



船舶与海洋工程

国家十二·五重点图书
船舶与海洋工程专业规划教材

MARINE DIESEL ENGINE PROPULSION SYSTEM

胡以怀 主编
朱建元 主审



上海交通大学出版社
SHANGHAI JIAO TONG UNIVERSITY PRESS

Marine Diesel Engine Propulsion System

主编 胡以怀
主审 朱建元

上海交通大学出版社

图书在版编目(CIP)数据

船用柴油机推进系统 = Marine Diesel Engine Propulsion System: 英文/胡以怀主编. —上海:上海交通大学出版社, 2012
(船舶与海洋工程系列)

ISBN 978-7-313-08113-1

I. 船... II. 胡... III. 船用柴油机推进系统—英文
IV. U664.121

中国版本图书馆 CIP 数据核字(2012)第 008457 号

船用柴油机推进系统

胡以怀 主编

上海交通大学出版社出版发行

(上海市番禺路 951 号 邮政编码 200030)

电话:64071208 出版人:韩建民

昆山市亭林印刷有限责任公司 印刷 全国新华书店经销

开本:787mm×1092mm 1/16 印张:29 字数:716 千字

2012 年 8 月第 1 版 2012 年 8 月第 1 次印刷

ISBN 978-7-313-08113-1/U 定价:75.00 元

版权所有 侵权必究

告读者:如发现本书有印装质量问题请与印刷厂质量科联系
联系电话:0512-57751097

ABSTRACT

Compiled in nine chapters this book describes typical constructions of marine propulsion system, marine diesel engine, air exchange & turbo-charging, fuel injection & combustion, cooling water, lubricant oil, fuel oil and treatment systems, control & maneuvering devices, routine & emergency operations in machinery space, vibration control & monitoring together with SOLAS and MAPPOL conventions. Different from other Chinese textbook of marine propulsion system, this book puts the introduction to marine propulsion system at the beginning of the book in order to make better understanding of the whole contents.

Chapter One firstly reviews the history of marine engineering, together with naval architecture afterwards. Functions, structures and characteristics of marine propulsion plant is introduced. Running performances, running range and match properties of propeller and main engine are also described. Finally, some latest energy saving technologies of slow marine diesel engine are introduced including slow steaming, waste heat recovery and contra-rotating propeller.

Chapter Two firstly describes the working principle of diesel engine and comparison between four stroke diesel engine and two stroke diesel engine. Structures of framework, cylinder block, cylinder jacket, cylinder liner and cylinder cover are introduced. Running gear of piston group, piston rings, connecting rod, crankshaft flying wheel are also introduced, together with routine maintenance of these components.

Chapter Three states four typical marine diesel engines of type Sulzer RTA 38 two stroke engine, MAN B&W MC two stroke engine, SEMT PIELSTICK PC 2.5 four stroke engine and WARTSILA 20 four stroke engine including framework and running gears. Electronically controlled diesel engines of Sulzer RTA Flex and MAN B&W ME are stated including their working principle, hydraulic servo system, common rail structure and working characters.

Chapter Four firstly introduces the air scavenging and pressure charging process. Air exchange Features of two stroke and four stroke diesel engine are compared together with air scavenging and pressure charging. Working principle, typical structure and performance matching of turbo-blower and engine are introduced, together with the structure of charge air cooler, turbo blower, compressor silencer, water washing device. Working principle and application of impulse and constant pressure turbo-charging is also described in many details.

Chapter Five firstly describes the working principle of diesel engine. Fuel oil injection and combustion systems are then introduced, together with different types of fuel pump and fuel injector including jerk, valve-controlled fuel pump, closed-type nozzle injector, pintle

nozzle injector, hydraulically operated injector and variable injection timing device. Finally, the main methods and their applications for emission control of marine diesel engine are also introduced including Fuel Water Emulsion (FEW), Exhaust Gas Recirculation (EGR), Selective Catalytic Reduction (SCR) and Residual Fuel Oil (RFO).

Chapter Six firstly introduces the properties of fuel oil. The transfer system, forwarding system and treatment system of fuel oil are then described. Lubricant oil properties, main lubrication system, cylinder oil system are introduced together with the introduction to ALPHA electronically controlled cylinder oil injector. Fresh water cooling system, jacket cooling water system and sea water cooling system are lastly introduced, together with the description of working principle and structure of shell and tube heat exchanger, plate type heat exchanger, magnetic strainer and separator.

Chapter Seven firstly describes the systems of starting, stopping, reversing and governing of main engine. Compressed air starting system, reversing mechanism, hydraulic governor, over-speed trip and safe guard mechanisms are then introduced. Working principle and performance of different governors of mechanical, hydraulic and electronic type are described in more details. Main engine operations in bridge control room, engine control room and at engine side are described with main engine pneumatic remote control illustration. A new digital central operation and control system of machinery space is also introduced.

Chapter Eight firstly introduces the working principle and structure of engine indicator. Features of different indicator diagrams under normal condition, failure condition and abnormal condition are introduced including too late fuel injection, too early fuel injection, too late valve timing, too early valve timing, valve leakage, high exhaust back pressure, weak indicator spring, wrong phase. Maintenance of main engine during starting, maneuvering, running in steady running, stopping and emergency operation is described including maintenance interval, maintenance procedure and maintenance tools. Routine check and failure analysis of marine diesel engine is introduced with plenty of practical symptomatic information.

Chapter Nine firstly analyses the excitation source and control methods of diesel engine vibration such as vibration balancer and isolator. Shaft torsional vibration mode, exciting torque calculation, torsional response calculation and measures to reduce torsional vibration are also introduced. Vibration meters and vibration standards for the condition monitoring and fault diagnosis on board ship are also introduced.

Appendix firstly introduces the historical background of SOLAS convention. Conventional requirements for ship structure, ship material, propulsor, fire detection, fire fighting, internal layout, life saving apparatus and communications are described. The historical background of MARPOL convention is then introduced together with conventional limitations on oil pollution, noxious liquid substances in bulk, sewage, garbage, air pollution and ballast water. The minimized requirement for deck and cargo handling machinery is also introduced.

PREFACE

It has been a long time that we have an idea of publishing textbook series for the students majored in marine engineering. After over seven years study and preparation of teaching materials, this textbook about marine diesel engine propulsion system has finally been presented to the public which, we hope, could promote the publish of their curriculum textbooks in English for the students majored in marine engineering.

This book is compiled in accordance with the revised competency examination outline for Chinese sea farers issued by Maritime Safety Bureau. Together with cutting edge of marine engineering technologies in the recent five years, this book introduces electronically controlled diesel engine of Sulzer RTA Flex and MAN B&W ME, energy saving technologies of slow steaming, waste heat recovery, contra-rotating propeller, exhaust emission control, vibratory condition monitoring and digitalized monitoring & control systems. Shaft torsional vibration of propulsion system is also introduced in order to satisfy the requirement of graduated students majored in marine engineering and naval architecture.

There are more and more Chinese seafarers in the recent years with the eastward moving of global seafarer market to oversea Asia. Compared to the seafarers from other parts of Asia like India, Philippines, Malaysia, most of Chinese seafarers are always poor at oral English communication, which has become the major obstacle to their future career. A number of questions are collected at the end of each chapter in this book, which could be utilized by students for either review by themselves or discussion by groups. So in this way students could have chances to practice their oral English and improve their listening comprehension as well.

This book was compiled by Professor Yihuai Hu and reviewed by Professor Jianyuan Zhu. Mr. Xianhu Wu also gave his comments on this book. Besides, any other comments, or suggestions on this textbook of marine propulsion system will also be warmly welcome.

Contents

PART ONE ENGINE STRUCTURE

CHAPTER 1 MARINE PROPULSION PLANT

1 Introduction	3
1.1 Historical Perspective	3
1.2 Marine Engineering Definition	6
2 Main Propulsion System	8
2.1 Transmission System	10
2.1.1 Thrust block	11
2.1.2 Shaft bearings	11
2.1.3 Sterntube bearing	13
2.1.4 Shafting	14
2.1.5 Propeller	14
2.1.6 Propeller mounting	15
2.1.7 Controllable pitch propeller	16
2.1.8 Cavitation	17
2.1.9 Propeller maintenance	17
2.2 Main Propulsion Devices	17
2.2.1 Turning gear	17
2.2.2 Medium and slow speed diesels	17
2.2.3 Couplings, clutches and gearboxes	18
2.2.4 Bearings	20
3 Performance of Diesel Engine	27
3.1 Characteristics of Diesel Engine	27
3.1.1 Engine ratings	27
3.1.2 Limits of engine performance	29
3.1.3 Fuel consumption	30
3.1.4 Lubricating-oil consumption	32
3.1.5 Intake air requirements	32
3.1.6 Turbocharger performance	33

3.2	Engine layout and load diagrams	35
3.2.1	Introduction	35
3.2.2	Propulsion and engine running points	36
3.2.3	Engine layout diagram	38
3.2.4	Load diagram	39
3.3	Engine matching and selection	42
3.3.1	Margins	42
3.3.2	Relation between ship speed and engine performance	43
3.3.3	Required engine rating	44
3.3.4	Engine selection	44
3.4	Energy saving	45
3.4.1	Slow steaming	46
3.4.2	Adapted ship designs	46
3.4.3	Waste heat recovery	48
3.4.4	Contra-rotating propeller	48

CHAPTER 2 PARTS AND COMPONENTS OF MARINE DIESEL ENGINE

1	Types of Marine Diesel Engines	51
1.1	The Four-stroke Cycle Engine	52
1.2	The Two-stroke Cycle Engine	54
1.3	Comparison of two-stroke and four-stroke cycles	55
2	Framework, Cylinders and Heads	56
2.1	Framework	56
2.1.1	Bedplates	57
2.1.2	Engine frames	58
2.1.3	Tie bolts or stay bolts	60
2.1.4	Engine seating	60
2.1.5	Engine chocks	60
2.1.6	Holding-down bolts	60
2.1.7	Camshafts	61
2.1.8	Camshaft drives	62
2.1.9	Camshaft roller chain	62
2.2	Cylinders	65
2.3	Cylinder heads	70
3	Running Gear	70
3.1	Pistons	70
3.2	Piston pins	74



3.3	Piston rings	76
3.4	Connecting rods	79
3.5	Crosshead	83
3.6	Crankshafts	84
3.7	Counterweights	88
3.8	Bearings	89
3.8.1	Definitions	89
3.8.2	Bearing classification	89
3.8.3	Bearing loads	90
3.8.4	Operating conditions	91
3.8.5	Bearing construction	92
3.8.6	Bearings for reciprocating motion	94
3.8.7	Crosshead guides	95
3.8.8	Bearings with rolling contact	95
3.9	Flywheels	96
3.9.1	Flywheel action	96
3.9.2	Uniformity of rotation	97
4	Operation and Maintenance	98
4.1	Cylinder liners	98
4.1.1	Cylinder liner cooling	100
4.1.2	Bore cooling	100
4.1.3	Cylinder jackets	101
4.1.4	Cylinder lubrication	101
4.1.5	Cylinder liner wear	103
4.1.6	Gauging	104
4.1.7	Fitting a new cylinder liner	106
4.2	Cylinder covers	108
4.3	Pistons	109
4.3.1	Large two-stroke engine pistons	109
4.3.2	Removing piston and rod	112
4.3.3	Piston skirts	114
4.3.4	Piston rods	114
4.3.5	Trunk pistons	114
4.3.6	Cylinder diaphragm and piston rod gland	115
4.4	Piston rings	117
4.5	Connecting rod	120
4.5.1	Characters	120



4. 5. 2	Engine guides	121
4. 5. 3	Crosshead	122
4. 5. 4	Crosshead or top end Bearing	122
4. 5. 5	Gudgeon pin bearings	123
4. 5. 6	Bottom end or big end bearings	123
4. 6	Crankshafts	124
4. 6. 1	Characters	124
4. 6. 2	Main bearings	126
4. 6. 3	Thrust bearing	127
4. 6. 4	Flywheel	127
4. 6. 5	Turning gear or barring motor	127
4. 6. 6	Crankshaft deflections	127

CHAPTER 3 TYPICAL MARINE DIESEL ENGINES

1	Sulzer RTA Two Stroke Deisel Engine	134
1. 1	Engine structure	134
1. 2	Running gear	137
1. 3	Bore cooling	138
1. 4	Cylinder liner and piston	139
1. 5	Piston rod packing gland	140
1. 6	Cylinder head and exhaust valve	141
1. 7	Camshaft	142
1. 8	Fuel injection	143
1. 9	Air and Exhaust System and Turbochargers	147
1. 10	Power Take-off	148
1. 11	Exhaust Gas Turbine	148
2	MAN-B&W MC Two Stroke Deisel Engine	149
2. 1	MAN-B&W K90 MC-C	149
2. 2	MAN-B&W S 26 MCE Engine	151
2. 3	B&W KEF Engine	153
3	Semt-Pielstick Four-Stroke Diesel Engine	154
3. 1	Frame	154
3. 2	Main bearings	155
3. 3	Crankshaft	156
3. 4	Camshafts, Reversing System, Timing Gears and Auxiliary Drive	157
3. 5	Cylinders	158
3. 6	Pistons	159



3.7	Connecting rods	159
3.8	Cylinder heads and valves	160
3.9	Fuel injection system	163
3.10	Turbocharging	165
4	Wartsila Four-Stroke Diesel Engine	165
4.1	Block	166
4.2	Main bearings	167
4.3	Crankshaft	167
4.4	Pistons	167
4.5	Connecting rods	167
4.6	Cylinder liners	168
4.7	Cylinder heads	168
4.8	Camshaft	169
4.9	Balancing gear	170
4.10	Fuel-injection pump and valve tappet assembly	170
4.11	Turbocharger, Charge Air and Exhaust Systems	171
5	Electrically Controlled Diesel Engines	172
5.1	MAN B&W ME Engine	172
5.2	Sulzer RTA-Flex Engine	175

PART TWO ENGINE WORKING PRINCIPLE

CHAPTER 4 AIR SCAVENGING AND TURBO-CHARGING

1	Scavenging	185
2	Pressure-Charging	187
2.1	Four-stroke Engines	188
2.2	Two-stroke Engines	188
2.3	Charged-air Cooling	189
2.4	Importance of Adequate Scavenging	191
2.5	Turbo-blowers	193
2.6	Noise	200
2.7	Boost Blowers	201
2.8	Turbocharger Water Washing Systems	201
2.9	Two-stage Turbocharging	201
3	Intake and Exhaust Systems	202
3.1	Intake System	202
3.1.1	Direct versus external air intake	202

3. 1. 2	Intake filter and silencer	202
3. 1. 3	Charge air cooler	203
3. 1. 4	Charge air heating	203
3. 1. 5	Air manifold	204
3. 2	Exhaust System	204
3. 2. 1	Pulse versus constant pressure turbo-charging	204
3. 2. 2	Exhaust gas heat recovery	205
3. 3	Turbo-charger	206

CHAPTER 5 FUEL INJECTION AND COMBUSTION

1	How Dose a Marine Diesel Engine Work	208
2	Fuel Oil System	209
2. 1	Fuel oil supply for a two-stroke diesel	209
2. 2	Fuel injection	210
2. 3	Jerk pump system	210
2. 4	Common rail system	210
2. 5	Injector pump	210
2. 6	Timing valve	212
2. 7	The fuel injector	212
3	Injection and Combustion	213
3. 1	Introduction	213
3. 2	Jerk Pump Injection System	214
3. 2. 1	Injection pumps	215
3. 2. 2	Injectors	216
3. 2. 3	High pressure fuel line	217
3. 2. 4	Jerk pump injection system problems	217
3. 3	Combustion	218
3. 3. 1	Phases of combustion	219
3. 3. 2	Combustion problems	219
4	Fuel Pump and Injectors	220
4. 1	Jerk Pumps	220
4. 2	Fuel Nozzles	228
4. 3	Unit Injector	229
4. 4	Variable Injection Timing (VIT)	231
4. 5	Pilot Injection	231
4. 6	Fuel Injectors	232
5	Exhausted Emission Control	235



5.1	Fuel Water Emulsification	237
5.2	Exhaust Gas Recirculation	237
5.3	Selective Catalytic Reduction	240
5.4	Residual Fuel Oil	241

CHAPTER 6 FUEL OIL, COOLING WATER, LUBRICANT OIL AND TREATMENT SYSTEMS

1	Fuel Oil System	244
1.1	Fuel oils	245
1.2	Filling and transfer systems	246
1.3	Fuel treatment systems	248
1.4	Fuel forwarding system	250
2	Lubrication Oil System	252
2.1	Lubricating oils	253
2.2	Main engine LO circulating system	254
2.3	Main engine cylinder oil system	258
2.4	Alpha electronically controlled lubricator system	259
2.5	LO storage, transfer and purification system	261
3	Cooling Water System	262
3.1	Fresh water cooling system	264
3.1.1	Jacket water cooling system	265
3.1.2	Piston cooling water system	267
3.1.3	Injector cooling system	267
3.1.4	Diesel generator cooling system	267
3.1.5	Central freshwater cooling systems	267
3.2	Sea water cooling system	268
3.3	Heat exchangers	271
3.3.1	Coolers	271
3.3.2	Shell and Tube	271
3.3.3	Plate Type	272
3.3.4	Operation	272
3.3.5	Maintenance	273
3.3.6	Heaters	273
4	Oil Treatment Devices	273
4.1	Centrifuging	274
4.2	The purifying process	274
4.3	The clarifying process	275
4.4	The bowl discs	275

4.5 Non-continuous operation 275
4.6 Continuous operation 275
4.7 Lubricating oil centrifuging 276
4.8 Filters and strainers 277

PART THREE OPERATION AND MAINTENANCE

CHAPTER 7 MANEUVERING SYSTEM OF MAIN ENGINE

1 Control System 281
1.1 Starting System 281
1.2 Stopping 283
1.3 Reversing System 283
1.4 Speed Control 286
1.5 Monitoring and Automatic Shutdown 288
1.5.1 Overspeed trip 288
1.5.2 Cylinder relief valve 289
1.5.3 Crankcase oil mist detector 290
1.5.4 Explosion relief valve 290
2 Starting Air System 291
3 Speed Governor 296
3.1 Functions of a Governor 296
3.2 Governor Characteristics 297
3.3 Governor Types 300
3.4 Mechanical Governors 300
3.5 Relay-type Governors 305
3.6 Load-limit Governors 309
3.7 Electric Governor 311
3.8 Overspeed Governors and Trips 311
4 Maneuvering System 312
4.1 Main Engine Pneumatic Remote Control System 313
4.1.1 Remote control from engine control room 313
4.1.2 Remote control from bridge 315
4.1.3 Emergency control from engine side 315
4.1.4 Crash-stop 320
5 Unattended Machinery Space 320
5.1 Centralized Control 320
5.2 Bridge Control 321



5.3	Machinery Remote Control System	322
5.4	Digital Central Operation and Control System	324
5.4.1	System hardware	324
5.4.2	System software controlled functions	326

CHAPTER 8 NORMAL AND EMERGENCY OPERATION IN ENGINE ROOM

1	Indicator Diagrams	330
1.1	Indicator Diagrams	330
1.2	Indicators	333
1.3	Offset diagrams	336
1.4	Draw cards	337
1.5	Firing diagrams	338
1.6	Intake and exhaust	340
1.7	Pressure-time diagrams	341
1.8	Mean indicated pressure	341
1.9	Indicated horsepower	341
1.10	Brake horsepower	342
1.11	Indicator diagrams analysis	342
2	Normal Operations of Main Engine	348
2.1	Starting	348
2.2	Maneuvering	350
2.3	Running-in after overhaul	351
2.4	Steady running	351
2.5	Stopping	352
2.6	Electrical supply control	353
2.7	Emergency operation	353
3	Maintenance	354
3.1	Performance data analysis	354
3.2	Maintenance schedules	356
3.3	Special tools and maintenance aids	359
3.4	Maintenance and precaution	360

CHAPTER 9 CONTROL AND APPLICATION OF VIBRATION SIGNALS

1	Vibrations and Balancing	376
1.1	Causes of vibration	376
1.2	Engine vibrations	377
1.3	Unbalanced engine forces	378

1.4	Crankshaft balance	380
1.5	Balancers	382
1.6	Vibration absorbers	382
1.7	Torsional vibration	384
1.8	Dampers and absorbers	386
2	Torsional Vibration	388
2.1	Determination of natural frequency	388
2.2	Excitation factors	392
2.3	Damping	398
2.4	Vibratory Torque Calculations	400
2.5	Acceptable Limits for Torsional Vibration	401
3	Vibration Signals Application Onboard Ship	403
3.1	Torsional Vibration and Balancing	403
3.1.1	Balancers and dampers	403
3.1.2	Case study of a four-cylinder, two-stroke engine	404
3.2	Vibration Analysis on Shipboard	409
3.2.1	Inspection of new machinery and preventive maintenance	409
3.2.2	Investigation of suspected problems	409
3.2.3	Evaluation of machinery repairs	409
3.2.4	Baseline vibration signature	409
3.2.5	Economic benefits of vibration analysis	409
3.2.6	Shipboard applications of vibration analysis	410
3.3	Condition Monitoring and Fault Diagnosis	411
3.3.1	Machinery vibration acceptable limits	411
3.3.2	Programs for preventive maintenance	413
3.4	Interpreting Results of Vibration Measurements	416
3.5	Characteristics of Specific Machinery Defects	419
3.5.1	Mechanical unbalance	420
3.5.2	Misalignment (shafts, couplings, bearings)	420
3.5.3	Bent shaft	420
3.5.4	Defective ball and roller bearings	420
3.5.5	Defective gear teeth	420
3.5.6	Mechanical looseness	420
3.5.7	Bad drive belts	420
3.5.8	Aerodynamic/hydraulic pulsation	421
3.5.9	Rubbing	421
3.5.10	Resonance	421



3.5.11 Summary of measurement interpretation	421
3.6 Marine Vibration Case Histories	422
3.7 Glossary	423

APPENDIX SOLAS AND MARPOL INTERNATIONAL CONVENTIONS

1 SOLAS Convention	427
1.1 Some history background	427
1.2 Effect on Structure	428
1.3 Effect on materials	429
1.4 Effect on propulsion arrangements	430
1.5 Effect on Fire Detection	431
1.6 Effect on Fire Fighting	431
1.7 Effect on Internal Layout	434
1.8 Effect on Life Saving Apparatus	434
1.9 Effect on Communications	435
2 MARPOL Convention	436
2.1 Some Historical Background	437
2.2 Rules about Oil Pollution	437
2.3 Rules about Noxious Liquid Substances in Bulk	438
2.4 Rules About Sewage	439
2.5 Rules about Garbage	440
2.6 Rules about Air Pollution	441
2.7 Rules about Ballast Water	442
3 Deck Machinery	443
3.1 Mooring Winches and Anchor Handling Equipment	444
3.2 Cargo Handling Equipment	444