

The theory of compression ignition engines

Contents

1.1	Introduction	5
1.1.1	Historical	5
1.1.2	Classifications	5
1.2	Two-stroke and four-stroke engines	5
1.2.1	Two-stroke engines	6
1.2.2	Four-stroke engines	7
1.2.3	Evaluation of power output of two-stroke and four-stroke engines	7
1.2.4	Other operating parameters	8
1.3	Air standard cycles: constant pressure—constant volume—dual combustion	9
1.3.1	Theoretical expressions for air standard cycles	9
1.3.2	Further comments on air standard cycles	13
1.4	Basic thermodynamics of real gases	14
1.4.1	Gas properties	14
1.4.2	Combustion	15
1.4.3	Dissociation and reaction kinetics	17
1.5	Real diesel engine cyclic processes	17
1.5.1	Closed period	17
1.5.2	Open period	19
1.6	Detailed cycle analysis methods	21
1.6.1	Closed period	21
1.6.2	Open period (gas exchange process)	22
1.6.3	Completion of calculation sequence	25
	References	25

2

The theory of turbocharging

Contents

2.1	Introduction	29	2.6	Turbocharger matching	59
2.2	Turbocharging	30	2.6.1	Introduction	59
2.2.1	Turbochargers for automotive diesel engines	30	2.6.2	Air flow characteristics of engine and turbocharger	61
2.2.2	Small industrial and marine engine turbochargers	33	2.6.3	Matching for constant speed operation	62
2.2.3	Large industrial and marine engine turbochargers	34	2.6.4	Matching the marine engine	63
2.3	Turbocharger performance	35	2.6.5	Matching for diesel-electric traction	64
2.3.1	Compressor and turbine efficiency	35	2.6.6	Matching for other industrial duties	65
2.3.2	Non-dimensional representation of compressor and turbine characteristics	37	2.6.7	Matching the four-stroke vehicle engine	65
2.3.3	Compressor performance	38	2.6.8	Matching the two-stroke vehicle engine	67
2.3.4	Turbine performance	38	2.7	Changes in ambient conditions	69
2.4	Turbocharging systems—principles	40	2.7.1	Introduction	69
2.4.1	The energy in the exhaust system	40	2.7.2	Operation under changing ambient conditions	69
2.4.2	Principles of constant pressure turbocharging	41	2.7.3	Rematching to suit local ambient conditions	70
2.4.3	Principles of pulse turbocharging	44	2.8	Closure	70
2.4.4	Principles of pulse converter and other turbocharging systems	53		References	71
2.5	Charge air cooling	55		Acknowledgements	71
2.5.1	Charge cooling principles	55		Nomenclature	71
2.5.2	Charge air cooling and engine performance	57			

Compound and other engine systems

Contents

3.1	Introduction	75
3.2	Gas generator and compound schemes compared with the turbocharged engine	75
3.3	Analysis of turbocharged and compound engine systems based on full cycle simulation	76
3.3.1	Analysis based on compression and expansion machines with fixed polytropic efficiencies of 85% and 80%, respectively	76
3.3.2	Analysis based on fully modelled system, including compressor, turbine and cooler characteristics	78
3.4	Other compounded or related engine schemes	81
3.4.1	The differential compound engine (DCE)	81
3.4.2	The differentially supercharged diesel engine (DDE)	83
3.5	Other turbocharged or pressure charging systems	84
3.5.1	Two-stage turbocharging	84
3.5.2	Variable geometry turbocharging	85
3.5.3	The pressure wave supercharger	86
	References	87

Diesel combustion and fuels

Contents

4.1	Diesel combustion	91
4.1.1	Basic combustion theory	91
4.1.2	Ignition delay	92
4.1.3	Mixing controlled combustion	93
4.1.4	Combustion system design	94
4.1.5	Analysis of cylinder pressure data	96
4.2	Diesel fuels	98
4.2.1	Hydrocarbon types	98
4.2.2	Petroleum-derived fuels	99
4.2.3	Diesel fuel properties	100
4.2.4	Diesel fuel quality issues	102
4.2.5	Diesel fuel specifications	102
4.2.6	Alternative fuels	103
	References	104

Thermal loading

Contents

5.1	Introduction	107
5.2	Gross heat losses	107
5.3	Prediction of local heat flows	107
5.4	Heat transfer at coolant side	109
5.4.1	Stationary surfaces—cylinder head and liner	109
5.4.2	Moving components—pistons	112
5.4.3	Establishing temperature maps	113
5.5	Thermal stress	113
5.5.1	Thermal stress failures	113
5.5.2	Materials	113
5.5.3	Strongbacked constructions	114
5.5.4	Calculation of thermal stress	114
5.6	Limiting conditions in operation	115
5.6.1	To meet lubrication requirements	115
5.6.2	For thermal strength	116
5.6.3	Fuel injector	116
5.7	Designing to meet thermal requirements	116
5.7.1	Cylinder head	116
5.7.2	Cylinder liner	118
5.7.3	Piston design	118
5.7.4	Injector cooling	118
5.8	Measurement of local temperature gradients and heat fluxes	119
5.8.1	Fixed thermocouples	120
5.8.2	Traversing thermocouples	120
5.8.3	Hardness recovery methods	120
5.8.4	Fusible plugs	120
5.9	Exhaust valves and seats	120
	Acknowledgements	120
	References	120

Thermodynamic mathematical modelling

Contents

6.1	Introduction	127
6.2	Fundamentals and the energy equation	127
6.3	Gas properties	129
6.4	Pipe flows, valves, throttles and flow restrictions	131
6.5	Turbomachinery and charge air coolers	134
6.6	The cylinder	137
6.7	Injection and combustion	139
6.8	Heat transfer and friction	141
6.9	Model results and engine performance	144
6.10	Transient modelling	145
6.11	Other engine components	146
6.11.1	Turbomachinery	146
6.11.2	Control valves	147
6.11.3	Indirect injection and other fuelling methods	147
6.11.4	Two-stroke engines	148
6.12	Energy equation, gas properties and combustion extensions	148
6.13	Gas dynamics	149
	References	151

Computational fluid dynamics

Contents

7.1	Introduction	155
7.2	Model description	155
7.2.1	Gas-phase modelling	155
7.2.2	Liquid-phase modelling	156
7.2.3	Ignition, combustion and emissions	159
7.3	Applications	161
7.3.1	Modelling the gas-exchange process	161
7.3.2	Combustion and emissions model validation	163
7.3.3	Effect of multiple injections	166
7.3.4	Use of CFD in engine design	168
7.4	Summary and conclusions	168
	Acknowledgements	169
	References	169
	Nomenclature	171

Modern control in diesel engine management

Contents

8.1	What is the purpose of control	175
8.1.1	Fundamental components	175
8.1.2	The structure of a control system	175
8.1.3	The shape of the future—model-based control	176
8.2	The context of engine control	179
8.3	What a control system does	179
8.3.1	Sensors for control	181
8.3.2	Actuators for control	182
8.4	Current engine control technology	183
8.5	Algorithms for control	183
8.5.1	Predictors and filters	188
8.5.2	The Future	188
8.5.3	Modern control—an example	188
8.6	Designer's guide	189
8.6.1	Developing control systems	189
8.6.2	General comments about system development	190
8.6.3	Specifying functions	190
	References	194

Inlet and exhaust systems

Contents

9.1	Introduction	201
9.2	Gas flow	201
9.3	Four-stroke engines	201
9.3.1	Valve timings	202
9.3.2	Valve areas	203
9.3.3	Determination of flow coefficients	204
9.3.4	Engine breathing demands	207
9.3.5	Actual non-swirling port shapes	207
9.3.6	Swirl producing ports	207
9.4	Turbocharging	211
9.5	Two-stroke engine scavenging	211
9.5.1	Cross scavenging	211
9.5.2	Loop scavenging	211
9.5.3	Uniflow scavenging	212
9.5.4	Port areas and timings	213
9.6	Silencers	214
	References	215

Contents

10.1	Introduction	219
10.2	The balancing of engines	219
10.2.1	Consideration of the forces involved	219
10.2.2	Balance of a single-cylinder engine	222
10.2.3	Two-cylinder engines	224
10.2.4	Four-cylinder in-line engines	225
10.2.5	Three-cylinder engines	226
10.2.6	Six-cylinder engines	227
10.2.7	Vee engines	227
10.2.8	Two-stroke engines	230
10.2.9	Control of torque reaction	231
10.3	Torsional vibration	231
10.3.1	Simple systems	231
10.3.2	The solution of multi-cylinder crankshaft systems	235
10.3.3	Vibration dampers	242
10.3.4	Torsiographs and torsional vibration tests	245
10.4	General design practice and use of materials	246
10.4.1	Introduction	246
10.4.2	The design process	246
10.4.3	General properties of materials	247
10.4.4	Behaviour of materials under repeated loads—fatigue	248
10.4.5	Typical materials used in production	252
	References	260

Contents

11.1	Introduction	263	11.3	Diesel fuel injection systems—Robert Bosch Corp.	280
11.2	Diesel fuel injection systems—Lucas Diesel Systems	263	11.3.1	Fuel-injection systems	280
11.2.1	Compression ignition combustion processes	263	11.3.2	Fuel-injection techniques	280
11.2.2	Formation of nitric oxide by lean combustion	266	11.3.3	Pump-and-barrel assemblies (pumping elements)	282
11.2.3	Unburned hydrocarbons	266	11.3.4	Standard PE in-line injection pumps	285
11.2.4	Origins of noise in diesel combustion processes	267	11.3.5	PE in-line injection pumps for alternative fuels	290
11.2.5	Particulate emissions	267	11.3.6	In-line control sleeve fuel-injection pumps	291
11.2.6	Traditional jerk pump	268	11.3.7	Electronic Diesel Control (EDC)	292
11.2.7	Unit injectors	269	11.3.8	Bosch—Single-plunger fuel-injection pumps	294
11.2.8	DP rotary distributor pumps	269	11.3.9	Innovative fuel-injection systems	296
11.2.9	Electronically controlled rotary pumps (EPIC)	272	11.3.10	Peripheral equipment for diesel fuel-injection systems	297
11.2.10	Advanced rotary distributor pumps	273	11.3.11	Bosch—Distributor injection pumps VE	300
11.2.11	Control of rate of injection with conventional FIE	274	11.4	Diesel fuel injection systems—Caterpillar Inc.	301
11.2.12	Lubrication of fuel injection components	276	11.4.1	Caterpillar's hydraulically-actuated electronic unit injector (HEUI) fuel system	302
11.2.13	Common rail systems	276	11.4.2	Next generation: HEUI-B	304
11.2.14	Integrated fuel injection systems	277			
11.2.15	Summary	279			
11.2.16	Acknowledgement	280		References	304

Contents

12.1	Introduction	309
12.2	Lubricating oils	309
12.2.1	Mineral oils	309
12.2.2	Synthetic oils	310
12.3	Viscosity—its significance in lubrication	310
12.3.1	Viscosity and coefficient of friction	310
12.3.2	Viscosity measurement and units	311
12.3.3	Change in viscosity with temperature and pressure	311
12.3.4	Viscosity classification	311
12.3.5	Low-temperature viscosity and ease of starting	312
12.3.6	Viscosity at running temperatures; friction losses and oil consumption	313
12.4	Additives	313
12.5	Oil deterioration	313
12.6	Operational problems	315
12.6.1	Piston deposits	315
12.6.2	Engine wear	315
12.6.3	Bearing corrosion	316
12.6.4	Sludge	316
12.7	API classification	316
12.8	Engine tests and associated specifications	316
12.8.1	Engine test rating	323
12.9	Laboratory inspection tests	323
12.10	Spot tests	326
	Acknowledgement	326
	References	327
	Abbreviations	327

Bearings and bearing metals

Contents

13.1	Introduction	331
13.2	Bearing design	331
13.2.1	Wall thickness	331
13.2.2	Interference fit	331
13.2.3	Locating tangs	332
13.2.4	Free spread	332
13.2.5	Loading on crankpin and main bearings	333
13.2.6	Prediction of oil film thickness	333
13.2.7	Grooving configuration	334
13.2.8	Clearance	335
13.3	Bearing damage	335
13.3.1	Abrasion	335
13.3.2	Fatigue	336
13.3.3	Corrosion	336
13.3.4	Wiping	337
13.3.5	Cavitation	337
13.3.6	Fretting	337
13.3.7	Design faults	337
13.3.8	Incorrect assembly	338
13.3.9	Environmental factors	338
13.3.10	Geometric factors	339
13.4	Slow-speed engine crosshead bearings	339
13.5	Bearing metals	340
13.5.1	Fatigue strength	340
13.5.2	Scuff resistance	340
13.5.3	Wear resistance	341
13.5.4	Cavitation erosion resistance	341
13.5.5	Overlays	341
13.5.6	White metals	342
13.5.7	Copper-lead and lead-bronze alloys	343
13.5.8	Aluminium-tin alloys	344
13.5.9	Aluminium-silicon alloys	345
	References	345

Contents

14.1	Introduction	349
14.2	Pistons	349
14.2.1	Introduction	349
14.2.2	Piston loading	349
14.2.3	Piston design	350
14.2.4	Piston types	352
14.2.5	Gudgeon pins	356
14.2.6	Piston design analysis	357
14.3	Rings	358
14.3.1	Introduction	358
14.3.2	Ring design	359
14.3.3	Ring types	360
14.3.4	Ring packs	362
14.3.5	Ring materials	362
14.3.6	Ring coatings	363
14.3.7	Oil consumption and blow-by	364
14.3.8	Scuffing	364
14.3.9	Ring research	364
14.4	Liners	365
14.4.1	Introduction	365
14.4.2	Dry liners	365
14.4.3	Wet liners	366
14.4.4	Liner shape and surface finish	366
14.4.5	Material	366
14.4.6	Bore polish	367
	References	368

Contents

15.1	Governors and governor gear	373
15.1.1	Introduction	373
15.1.2	Basic principles	373
15.1.3	Basic governing terms	375
15.1.4	Typical governors	376
15.1.5	Application requirements and governor selection	384
15.1.6	Typical applications	385
15.1.7	Conclusion	387
15.2	Starting gear and starting aids	387
15.2.1	Introduction	387
15.2.2	Unaided cold starting ability	387
15.2.3	Improving the unaided cold starting ability	388
15.2.4	Engine cranking requirements	389
15.2.5	Methods of starting	390
15.2.6	Starting aids	399
15.3	Heat exchangers	402
15.3.1	Introduction	402
15.3.2	Operating conditions	403
15.3.3	Water-cooled systems	403
15.3.4	Evaporative systems	406
15.3.5	Temperature control	406
15.3.6	Air-cooled systems	407
15.3.7	Heat transfer	408
15.3.8	Construction and design	411
15.3.9	Materials	420
15.3.10	Corrosion	421
15.3.11	Maintenance	421
15.3.12	Water treatment	422
	References	422

Contents

16.1	Introduction	425
16.2	Design features and functional aspects	427
16.2.1	Crankcase	427
16.2.2	Cylinder unit	427
16.2.3	Heat exchangers	433
16.2.4	Fan control	434
16.3	Cooling fan	435
16.3.1	General aspects	435
16.3.2	Layout and design of axial fans	435
16.3.3	Stators	437
16.3.4	Fan noise and its reduction	438
16.3.5	Other design considerations	439
16.3.6	Manufacturing considerations	440
16.4	Environmental aspects	440
16.4.1	Exhaust emissions	440
16.4.2	Engine noise	440
16.4.3	Noise characteristics of aircooled engines	440
16.4.4	Noise attenuation by secondary measures	441
16.5	Applications	442
	References and Bibliography	446

Contents

17.1	Introduction	451
17.2	Oil mist in crankcases	451
17.3	Explosion effects	451
17.4	Incidence of crankcase explosions	452
17.5	Prevention of explosions	452
17.6	Design aspects	452
17.7	Explosion relief valves	452
17.8	Crankcase monitoring systems	453
17.9	Oil mist detectors	453
17.9.1	Graviner systems	453
17.9.2	Schaller Visatron systems	454
17.9.3	Location of sampling points	455
17.10	Practical aspects	455
	References	455

Exhaust smoke, measurement and regulation

Contents

18.1	General considerations	461
18.2	Instrumentation	461
18.2.1	Comparators	461
18.2.2	Filter-soiling 'spot' meters	462
18.2.3	Opacimeters	462
18.3	Calibration and correlation of smokemeters	465
18.4	Optical system—spectral response	466
18.5	Opacimeter specifications	466
18.6	Visibility criterion—public objection	467
18.7	Test methods and procedures	468
18.8	Typical smoke regulations	470
18.8.1	Road vehicle applications	470
18.8.2	Regulations other than for road vehicles	470
18.9	Conclusions—future legislation	470
	References	470

Contents

19.1	Introduction	473
19.2	Legislation	473
19.2.1	USA	473
19.2.2	Europe	475
19.2.3	Japan	475
19.2.4	Concluding remarks	475
19.3	Analysers	475
19.3.1	Carbon dioxide	476
19.3.2	Carbon monoxide	476
19.3.3	Nitric oxide	476
19.3.4	Hydrocarbons	477
19.3.5	Oxygen	477
19.3.6	Particulates	478
19.4	Formation and control	478
19.4.1	Carbon dioxide	478
19.4.2	Carbon monoxide	479
19.4.3	Unburnt hydrocarbons	479
19.4.4	Nitrogen oxides	479
19.4.5	Odour	480
19.4.6	Particulates	480
19.5	Unregulated emissions	481
19.5.1	Aldehydes	481
19.5.2	Polycyclic aromatic hydrocarbons	481
19.5.3	Nitrated polycyclic aromatic hydrocarbons	481
19.5.4	Vapour-phase hydrocarbons	481
19.5.5	Particle size	482
19.6	Conclusions	482
	Appendix	483
	Bibliography	483

Engine noise

Contents

20.1	Introduction	487
20.2	Theory and definitions	487
20.2.1	Amplitude	487
20.2.2	Effect of distance on sound pressure level	487
20.2.3	Frequency and wavelength	487
20.2.4	Sound power level	488
20.2.5	Addition and subtraction of sound sources	488
20.2.6	Averaging decibel levels	489
20.2.7	Calculating relative levels	489
20.2.8	Weighting curves	489
20.2.9	Noise dose level	490
20.3	Legislation	490
20.3.1	On-highway vehicles	490
20.3.2	Off-highway machines	490
20.4	Measurement and analysis of noise	491
20.4.1	Measurement environments	491
20.4.2	Equipment	491
20.4.3	Frequency analysis	492
20.4.4	Tracking analysis	493
20.4.5	Sound quality analysis	494
20.5	Noise characteristics of diesel engines	494
20.5.1	Engine overall noise levels	495
20.5.2	Assessment of combustion noise	495
20.5.3	Assessment of mechanical noise	497
20.5.4	Engine radiated noise	497
20.5.5	Vehicle and machine noise assessment	499
20.6	Methods for control of diesel engine noise	501
20.6.1	Combustion noise	501
20.6.2	Mechanical noise	502
20.6.3	Predictive analysis	502
20.6.4	Palliative treatments and enclosures	505
20.6.5	Vehicle and machine refinement	506
20.7	Conclusion	506
	References	506
	Bibliography	506

Larger engine noise and vibration control

Contents

21.1	Introduction	511
21.2	Noise	511
21.3	Vibration	512
	References	519

Contents

22.1	Introduction	525
22.2	Vehicle specific requirements	530
22.3	Current engine technology	530
22.3.1	Combustion systems	530
22.3.2	Design features	535
22.3.3	Fuel injection equipment	540
22.3.4	Exhaust gas aftertreatment	541
22.3.5	Electronic control systems	543
22.4	Performance and emissions characteristics	543
22.4.1	Power and torque	543
22.4.2	Fuel consumption	544
22.4.3	Exhaust emissions	545
22.4.4	Noise, vibration, and harshness (NVH)	547
22.5	Future developments	548
	References	551

Contents

23.1	Market demands	555	23.9	Flywheel housing	565
23.1.1	Size and physical constraints	555	23.10	Geartrain	565
23.1.2	Weight	555	23.11	Gear case and cover	566
23.1.3	Cost	555	23.12	Electronic control system	566
23.1.4	Durability and reliability	555	23.12.1	ECM	566
23.1.5	Performance	555	23.12.2	Sensors	568
23.1.6	Fuel economy	555	23.12.3	Interconnections and wiring	569
23.1.7	Gaseous and noise emissions	556	23.12.4	Communications	569
23.1.8	Electronics	556	23.13	Fuel injection system	570
23.1.9	Product support	556	23.13.1	Electronic fuel injection devices	570
23.2	Starting point	556	23.13.2	Fuel (transfer) pump	572
23.2.1	Cylinder block and head	556	23.13.3	Fuel lines	572
23.3	Cylinder kit components	557	23.13.4	Fuel filters	572
23.3.1	Pistons	557	23.13.5	Fuel heaters and coolers	572
23.3.2	Piston rings	558	23.13.6	Fuel and water separators	572
23.3.3	Cylinder liner	558	23.14	Air system	572
23.4	Connecting rod assembly	559	23.14.1	Turbocharger	573
23.4.1	Connecting rods and bearing caps	559	23.14.2	Charge cooler	575
23.4.2	Piston pin bearings and connecting rod-to-crankshaft bearings	559	23.14.3	Intake and exhaust manifolds	576
23.5	Crankshaft assembly	559	23.15	Lubrication system	576
23.5.1	Crankshaft	559	23.15.1	Oil pump	576
23.5.2	Crankshaft oil seals	560	23.15.2	Regulator	577
23.5.3	Crankshaft main bearings	560	23.15.3	Relief valve	577
23.5.4	Crankshaft pulley	560	23.15.4	Filters	577
23.5.5	Crankshaft vibration damper	561	23.15.5	Oil cooler	577
23.6	Camshaft assembly	561	23.15.6	Dipstick	577
23.6.1	Camshaft	561	23.15.7	Oil pan	577
23.6.2	Camshaft bearings and caps	561	23.15.8	Crankcase ventilation	577
23.6.3	Camshaft drive gear	561	23.15.9	Oil quality	578
23.7	Overhead components	561	23.16	Coolant system	578
23.7.1	Valve train assembly	562	23.16.1	Coolant	578
23.7.2	Rocker assemblies	563	23.16.2	Coolant filter and conditioner	578
23.7.3	Rocker cover assembly	563	23.16.3	Water pump	578
23.7.4	Engine retarders	563	23.16.4	Thermostats	579
23.8	Flywheel	564	23.17	Typical engines	579
			23.17.1	Product overview	579

23.17.2 Caterpillar engines	579
23.17.3 Cummins engines	580
23.17.4 Detroit diesel engines	581
23.17.5 Mack engines	581
23.17.6 Mercedes-Benz engines	581
23.17.7 Navistar engines	582
23.17.8 VarityPerkins engines	582
23.17.9 Volvo engines	582
Bibliography	585

Contents

24.1	Introduction	589
24.2	Development trends	589
24.2.1	Emissions	589
24.2.2	Engine weight	592
24.2.3	Reliability and durability	592
24.3	Engine descriptions	593
24.3.1	Caterpillar 3500	593
24.3.2	Caterpillar 3600	593
24.3.3	Dalian 240 ZD	593
24.3.4	General Electric 7FDL™	597
24.3.5	General Electric 7HDL™	598
24.3.6	General Motors EMD 645 and 710	598
24.3.7	General Motors EMD H engine	598
24.3.8	Kolomna D 49	601
24.3.9	MTU/DDC 4000 series	603
24.3.10	Paxman VP 185	603
24.3.11	Pielstick PA4 200 VG	605
24.3.12	Pielstick PA6B	607
24.3.13	Ruston RK215	609
24.4	Summary of engine design features and future trends	609
24.5	Railcar engines	609
24.5.1	Cummins	611
24.5.2	MAN	611
24.5.3	MTU	611
24.5.4	Niigata	611
	Acknowledgements	611
	References	611
	Further reading	612

Contents

25.1	What is a dual fuel engine?	615
25.2	Combustion in dual fuel engines	615
25.3	Gas properties and their effects	615
25.3.1	Heat value of a stoichiometric mixture volume	615
25.3.2	Net heating value (kJ/m^3)	615
25.3.3	Anti-detonation properties	615
25.3.4	Pre-ignition tendency	616
25.3.5	Flame speed	616
25.4	Combustion system	617
25.4.1	The 'conventional' dual fuel engine	619
25.4.2	The 'low NO _x ' dual fuel engine	619
25.4.3	The 'gas diesel' engine	621
25.4.4	Other combustion systems	622
25.5	Air-fuel ratio control systems	626
25.5.1	Intake throttle	626
25.5.2	Exhaust by-pass	626
25.5.3	Compressor by-pass	626
25.6	Safety systems	626
25.7	Applications	628
25.7.1	Automotive	628
25.7.2	Locomotive	629
25.7.3	Stationary (power generation and mechanical drive)	629
25.7.4	Marine and offshore	629
	References	629
	Bibliography	630

Contents

26.1	High speed engines	633
26.1.1	Caterpillar	633
26.1.2	Cummins	634
26.1.3	Deutz MWM	634
26.1.4	GMT	635
26.1.5	Isotta Fraschini	637
26.1.6	MAN B&W Holeby	637
26.1.7	Mitsubishi	640
26.1.8	MTU	640
26.1.9	MTU/DDC designs	644
26.1.10	Niigata	647
26.1.11	Paxman	647
26.1.12	SEMT-Pielstick	651
26.1.13	Wärtsilä diesel	652
26.1.14	Automotive-derived engines	655
26.2	Low speed engines	655
26.2.1	Introduction	655
26.2.2	Intelligent engines	658

Contents

27.1	Introduction	667
27.2	A typical condition monitoring system	667
27.3	Instrumentation for condition monitoring	667
27.3.1	Vibration monitoring	668
27.3.2	Temperature measurements	668
27.4	Instrumentation for condition monitoring indirect methods	669
27.5	Fuel monitoring	670
27.6	Exhaust emissions	670
27.7	Conclusion	670
	References	670