ROTARY DRILLING

Diesel Engines and Electric Power

Third Edition, Rev.

UNIT I • LESSON 8

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ROTARY DRILLING SERIES

Unit I: The Rig and Its Maintenance

Lesson 1: The Rotary Rig and Its Components
Lesson 2: The Bit
Lesson 3: Drill String and Drill Collars
Lesson 4: Rotary, Kelly, Swivel, Tongs, and Top Drive
Lesson 5: The Blocks and Drilling Line
Lesson 6: The Drawworks and the Compound
Lesson 7: Drilling Fluids, Mud Pumps, and Conditioning Equipment
Lesson 8: Diesel Engines and Electric Power
Lesson 9: The Auxiliaries
Lesson 10: Safety on the Rig

Unit II: Normal Drilling Operations

Lesson 1: Making Hole
Lesson 2: Drilling Fluids
Lesson 3: Drilling a Straight Hole
Lesson 4: Casing and Cementing
Lesson 5: Testing and Completing

Unit III: Nonroutine Operations

Lesson 1: Controlled Directional Drilling
Lesson 2: Open-Hole Fishing
Lesson 3: Blowout Prevention

Unit IV: Man Management and Rig Management

Unit V: Offshore Technology

Lesson 1: Wind, Waves, and Weather
Lesson 2: Spread Mooring Systems
Lesson 3: Buoyancy, Stability, and Trim
Lesson 4: Jacking Systems and Rig Moving Procedures
Lesson 5: Diving and Equipment
Lesson 6: Vessel Inspection and Maintenance
Lesson 7: Helicopter Safety
Lesson 8: Orientation for Offshore Crane Operations
Lesson 9: Life Offshore
Lesson 10: Marine Riser Systems and Subsea Blowout Preventers

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Contents

Figures and Table ix
Foreword xi
Preface xiii
Acknowledgments xv
Units of Measurement xvi
DIESEL ENGINES 1
Introduction 1
  Engine Power and Transmission 1
  Power Transmission 2
    Mechanical Transmission and the Compound 2
    Electric Transmission 3
  Engines Versus Motors 4
Diesel Engines 5
  How Engines Operate 5
  Engine Fuels 6
  Gas or LPG Engines and Diesel Engines 7
    Spark Ignition 7
    Fuel-to-Air Ratio in Spark Ignition (SI) Engines 7
    Compression Ignition (CI) Engines 7
    Fuel-to-Air Ratio in Compression Ignition (CI) Engines 8
    Strokes and Cycles 8
  Forced-Air Induction and Natural Aspiration 9
    Natural Aspiration 9
    Forced-Air Induction 10
    Forced-Air Induction and Power 11
  Four-Stroke Diesel Engines 12
    Intake Stroke 13
    Compression Stroke 13
    Power Stroke 13
    Exhaust Stroke 13
    The Four-Stroke Cycle 13
    Four-Stroke Engines and Valve Action 13
    Four-Stroke Firing Details 14
    Diesel Fuel Injection 15
    Lugging Power 16
  Cutaway of a Four-Stroke Diesel Engines 17
    Breather Cap and PCV Valve 18
    Combustion Cup 18
    Fuel Injector 18
  Two-Stroke Diesel Engines 19
    Two-Stroke Power 20
    Concurrent Events in Two-Stroke Engine 20
    Power, Exhaust, and Intake Stroke 20
    Compression and Power Stroke 20
    Cutaway of a Two-Stroke Diesel 21
  To Summarize 23
Diesel Fuel 25
  Specific Gravity and API Gravity 25
  Fuel Quality 26
    Volatility 26
    Amount of Carbon Residue 27

Petroleum Extension-The University of Texas at Austin

    - Viscosity 27
    - Sulfur Content 27
    - Ash, Sediment, and Water Content 28
    - Flash Point 28
    - Pour Point 28
    - Acid Corrosiveness 28
    - Ignition Quality and Cetane Number 29
  - Effects of Unsatisfactory Fuel 30
  - Fuel Supply Systems 32
    - System Using Separate Injection Pump and Day Tank 32
    - Main Tanks and Day Tanks 32
    - Pumps Versus Gravity 33
    - System with Built-In Pumps 33
    - Fuel Pump 33
    - Excess Fuel 33
    - Fuel Tank Vents 34
    - Total Volume and Useful Volume 35
    - Fuel Handling Tip 35
    - Delivery Line Location 35
    - Filters, Strainers, and Centrifuges 36
  - Transfer Pumps
    - Pump Sizing
    - Pump Location
    - Fuel Lines 41 -
  - Fuel Return Lines 43
  - Primary Pump and Injector Pump 43 -
  - Starting an Engine 43 -
  - Air Knocking 44 -
  - Removing Air 44 -
  - To Summarize 44 -

- Fuel-Injection Systems 47
  - Injection System Requirements 47
    - Accurate Fuel Metering 47
    - Proper Injection Timing 47
    - Fuel-Injection Rate 48
    - Fuel Atomization 48
    - Good Fuel Distribution 48
  - Types of Injection Systems 48
    - Multipump Injectors 49
  - One Pump on Each Cylinder 50
  - Single-Unit Multiple Pumps 51
    - How Cam-Operated Plunger Pumps Work 51
    - Unit Fuel Injection 57
    - Distributor Injection 61
    - Common-Rail Injection 64
  - To Summarize 66

- Governors 67
  - Centrifugal Force 68
  - Flyweights, Springs, and Oil Pressure 68
  - Terms Used with Governors 69
  - Types of Governors 69
    - Mechanically Actuated Governors 70
    - Hydraulically Actuated Governors 73

Petroleum Extension- The University of Texas at Austin

    - Variations in Speed 74
    - Electrically Actuated Governors 76
  - To Summarize 78
- Lubrication Systems 81
  - What Lubricating Oil Does 81
  - Oil Pumps 82
    - Oil Flow Rates 82
    - Relief Valves 82
  - Oil Strainers and Filters 83
    - Strainers 83
    - Filters 83
  - Filter Pressure Gauges 86
  - Filter Bypass Valves 86
  - Oil Coolers 86
  - Oil Cooler Bypass System 87
  - Engine Oil Supply Areas 88
    - Crankshaft Lubrication 89
    - Piston Lubrication 89
    - Camshaft Lubrication 89
    - Rocker Arm and Valve Lubrication 90
    - Timing Gear Lubrication 90
    - Injector Pump and Governor Lubrication 92
  - Prestart Lubrication Systems 92
  - Explosion Covers 93
  - Oil Quality 93
  - Sulfur Content of Fuels and Oil Quality 94
  - Using the Proper Oil 94
  - Detergent Oils 95
  - Oil Contamination 95
  - Oil Testing 95
  - To Summarize 96
- Cooling Systems 97
  - Purpose of the Cooling System 97
  - Coolant 97
  - Radiators 98
    - Fins 98
    - Engine Fans 98
  - Heat Exchangers 99
  - Coolant Flow 100
  - Pressurized Cooling Systems 100
  - More About Radiators 101
    - Radiator Size 102
    - Coolant Flow 102
    - Fans 102
    - Thermostats (Temperature Regulators) 102
  - How Radiators Work 103
    - Top Tank 103
    - Fins 104
    - Tube Spacing 104
    - Air Flow 105
  - Coolant Water Quality 106

Petroleum Extension-The University of Texas at Austin

        Dirt 106
        Dissolved Minerals 106
        H_2S and CO_2 106
        Oxygen 106
    How to Protect the Cooling System 107
    Cooling System Checks 108
    Engine Rooms and Ventilation 109
    More About Heat Exchangers 110
    To Summarize 112

Air-Intake Systems 113
    Air Cleaners 114
        Types of Air Cleaners 114
        Dry Air Cleaners 114
        Oil-Bath Air Cleaners 117
        Additional Cleaner Maintenance 119
    Blowers (Superchargers) 120
        Roots Blowers 120
        Causes of Blower Failure 122
    Turbochargers 122
        Aftercoolers 124
        Back-Pressure and Temperature Effects 124
    To Summarize 125

Exhaust System 127
    Purposes 127
    Exhaust System Parts 128
        Exhaust Manifold 128
        Exhaust Pipe 129
        Mufflers 130
        Tail Pipe 131
    To Summarize 132

Starting Systems 133
    Types of Starters 133
    Why Diesel Engines May Not Start 133
        Low-Pressure Problems 133
        Low-Temperature Problems 134
    Electric Starters 135
        Direct Current Versus Alternating Current 135
        Starter System Parts 135
        How Electric Starters Work 136
        Generators and Cutouts 137
        Batteries 138
    Air-Motor Starters 139
        Air Requirements 140
        Cleaning an Air Starter 140
    Hydraulic Starters 140
    Gasoline Engine Starters 141
    Compressed-Air Starting 142
    To Summarize 143

Instruments 145
    Pyrometers 145
        Estimating Engine Load 145

Petroleum Extension-The University of Texas at Austin

    - Cylinder Temperatures 146
    - Dividing Loads Equally 146
  - Oil-Pressure Gauges 146
    - Low Oil Pressure 146
    - High Oil Pressure 147
  - Oil-Temperature Gauges 148
    - Lower-than-Normal Oil Temperature 148
    - Higher-than-Normal Oil Temperature 148
  - Coolant-Temperature Gauges 148
    - Inlet Versus Outlet Temperature 149
  - Air Manifold-Pressure Gauge 149
    - Dirty Air Filters 149
  - Tachometers 149
  - To Summarize 149
- Alarms and Shutdown Systems 151
  - Overspeed Trip Devices 151
    - Checking Overspeed Trips 152
    - Compounded Engines and Overspeeding 152
  - Low Oil-Pressure Alarms 152
  - Low Oil-Pressure Shutdowns 153
    - Engine Start-up with Low-Oil Pressure Alarms and Shutdowns 153
    - Testing Low Oil-Pressure Alarms and Shutdowns 153
  - High Coolant-Temperature Alarms and Shutdowns 153
  - Engine Shutdown Considerations 154
    - Blowouts and Natural Gas 154
    - Turbochargers and Oil 154
    - Using CO_2 to Stop an Engine 154
  - To Summarize 155
- Engine Operation 157
  - Prestart Checks 157
  - Start-Up 159
  - Engine Warm-Up 160
  - Warm-Up Speeds 160
  - Putting an Engine to Work 161
    - Engines Driving a Mechanical Assembly 162
    - Engines Driving a Generator 162
  - Checks to Make While Engine Runs 162
  - To Summarize 163
- Reports 165
  - Engine Monitoring 167
  - Exhaust Monitoring 167
  - Maintenance Schedules 167
  - To Summarize 168
- ELECTRIC POWER 169
- Introduction 169
- Generators and Alternators 171
  - Advantages of AC Generators 172
  - DC Generators 173
  - AC Generators 176
  - To Summarize 177

Petroleum Extension-The University of Texas at Austin

DC Electric Drive 179
  Advantages of Electric Drive 179
  Exciters 180
  Running Engines at Constant Speed 180
  Running Engines at Varying Speeds 180
  DC-DC Schematic 181
    Assigning Power 183
    Using the Throttles 184
  Drillers's Control Panel 184
  Main Control Cabinet 185
  Maintenance 186
  SCR Systems 187
  SCRs, or Thyristors 188
  Controlling Power 188
  AC Bus and Control Units 189
  Meeting Power Needs 191
  Special Considerations 191
    Engine and AC Generator Speed 191
    Electronic Governors 192
    Adding or Removing Generators from the Line 192
    Malfunctions 194
    Auxiliary Power Supply 195
  To Summarize 196
Glossary 197
Review Questions 219
Index 227 -
Answers 237

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Units of Measurement

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Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is one of only a few countries that employ the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the Système International (SI) d'Unités. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The Rotary Drilling Series gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is metre, not meter. (Note, however, that the unit of weight is gram, not gramme.)

To aid U.S. readers in making and understanding the conversion system, we include the table on the next page.

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English-Units-to-SI-Units Conversion Factors

Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m^3)
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m^3/stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches ($in.^3$)	16.387	cubic centimetres (cm^3)
	cubic feet (ft^3)	28.3169	litres (L)
		0.0283	cubic metres (m^3)
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m^3)
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m^3)
	barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m^3/t)
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m^3/min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m^3/h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m^3/stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m^3/min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{^\circ F - 32}{1.8}$	degrees Celsius (°C)
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m^3)
	pounds per cubic foot (lb/ft^3)	16.0	kilograms per cubic metre (kg/m^3)
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.75	kilowatts (kW)
Area	square inches ($in.^2$)	6.45	square centimetres (cm^2)
	square feet (ft^2)	0.0929	square metres (m^2)
	square yards (yd^2)	0.8361	square metres (m^2)
	square miles (mi^2)	2.59	square kilometres (km^2)
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

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DIESEL ENGINES
Introduction

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Engine Power and Transmission

The main purpose of a rotary rig is to drill a hole. To "make hole," the rig must have a source of power. What is more, the rig must be able to transmit this power to equipment that needs it. For example, the mud pumps need power to move drilling fluid. The drawworks also needs power to do its work.

Usually, large internal combustion engines power the rig (fig. 1). A mixture of fuel and air burns inside the engine to make it run. If the engine is running correctly, the fuel-air mixture burns at a controlled rate. Keep in mind that an engine must get oxygen from the atmosphere before the fuel can burn.

Figure 1. Large internal combustion engines power drilling rigs.

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How Engines Operate

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In this chapter:

- Creating energy to do work
- How a two-stroke diesel engine burns fuel
- How a naturally aspirated four-stroke diesel engine burns fuel
- Making the engine more powerful

Engines take in air and fuel. They burn this air and fuel mixture to create energy to do work.

Engines burn fuel and air to move pistons up and down in cylinders (fig. 5). Intake valves or intake ports let air into each cylinder, where it mixes with the fuel. A spark or some other heat source ignites the

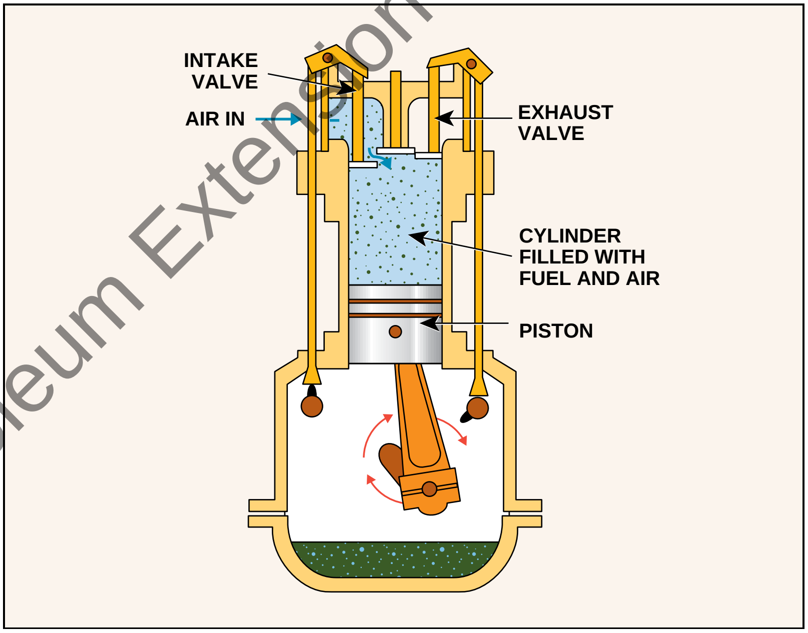

Figure 5. Diagram of an internal combustion engine

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Diesel Fuel

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In this chapter:

- Properties of good fuels for diesel engines
- Effects of poor fuel quality on the engine
- Components of fuel supply systems
- Making use of gravity or pumps to move fuel
- Keeping air and water out of the fuel supply system

Low-speed diesel engines operate on almost any liquid fuel, from kerosene to crude oil. Modern, high-speed diesel engines, however, require a lightweight fuel oil. High-speed diesels run so fast that the fuel has a shorter time to burn inside the cylinder. As a result, the weight, or density, of the fuel has to be relatively light.

Specific Gravity and API Gravity

API gravity (expressed in degrees) is the measure of an oil's weight, or density.

High-speed engines require diesel fuel with a *specific gravity* of about 0.82 to 0.89 (41° to 27° API). Other diesel engines can use fuel with a specific gravity of about 0.91 (24° API). Specific gravity is the ratio of the weight of one volume of liquid (diesel oil, in this case) to the weight of an equal volume of water. Water has a specific gravity of 1. Thus, a fuel with a specific gravity of less than 1 weighs less than water.

Many years ago, the oil industry established *API gravity* as a density measure for oil and oil products. API gravity is given in degrees API. The API (*American Petroleum Institute*) sets standards, recommends practices, and issues bulletins on all phases of the oil industry.

Two equations show the relation between API gravity and specific gravity:

$$\text{API gravity} = (141.5 \div \text{specific gravity}) - 131.5 \qquad \text{(Eq. 1)}$$

$$\text{Specific gravity} = 141.5 \div (\text{API gravity} + 131.5) \qquad \text{(Eq. 2)}$$

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Fuel-Injection Systems

In this chapter:

- Accurate metering and precise fuel injection
- Multipump, unit-fuel, distributor, and common-rail injectors
- Configuration of pumps
- Components that control fuel output

A diesel engine's fuel-injection system must inject fuel at the right time, inject the right amount, fully atomize it, and inject it in a proper spray pattern.

The injector fully atomizes a fuel when it breaks it into very small droplets that thoroughly mix with the air. The injection system must be efficient and dependable under all speed and load conditions.

Injection System Requirements

A fuel-injection system must:

- Accurately meter the fuel
- Inject the fuel at the right time
- Inject the fuel at the correct rate
- Properly atomize the fuel
- Properly distribute the fuel in the combustion space

Accurate Fuel Metering

To obtain accurate fuel metering, the injection system must:

- Sense the correct amount of fuel to inject for the engine load
- Inject the same amount of fuel into each cylinder's combustion chamber

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Governors

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In this chapter:

- Controlling the speed of the engine
- Types of governors
- Operating a mechanically actuated governor
- Use of overspeed governors as back-ups

In a diesel engine, the amount of fuel injected into the cylinders controls speed. Many ways exist to regulate the amount of fuel injected. One way (as mentioned earlier) is to use a rack-and-pinion gear, which is usually shortened to just "rack." The rack regulates the position of the plunger in a fuel injector (fig. 33). Pushing the rack to the left increases the quantity of fuel injected. Pulling it to the right decreases the amount. Virtually all drilling rig engines have a governor that moves a rack to regulate speed.

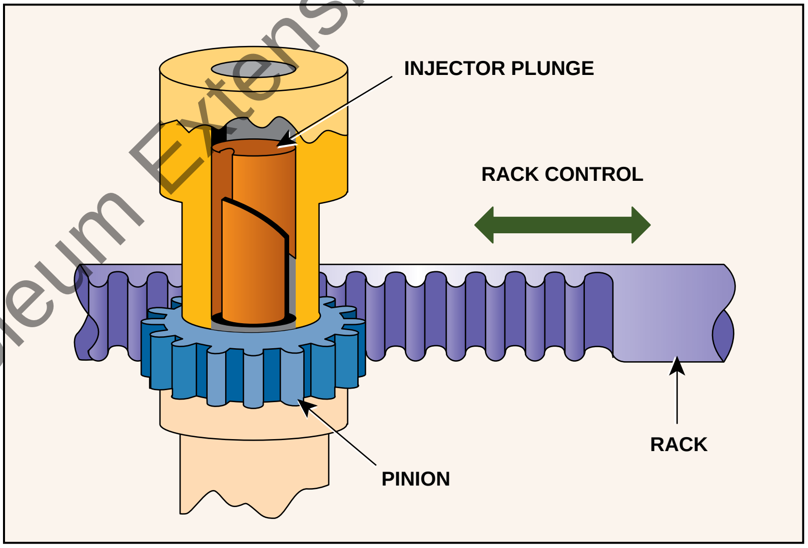

Figure 33. Rack and pinion controls fuel metering.

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Lubrication Systems

In this chapter:

- Purposes of lubricating oils in an engine
- Components of a lubricating system
- Keeping filters clean and warming engine oil
- Areas of the engine supplied with oil
- Assuring the quality of oil used in an engine

A 1,000-horsepower (hp), or 700-kW, engine may weigh 20,000 pounds (lb), or 10,000 kilograms (kg) or more. It has hundreds of moving parts that should give thousands of hours of service. In spite of its size and number of parts, a large engine operates on a relatively small amount of oil. A little oil goes a long way, because it has to form only a very thin film between the moving parts to do its job. The thin film of oil reduces the destructive friction that results when parts move against each other.

The *crankcase* is the frame of the engine, and lubricating oil is stored in the bottom of it. In a large engine, the crankcase may contain 100 gallons (gal), or 380 litres (L), of oil; however, only about 5 gal (20 L) of oil forms the film in the engine. When the engine is running, therefore, about 80 percent of the oil remains in the crankcase, while the rest flows through the oil filter, the oil cooler, the oil pump, and the lubricating lines.

What Lubricating Oil Does

Lubricating oil in a heavy-duty engine:

- Provides a film between moving parts. This film prevents metal-to-metal contact and reduces friction and wear.
- Cools the internal engine parts that it touches, such as the underside of a piston or the moving parts of a bearing.

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Cooling Systems

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In this chapter:

- How to remove heat from coolant
- Advantages of pressurized cooling systems
- How thermostats regulate the flow of coolant
- Maximizing cooling system performance and minimizing damage

As an engine runs, it produces heat. This heat comes from the burning of fuel and from the friction of moving parts. About a third of the heat put out by an engine goes into mechanical energy (work). The engine has to get rid of the other two-thirds, or it will overheat and stop running. Another third (approximately) of this heat is lost through radiation (heat thrown off by the engine) and through the exhaust system. The engine's cooling system takes up (absorbs) the remaining one-third of the heat.

A cooling system:
- Helps the engine perform
- Prevents damage to the engine

Purpose of the Cooling System

Normal combustion of fuel in an engine produces temperatures as high as 3,000° to 5,000°F (1,600° to 2,800°C). Much of this heat goes to the cylinder heads and walls, the pistons, and the valves. Unless the cooling system carries this heat away, it damages the engine. A cooling system, therefore, prevents damage to vital engine parts. The cooling system also keeps the parts cool enough to work at their best. That is, a part running too hot may not fail, but it will not give maximum performance.

Coolant

The engine transfers heat to a fluid called *coolant*. A common coolant is a mixture of water, ethylene glycol (commonly called antifreeze), and other additives. Antifreeze not only lowers the freezing point of water, it also raises the boiling point. Thus, a mechanic adds antifreeze

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Air-Intake Systems

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In this chapter:

- Dry and oil-bath air cleaners and their maintenance
- Air compressors in diesel engines
- Removing heat in air from the turbochargers
- Back-pressure as a disadvantage of turbochargers

Ways of introducing air into a diesel engine's cylinders:
- Forced-air induction
- Natural aspiration

A diesel engine needs air to run. In each engine cylinder, a piston compresses the air to a high temperature. When the engine injects fuel into the hot air, the fuel-air mixture burns to provide power. A typical diesel needs 12,000 gal (45 m^3) of air for every 1 gal (3.8L) of fuel it burns. If the engine does not get enough air, it will overheat, and carbon deposits will rapidly form.

The air for combustion must be clean. Even a small amount of dust in the air going into the engine can grow large in a few hours because of the large amount of air the engine needs to run.

As mentioned earlier, manufacturers naturally aspirate some engines: a *naturally aspirated engine* takes in air at atmospheric pressure. Manufacturers also supercharge some engines: a supercharger forces air into the engine under pressure. Engine builders must supercharge two-stroke engines. The supercharger (the blower) forces exhaust gases out of the cylinder and injects intake air for combustion.

On two-stroke engines, the blower is a gear-driven compressor—that is, the engine drives the compressor by means of gears on the engine that mesh with gears on the compressor. On four-stroke engines, the blower is a high-speed centrifugal compressor—a turbocharger. The engine's exhaust powers the compressor (the turbine). Whether on a two-stroke or a four-stroke engine, the blower always compresses the air and forces it into the intake manifold.

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Exhaustive System

In this chapter:

- How water jackets cool the exhaust manifold
- Size and shape requirements for exhaust pipes and tail pipes
- How mufflers reduce noise
- Preventing back-pressure in the exhaust system

The exhaust system's main job is to conduct exhaust gases from the engine cylinders to the atmosphere. A good system takes out exhaust gases with little resistance. If the exhaust system puts too much resistance on the engine's exhaust, back-pressure builds up. As stated earlier, back-pressure is pressure acting against the free flow of gases from the engine. It reduces engine power.

Purposes

The *exhaust system* is designed to conduct exhaust gases and smoke from the engines, which are often in an enclosed space. It is also designed to reduce (muffle) the noise of gases as they escape from the engines, and it may power a supercharger, as well.

Because exhaust gases are so hot, they ignite any flammable foreign material that may be in them. The particle is usually very small, so that it burns as a spark rather than as a flame. Exhaust systems include mechanisms to quench these sparks and remove them from the exhaust gases.

Finally, the exhaust system may also furnish heat to (1) make steam for heating and cleaning the rig, (2) distill seawater to make fresh water, and (3) warm other equipment.

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Instruments

In this chapter:

- General signs of how the engine is running
- Diagnosing engine problems
- Indications of problems with the oil
- Indications of problems with the air

Instruments that keep track of an engine's operation are essential. A doctor needs to monitor a patient's pulse, temperature, respiration, and other vital signs to tell whether the patient is well. Similarly, an engine operator needs to know the engine's temperature, speed, oil pressure, and other signs to tell whether the engine is running well. The vital signs of engines are measured by pyrometers, oil-pressure gauges, oil temperature gauges, coolant temperature gauges, air manifold pressure gauges, and tachometers.

Pyrometers

A *pyrometer*—a thermometer that measures high temperatures—is used to measure the temperature of the engine's exhaust. Alert operators can get a lot of information from pyrometer readings.

Estimating Engine Load

For example, they can estimate an engine's load. Suppose the engine manufacturer recommends that the exhaust temperature not exceed 1,000°F (540°C). The pyrometer, however, shows an exhaust temperature of 1,075°F (580°C). This higher-than-normal temperature indicates that the engine does not have enough horsepower (kilowatts) to adequately power the load the operator has put on it. Overloading an engine wears it out faster than normal; in fact, extreme overload can destroy an engine in a matter of minutes.

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Alarms and Shutdown Systems

In this chapter:

- Alarms and shutdown devices
- Emergency shutdowns
- Alarms: low oil pressure and high coolant temperature
- Testing alarms and shutdown devices

Engine builders equip most engines with alarms and safety *shutdown* devices. Having an alarm sound or a shutdown occur does not necessarily mean that the engine operator is doing a bad job. Instead, alarms and shutdown devices prevent engine damage when an upset occurs. Most engines have two alarms: one for low oil pressure and the other for high coolant temperature. Also, most engines have three emergency shutdowns: one for low oil pressure, one for high coolant temperature, and a third for *overspeeding*.

Overspeeding alarms are not installed on engines because, once an engine starts overspeeding, time is critical. By the time an operator could get to the engine upon hearing an alarm, it probably would have destroyed itself. A shutdown device is therefore essential to prevent overspeeding.

Immediate shutdown devices are activated when an alarm would not allow the operator enough time to act before damage occurs.

Overspeed Trip Devices

Should an engine overspeed, one kind of *overspeed trip device* immediately shuts off the fuel. Another kind of trip device shuts off both fuel and air. Operators should remember not to drop the load from an engine suddenly, because it may overspeed momentarily and trip the shutdown device.

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Engine Operation

In this chapter:

- Checking engine systems first
- Starting and warming up
- Setting the proper speed
- Running the engine

Engine operators should follow proper procedures when starting an engine and putting it to work. Many rig owners and operators use the following steps.

Prestart Checks

1. All moving parts of the engine should be examined for proper adjustment, alignment, and lubrication. Parts to check include the valves, cams, valve gear, fuel pumps, fuel-injection system, governor, lubricators, oil and water pumps, and the main machinery being driven by the engine.
2. The engine and machinery should be examined for loose nuts, broken bolts, loose connections, and leaks in jackets, joints, or valves. Nothing that must be tight should be loose and nothing that must be loose should be tight.
3. All pipes, valves, and ducts that carry fuel, oil, coolant, or air must be checked to make sure that they are not clogged, improperly adjusted, or dirty. If the engine has been idle for some time and is about to be put into service, the piping systems should be checked carefully for foreign matter. Many engine operators blow out the entire piping system with compressed air if the engine has been sitting idle for quite some time.

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Reports

In this chapter:

- How engine logs help to analyze performance
- What is recorded in engine logs
- How to monitor the engine and the exhaust
- Maintaining engines properly

Engine operators should keep accurate records of engine performance on a regular basis. By comparing engine logs, operators can spot trends that indicate abnormal performance and wear. Also, rig owners can compare the performance of different engines on different rigs and improve engine operations. What is more, engine manufacturers can get a good idea of how their engines perform, which often leads to performance improvements. Engine logs vary from rig to rig and company to company, but many rig owners include the following items in their reports:

- *Time*. The time of day when writing down the engine readings is noted.
- *Engine load*. In the case of an electric load, the volt and ampere readings are entered.
- *Engine speed*. Engine speed is measured with a tachometer or an adding revolution counter. If using a revolution counter, the operator also needs a large electric clock with a hand indicating seconds. A large clock makes it easy to read the counter at exact time intervals.
- *Fuel consumption*. If using a fuel meter to determine fuel consumption, the operator should take meter readings at exact time intervals.

Engine logs allow:
- Operators to spot abnormal performance and wear
- Rig owners to compare performance of different engines
- Engine manufacturers to improve engine designs

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ELECTRIC POWER
Introduction

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As mentioned earlier, rigs transfer engine power to equipment in two ways: mechanical and electrical. On an electric-drive rig, the diesel engines drive generators, which produce electricity. Heavy-duty cables send the electricity to motors mounted on or near the equipment needing power. The electric motors power the equipment (fig. 71).

Figure 71. Drilling rig using electical power

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Generators and Alternators

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In this chapter:

- How generators power motors for the drilling equipment
- How current from AC generators is converted for DC motors
- Advantages of AC generators
- How generators convert mechanical energy to electrical energy

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Most rigs use AC generators. Equipment converts the AC current to DC current for use with the engines that power the drilling equipment.

Generators change mechanical power developed by the engines into electrical power. The first diesel-electric rigs used direct current (DC) generators. Drilling contractors still use DC rigs because many such rigs were built and are still in use. Today, however, most rig generators are alternating current (AC) generators, which generate AC electricity. AC generators are also called *alternators*.

Usually, AC or DC generators make electricity to power large DC motors, which are usually mounted on or very near the equipment they are powering. If the rig has AC generators, it also has equipment to convert *(rectify)* the AC to DC, since most motors operate on DC. Until recently, rig owners preferred DC motors to AC motors because DC motors develop the most torque at low speeds. Since rigs require a lot of power, often when the motors are fully loaded and turning slowing, DC motors won out over AC motors.

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DC Electric Drive

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In this chapter:

- Advantages of an electric drive
- Controls in the driller's panel and main cabinet
- How SCRs convert AC current to DC current
- Cleaning electrical equipment
- Powering auxiliary equipment with AC current

The first diesel-electric rigs routinely started drilling holes in the 1960s. They rapidly began replacing mechanical rigs, especially offshore. On these early electric-drive rigs, diesel engines drove DC generators coupled to the engines. The direct current went through heavy-duty controls, switches, and electric cables to DC motors. The rig builder mounted the DC motors on or near the equipment requiring power. Today, many rigs still use DC-to-DC electric drive.

Advantages of Electric Drive

Converting mechanical power produced by an engine into electrical power and then back into mechanical power may seem like a long way around, but it has advantages. Unlike a mechanical rig, where machinery transfers engine power, on an electric rig, the flow of power from the engines to the driven equipment is smooth. The driven machinery delivers no shock back to the engine. A DC motor produces its greatest torque when it stalls, and the engines continue to put out full torque even if the motor stalls. As a result, a lot of torque is available to turn the equipment at very low speed and under heavy load.

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Index

Throughout this index, *f* indicates a figure on that page.

AC bus, 190, 190*f*
AC generators (alternators), 176*f*
  about, 176–177
  advantages of, 172–173
  commutators and, 173
  speed, engine and, 191
AC power. *See* alternating current (AC)
aftercoolers
  supercharged air and, 114
  turbocharger and, 124
air, removal of, 44
air cleaner(s). *See also* dry air cleaners; oil-bath air cleaners
  cleaning, 116–117
  maintenance, additional, 119
  operation of, 115
  parts of, 115*f*
  types of, 114
air filters, dirty, 149
air-intake manifold, 18, 121
air-intake systems. *See also* air cleaners; blowers (superchargers); oil-bath cleaners
  about, 113–114
  turbochargers, 122–124, 123*f*
air knocking
  about, 44
  bleeding process and, 43
air manifold-pressure gauges, 149, 150
air-motor starters, 139–140, 139*f*
  about, 143
  air requirements, 140
  cleaning, 140
air-shutoff valve, 154
air throttles, 181*f*, 184
alarms and shutdown systems. *See also* overspeed trip devices
  about, 151, 155
  engine shutdown considerations, 154
  high coolant-temperature alarms and shutdown, 153
  low oil-pressure alarms, 152
  low oil-pressure shutdowns, 153
  overspeed trip devices, 151–152
alternating current (AC)
  direct current (DC) versus, 135
  rig equipment and, 195*t*
alternator(s). *See also* AC generators (alternators)
  generators and, 171–172
  three-phase, rig engines and, 189, 189*f*
American Petroleum Institute (API), 94
ammeter, 184
amperes (amps), 184
antifreeze, 97–98, 100, 107
API gravity, specific gravity and, 25–26
armature (rotor), 175, 175*f*
aspiration, 9–10, 23
assignment switch, DC electric drive, 183, 183*f*
atmospheric pressure, 9, 10
atomization, fuel, 18, 47, 48
auxiliary power supply, DC electric drive, 195
auxiliary power unit, battery-operated electric starter on, 135*f*

back-pressure, 124
baffle plates, 130
bag filters, 37
ball bearing, 121*f*
barring an engine, 142
batteries. *See also* storage battery
  about, 138
  care of, 138–139
bearing(s)
  damage to, 84*f*
  failure of, 147
  types of, 6
Bendix-type starting motor, small engines and, 136*f*
bleed-off valve, 43
blow-by, 18
blowers (superchargers)
  about, 120
  air-manifold pressure gauge and, 149
  components, exploded view of, 121*f*
  exhaust gases and, 19
  failure, causes of, 122
  impellers and, 10–11, 10*f*

Petroleum Extension-The University of Texas at Austin

    roots blowers, 120, 120*f*, 121
blowouts and natural gas, engine shutdown and, 154
booster (priming) pump, 43, 44
bottom dead center (BDC), 9*f*, 15, 20
breather cap, PVC valve and, 17*f*, 18
brush holders, 187, 187*f*
bus bars, 190
bypass (relief) valve, 86

cam, 17*f*
    two-stroke diesel and, 21, 22, 22*f*
cam-operated plunger pumps
    fuel pump and, 52, 52*f*
    governor and, 52, 56
    injection lines and, 56
    injection system and, 51, 51*f*
    injector pump and, 54, 54*f*
    injector valves and, 57
    operation of, 55–56, 55*f*
    plunger operation and, 53, 53*f*
camshaft lubrication, 89
carbon residue, 26, 27, 44, 45
center of spin, centrifugal force and, 68, 68*f*
centrifugal force, 68*f*
    about, 68
    engines and, 149
    spring force and, 71
centrifuges, 35
cetane number
    about, 29
    determining, 29–30
check(s)
    overspeed and, 152
    prestart, engine and, 157–159, 163
    while engine is running, 162
chromates, 98
clearance, 82
CO_2 and H_2S, 106
combustion, 7
combustion cup, 17*f*, 18
common bus, 190, 190*f*
common-rail injection system, 64*f*
    about, 64
    fuel-flow control, 65
    fuel metering and injection, 65
commutators, 136*f*, 137*f*, 175*f*
    about, 173
    maintenance and, 186
compensator, 74
compensator governors, 74
compound
    engine power and, 3, 23
    mechanical transmission and, 2, 2*f*
compounded engines, overspeeding and, 152
compressed-air starting, 142–143, 144
compression ignition (CI) engines
    about, 7
    fuel-to-air ratio in, 8
compression ratio, 29, 30
compression stroke
    four-stroke diesel engines, 12*f*, 13, 14
    two-stroke diesel engines, 20
compressor, tachometers and, 149
condensate trap, 130
connecting rods, 6, 17*f*
contactors, electrical, 181*f*, 183
control panel, driller's, 184, 184*f*
control sleeve, 70-74, 70*f*
control units, AC bus and, 189–190, 189*f*, 190*f*
control voltage, 188
conversion factors, English-units-to-SI-units, xix*t*
coolant
    about, 112
    flow of, 100, 100*f*
coolant pump, 98
coolant-temperature gauges, 148–149, 150
coolant water quality, 106
cooling systems. *See also* radiator(s)
    about, 112
    checkpoints, 108, 112
    coolant and, 97–98
    coolant flow and, 100, 100*f*
    coolant water quality, 106
    engine rooms and ventilation, 109
    heat exchangers and, 99, 99*f*, 110, 110*f*
    pressurized, 100–101
    purpose of, 97
    water pump shaft packing, 108, 108*f*
corrosion, 27, 28, 42, 102
corrosion inhibitor, 98
crankcase, 81
crankshaft, heavy-duty diesel engine, 89*f*
crankshaft lubrication, 89
crank throws, 89
cutaway
    four-stroke diesel engine, 17–18, 17*f*, 21*f*
    two-stroke diesel engine, 21–22
cutoff valve, 153
cutouts, generators and, 137
cylinders, overloaded, 146, 150, 167

day tank(s), 31*f*
    fuel return lines and, 43
    injection pump and, 30
    main tanks and, 31
DC-DC schematic, 180*f*

Petroleum Extension-The University of Texas at Austin

  about, 181–182
  assigning power and, 181*f*, 183
  assignment switch, 183, 183*f*
  power, assignment of, 181*f*, 183
  throttles, using, 181*f*, 184
DC electric drive. *See also* DC-DC schematic
  about, 179, 196
  AC bus and control units, 189–190, 189*f*, 190*f*
  adding or removing generators from line, 192–193
  advantages of, 179–180
  assignment switch, 183, 183*f*
  auxiliary power supply, 195
  control cabinet, main, 185, 185*f*
  control hook-up of, 181*f*
  controlling power and, 188–189, 188*f*
  driller's control panel, 184, 184*f*
  electronic governors and, 192
  engine and AC generator speed, 191
  exciters, 180
  maintenance and, 186–187, 196
  malfunctions and, 194
  power needs, meeting, 191
  running engines at constant speed, 180
  running engines at various speeds, 180
  SCRs, thyristors or, 188
  SCR systems and, 187
  special considerations, 191–195
DC electric motor, drilling rig and, 182*f*
DC generators, 174*f*
  about, 173–175
  simple, 174*f*
DC power. *See* direct current (DC)
DC voltage, sine wave, 188*f*
detergent oils, 95
diesel engine(s). *See also* engine(s); exhaust system, diesel engine; heavy-duty diesel engine(s)
  electric drive system and, 3*f*, 169
  exhaust piping, approximate sizes for, 129–130, 129*t*
  fuels for, 6
  fuel supply system, 30*f*
  gas or LPG engines and, 7–9
  lubrication of oil pump for, 82–83, 82*f*
  not starting, reasons for, 133–134
  offshore rig and, xx*f*
  oil cooler bypass system, 87, 87*f*
  oil filter units on, 85, 85*f*
  operation of, 5–6
  power transmission and, 2–3
diesel fuel. *See also* fuel quality
  about, 25, 44
  specific gravity and API gravity, 25–26
  unsatisfactory, effects of, 30
diesel service (DS), 94
diodes, 188
direct-acting electric actuator, 77
direct current (DC)
  alternating current (AC) versus, 135
  batteries and, 138
  electric starters and, 135
dirt and dust
  bearing damage and, 84*f*
  coolant water quality and, 106
  DC electric drive and, 186–187
  radiator passages and, 104*f*
dirty air filters, 149
disposable fuel filters, 38, 38*f*
dissolved minerals, 106
distillation, 26
distributor, 18
distributor injection pump, 17*f*, 18
distributor injector pump, 17*f*
  about, 61
  beginning of delivery, 62, 62*f*
  delivery, 62*f*, 63
  end of delivery, 62*f*, 63
  firing order and, 61
  fuel metering and, 63
  intake, 61, 62*f*
  operation of, 62*f*
  pump operation and, 61, 61*f*
  throttling back and shutting down, 63
  throttling up, 64
driller's control panel, 184, 184*f*
drilling rig(s). *See also* rig
  DC electric motor used on, 182*f*
  electrical power for, 169*f*
  internal combustion engines and, 1*f*
dry air cleaners
  about, 114–117, 125
  cleaning, 116–117
  parts of, 115*f*

electrically actuated governors, 76*f*
  about, 76–77, 79
  direct-acting or reverse acting, 77
  fuel modulators and, 77
electrical power, drilling rig using, 169*f*
electrical shock, prevention of, 185
electrical transmission, 3
electric drive system, diesel engine and generator in, 3*f*
electric generators, offshore rig and, xx*f*
electric motors
  DC, on drilling rig, 182*f*
  mud pump and, 3*f*
electric power, drilling rig using, 169*f*
electric starters, 135*f*

Petroleum Extension-The University of Texas at Austin

  about, 135, 143
  batteries, 138–139
  battery-operated, 300-kW auxiliary power unit, 135*f*
  direct current versus alternating current, 135
  generators and cutouts, 137
  operation of, 136–137
  solenoid and, 137, 137*f*
  starter system parts, 135
electric transmission, 3
electrolyte, 138
electronic governors, 192
engine(s). *See also* diesel engine(s); four-stroke diesel engines; load(s); two-stroke diesel engines
  about, 23
  AC generator speed and, 191
  barring an, 142
  Bendix-type starting motor for, 136*f*
  compounded, overspeeding and, 152
  cooling system, coolant flow and, 100, 100*f*
  idling of, 137, 159, 160
  internal combustion, 1*f*, 5*f*
  loading, 164
  lubricating oil for parts of, 88*f*
  malfunctions and, 194
  versus motors, 4
  naturally aspirated, 113
  overloaded, 150, 162
  running at constant speed, 180
  running at various speed, 180
  spark ignition (SI), 7–9
  starting, 43
  start-up with low-oil pressure alarms and shutdowns, 153
  using CO_2 to stop, 154
  warm-up of, 159, 163
engine fans, 99
engine monitoring report, 167
engine oil supply areas
  camshaft lubrication, 89
  crankshaft lubrication, 89, 89*f*
  injector pump and governor lubrication, 92
  piston lubrication, 89
  rocker arm and valve lubrication, 90, 90*f*
  timing gear lubrication, 90, 91*f*
engine operation
  about, 5–6, 163–164
  checks while running, 162
  prestart checks, 157–159
  putting engine to work, 161–162
  start-up, 159
  warm-up, 159
  warm-up speeds and, 160–161
engine power and transmission, 1
engine rooms and ventilation, 109
engine shutdown considerations, 154
engine speeds. *See* speed(s)
engines versus motors, 4
engine temperature switch (ETS), 111
English-units-to-SI-units conversion factors, xix*t*
exchanger. *See* heat exchangers
exciters, 180
exhaust manifold, 128–129, 128*f*
exhaust monitoring report, 167
exhaust pipe, 129–130, 129*t*
exhaust silencers. *See* mufflers
exhaust stacks, 131*f*
exhaust stroke
  four-stroke diesel engines, 12*f*, 13, 16
  two-stroke diesel engines, 20
exhaust system, 128*f*. *See also* mufflers
  exhaust manifold, 128–129, 128*f*
  exhaust pipe, 129–130, 129*t*
  parts of, 128, 132
  purposes, 127, 132
  tail pipe and, 128*f*, 131
exhaust valves, 5*f*
  burned gases and, 6
  two-stroke diesel and, 21*f*, 22
  valve overlap and, 16
explosion covers (doors), 93

fan(s)
  about, 99
  radiator and, 102
filter bypass valves, 86
filtering, importance of, 84, 84*f*
filter pressure gauges, 86
filters. *See also* fuel filters; oil strainers and filters
  about, 83
  bag, 37
  fuel supply systems and, 31*f*, 33*f*
  number of, 85
  primary and secondary, 37
  strainers and, 35
  tank, 36, 36*f*
fins, 98
firing cycle(s)
  four-stroke diesel engines, 13, 15, 24
  two-stroke diesel engines, 19, 24
firing order, 61
flash point, 28
flux, 173, 175*f*
flyweight(s), 70*f*, 75*f*
  engine speeds and, 71
  springs, oil pressure and, 68
flywheel, 6

Petroleum Extension-The University of Texas at Austin

forced-air induction. *See also* blowers (superchargers); turbochargers
  about, 10–11, 23–24
  natural aspiration and, 9–11, 23
  power and, 11
four-stroke diesel engines, 12*f*
  breather cap and PCV valve, 17*f*, 18
  combustion cup, 17*f*, 18
  compression stroke, 12*f*, 13, 14
  cutaway of, 17–18, 17*f*
  diesel fuel injection, 15
  exhaust stroke, 12*f*, 13, 16
  firing details, 14–15
  four-stroke cycle, 12*f*, 13, 15, 17*f*, 24
  fuel injector and, 17*f*, 18
  ignition and, 14, 15
  intake stroke, 12*f*, 13, 14
  lugging power, 16
  power stroke, 12*f*, 13, 15
  valve action and, 13
fuel(s). *See also* diesel fuel; oil(s)
  about, 23
  adding water to, cleaning and, 40
  atomization of, 18, 47, 48
  contaminated, cleaning, 40
  diesel engine, 6
  removal of air from, 44
  unsatisfactory, effects of, 30, 45
fuel atomization, 48
fuel centrifuge, 40
fuel distributor, 18
fuel filters
  disposable, 38, 38*f*
  heavy-duty spin-on, 39*f*
  spin-on, 39, 39*f*
  tank-type, 36, 36*f*
fuel injection, 49*f*
  diesel, 15
  plunger pump for, 49, 49*f*
fuel-injection rate, 48
fuel-injection systems. *See also* distributor injector pump; injection system requirements; single-unit multiple pumps; unit fuel injection
  about, 47, 66
  common-rail, 64–65, 64*f*
  multipump injectors, 49, 49*f*
  one pump on each cylinder, 50, 50*f*
  types of, 48–49, 66
fuel injector(s)
  about, 18
  cetane number and, 29
  fuel tank vents and, 33*f*
fuel injector pump, 51, 51*f*
fuel inlet, 55, 55*f*
fuel lines
  about, 41–42
  connections and, 43
  flexible hoses and, 43
  paraffin and, 42
  return lines, 42
  transfer pumps and, 41–43
  unions, gaskets, and galvanized pipe, 42
fuel metering, 63, 65
  accuracy and, 47–48
  rack and pinion control of, 67*f*
fuel modulators, 77
fuel pump(s)
  fuel supply systems and, 32
  fuel tank vents and, 33*f*
  gear-type, 32
fuel quality
  about, 26
  acid corrosiveness, 28
  ash, sediment, and water content, 28
  carbon residue and, 27
  cetane number and, 29–30
  flash point, 28
  ignition quality, 29
  pour point, 28
  sulfur content, 27
  viscosity, 27
  volatility, 26
fuel return lines, 42
fuel supply system(s). *See also* fuel injector(s)
  about, 45
  bag filters and, 37
  built-in pumps for, 32
  centrifuges and, 35
  delivery line location, 34
  diesel engine, 30*f*
  excess fuel and, 32
  filters and, 35–39, 36*f*, 38*f*, 39*f*
  fuel handling tip, 34
  fuel pump and, 32
  fuel tank vents, 33, 33*f*
  main tanks and day tanks, 31–32
  pumps versus gravity, 32
  strainers and, 35
  system using separate injection pump and day tank, 30, 30*f*
  tank filters and, 36, 36*f*
  total volume/useful volume, 34
fuel tanks
  baffles, 33*f*
  vents, 33–34, 33*f*
fuel-to-air ratio
  compression ignition (CI) engines, 8

Petroleum Extension-The University of Texas at Austin

  spark ignition (SI) engines, 7
fuel-transfer pumps. *See* transfer pumps

gaskets, 42, 115, 119
gasoline engine starters, 141, 144
gas or LPG engines and diesel engines
  compression ignition (CI) engines, 7
  fuel-to-air ratio in compression ignition (CI) engines, 8
  fuel-to-air ratio in spark ignition (SI) engines, 7
  spark ignition, 7
  strokes and cycles, 8
gate voltage, 188
generator(s), 3. *See also* AC generators (alternators); DC generators
  about, 177
  adding or removing from line, 192–193
  alternators and, 171–172
  cutouts and, 137
  electric drive system and, 3*f*, 169
  engines driving, 162
  malfunctions and, 194
  rotor (armature) for, 175*f*
  tachometers and, 149
generator stator, 175*f*
glow plugs, 7, 21*f*, 134
GM Hydrostarter, 140, 140*f*
governor(s). *See also* electrically actuated governors; hydraulically actuated governors; mechanically actuated governors
  about, 67, 78–79
  centrifugal force and, 68, 68*f*
  compensator, 74
  electronic, 192
  flyweights, springs, and oil pressure, 68
  functions of, 52, 56
  hunting and, 69, 74
  isochronous, 69
  lubrication of, 92
  overspeed, 78
  spring-loaded centrifugal, 68
  terms used with, 69
  types of, 69

H_2S and CO_2, 106
header, 64, 64*f*
heat exchanger(s)
  about, 99, 110–111
  features of, 99*f*
heat-exchanger cooling system, 110, 110*f*
heavy-duty diesel engine(s)
  crankshaft of, 89*f*
  oil filter units on, 85*f*
  timing gears in, 91*f*
heavy-duty spin-on filter, 39*f*
high coolant-temperature alarms and shutdown, 153
high-detergent (HD) additives, 94
high oil pressure, 147
horsepower (hp), 129, 129*t*, 145, 172
hunting, 69, 74
hydraulically actuated governors
  about, 79
  compensator and, 74, 75*f*
  maintenance of, 75
  needle valve and, 73*f*, 74
  principles of, 73, 73*f*
  speed, variations in, 74
hydraulic starters, 140–141, 140*f*, 144
hydrocarbon, 29
hydrometer, 138
hydrostarter, 140, 140*f*

idling engine, 137, 159, 160
ignition quality, cetane number and, 29
immersion heater temperature switch (IHTS), 111
impellers, 10–11, 10*f*
injection lines, 56
injection pump, distributor, 18
injection system, multipump, 49
injection system requirements
  about, 47
  fuel atomization, 48
  fuel distribution, good, 48
  fuel-injection rate, 48
  fuel metering, accuracy and, 47–48
  timing, proper injection, 48
injection systems, types of, 48–49
injection timing, 48
injector pump(s). *See also* distributor injector pump
  camshaft and, 54, 54*f*
  distributor-type
  lubrication of, 92
  primary pump and, 43
injectors. *See* fuel injector(s)
injector system, common-rail, 64, 64*f*
injector unit, single, 52, 52*f*
injector valves, 57
inlet port, 55, 55*f*
inlet versus outlet temperature, coolant temperature gauges and, 149–150
instruments
  air manifold-pressure gauge, 149
  coolant-temperature gauges, 148–149
  oil-pressure gauges, 146–147
  oil-temperature gauges, 148

Petroleum Extension-The University of Texas at Austin

    pyrometers, 145–146
    tachometers, 149
intake stroke
    four-stroke diesel engines, 12*f*, 13, 14
    two-stroke diesel engines, 20
intake valves, 5, 5*f*, 12*f*, 13
internal combustion engine, 5*f*
isochronous governor, 69

kilowatts, 129, 145, 172

lead-acid batteries, 138
lifter, 54, 54*f*
liquefied petroleum gas (LPG), 6
load(s)
    dividing equally, 146
    estimating engine, 145
    exhaust manifold and, 129
    going up/going down, 56, 71
lock-out procedures, 185
low oil pressure
    about, 146
    bearing failure and, 147
    blocked suction screen, 147
    low oil level, 147
    oil dilution and, 147
low oil-pressure alarms, 152
low oil-pressure shutdowns, 153
low-pressure problems, starting devices and, 133
low-temperature problems, starting devices and, 134
LPG engines, 7–9
lubricating oil, 122, 134, 166
    channels to timing gears, 91*f*
    engine parts and, 88*f*
    valve and rocker arm, 90*f*
lubrication systems, 82*f*, 88*f*. *See also* engine oil supply areas; oil cooler(s); oil quality; oil strainers and filters
    about, 81–82, 88, 96
    camshaft and, 89
    detergent oils, 95
    explosion covers, 93
    filter bypass valves, 86
    filter pressure gauges, 86
    lubricating oil and, 81–82
    oil contamination, 95
    oil cooler bypass system, 87, 87*f*
    oil coolers and, 86–87, 86*f*
    oil pumps and, 82–83, 82*f*
    oil testing, 95
    pistons and, 89
    prestart, 92
    proper oil, using, 94
lugging power, 15, 16
lugging power, diesel engines, 16

magnetic flux, 173, 175*f*
main bearings, 6, 87*f*, 89
maintenance
    DC electric drive, 196
    hydraulically actuated governors and, 75
maintenance schedule reports, 167
"making hole," 1
manifold(s)
    coolant flow and, 100
    defined, 18
    fuel, 33*f*
manifold-pressure gauge, 149
manometer, 130
measurement, units of, xviii, xix*t*
mechanical assembly, engines driving, 161
mechanical drive, prime movers and compound in, 2*f*
mechanically actuated governors
    about, 79
    adjustments to, 71
    disadvantages of, 73
    principle of, 70, 70*f*
    speeder spring and control sleeve, 70
    spring force and centrifugal force, 71
    two-speed, 72, 72*f*
mechanical transmission, compound and, 2
metal-edge strainers, 35
micropore paper, 37, 38*f*
minerals, dissolved, 106
motors versus engines, 4
mud pump, electric motors and, 3*f*
mufflers, 128*f*
    about, 130–131
    exhaust pipe and, 129
multipump injectors, 49, 49*f*

natural aspiration, 9–10, 23
natural gas and blowouts, engine shutdown and, 154
natural gas engines, 7–9
naturally aspirated engine, 113
needle valve, 59*f*, 60, 74
nozzle, 18

offshore rig, power generation for, xx*f*
oil(s). *See also* lubricating oil
    contamination of, 95
    detergent, 95
    turbochargers and, engine shutdown, 154
    using proper, 94
oil-bath air cleaners
    about, 125

Petroleum Extension-The University of Texas at Austin

- air flow and, 117*f*
- dry air cleaners versus, 114
- heavy-duty oil bath, air flow through, 117*f*
- operation of, 118
- parts of, 117
- servicing of, 118–119
- types of, 117

oil contamination, 95
oil cooler(s), 86
- bypass system, diesel engine, 87, 87*f*
- placement of, lubrication system and, 86–87, 86*f*

oil filter units, 85, 85*f*
oil flow rates, 82
oil pressure. *See* high oil pressure; low oil pressure
oil-pressure gauges
- about, 150
- high oil pressure, 147
- low oil pressure, 146–147

oil pumps, lubrication of, 82–83, 82*f*
oil quality
- about, 93
- sulfur content of fuels and, 94

oil strainers and filters. *See also* filters; strainers
- about, 83
- bearing damage and, 84, 84*f*
- filtering, importance of, 84
- number of filters and, 85

oil-temperature gauges, 148, 150
oil testing, 95
orifice, 27
oscilloscope, 188
overloaded cylinders, 146, 150, 167
overloaded engine, 150, 162
overload protection system, 194
overspeed governors, 78, 79
overspeeding. *See* alarms and shutdown systems; overspeed trip devices
overspeed trip devices
- about, 151
- checking overspeed tips, 152
- compounded engines and overspeeding, 152
- overspeed governors, 78, 79

oxygen, 106

paraffin, 42
PCV valves, 18
pigtail, 187, 187*f*
pinion, 53, 53*f*
pipe(s)
- exhaust, 129–130, 129*t*
- fittings and, 41–42
- galvanized, 42, 42*f*
- stainless steel union connecting lengths of, 42, 42*f*
- tail, 181
- unions, gaskets, and, 42*f*

piston
- at BDC, 9*f*, 14
- at TDC, 9*f*, 13, 14

piston lubrication, 89
plug-in connector, 185*f*
plunger, 18
plunger operation
- camshaft and, 54, 54*f*
- pinion and, 53, 53*f*

plunger pump
- cam, rocker arm and, 22
- fuel injection and, 49, 49*f*
- high-pressure, 21

positive crankcase ventilation (PCV) valves, 18
pour point, 28
power stroke
- four-stroke diesel engines, 12*f*, 13, 15
- two-stroke diesel engines, 20

power supply, auxiliary, 194
power transmission
- about, 23
- diesel engines and, 2–3

pressure gauges, 86
pressurized cooling systems, 100–101
prestart checks, engine, 157–159, 163
prestart lubrication systems, 92
primary filters, 37
primary pump, injector pump and, 43
priming (booster) pump, 43
pump(s). *See also* distributor injector pump; injector pump(s); plunger pump; unit injector
- booster (priming), 43
- coolant, 98
- fuel, 33*f*
- fuel injector, 51, 51*f*
- gravity versus, 32
- oil, lubrication of, 82–83, 82*f*
- primary and injector, 43
- tachometers and, 149
- unit injector, 43, 59*f*
- water, shaft packing for, 108, 108*f*

pump plunger, operation of, 55, 55*f*
pushrod, 64, 64*f*, 89
pushrod guides, 88*f*, 89
pyrometers
- about, 149–150
- cylinder temperatures, 146
- engine load, estimating, 145
- loads, dividing equally, 146

questions, review, 219–228

Petroleum Extension-The University of Texas at Austin

rack, 67, 67*f*
rack and pinion control, fuel metering, 67, 67*f*
radiator(s)
  about, 98, 101
  air flow and, 104*f*, 105
  automatic shutter arrangement for, 105, 105*f*
  coolant flow and, 102
  damage, air flow and, 104, 104*f*
  engine fans and, 99
  fans and, 102
  features of, 98*f*
  fins and, 98, 104
  operation of, 103–105
  size of, 102
  thermostats (temperature regulators), 102–103
  top tank, 103
  tube spacing and, 104
radiator core, 103, 105
radiator fins, 98
raw water, 110
rectifiers, 187
relief valves, 82–83
reports
  about, 165–166, 168
  engine monitoring, 167
  exhaust monitoring, 167
  maintenance schedule, 167
reverse-acting electric actuator, 77
reverse current relay, 194
rheostats, 181, 181*f*
rig. *See also* drilling rig
  engines, three-phase alternators connected to, 189, 189*f*
  equipment, AC power and, 195*t*
  offshore, power generation for, xx*f*
  power, loss of, 194
  system, SCR (AC to DC), 190*f*
rocker arm, 17*f*
  about, 22
  two-stroke diesel and, 21*f*
  valve lubrication and, 90, 90*f*
roller bearings, 121
roots blowers, 120, 120*f*, 121
rotor (armature), 175, 175*f*
rpm instrument. *See* tachometers

Saybolt seconds universal (SSU), 27
Saybolt viscometer, 27
scavenging efficiency, 20
SCR (AC to DC) rig system, 190*f*
SCR converters, 191
SCRs, thyristors or, 188
SCR system(s)
  about, 187, 196
  overload protection and, 194
secondary filters, 37
sensitivity, 69
shell, 39*f*, 57, 57*f*
shutdown systems. *See* alarms and shutdown systems; overspeed trip devices
silicon-controlled rectifiers. *See* SCR systems
sine wave, DC voltage as, 188*f*
single injector unit, 52, 52*f*
single-unit multiple pumps. *See also* common-rail injection system; distributor injector pump; unit fuel injection
  about, 51
  cam-operated plunger pumps, 51–56, 51*f*
slip rings, 176, 176*f*, 177
sludge formation, prevention of, 18
solenoid, electric starter using, 137, 137*f*
spark ignition (SI) engines
  about, 7–9
  fuel-to-air ratio in, 7
spark plugs, 7, 15
specific gravity, API gravity and, 25–26
speed(s). *See also* alarms and shutdown systems
  AC generator speed, engine and, 191
  engine and AC generator, 191
  flyweights and, 71
  hunting and, 69
  tachometers and, 149
  warm-up of engine and, 159
speed drop, 69, 74
speeder spring, control sleeve and, 70, 70*f*
speed limiter, 92
spin-on filters, 39, 39*f*
spray nozzle valve, closed position, 57, 57*f*
spring-loaded centrifugal governors, 68
spring shunt, 187, 187*f*
stack, 131, 131*f*
starter systems parts, 135
starting an engine
  about, 43, 159
  direct current (DC) and, 135
  low-oil pressure alarms and shutdowns and, 153
  oil viscosity and, 133
  steps in, 163
starting motor, small engine, 136*f*
starting systems. *See also* electric starters
  about, 133, 143
  air-motor starters, 139–140, 139*f*
  compressed-air starting, 142–143
  electric starters, 135
  gasoline engine starters, 141

Petroleum Extension-The University of Texas at Austin

    hydraulic starters, 140–141, 140*f*
    types of, 133
    why diesel engines may not start, 133–134
stator, 174, 175, 175*f*
storage battery, 135
strainers, 33*f*. *See also* oil strainers and filters
    about, 83
    filters, centrifuges and, 35
    metal-edge, 35
    primary and secondary, 37
strokes and cycles, 23. *See also* four-stroke diesel engines; two-stroke diesel engines
suction screen, blocked, 147
sulfur content of fuels, oil quality and
superchargers. *See* blowers (superchargers)
synchronous speed, 192
synchroscope, 193

tachometers, 149, 150
tag-out procedures, 185
tail pipe, 128, 128*f*, 131
tank-type fuel filters, 36, 36*f*
temperature, inlet versus outlet, 149
temperature gauges
    coolant, 148–149
    oil, 148
temperature regulators, 102–103
testing
    low oil pressure alarms and shutdowns, 153
    oil, 95
thermostats, 102–103
thyristors, 187, 188
timing gear(s)
    heavy duty diesel engine, 91*f*
    lubrication and, 90, 91*f*
timing gear train, 90
top dead center (TDC), 9*f*, 13, 15
torque, 6, 16
total volume/useful volume, 33*f*, 34
transfer pumps
    about, 41
    fuel lines and, 41–43
    pump location and, 42
    pump sizing and, 41
    unions, gaskets, and galvanized pipe, 42, 42*f*
transmission, engine power and, 1
'trips.' *See* overspeed trip devices
turbine, 122
turbochargers
    aftercoolers and, 124
    back-pressure and temperature effects, 124
    flow of air and exhaust through, 123*f*
    oil and, engine shutdown, 154
    schematic, 123*f*
two-stroke diesel engines, 19*f*
    about, 19, 23–24
    blower and intake ports, 22
    compression and power stroke, 20
    concurrent events in, 20
    cross section, 21*f*
    firing cycle in, 19, 24
    power, exhaust, and intake stroke, 20
    two-stroke power, 20

union, 42, 42*f*
unit fuel injection
    control rack and, 60
    electric control of, 57
    fuel delivery and, 60
    fuel flow, continuous, 60
    injector operation and, 60
    pump action and, 60
    spring and cam follower, 58*f*, 59
unit injector
    assembly, 58, 58*f*
    pump, cutaway view of, 59*f*
useful volume/total volume, 33*f*, 34
using CO 2 to stop an engine, 154

"vacuator" valves, 115, 115*f*
vacuum, 9
valve and rocker arm lubrication, 90*f*
valve overlap, 16
valves, injector, 57
vapor lock, 32, 43
viscosity, 27
volatility, fuel quality and, 26
voltage, 184
voltmeter, 184

warm-up of engine, 159, 163
water
    adding to fuel, cleaning and, 40
    electrical equipment and, 186
    raw, 110
water jacket, 128
water pump shaft packing, 108, 108*f*
water quality, coolant, 106
water separators, 40
wet air cleaners. *See* oil-bath cleaners
windings, 174, 175*f*
worm gear, 143
wrist pins, 89

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ISBN 0-88698-169-7
9 780886 981693

2.108302
0-88698-169-7