

Contents

| | | |
|----------|---|-----|
| 1 | Introduction | 1 |
| 2 | History of Gasoline Direct Injection | 3 |
| 3 | Mixture Formation and Combustion Processes | 27 |
| 3.1 | Basics of mixture formation. | 29 |
| 3.1.1 | Fuel preparation. | 30 |
| 3.1.2 | Flow characteristics. | 34 |
| 3.2 | Direct injection with homogeneous mixtures | 39 |
| 3.3 | Direct injection with stratified mixtures. | 49 |
| 3.3.1 | Wall-guided combustion process. | 52 |
| 3.3.2 | Air-guided combustion processes | 56 |
| 3.3.3 | Spray-guided combustion processes | 58 |
| 3.4 | Ignition and combustion. | 70 |
| 3.5 | Gasoline direct injection with homogeneous charge compression ignition | 84 |
| 3.5.1 | Thermodynamics | 84 |
| 3.5.2 | Concepts and operating strategies for gasoline auto-ignition | 88 |
| 3.5.3 | Intervention options for direct injection | 92 |
| 3.5.4 | Potential with regard to consumption and pollutant emissions | 93 |
| 3.5.5 | Acoustics | 95 |
| 3.6 | The combined diesel/gasoline engine combustion process | 103 |
| 4 | Injection Systems and System Overview | 111 |
| 4.1 | Low pressure air assisted direct injection | 112 |
| 4.2 | High pressure common rail direct injection. | 115 |
| 4.2.1 | High pressure fuel pumps | 117 |
| 4.2.2 | Rail. | 122 |
| 4.2.3 | High pressure injection valves and injection nozzles | 124 |
| 4.2.4 | Injection strategies. | 135 |
| 5 | Power and Torque | 143 |
| 6 | Supercharging | 153 |
| 6.1 | Mechanical Supercharging | 156 |
| 6.2 | Exhaust-gas turbocharging | 161 |
| 6.3 | Synergies between exhaust-gas turbocharging and direct injection in gasoline engines | 168 |
| 6.4 | High pressure supercharging with an electrically driven supercharger | 171 |
| 6.5 | Complex supercharging | 174 |

| | |
|--|-----|
| 7 Fuel Consumption | 181 |
| 8 Downsizing and Downspeeding | 197 |
| 8.1 Downsizing | 197 |
| 8.2 Downspeeding | 201 |
| 9 Exhaust Emissions and Pollutant Reduction | 205 |
| 9.1 Formation of pollutants during engine operation | 205 |
| 9.2 Statutory regulations | 210 |
| 9.3 Pollutant reduction including particulates | 219 |
| 10 Noise Emission | 235 |
| 10.1 Legal requirements | 235 |
| 10.2 Combustion noise | 237 |
| 10.2.1 Comparison between gasoline direct injection (homogeneous GDI) and stratified GDI | 238 |
| 10.2.2 Effect of the swirl and tumble level on combustion excitation | 239 |
| 10.2.3 Effect of the exhaust-gas recirculation rate (EGR) on the combustion noise | 240 |
| 10.2.4 Effect of changes in operating mode | 241 |
| 10.2.5 Optimization of idle operation in stratified operating mode | 242 |
| 10.2.6 Acoustic aspects of GDI downsizing concepts | 242 |
| 10.2.7 Effect of fuel quality on acoustics | 244 |
| 10.3 Mechanical noise | 246 |
| 10.3.1 Optimization of the knock control system | 247 |
| 10.3.2 Effect of high pressure fuel distribution system | 248 |
| 11 Effects of Gasoline Direct Injection on Other Engine Systems | 253 |
| 11.1 Ignition systems | 253 |
| 11.1.1 Spark ignition systems | 253 |
| 11.1.2 Laser ignition | 263 |
| 11.1.3 Microwave ignition | 267 |
| 11.2 Pistons | 269 |
| 11.2.1 Materials | 270 |
| 11.2.2 Manufacturing process | 272 |
| 11.2.3 Design and component strength | 274 |
| 11.3 Valves, valve seat inserts and valve guides | 278 |
| 11.3.1 Valves and valve seat inserts | 278 |
| 11.3.2 Intake valve deposits on gasoline direct injection engines | 280 |
| 11.3.3 Valve guides | 281 |
| 11.3.4 Lightweight valves | 282 |
| 11.4 Air intake systems in modern gasoline engines | 283 |
| 11.4.1 Thermodynamics of the air intake system | 284 |
| 11.4.2 Intake manifolds for naturally aspirated engines | 287 |

| | |
|--|------------|
| 11.4.3 Intake manifolds for supercharged gasoline engines | 289 |
| 11.4.4 Intake manifolds of supercharged gasoline engines with direct injection | 290 |
| 11.5 Crankcase ventilation | 291 |
| 11.6 Air cycling valves | 297 |
| 11.6.1 Technology description | 297 |
| 11.6.2 Design principle and boundary conditions | 298 |
| 11.6.3 Thermodynamic potential | 300 |
| 11.7 Canister purge | 309 |
| 11.8 Auxiliary heating systems for passenger compartments | 312 |
| 11.8.1 Introduction | 312 |
| 11.8.2 Auxiliary heating systems | 312 |
| 11.8.3 Electric auxiliary PTC heater, air-side | 313 |
| 11.8.4 Electric cooling water heater | 316 |
| 11.8.5 Auxiliary fuel heater | 318 |
| 11.8.6 Visco heater | 319 |
| 11.8.7 Auxiliary exhaust-gas heater | 320 |
| 11.8.8 Summary and future prospects | 321 |
| 12 Gasoline Direct Injection in Electric Hybrid Systems | 325 |
| 12.1 Introduction | 325 |
| 12.2 Hybrid drives for passenger cars | 327 |
| 13 Fuels and Lubricants | 339 |
| 13.1 Gasoline fuels | 339 |
| 13.1.1 Introduction | 339 |
| 13.1.2 General principles | 339 |
| 13.1.3 Gasoline fuel components and gasoline fuel mixture | 341 |
| 13.1.4 The practical significance of gasoline fuel requirements | 343 |
| 13.1.5 Effects of the fuel on exhaust emissions | 348 |
| 13.1.6 Gasoline fuels with bio-components: bio-ethanol and ethyl tertiary butyl ether (ETBE) | 349 |
| 13.2 Lubricants for gasoline engines | 351 |
| 13.2.1 Lubricant types | 351 |
| 13.2.2 Functions of engine oils | 351 |
| 13.2.3 Engine oil requirements | 352 |
| 13.2.4 Engine oil composition | 352 |
| 13.2.5 Viscosity | 353 |
| 13.2.6 Basic oils | 355 |
| 13.2.7 Additives | 356 |
| 13.2.8 Performance classes of engine oils | 358 |
| 13.2.9 Fuel and lubricant specifications of passenger car manufacturers . | 363 |
| 13.2.10 Future prospects | 363 |

| | |
|---|-----|
| 14 Engine Concepts | 365 |
| 14.1 Series concepts | 365 |
| 14.1.1 History | 365 |
| 14.1.2 Stratified charge concepts: wall-guided and air-guided combustion processes | 367 |
| 14.1.3 Homogeneous mixture concepts | 374 |
| 14.1.4 Supercharging concepts | 377 |
| 14.1.5 Stratified charge concepts: spray-guided combustion processes | 382 |
| 14.2 Motor sports concepts and impetus for series development | 387 |
| 14.2.1 Introduction | 387 |
| 14.2.2 Gasoline direct injection in motor racing | 388 |
| 14.2.3 V8 bi-turbo with direct injection for the Le Mans 24-Hour Race | 389 |
| 14.2.4 Use in a 2 l production engine with direct injection and turbocharging | 393 |
| 14.2.5 Comparison of engines with direct injection for motor racing and for series production | 395 |
| 14.2.6 Summary and future prospects | 396 |
| 14.3 Two-stroke gasoline engines with direct injection | 396 |
| 14.3.1 Introduction | 396 |
| 14.3.2 History | 397 |
| 14.3.3 Series concepts | 402 |
| 14.3.4 Applications and future prospects | 406 |
| 15 Gasoline Direct Injection in the USA, Europe and Japan | 413 |
| 15.1 Introduction | 413 |
| 15.2 The markets: USA, Europe and Japan | 413 |
| 15.3 Future prospects | 416 |
| 16 Future Prospects | 417 |
| Subject Index | 423 |