

Contents

Preface

xiii

CHAPTER 1

A Brief History of Engine Indicators	<u>1</u>
1.1. Early Engine Indicators	<u>1</u>
1.1.1. The First Indicators	<u>1</u>
1.1.2. Early Developments in Indicator Technology	<u>3</u>
1.1.3. Further Developments in Indicator Technology	<u>5</u>
1.1.4. Analysis of Indicator Diagrams	<u>12</u>
1.2. The Electronic Age	<u>14</u>
1.2.1. Oscilloscope Recording	<u>14</u>
1.2.2. Digital Systems	<u>16</u>
1.3. A Typical Measurement System	<u>20</u>
1.3.1. Complete System Components	<u>20</u>
Further Information	<u>22</u>

CHAPTER 2

The Measurement Chain: Encoders	<u>25</u>
2.1. The Angle Encoder	<u>25</u>
2.1.1. Basic Function	<u>25</u>
2.1.2. Required Resolution	<u>27</u>
2.1.3. Encoder Output Signals	<u>28</u>
2.1.4. Encoder Types	<u>30</u>
2.1.4.1. Standard—Closed Encoder	<u>30</u>
2.1.4.2. Open Encoders	<u>30</u>
2.1.5. Processing an Existing Encoder Signal	<u>34</u>

CHAPTER 3**The Measurement Chain: Combustion Pressure Transducers 39**

3.1. Cylinder Pressure Transducers	<u>39</u>
3.1.1. Introduction	<u>39</u>
3.1.2. Piezoelectric Pressure Transducers for Engine Combustion Measurement	<u>40</u>
3.1.2.1. Introduction	<u>40</u>
3.1.2.2. Crystal Materials Used	<u>42</u>
3.1.2.3. Transducer Construction and Types	<u>44</u>
<i>Cooled Type</i>	<u>46</u>
<i>Uncooled Type</i>	<u>49</u>
3.1.2.4. Piezoelectric Transducer Properties	<u>50</u>
<i>Introduction</i>	<u>50</u>
<i>Environment Effects</i>	<u>50</u>
<i>Transducer Properties and Specifications</i>	<u>51</u>
<i>Transducer Thermodynamic Properties</i>	<u>56</u>
<i>Summary: Transducer Design</i>	<u>63</u>
3.1.2.5. Transducer Installation and Adaptors	<u>64</u>
<i>Introduction</i>	<u>64</u>
<i>Intrusive Mounting</i>	<u>64</u>
<i>Transducer Mounting Considerations and Positions</i>	<u>65</u>
<i>Installation of Mounting Bores</i>	<u>69</u>
<i>Nonintrusive Mounting</i>	<u>70</u>
<i>Spark Plug Adaptors</i>	<u>73</u>
<i>Glow Plug Adaptors</i>	<u>77</u>
3.1.2.6. Transducer Selection and Applications	<u>81</u>
<i>Introduction</i>	<u>81</u>
<i>Requirements of the Application</i>	<u>81</u>
<i>Categories of Transducers</i>	<u>83</u>
<i>Selection of Transducers for Common Applications</i>	<u>84</u>

CHAPTER 4**The Measurement Chain: Additional and Alternative Transducers 93**

4.1. Alternatives to Piezoelectric Sensors for Cylinder Pressure Sensing	<u>93</u>
4.1.1. Introduction	<u>93</u>
4.1.2. Piezoresistive	<u>94</u>
4.1.3. Optical	<u>94</u>
4.1.4. Ion Current	<u>96</u>

4.2. Other Transducer and Signals for Combustion Measurement Applications	<u>99</u>
4.2.1. Introduction	<u>99</u>
4.2.2. Ignition Signals	<u>99</u>
4.2.3. Line Pressure	<u>102</u>
4.2.4. Needle Lift	<u>103</u>
4.2.5. Valve Lift	<u>108</u>
4.2.6. Exhaust and Inlet Pressure	<u>110</u>

CHAPTER 5

The Measurement Chain: Measurement Hardware 115

5.1. Signal Conditioning	<u>115</u>
5.1.1. Introduction	<u>115</u>
5.1.2. Piezoelectric Signals—The Charge Amplifier	<u>117</u>
5.1.2.1. Basic Function and Operation	<u>117</u>
5.1.2.2. Time Constant	<u>119</u>
5.1.2.3. Drift and Drift Compensation	<u>120</u>
5.1.2.4. Cabling and Interfaces to the Charge Amplifier	<u>121</u>
5.1.3. Analogue Signals	<u>122</u>
5.1.4. Other Amplifiers	<u>123</u>
5.1.4.1. Ignition Timing Amplifier	<u>123</u>
5.1.4.2. Carrier-Frequency Amplifier	<u>125</u>
5.1.5. Intelligent Amplifiers	<u>127</u>
5.1.5.1. Introduction	<u>127</u>
5.1.5.2. Sensor Recognition	<u>129</u>
<i>TEDS</i>	<u>129</u>
5.1.5.3. Extended Functions for Monitoring and Measurement	<u>135</u>
<i>PMax Monitoring</i>	<u>135</u>
<i>Additional Evaluation Possibilities for Intelligent Amplifiers</i>	<u>136</u>
5.1.6. Summary—Signal Conditioning	<u>140</u>
5.2. Measurement Hardware—The Data Acquisition and Measurement System	<u>140</u>
5.2.1. Introduction and Overview	<u>140</u>
5.2.2. Operating Requirements	<u>141</u>
5.2.3. System Interfaces	<u>142</u>
5.2.3.1. Angle Encoder	<u>142</u>
5.2.3.2. Operator Interface	<u>143</u>

5.2.3.3. Analogue Inputs and Outputs	143
5.2.3.4. Digital Inputs and Outputs	145
5.2.4. A Typical System	146

CHAPTER 6

The Measurement Chain: Measurement System Software 149

6.1. Software—The User Interface	149
6.1.1. Introduction	149
6.1.2. User Interface	150
6.1.2.1. Parameterization	150
6.1.2.2. Display of Data	151
6.1.2.3. Data Management	152
6.2. Features and Operating Modes	154
6.2.1. Standard Measurement Operations	154
6.2.2. Special Measurement Modes	156
6.2.3. Other Applications	160
6.3. Software Interfaces	161
6.3.1. Remote System	161
6.3.2. Interface to the Engine Electronics Systems	163
6.3.3. CAN (Controller Area Network)	165
6.4. Calculations and Results	167
6.4.1. Introduction	167
6.4.2. Real-Time Results	168
6.4.3. User-Defined Results	170
6.4.4. Future Developments	173
6.5. Postprocessing and Data Management	174
6.5.1. Introduction	174
6.5.2. Basic Requirements for Data Format and Export	174
6.5.3. Requirements for Engine and System Parameters	176
6.5.4. Typical Environment	177

CHAPTER 7

Applications 181

7.1. Introduction	181
7.2. Measurement Chain Properties	182
7.2.1. Introduction and Overview	182

7.2.2.	Special Considerations for Combustion Measurement Instrumentation	<u>182</u>
	Measurement in the Angle Domain	<u>182</u>
	Angle Encoders	<u>183</u>
	Pressure Measurement	<u>183</u>
	Signal Conditioning	<u>183</u>
	Measurement Hardware	<u>184</u>
	External Interfaces for Control and Data Transfer	<u>184</u>
7.3.	Zero-level Correction, or Pegging	<u>184</u>
7.3.1.	Introduction	<u>184</u>
7.3.2.	Fixed Point and Reference Value	<u>185</u>
7.3.3.	Fixed Point and Measured Value	<u>185</u>
7.3.4.	Thermodynamic	<u>187</u>
7.3.5.	Alternative Methods via Post Processing	<u>189</u>
7.3.6.	General Comments	<u>189</u>
7.4.	TDC Measurement	<u>190</u>
7.4.1.	Introduction	<u>190</u>
7.4.2.	Methods	<u>192</u>
	7.4.2.1. Static Determination	<u>192</u>
	7.4.2.2. Pressure Curve Determination	<u>193</u>
	AVL	<u>195</u>
	FEV	<u>195</u>
	D2T	<u>195</u>
	General Comment-Motored Curve Method	<u>196</u>
	7.4.2.3. Capacitive Probe	<u>196</u>
7.4.3.	Comparison and Discussion of the Methods	<u>199</u>
7.4.4.	General Considerations	<u>204</u>
7.5.	Thermodynamic Analysis	<u>205</u>
7.5.1.	Introduction	<u>205</u>
7.5.2.	Basic Principles and Early Work	<u>207</u>
7.5.3.	Methods for Real-Time Analysis	<u>208</u>
7.5.4.	Further Discussion—Offline Analysis	<u>211</u>
	7.5.4.1. Wiebe Function	<u>211</u>
7.5.5.	General Comments	<u>211</u>
7.6.	Low Pressure Measurement and Gas Exchange Analysis	<u>213</u>
7.6.1.	Introduction	<u>213</u>
7.6.2.	Measurement Task and Goal	<u>214</u>
7.6.3.	Typical Measurement Setup	<u>216</u>
7.6.4.	Measurement and Analysis	<u>217</u>
7.6.5.	Summary	<u>220</u>

CHAPTER 8

Abnormal Combustion Measurement and Evaluation	<u>223</u>
8.1. Combustion Knock and Abnormal Combustion (SI Engines)	<u>223</u>
8.1.1. Introduction	<u>223</u>
8.1.2. What Are Abnormal Combustion and Knock?	<u>224</u>
8.1.3. Why Is Knock Important?	<u>226</u>
8.1.4. Knock Measurement and Analysis	<u>227</u>
8.1.4.1. Knock Measurement Techniques	<u>227</u>
8.1.4.2. Knock Detection via Cylinder Pressure Measurements	<u>229</u>
<i>Introduction</i>	<u>229</u>
<i>Frequency of Knock</i>	<u>229</u>
<i>Signal Processing</i>	<u>230</u>
<i>Filtering</i>	<u>230</u>
<i>Acquisition Frequency</i>	<u>231</u>
<i>Acquisition Window</i>	<u>232</u>
<i>Calculation of Knock Overpressure</i>	<u>232</u>
8.1.4.3. Further Processing and Calculation Methods	<u>232</u>
<i>Knock Pressure Peak and Knock Intensity</i>	<u>234</u>
<i>AVL Real Time</i>	<u>235</u>
<i>FEV CAS</i>	<u>237</u>
<i>AVL KI (Knock Index)</i>	<u>238</u>
<i>AVL Transient/VDO</i>	<u>239</u>
<i>AVL Histogram</i>	<u>240</u>
<i>Third Derivative</i>	<u>242</u>
8.1.4.4. Considerations for Knock Measurements	<u>243</u>
<i>Transducer Position, Type, and Properties</i>	<u>243</u>
<i>Measurement Range and Resolution</i>	<u>245</u>
<i>Measurement System Setup</i>	<u>245</u>
8.1.4.5. Summary	<u>246</u>
8.2. Combustion Noise	<u>247</u>
8.2.1. Introduction	<u>247</u>
8.2.2. What Is Combustion Noise?	<u>248</u>
8.2.3. Measuring Combustion Noise	<u>249</u>
Signal Processing and Calculation	<u>249</u>
<i>Filters Used in the Calculation</i>	<u>252</u>
8.2.4. Summary	<u>253</u>
8.3. Cold Start	<u>255</u>
8.3.1. Introduction	<u>255</u>
8.3.2. What Is a Cold Start Measurement?	<u>255</u>

8.3.3. Typical System Configuration and Results	<u>256</u>
8.3.3.1. Preconditions Prior to Measurement	<u>256</u>
8.3.3.2. Executing the Measurement	<u>258</u>
8.3.3.3. Data Visualization and Processing	<u>259</u>
8.3.4. Summary	<u>260</u>

CHAPTER 9

Successful Measurements 263

9.1. Problems and Errors	<u>263</u>
9.1.1. Introduction	<u>263</u>
9.1.2. Typical Sources of Error	<u>264</u>
9.1.2.1. Transducer	<u>264</u>
9.1.2.2. Cabling	<u>265</u>
9.1.2.3. Encoder	<u>266</u>
9.1.2.4. Amplifier	<u>266</u>
9.1.2.5. Measurement Device	<u>267</u>
9.1.2.6. Summary	<u>268</u>
9.2. Successful Setup and Diagnostics	<u>269</u>
9.2.1. Basic Setup	<u>269</u>
9.2.2. System Prechecks	<u>270</u>
9.2.2.1. Introduction	<u>270</u>
9.2.3. Diagnostic and Reference Measurements	<u>272</u>
9.3. Software and Data Handling	<u>276</u>
9.3.1. Introduction	<u>276</u>
9.3.2. Measured Data Requirements	<u>277</u>
9.3.3. Plausibility Checks and Data Validation	<u>280</u>
9.3.4. Best Practice and Summary	<u>281</u>
9.4. Hardware Handling and Maintenance	<u>283</u>
9.4.1. Introduction	<u>283</u>
9.4.2. Measurement Hardware and System	<u>283</u>
9.4.3. Engine-Mounted Equipment: Encoder	<u>284</u>
9.4.4. Engine-Mounted Equipment: Transducers	<u>286</u>
9.4.4.1. Introduction	<u>286</u>
9.4.4.2. Installation and Handling	<u>286</u>
9.4.4.3. Maintenance and Repair	<u>287</u>
9.4.4.4. Calibration	<u>288</u>
9.5. Summary	<u>292</u>

CHAPTER 10

Specification and Integration into the Test Environment	<u>295</u>
10.1. Introduction	<u>295</u>
10.2. Technical Considerations—Features and Functions	<u>296</u>
10.2.1. Introduction	<u>296</u>
10.2.2. Typical Systems and Applications	<u>298</u>
10.2.2.1. Low-End System	<u>298</u>
10.2.2.2. Mid-Range System	<u>300</u>
10.2.2.3. High-End System	<u>302</u>
10.3. Interfaces to Additional Equipment	<u>304</u>
10.3.1. Introduction	<u>304</u>
10.3.2. Interfaces—Measurement Chain Components	<u>304</u>
10.3.2.1. Angle Encoder to Measurement System	<u>304</u>
10.3.2.2. Transducer to Charge Amplifier	<u>305</u>
10.3.2.3. Charge Amplifier to Measurement System	<u>305</u>
10.3.3. Interfaces—Data Transfer and Control	<u>307</u>
10.3.3.1. Digital Control and Data Transfer Interface	<u>307</u>
10.3.3.2. Analogue and Digital Hybrid Interface	<u>308</u>
Bibliography	<u>311</u>
References	<u>313</u>
About the Author	<u>317</u>
Index	<u>319</u>