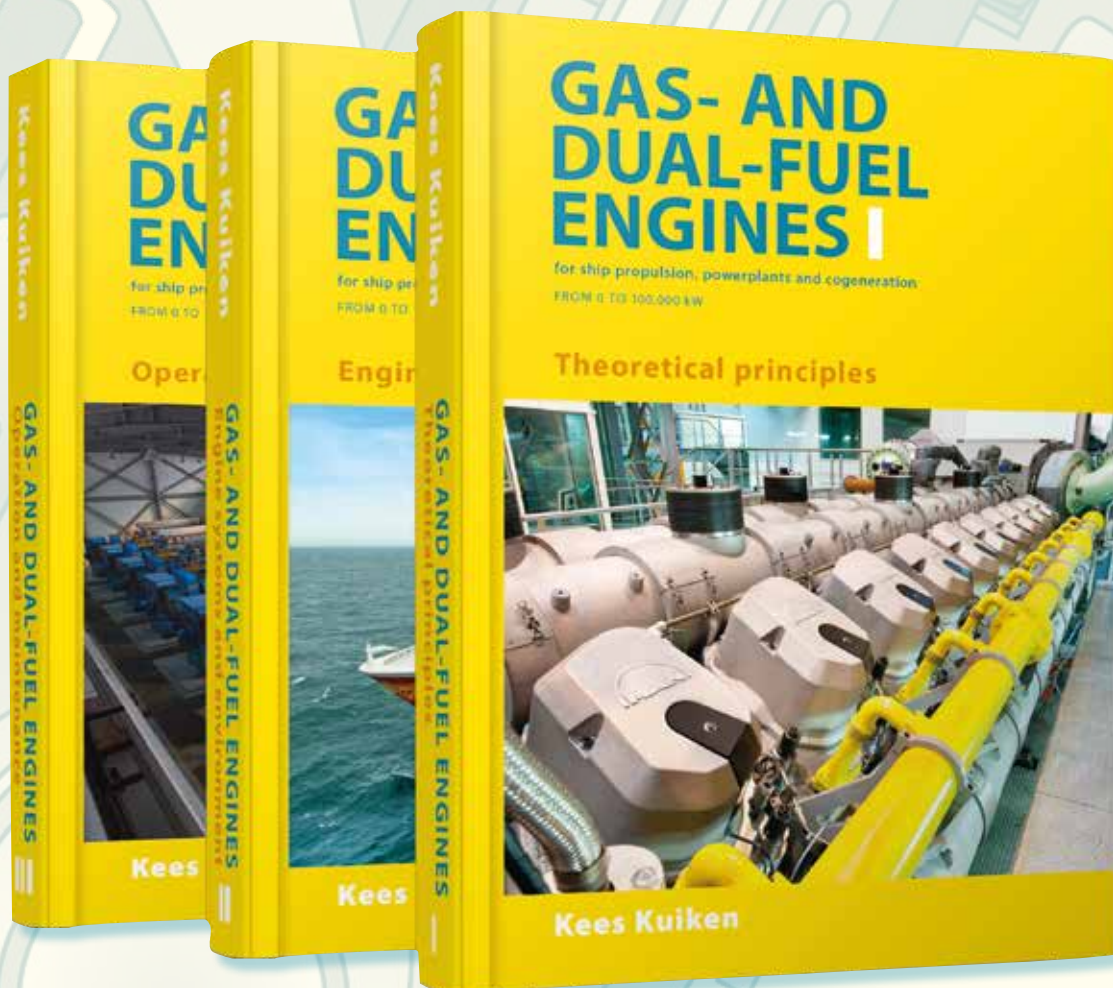


The new gas- and dual-fuel engine book

for ship propulsion, power plants
and cogeneration



Kees Kuiken
Target Global Energy Training

GAS- AND DUAL-FUEL ENGINES

for ship propulsion, power plants and cogeneration
from 0 to 100,000 kW



This first edition of a three-part book on gas- and dual-fuel engines is intended for all who work with gas- and dual-fuel engines for maritime propulsion, power generation and cogeneration:

- Maritime training institutes and maritime universities;
- Maintenance and reconditioning companies;
- Shipping companies deep-sea, inland, towage, dredging and heavy-load cargo;
- Insurance companies, classification bureaus, surveyors;
- Shipping industry suppliers, suppliers of engine parts, fuel and lubricating oil;
- Engine manufacturers and dealers;
- Power Plants;
- Cogeneration.

When compiling this book, a practical approach was chosen using ample authentic graphic material with detailed explanations allowing the reader to gather pertinent information without laboriously going through the main text.

Important subjects: principles, gaseous and liquid fuels for gas-, dual-fuel- and diesel engines, ignition systems, new technologies, engine systems and environment, endoscopy and measurements, cogeneration.

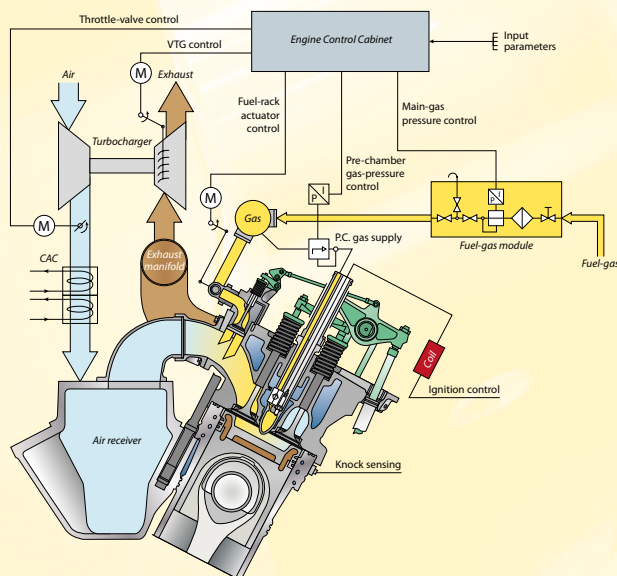
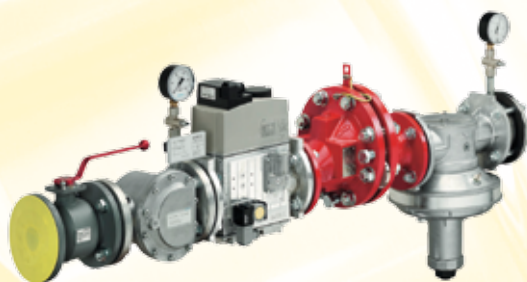
Leading companies and institutes have contributed to the realisation of this book by providing information, photographs and interviews. Ninety per cent of the more than 2900 pictures are in colour.

The three volumes consist of 488, 544 and 534 pages each.

Price of one book (three parts) 2016: The Netherlands, € 210,- inclusive packing, shipping and 6% VAT; EU I, II and III €225,-; Rest of the world € 250,- all-inclusive packing and shipping costs.

Discounts for orders over 25 books. Maritime Institutes and Training Centres up to 20% discount.

The three parts will be sealed and delivered in heavy-duty carton packaging at cost price.





The companies mentioned below all have contributed to the realisation of this book. This has been made possible by allowing interviews, consenting to the use of photographs, providing abundant information or by correcting texts. For this we would like to express our sincere gratitude: A.M.W. Marine (The Netherlands), ABB B.V. (The Netherlands), ABB Turbochargers (Switzerland), ABC, Anglo Belgium Corporation (Belgium), Alfa Laval Benelux B.V. (The Netherlands), August Storm (Germany), August Storm B.V. (The Netherlands), Bergen Engines B.V. (The Netherlands), Breko Reparatie B.V. (The Netherlands), Brinkman & Niemeijer Motoren B.V. (The Netherlands), Caterpillar Marine Power Systems (Germany), Caterpillar Motoren GmbH (Germany), CENTA Nederland B.V. (The Netherlands), Chemgas Shipping (The Netherlands), Chris Marine (Sweden), Controlin (The Netherlands), Cummins Holland B.V. (The Netherlands), DBR (The Netherlands), Den Hartog B.V. (The Netherlands), Denso Europe B.V. (The Netherlands), Det Norske Veritas GL (The Netherlands), Diesel Engines Online B.V. (The Netherlands), Diesel Publications (USA), Discom B.V. (The Netherlands), Dungs (The Netherlands), Easy Connections B.V. (The Netherlands), Ener-G Nedalo (The Netherlands), Fjord Line (Norway), G.M.S. Instruments B.V. (The Netherlands), Gate Terminal Rotterdam (The Netherlands), GE Power & Water (The Netherlands), Gebroeders Sol (The Netherlands), Geislinger GmbH (Austria), Genpower B.V. (The Netherlands), Goltens Dubai (UAE), Goltens Rotterdam B.V. (The Netherlands), Hanwell Environment & Energy B.V. (The Netherlands), Hatz Nederland B.V. (The Netherlands), Heinzmann GmbH CO.KG (Germany), Holland Roerpropeller B.V. (The Netherlands), IHC Holland (The Netherlands), IHC Lagersmit B.V. (The Netherlands), JR SHIPPING B.V. (The Netherlands), Kemper en Van Twist Diesel B.V. (The Netherlands), Koedood Dieselservice B.V. (The Netherlands), L'Orange (Germany), L.P. Koster & Zn. B.V. (The Netherlands), Lek/Habo (The Netherlands), Ludwig Hunger (Germany), M. Jürgensen GmbH & Co KG (Germany), M.R.C. (The Netherlands), Machinefabriek Bolier B.V. (The Netherlands), Machinefabriek G. Olthof N.V. (The Netherlands), Maschinenfabrik Alfing Kessler GMBH (Germany), Maerkisches Werk GmbH (Germany), Maersk Line (Denmark), Maersk Ship Management (The Netherlands), Mahle GmbH (Germany), Maine Maritime Academy (USA), MAK Nederland B.V. (The Netherlands), MAN Diesel & Turbo (Germany), MAN Diesel A/G (Germany), MAN Diesel A/S Alpha (Denmark), MAN Diesel Prime Serv Academy (Denmark), MAN Prime Serv (The Netherlands), MAN Rollo B.V. (The Netherlands), Maritime Institute Willem Barentsz (The Netherlands), Mark van Schaick B.V. (The Netherlands), Maritime Academy (USA), Mastervolt B.V. (The Netherlands), Merford (The Netherlands), Miba Bearing Group (Austria), Mobil Oil B.V. (The Netherlands), MOTORTECH GmbH (Germany), MTI Holland B.V. (The Netherlands), MTU Benelux B.V. (The Netherlands), MTU Friedrichshafen GmbH (Germany), MWM Benelux (The Netherlands), N.V. Nederlandse Gasunie (The Netherlands), Nicoverken Holland B.V. (The Netherlands), Noord-Hollandse Motorenrevisie B.V. (The Netherlands), Paman Motoren & Aggregaten (The Netherlands), Perkins (UK), PK OEM Parts (The Netherlands), Pon Power B.V. (The Netherlands), RDA Ship Support (The Netherlands), Rederij Doeksen (The Netherlands), Regulateurs Europa (The Netherlands), Rolls-Royce Marine AS (Norway), Rolls-Royce Power Systems (Germany), Royal Huisman Shipyard (The Netherlands), Rubber Design B.V. (The Netherlands), Ruysch International B.V. (The Netherlands), Sandfirden Technics (The Netherlands), SKF Marine Service Centre (The Netherlands), Stena Line Ferries (The Netherlands), Støvring Kraftvarmeværk (Denmark), The Swedish Club (Sweden), The Vestfold Academy (Sweden), Topec B.V. (The Netherlands), Total Nederland N.V. (The Netherlands), Turbo's Hoet Nederland B.V. (The Netherlands), Turner Engine Controls Solutions (The Netherlands), UK 284, Cornelis Zeeman (The Netherlands), VAF Instruments B.V. (The Netherlands), Van Dinteren Technische Handelsonderneming (The Netherlands), Van West-Holland B.V. (The Netherlands), Vereniging Importeurs Verbandsmotoren (The Netherlands), Vetus B.V. (The Netherlands), Wagenborg Shipping B.V. (The Netherlands), Wartsila Italia (Italy), Wärtsilä Netherlands B.V. (The Netherlands), Wärtsilä Schweiz A.G. (Switzerland), Waterschap Groot Salland (The Netherlands), Westfalia Separator Nederland B.V. (The Netherlands), Woodward Nederland B.V. (The Netherlands), Zantingh Energy Services (The Netherlands)



4.1.1 Introduction

Over the last few decades, the internal combustion engine has become an important part of our lives...

A modern 1000 kW engine is a masterpiece of engineering...

A modern 1000 kW engine is a masterpiece of engineering...

A modern 1000 kW engine is a masterpiece of engineering...



4.1.2 Operation

The internal combustion engine is a complex machine...

The internal combustion engine is a complex machine...

The internal combustion engine is a complex machine...

The internal combustion engine is a complex machine...

The internal combustion engine is a complex machine...

4.2.1 Greenhouse cultivation

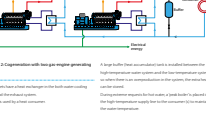
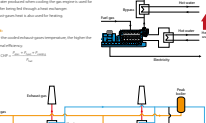
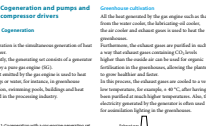
Greenhouse cultivation is a method of growing plants...

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Greenhouse cultivation is a method of growing plants...

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4.2.2 Operation

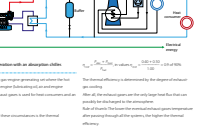
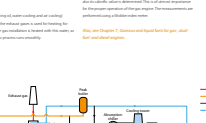
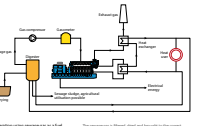
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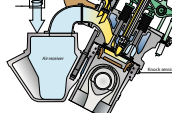
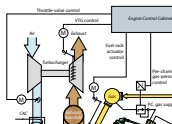
4.3.1 Floating LNG installations

There are many types of floating LNG installations...

There are many types of floating LNG installations...

There are many types of floating LNG installations...

There are many types of floating LNG installations...



4.3.2 Storage of natural gas on land

There are many ways to store natural gas on land...

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There are many ways to store natural gas on land...

There are many ways to store natural gas on land...



4.3.3 Floating LNG installations

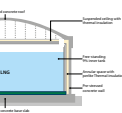
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4.3.3 Floating LNG installations

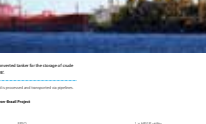
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There are many types of floating LNG installations...



4.3.4 Example of a 3-DK turbo system

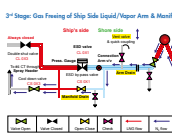
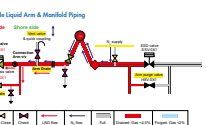
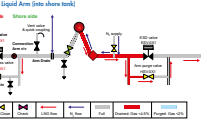
The 3-DK turbo system is a complex system...

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4.3.5 The heat setting and the type of spark plug

The heat setting of a spark plug is an important factor...

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4.3.6 The heat setting and the type of spark plug

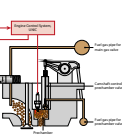
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4.3.7 The heat setting and the type of spark plug

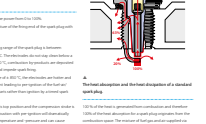
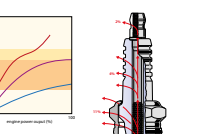
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26.18.2 The Striber

The Striber is a new type of marine diesel engine developed by the company Striber. It is a 4-stroke, turbocharged, common rail diesel engine with a displacement of 14.8 liters. The Striber is a 14.8 liter engine with a displacement of 14.8 liters. It is a 4-stroke, turbocharged, common rail diesel engine with a displacement of 14.8 liters.

26.18.3 The diesels of the Mercedes 6,200

The Mercedes 6,200 is a 4-stroke, turbocharged, common rail diesel engine with a displacement of 14.8 liters. It is a 4-stroke, turbocharged, common rail diesel engine with a displacement of 14.8 liters.

26.18.4 3D measurements

3D measurements of the cylinder head with the Striber valves. The 3D measurements of the cylinder head with the Striber valves. The 3D measurements of the cylinder head with the Striber valves.

26.18.5 Operation of flexible bearings

The flexible bearings are used in the Mercedes 6,200 diesel engine. They are used to support the crankshaft and to reduce the friction between the crankshaft and the cylinder walls. The flexible bearings are made of a special material and they are designed to last for a long time.

26.18.6 Performance graphs

The performance graphs show the operating characteristics of the engine. They include the torque curve, the power curve, and the fuel consumption curve. The torque curve shows the torque in Nm as a function of the engine speed in rpm. The power curve shows the power in kW as a function of the engine speed in rpm. The fuel consumption curve shows the fuel consumption in g/kWh as a function of the engine speed in rpm.

26.21.17 Adjustment of the Top Dead Centre (TDC)

The adjustment of the Top Dead Centre (TDC) is a critical task in the maintenance of a diesel engine. It involves adjusting the timing of the valves and the injection pump. The adjustment of the TDC is done by using a special tool called a TDC indicator.

26.21.18 Thermal map

The thermal map shows the temperature distribution in the engine. It is a 2D plot of the engine temperature as a function of the engine speed and the engine load. The thermal map is used to identify the hot spots in the engine and to optimize the cooling system.

26.21.19 Fuel injection system

The fuel injection system of the Mercedes 6,200 diesel engine is a common rail system. It consists of a fuel tank, a fuel filter, a fuel pump, and a common rail. The fuel is pumped from the tank to the common rail and then injected into the cylinders. The common rail system allows for precise control of the fuel injection and for high injection pressures.

26.21.20 Fuel injection system

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27. Example V-MAN BSW ME GL, two-stroke crosshead engine, CATERSITY IV

The V-MAN BSW ME GL is a two-stroke, crosshead diesel engine. It is a 4-stroke, turbocharged, common rail diesel engine with a displacement of 14.8 liters. It is a 4-stroke, turbocharged, common rail diesel engine with a displacement of 14.8 liters.

27.1.1 Engine Control System (ECS)

The Engine Control System (ECS) is responsible for controlling the engine's operation. It includes the engine control unit (ECU), the sensors, and the actuators. The ECS controls the fuel injection, the valve timing, and the engine speed.

28.2 Gear transmission

The gear transmission is a key component of the engine's drivetrain. It is used to transmit the power from the engine to the propeller. The gear transmission consists of a propeller shaft, a gear box, and a propeller. The gear transmission is designed to handle the high torque and high speeds of the engine.

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1 The use of industrial gas- and dual-fuel engines Introduction – The Otto cycle – The Diesel cycle – Internal combustion engines with two fuels, often called 'dual-fuel' engines – Uses of Otto engines – Uses of Diesel engines **2 Classification of gas- and dual-fuel engines** Introduction – Operating principle – Design – Rotational speed – Power output or shaft power – Fuels used – Uses of gas- and dual-fuel engines – Other characteristics of gas- and dual-fuel engines – Numbering the cylinders – Natural aspiration and turbocharging **3 Working principles of gas-, dual-fuel- and diesel engines** Operating principles – Design of the four-stroke gas engine – Two-stroke crosshead engines – A few significant differences between the two-stroke and four-stroke cycles – Important terms and definitions in gas-, dual-fuel- and diesel engines – Examples of engine names **4 Efficiencies and losses in gas- and dual-fuel engines** Efficiencies and losses – The Indicator diagram – Parameters of 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MAN Nutzfahrzeuge, Werk Nurnberg, Germany – Mitsubishi Heavy Industries, Tokyo, Japan – MWM, Mannheim, Germany – Niigata Power Systems, Tokyo, Japan – Perkins, Peterborough, United Kingdom – Rolls-Royce PowerSystems, London, United Kingdom – Rumo, Nizhny Novgorod, Russia – Scania, Södertälje, Sweden – Wärtsilä, Helsinki, Finland – Yanmar, Osaka, Japan – Dresser Rand, Houston, United States of America – Fairbanks Morse, Beloit, Wisconsin, United States of America – Guangzhou, China – Junan, Junan city, China – Lister-Petter, Dursley, England – Liebherr, Bulle, Switzerland – Cummins Westport, Vancouver, British Columbia, Canada – Cummins, Columbus, Indiana, United States of America – EMD-Electromotive Diesel, LaGrange, Illinois, United States of America

19 Emissions in gas-, dual-fuel- and diesel engines Emissions in gas- and dual-fuel engines – Introducing ‘the fossil fuel’ society – Exhaust-gas composition – Units of contamination – Methods for the reduction of noxious emissions in exhaust-gases – Primary methods – Secondary methods – Reduction of sulphur oxides in exhaust gases – Removal of fine particles from exhaust gases – Examples of the techniques that engine manufacturers apply to reduce emissions – Measures taken on-board large modern sea-going vessels – New techniques: the Miller process – New developments: the Hercules project – Noxious emissions in gas-and dual-fuel engines: nitrogen oxides, carbon monoxides and hydrocarbons – Development of gas-and dual-fuel engines – The composition of exhaust gases in gas- and dual-fuel engines – Greenhouse gases – Emission regulations for the international shipping industry established by the IMO – Exhaust-gas emissions in dual-fuel engines – An example of a Wärtsilä 50DF dual-fuel engine – Exhaust-gas purification for gas-, dual-fuel-, diesel- and heavy-fuel oil engines – Particulate matter – International Association of Ports and Harbours IAPH – The Baltic Dry Index – Ships either LNG fuelled or capable of running on LNG

20 Endoscopy and measurements Borescope: design and capabilities – Monitoring the state of repair of engine parts as part of a condition based maintenance – Examples of damage – Measurements: foil strain gauge with respect to piezo resistors – Preparing the engine for inspection using, for example, indicator cocks – Attaching and configuring the TDC-sensors for a four-stroke engine – Attaching and configuring the TDC-sensors for a two-stroke crosshead engine – Recording additional data during the measurement process on a performance sheet – Removing the sensors from a hot engine after the measurement process – Measurements with the IMES EPM-XP Visualization software – Measuring and fine-tuning with the DocSoft e-3 software – Different methods to achieve fuel savings – Measurements captured with the software *The Doctor* – The ISO correction according to ISO 3046-1: 2002 for shipping – Power indicator diagrams – Measuring the shaft power with strain gauges – The state of repair of gas- and dual-fuel engines: inspections with borescopes and electronic measurements – Measurement methods that can be used with the borescope – The use of borescopes in engines, turbochargers and gear boxes – False brinelling – Two-stroke Wärtsilä crosshead engines measurements – Example of an Engine Management System category III, MAN 51/60 DF – Measurements with electronic equipment, such as, *The doctor* and/or IMES and others – Balancing of no load engine at stationary speed (idle) – Crystals used for measurements – Examples of measurements – Organ pipe resonance effect or the source of the higher measured pressures than actual pressures in the engine cylinder – Specific features of measurements for gas- and dual-fuel engines

21 Cogeneration Introduction – Natural gas discoveries – Traditional generation using steam boilers and steam turbines – Contemporary generation of electricity with a combination of a steam- and gas turbine (STAG) – Generation of electricity with an internal combustion engine – Comparing separate and combined generation of heat and power – Reduced emissions with cogeneration – The speeds in gas- and dual-fuel engines – The uses of the thermal output by gas- and dual-fuel engines in cogeneration installations – Examples of cogeneration with gas engines – The ratio of the electrical power of a gas-engine generating set with respect to the available thermal output – Heat buffers and cogeneration – Assimilation – Tariffs for natural gas, electricity and heat – A few design factors involved in cogeneration with gas engines (power output of one gas engine between 10 and 20,000 kW) – The integration of a cogeneration system in installations – Continuation of examples of cogeneration – Summary of cogeneration with gas engines – Data for Wärtsilä 34 SG gas engines operating at full load

Book III: Operation and maintenance

22 Use of materials for gas-, dual-fuel- and diesel engines General use of materials – Cast iron – Steel – Cast steel – Forged steel – Steel alloys – Aluminium – Ceramic materials – Specific materials for engine parts: engine classification according to the four categories – Special finishes and heat treatments – Examples of modern material usage

23 Casting, forging and welding engine parts Introduction – Cast-iron parts for diesel engines – Advantages of cast engine-parts – Foundries – Casting process – Casting location – Moulds – Filling the casting dies – Mould assembly – Cleaning the castings – Casting stresses – Checking for air inclusions and damage – Dimensional checks – Operations at the machining factory – Forging crankshafts – Forging gear parts for two-stroke crosshead engines – Building a two-stroke crosshead engine A-frame – Forging crankshafts, 2009 report – Manufacturing pistons – Manufacture of inlet and outlet valves – Manufacturing cylinder liners

24 Reconditioning engines and their parts Introduction – Four-stroke engines – Two-stroke engines – Reconditioning gas- and dual-fuel engines – The Swedish Club: Main Engine Damage

25 Maintenance and repairs Introduction – Types of maintenance – Instruction manuals/ Maintenance manuals – Engine maintenance – Maintenance for small engines, category I – Examples of maintenance for engines, category III – Some examples of maintenance for large two-stroke crosshead engines, category IV – Excessive wear or ‘scuffing’ of the cylinder liners in a two-stroke crosshead engine – Trouble shooting excessive cylinder liner wear – Damage report Wärtsilä Vasa 4R32 – Sleeve bearings, theory and damage – Special maintenance for gas- and dual-fuel engines

26 Calculating fuel- and lubricating-oil consumption Introduction – Diesel-engine efficiency – Shaft power in kW or MW – Specific fuel consumption – Fuel consumption – Fuel consumption for engines in diesel power-plants – Fuel consumption for propulsion diesel engines – Fuel consumption for gas- and dual-fuel engines – Lubricating-oil consumption and specific lubricating-oil consumption – Measuring fuel consumption – Fuel consumption measured in trials – Oil-price development – Sailing at reduced engine power or ‘slow steaming’ – VAF Instruments T-Sense® torque and power measurement of the propeller shaft

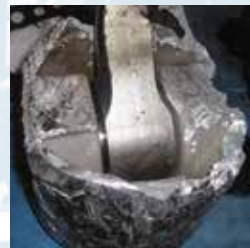
27 Operational management and automation Introduction – Example I: Wärtsilä 34 DF, four-stroke, category III – Example II: MAN 51-60 DF IMO Tier II, four-stroke, category III – Example III: Rolls-Royce gas engine, four-stroke engine, category III – Example IV: Sandfirden SGI 16 Marine generator sets, four-stroke engine, category II – Example V: Man B&W ME GI, two-stroke crosshead engine, category IV

28 Transmission gears, flexible couplings, vibration dampers, shafting and shaft generator drives Introduction – Diesel-engine arrangements – Gear transmission – Constructions and designs of gear transmissions – Position of the input- and output shaft – Types of teeth – Gear transmission for shaft generators – Couplings – Torsional-vibration dampers – Engine shafts – Examples of complete systems with diesel engines, reduction gearing, shafting, couplings and vibration dampers – Vibration dampers below the engine block or frame – Examples of engine arrangements with flexible vibration dampers – Flexible connections to the diesel engine – Double-spring alignment: a new design

29 Bedplates and engine alignments, gearboxes, shafts, propeller shafts and generators Introduction – Ship propulsion – Construction of the bedplate, engine category IV – Examples of rigid mounting, engine category III – Flexible mounting of propulsion engines; engine categories I, II and III – Engine alignment – Flexible arrangement of diesel engines and the piping, wiring and other equipment attached to the engine – Mounting methods for propulsion engines and other components with critical alignments

30 Regulations for propulsion engines, classification, repair and damage Introduction – The IMO: International Maritime Organization – Classification societies – Periodic inspection of the diesel engine and its parts – Examples: Germanischer Lloyd – Materials for diesel engines – Tests and trials – Testing mass-produced engines – Shipboard trials – Some important points – Regulations for propulsion engines – Engine alignment – The standard measurements and calculations to determine the crankshaft deflection measurement (r_c) for four different types of crankshafts – Procedure for reconditioning parts – New parts – Special cases of wear and damage to engine parts – Damages to the engine or engine parts – Damage – Examples of certificates – Interim guidelines on safety for natural gas-fuelled engine installations in ships

31 Ship propulsion Introduction – Ship types and hull resistance – Load lines of a ship – Ship dimensions – Hull shape – Ship’s resistance R – Screw propulsion – Propeller types – Flow conditions around the propeller – Propeller dimensions – Operating conditions of a propeller – Increasing ship speed – Parameters causing heavy running conditions – Manoeuvring speeds – Direction of propeller rotation: lateral forces – Engine layouts and load diagrams – Propulsion- and engine characteristics – Electronic governors with load limitation – Use of diagrams – Summarising the effects of the various types of resistance on engine operation – Comments – Future improvements in propulsion efficiency and reduction of CO₂ – March 2016 – Some distinctive issues – Slow steaming of merchant ships – Ship propulsion with gas-and dual-fuel engines





The author

Kees Kuiken started his career in 1963 by enrolling as a marine engineering student at the Maritime Institute at Terschelling, The Netherlands.

After graduation, he joined the United Dutch Shipping Company (Verenigde Nederlandse Scheepvaartmaatschappij, VNS).

In 1978, he went on to become a lecturer in marine engineering at the Maritime Academy at Delfzijl and Groningen, and also worked in the mechanical engineering- and operational technology departments. He was passionate about building a large and advanced practical lab for both intermediate and higher maritime education, as well as for trade and industry.

In 1995 he founded the European Training Centre for engine technology, the ETM, an educational foundation.

In 2000, he left regular teaching and established Target Global Energy Training.

The company conducts training sessions worldwide in diesel- and gas engine technologies, gas- and steam turbines, compressors and cogeneration.

Furthermore, Target provides solutions for a myriad of technical problems and publishes books and manuals.

All the training programs are tailor-made and given on location.

In 2012 the second edition of the diesel engine book came onto the market and in 2016 this new book *Gas-and dual-fuel engines for ship propulsion, power plants and cogeneration*.



This book can be ordered directly from
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