 High-Pressure Sensors
    18.4.3.1 Technical Boundary Conditions
    18.4.3.2 Signal Transmission
    18.4.3.3 Measuring Precision
18.5 Air Mass Sensors
  18.5.1 Comparison of Air Mass-Controlled and Intake Manifold Pressure-Controlled Systems
  18.5.2 Measuring Principles
  18.5.3 Hot-Film Anemometer
  18.5.4 Secondary Air Mass Sensors (SAF)
18.6 Speed Sensors
  18.6.1 Passive Speed Sensors
  18.6.2 Active Sensors

19 Actuators
19.1 Drives for Charge Controllers
  19.1.1 Pneumatic Drives
  19.1.2 Electric Drives
    19.1.2.1 Stepping Motor
    19.1.2.2 DC Motor
    19.1.2.3 Torque Motor
19.2 Throttle Valve Actuators
  19.2.1 Key Function in SI Engines
  19.2.2 Key Function in Diesel Engines and in Quality-Controlled SI Engines (Direct Injection)
  19.2.3 Additional Functions
    19.2.3.1 Idle-Speed Control of SI Engines
    19.2.3.2 Position Signal
    19.2.3.3 Dashpot Function
    19.2.3.4 Cruise Control Function
  19.2.4 “Drive by Wire”/E-Gas
  19.2.5 Charge Pressure Control
19.2.6 Vacuum/Prethrottle Actuators
19.3 Swirl and Tumble Plates
  19.3.1 Swirl Plate Actuators (Swirl/Tumble Actuators)
19.4 Exhaust Gas Recirculation Valves
19.5 Evaporative Emissions Components
  19.5.1 Canister-Purge Valves
  19.5.2 Evaporative Emissions Diagnostics
    19.5.2.1 Tank Diagnostics with Pressure
    19.5.2.2 Tank Diagnostics with Vacuum

20 Cooling of Internal Combustion Engines
  20.1 General
  20.2 Demands on the Cooling System
  20.3 Principles for Calculation and Simulation Tools
  20.4 Engine Cooling Subsystems
    20.4.1 Coolant Cooling
      20.4.1.1 Radiator Protection Media
    20.4.2 Intercooling
    20.4.3 Exhaust Gas Cooling
    20.4.4 Oil Cooling
    20.4.5 Fans and Fan Drives
  20.5 Cooling Modules
  20.6 Overall Engine Cooling System

21 Exhaust Emissions
  21.1 Legal Regulations
    21.1.1 Europe
    21.1.2 California, USA
    21.1.3 Japan
    21.1.4 Harmonizing Exhaust Emission Regulations
  21.2 Measuring Exhaust Emissions
    21.2.1 Measuring Techniques for Certifying Automobiles
    21.2.2 Measuring Technology for Engine Development
  21.3 Pollutants and Their Origin
    21.3.1 Spark-Injection Engines
      21.3.1.1 Restricted Exhaust Emission Components
      21.3.1.2 Unrestricted Exhaust Components
    21.3.2 Diesel Engines
      21.3.2.1 Restricted Exhaust Components
      21.3.2.2 Unrestricted Exhaust Emission Components
  21.4 Reducing Pollutants
    21.4.1 Engine-Related Measures
      21.4.1.1 Spark-Injection Engines
      21.4.1.2 Diesel Engines
    21.5 Exhaust Gas Treatment for Spark-Ignition Engines
      21.5.1 Catalytic Converter Design and Chemical Reactions
      21.5.2 Catalytic Converter Approaches for Stoichiometric Engines
  21.5.2.1 Three-Way Catalytic Converter
  21.5.2.2 Oxygen Storage Mechanism
  21.5.2.3 Cold Start Strategies
  21.5.2.4 Deactivation and Its Effect
  21.5.3 Catalytic Converter Approaches for Lean-Burn Engines
    21.5.3.1 Options for NOx Reduction in Lean Exhaust Gas
    21.5.3.2 The NOx Storage Catalytic Converter
    21.5.3.3 System with a Precatalytic Converter and NOx Adsorber
  21.5.4 Metal Catalytic Converter Substrates
  21.6 Exhaust Treatment in Diesel Engines
    21.6.1 Diesel Oxidation Catalytic Converters
      21.6.1.1 Pollutants in Diesel Exhaust
      21.6.1.2 Characteristics of Diesel Oxidation Catalytic Converters
      21.6.1.3 Deactivating the Catalyst Surface
      21.6.1.4 Evaluating Diesel Oxidation Catalytic Converters
    21.6.2 NOx Adsorbers for Diesel Passenger Cars
      21.6.2.1 Operating Range of Storage Catalytic Converters
      21.6.2.2 Desulfurization
      21.6.2.3 Regeneration Methods
    21.6.3 Particle Filters
      21.6.3.1 Particle Definitions and Particle Properties
      21.6.3.2 Goals of Particle Filtration
      21.6.3.3 Requirements for Filter Media and Technical Solutions
      21.6.3.4 Deposition and Adhesion
      21.6.3.5 Regeneration and Periodic Cleaning
      21.6.3.6 Regeneration Emissions and Secondary Emissions
      21.6.3.7 Pressure Loss
      21.6.3.8 Installation Area and System Integration
      21.6.3.9 Damage Mechanisms, Experience
      21.6.3.10 Quality Criteria
      21.6.3.11 Performance Test, Type Test, OBD, Field Control
      21.6.3.12 Catalytic Soot Filter
21.6.3.13 Particle Measuring

22 Operating Fluids

22.1 Fuels

22.1.1 Diesel Fuel
22.1.1.1 Diesel Fuel Components and Composition
22.1.1.2 Characteristics and Properties
22.1.1.3 Additives for Diesel Fuel
22.1.1.4 Alternative Diesel Fuels

22.1.2 Gasoline
22.1.2.1 Gasoline Components and Composition
22.1.2.2 Characteristics and Properties
22.1.2.3 Alternative Gasolines

22.2 Lubricants

22.2.1 Types of Lubricants
22.2.2 Task of Lubrication
22.2.3 Types of Lubrication
22.2.4 Lubrication Requirements
22.2.5 Viscosity/Viscosity Index (V.I.)
22.2.5.1 Influence of Temperature on Viscosity
22.2.5.2 Influence of the Pressure on the Viscosity
22.2.5.3 Influence of Shear Speed on Viscosity

22.2.6 Basic Liquids
22.2.6.1 Mineral Basic Oils
22.2.6.2 Synthetic Basic Liquid

22.2.7 Additives for Lubricants
22.2.7.1 V.I. Improvers
22.2.7.2 Detergents and Dispersants
22.2.7.3 Antioxidants and Corrosion Inhibitors
22.2.7.4 Friction and Wear Reducers (EP/AW Additives)
22.2.7.5 Foam Inhibitors

22.2.8 Engine Oils for Four-Stroke Engines
22.2.8.1 SAE Viscosity Classes for Engine Oils
22.2.8.2 Single-Grade Engine Oil
22.2.8.3 Multigrade Oils
22.2.8.4 Fuel Economy Oils
22.2.8.5 Break-In Oils
22.2.8.6 Gas Engine Oils
22.2.8.7 Methanol Engine Oils
22.2.8.8 Hydrogen Engine Oils
22.2.8.9 Performance Classes
22.2.8.10 Evaluating Used Oil
22.2.8.11 Racing Engine Oils
22.2.8.12 Wankel Engine Oils

22.2.9 Engine Oils for Two-Stroke Engines
22.2.9.1 Two-Stroke Performance Classes
22.2.9.2 Two-Stroke Test Methods

22.3 Coolant
22.3.1 Frost Protection
22.3.2 Corrosion Protection
22.3.3 Specifications

23 Filtration of Operating Fluids

23.1 Air Filter
23.1.1 The Importance of Air Filtration for Internal Combustion Engines
23.1.2 Impurities in Engine Intake Air
23.1.3 Data for Assessment of Air-Filter Media
23.1.4 Measuring Methods and Evaluation
23.1.5 Requirements Made on Modern Air-Filter Systems
23.1.6 Design Criteria for Engine-Air Filter Elements
23.1.7 Filter Housings
23.1.7.1 Design of Filter Housings

23.2 Fuel Filters
23.2.1 Gasoline Fuel Filters
23.2.2 Diesel-Fuel Filters
23.2.3 The Performance Data of Fuel Filters

23.3 Engine-Oil Filtration
23.3.1 Wear and Filtration
23.3.2 Full-Flow Oil Filters
23.3.3 Removal Efficiency and Filter Fineness
23.3.4 Bypass Oil Filtration

24 Calculation and Simulation

24.1 Strength and Vibration Calculation
24.1.1 Procedures and Methods
24.1.2 Selected Examples of Applications
24.1.3 Piston Calculations

24.2 Flow Calculation
24.2.1 One- and Quasidimensional Methods
24.2.2 Three-Dimensional Flow Calculation
24.2.3 Selected Examples of Application

25 Combustion Diagnostics

25.1 Discussion
25.2 Indicating
25.2.1 Measuring Systems
25.2.2 Quality Criteria
25.2.3 Indicating: Prospects

25.3 Visualization
25.3.1 Functions and Discussion
25.3.2 Visualization Methods for Real Engine Operation
25.3.2.1 The Radiant Properties of Gas, Gasoline, and Diesel Flames
Internal Combustion Engine Handbook
Basics, Components, Systems, and Perspectives

25.3.2.2 Flame Spectroscopy
25.3.2.3 Flame Propagation in Premixed Charges with Supplied Ignition
25.3.2.4 Flame Propagation in Diffusion Combustion in a Diesel Engine
25.3.3 Visualization of Combustion in Real Engine Operation by the Flame’s Intrinsic Luminescence
25.3.3.1 Technical Exploitation: Flame Propagation
25.3.4 Visualization of Illuminated Processes
25.3.4.1 Visualization of Mixture Distribution
25.3.4.2 Visualization of Velocity Fields
25.3.5 Visualization: The Future

26 Fuel Consumption
26.1 General Influencing Factors
26.1.1 Air Resistance
26.1.2 Weight
26.1.3 Wheel Resistance
26.1.4 Fuel Consumption
26.2 Engine Modifications
26.2.1 Downsizing
26.2.2 Diesel Engine
26.2.3 Gasoline Engine
26.2.3.1 The Lean-Burn Engine Concept and Direct Injection
26.2.3.2 Variable Valve Timing
26.2.3.3 Ignition
26.2.4 Cylinder Shutoff
26.2.4.1 Concept for Reduction of Fuel Consumption
26.2.4.2 Consumption Benefits in the Part-Load Range
26.3 Transmission Ratios
26.3.1 Selection of Direct Transmission
26.3.2 Selection of Overall Transmission Ratio in the Highest Gear
26.4 Driver Behavior
26.5 CO₂ Emissions
26.5.1 CO₂ Emissions and Fuel Consumption
26.5.2 The Influence of Engine Use on CO₂ Emissions
26.5.3 The Trend in Global CO₂ Emissions

27 Noise Emissions
27.1 Basic Physical Principles and Terms
27.2 Legal Provisions Concerning Emitted Noise

27.2.1 Methods of Measuring Emitted Noise
27.2.2 Critical Evaluation of the Informational Value of the Emitted Noise Measuring Method
27.2.3 Emitted Noise Limits, International Legislation; Future Trends
27.3 Sources of Emitted Noise
27.4 Emitted Noise-Reduction Provisions
27.4.1 Provisions on the Engine
27.4.2 Provisions on the Vehicle
27.5 Engine Noise in the Vehicle Interior
27.6 Acoustic Guidelines for the Engine Designer
27.7 Measuring and Analytical Methods
27.8 Psychoacoustics
27.9 Sound Engineering
27.10 Simulation Tools
27.11 Antinoise Systems: Noise Reduction using Antinoise

28 Alternative Propulsion Systems
28.1 The Rationales for Alternatives
28.2 The Wankel Engine
28.3 Electric Propulsion
28.4 Hybrid Propulsion System
28.4.1 Storage Systems
28.5 The Stirling Engine
28.6 Gas Turbines
28.7 The Steam Motor
28.8 The Fuel Cell as a Vehicle Propulsion System
28.8.1 The Structure of the PEM Fuel Cell
28.8.2 Hydrogen as the Fuel
28.8.3 Methanol as the Fuel
28.8.4 Gasoline Engine Fuel
28.8.5 The Fuel Cell in the Vehicle
28.8.6 Evaluation of the Fuel Cell vis-à-vis Other Propulsion Systems
28.9 Summary

29 Outlook

Index

About the Editors

Color Section