14.0 SOME OTHER ENGINES

Learning Objectives

As a result of this lesson, you will be able to:

1. Recognize basic similarities and differences between the engines that power EDGs at nuclear power plants.

2. Use the tabulation at the end of this chapter to identify EDGs and associated equipment at some nuclear power plants.

14.1 EMD EDG Engines

The EMD EDG engines are the General Motors EMD 645 Series 2-stroke cycle 45^{o} Vee engine. These engines have intake ports in the lower end of each cylinder liner and four exhaust valves in each cylinder head.

During starting and up to approximately 40 percent load, cylinder exhaust scavenging and combustion air charging of the cylinders are supplied by the engine turbocharger which is gear driven until the exhaust gases get hot enough to drive the turbocharger faster than the drive gear. Then the drive gear is overridden (clutched out).

Each engine cylinder fuel pump and fuel injection nozzle are combined into a unit type construction thereby eliminating the need for high pressure fuel injection lines.

For each bank of this Vee engine, the cam shafts are located above the cylinder heads. From this location, they directly actuate two rocker arm assemblies:

- one for the four exhaust valves
- one for the unit fuel pump/injector

Unlike other engines, pushrods from the camshafts are not required.

Cylinders are directly opposite each other on this Vee engine. Connecting rods from directly opposite side cylinders use a common connecting rod journal without offset by means of their mating fork-and-blade slipper assembly.

Lubrication cooling of the each piston crown is accomplished by use of an engine frame-mounted piston-cooling oil pipe that is aligned with a hole in the piston carrier to send a jet stream of oil directly into the piston cocktail shaker for crown cooling and wrist pin lubrication. The oil then drops back into the crankcase.

Some design and performance data for the EMD engine are provided:

- Figure 14-1 is a cutaway cross section of the EMD 645 engine. It provides some perspective of engine con-figurations and component locations.

- Figure 14-2 is an EMD engine data sheet.

14.2 Cooper EDG Engines

The Cooper EDG engines are 4-stroke cycle Enterprise KSV V16 and V20 cylinder engines. Cylinders on opposite sides of the Vee are directly opposite each other. The use of articulating connecting rods permits the use of a single crankshaft journal without offset for both cylinders. There is a master connecting rod that provides the bearing and transmits both connecting rod

loads/power into the single crankshaft journal. The master rod has a bushing bearing for the slave rod. The connecting rods and bearings are shown in Figure 14-3.

Cooper engines had 13 crankcase explosion events attributed to lack of lubrication. These engines were designed for continuous use with minimum oil consumption. The lack of lubrication was corrected by removal of the lower scraper ring on each piston and removal of wrist pin bearing end caps.

Some design and performance data for the Cooper16- and 20-cylinder engines are provided:

- Figure 14-4 provides KSV design data.
- Two cutaway cross sections provide some perspective of engine configurations and components locations. (See Figures 14-5 & 14-6)
- Figure 14-7 provides a bar graph of engine timing. (Typical for 4-stroke cycle engines)

14.3 Nordberg EDG Engines

The Nordberg EDG engine is a 4-stroke cycle Vee engine. It has a unique cam shifting mechanism, which will shift combustion air inlet valve closure from its initial 18 degrees ABDC to 28 degrees BBDC at engine full load. Actuator sensing is of combustion air intake manifold pressure. The actuator is operated by a hydraulicly positioned linkshaft which repositions the camshaft. The inlet valve cams have an eccentric configuration. This system is illustrated in Figure 14-8.

Some design and performance data for the Nordberg engine are provided:

- Figure 14-9 provides general engine data.
- Figure14-10 provides recommended operating temperatures and pressures.
- Figure 14-11 is a cutaway cross section. It provides some perspective of engine configurations and components locations.

14.4 Worthington EDG Engines

The Worthington EDG engine is a 4-stroke cycle Vee engine. Opposite side cylinder connecting rods use a single crankshaft journal and mount directly beside each other.

At the D. C. Cook Plant, the high pressure fuel injection lines from the injection pumps to the injection nozzles have been prone to cavitation erosion failures in sharp bends made in routing the fuel lines from injection pumps to injection nozzles. This could be a generic problem.

Some design and performance data for the Worthington engine are provided:

- Figure 14-12 is a cutaway engine cross section. It provides some perspective of engine configurations and components locations.
- Figure 14-13 provides general engine data.
- Figure 14-14 provides a circle timing diagram to show the timing of all engine events during the 4-stroke

cycles of the engine. (Typical for other 4-stroke cycle engines.)

14.5 SACM EDG Engines

The SACM UD 45 V16 S5D engine is a 4-stroke cycle engine at Calvert Cliffs and Prairie Island nuclear stations.

The Calvert Cliffs configuration has two SACM engines connected in tandem to power a single 5400kw generator. There are two tandem units–one safety related and one SBO unit. Each engine is provided with a Woodward 2301A electrical governor and a Woodward EGB-35P governor actuator, which permits engine load sharing as they both power their common generator. IN-96-67 Vulnerability of Emergency Diesel Generator to Fuel Oil/ Lube Oil Compatibility. Following Calvert Cliffs' successful pre-op qualification testing of their new SACM safety related EDG, the licensee performed progressive external to internal and then to disassembly inspections of the engines.

Extensive cylinder liner/piston skirt damage was discovered. Root cause was a chemical reaction between combustion blowby water into the crankcase and a diester in the synthetic lube oil acid-neutralizing additives. This reaction formed hard deposits behind the piston rings which led to cylinder/liner scuffing. The inoperable piston rings could have led to early failures of the SACM EDG. A significant amount of water is formed during the combustion of fuel. NRC IN 96-97.

Corrective actions included engine repairs/ replacements and lube oil change to an API-CG-4 mineral-based oil recommended by the root cause analysis team.

- Figure 14-15 provides general engine data.
- Figure 14-16 provides general generator data.

The Prairie Island configuration of Unit 2 SACM EDG D5 and D6 not known.

NRC NOV EA-02-068 cited Prairie Island with a $60,000 penalty for failure to take action to address EDG problems in a timely manner.

14.6 DeLaval EDG Engines

The DeLaval EDG uses the 4-stroke cycle Enterprise RSV-V-16-4 engine.

The DeLaval engine like other EDG engines is subject to large pressures and forces as it operates. See Figure 14-16. Consider the 17-inch diameter piston in the DeLaval engine. With 1500 psi peak firing pressure, it must carry a peak load on each piston of the of 340,000 pounds 225 timing per minute. This load is transmitted from the piston through its wrist pin bearing to the connecting rod bearings and then to the crankshaft journal. The large forces of combustion are contained and resolved within the engine by structural components. Fortunately a large percentage of these forces create useful work by their rotation of the engine crankshaft to produce useable output power. However, when some cylinders fail to produce their share of output power, the unbalanced forces can be large enough to become destructive.
Some design and performance data for the DeLaval engine are provided:

- Figure 14-17 provides general engine data.

- Figure 14-18 provides a cross sectional illustration of the DeLaval articulating connecting rod assembly. It provides some perspective of engine configurations and components locations.

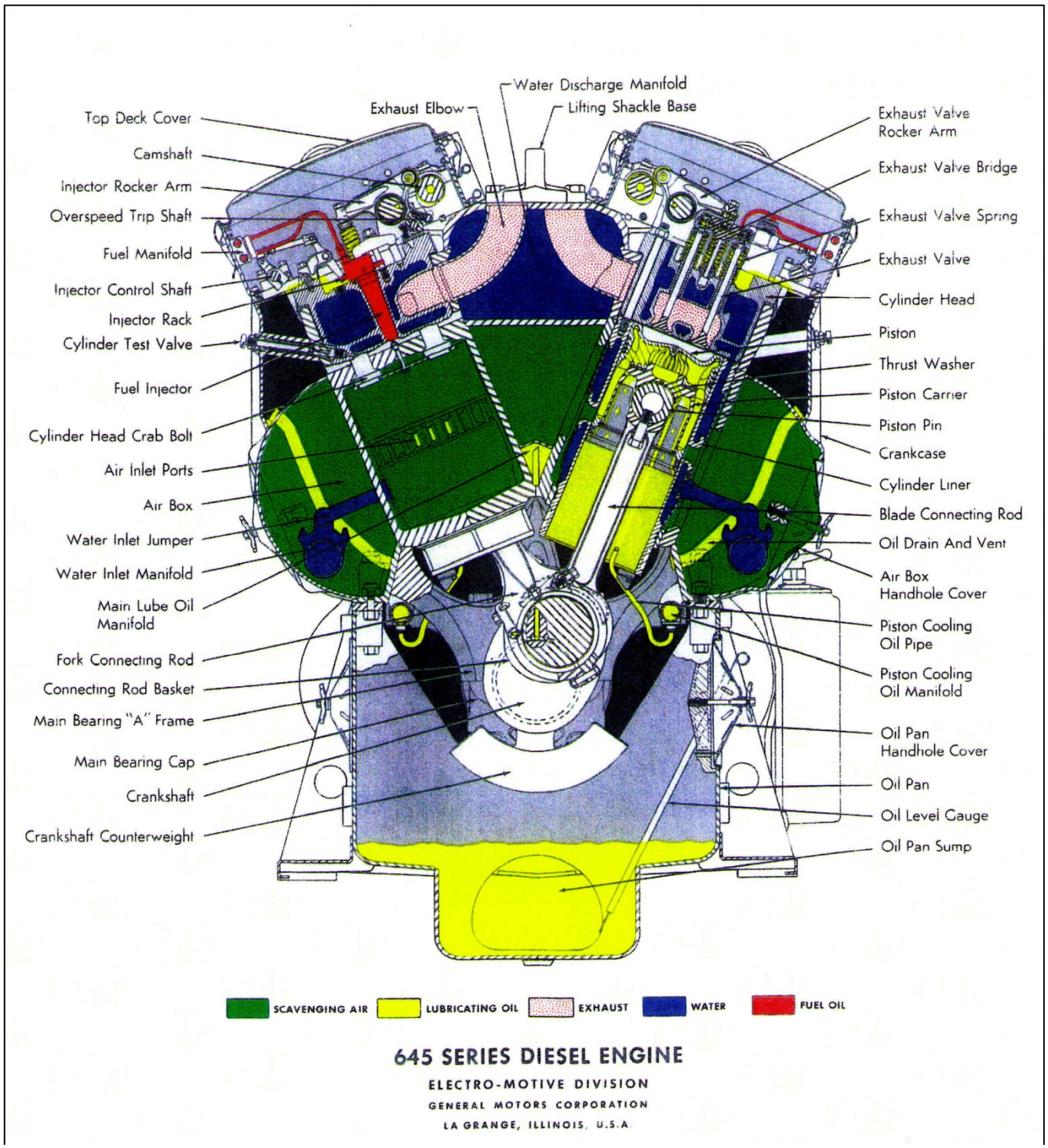


Figure 14-1 EMD Engine Cross Section

EMD 645 ENGINE
GENERAL DATA

Engine Type	Two-Stroke Cycle, Vee
Bore & Stroke	9 1/16 by 10 inches
Angle between Banks	45 degrees
Compression Ratio	14.5:1
Displacement per Cylinder	645 cu. inches
Rotation (facing rear end)	Counterclockwise
Firing Order (20-cylinder)	1, 19, 8, 11, 5, 18, 7, 15, 2, 17, 10, 12, 3, 20, 6, 13, 4, 16, 9, 14
Main Bearings	4
Scavenging	Turbo-Centrifugal
Cooling System	Pressurized
Water pumps	Centrifugal
Lubricating oil system	Full Pressure
Main Oil Pump & Piston Cooling Pump	2 Positive Displacement Pumps in 1 Housing; Siamesed Inlet; Double Discharge
Scavenging Oil Pump	Helical Gear Type
Fuel Pump/Injector	Unit Pump/Injector with Needle Valve
Engine Starting	Air or Electric Motors
Rating at 900 rpm	2500 KW
Idle/Rated Speed	450/900 rpm

Figure 14-2 EMD Engine Service Data Sheet

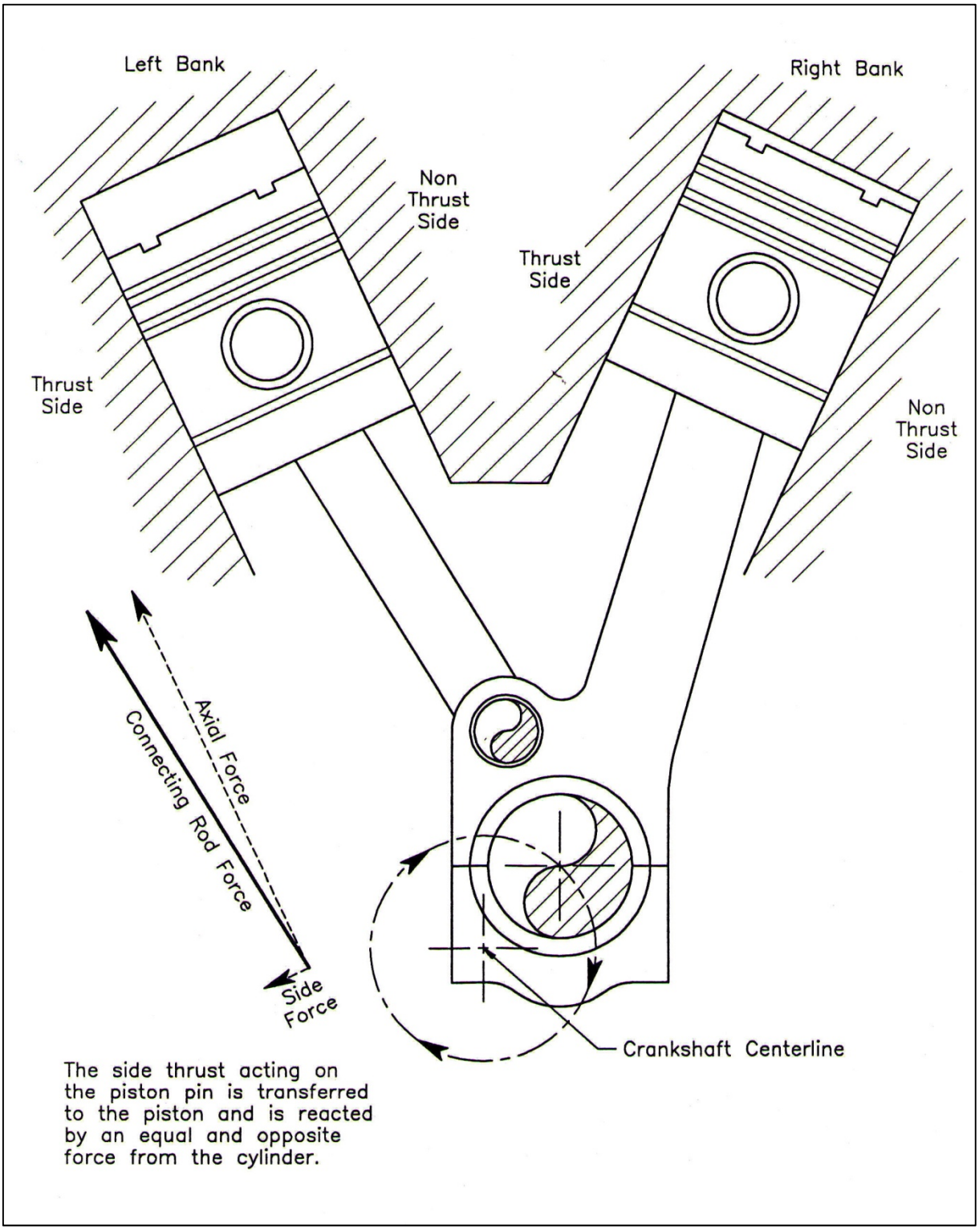


Figure 14-3 Cooper Engine Connecting Rods & Bearings

COOPER ENGINES
GENERAL DATA

	KSV-16-T	KSV-20-7
Engine Type	4-stroke cycle	4-stroke cycle
Cylinders	16	20
Bore	13.5 inches	13.5 inches
Stroke	16.5 inches	16.5 inches
RPM	600	600
KW	4000	5000
BHP	5580	6948
Max. PFP (PSI) Average	1690	1690/1850
Max Exhaust Temperature	980°F	905°F

Figure 14-4 Cooper Engine Service Data Sheet

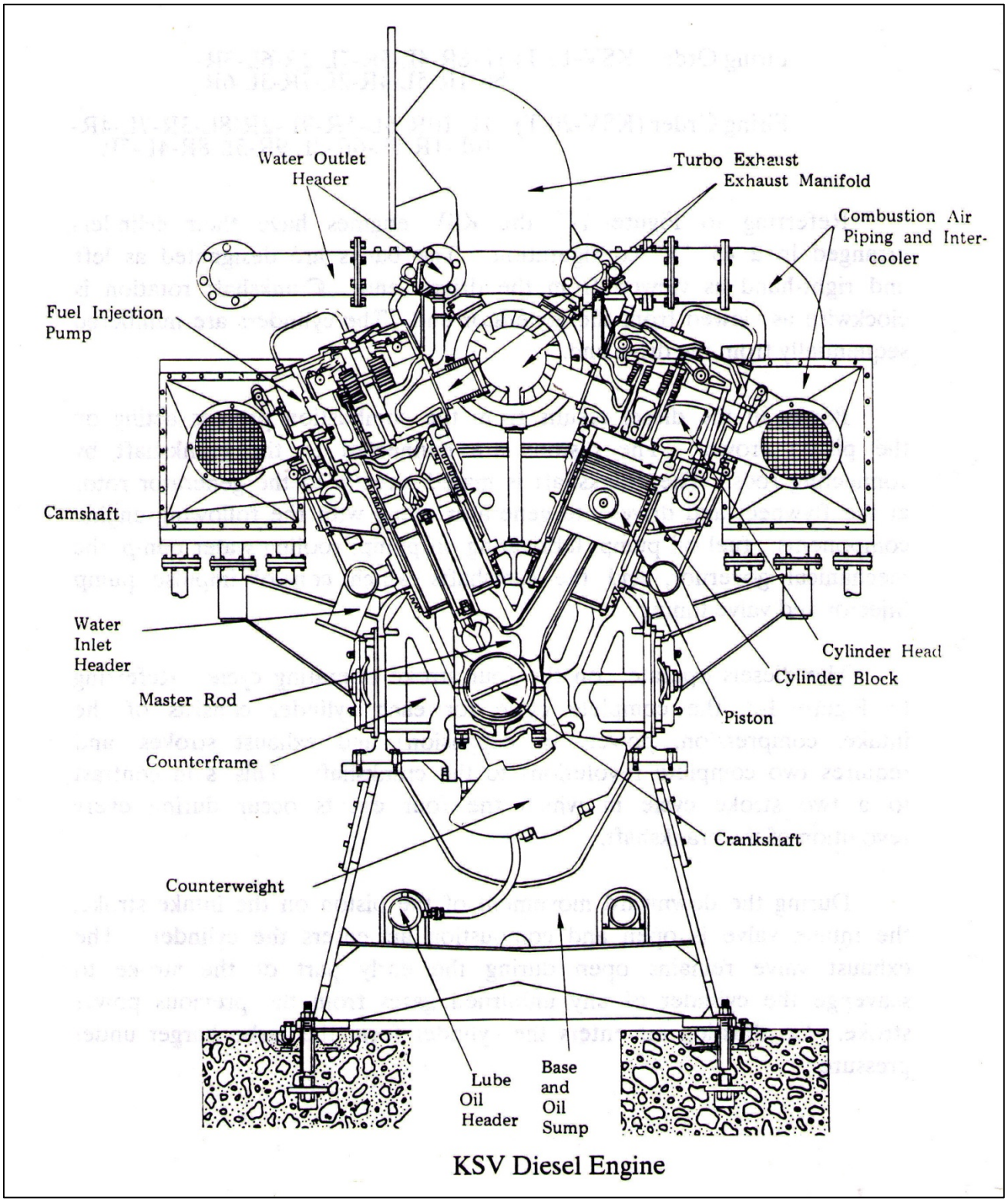


Figure 14-5 Cooper Engine Cross Section

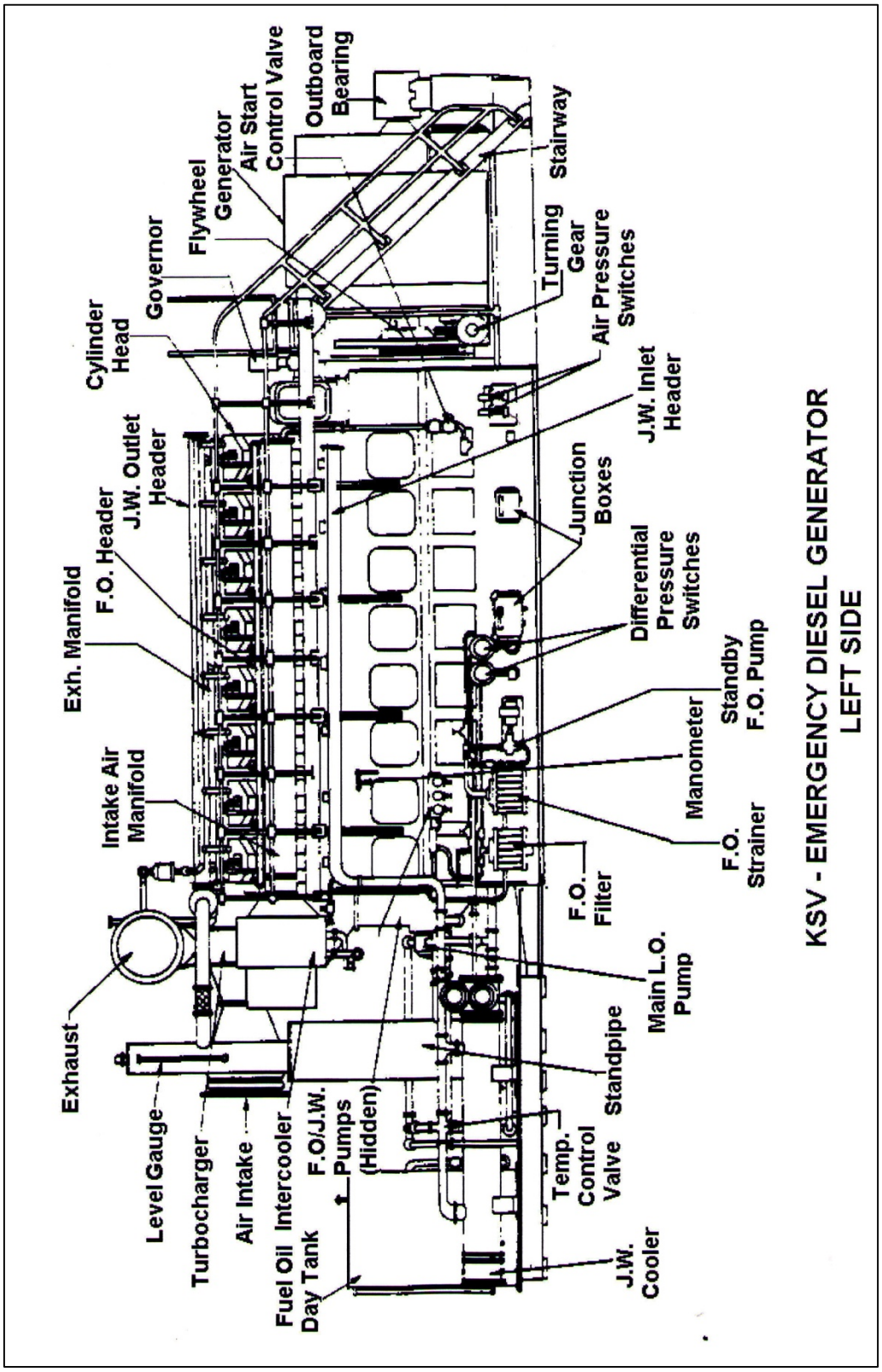


Figure 14-6 Cooper Engine Cross Section

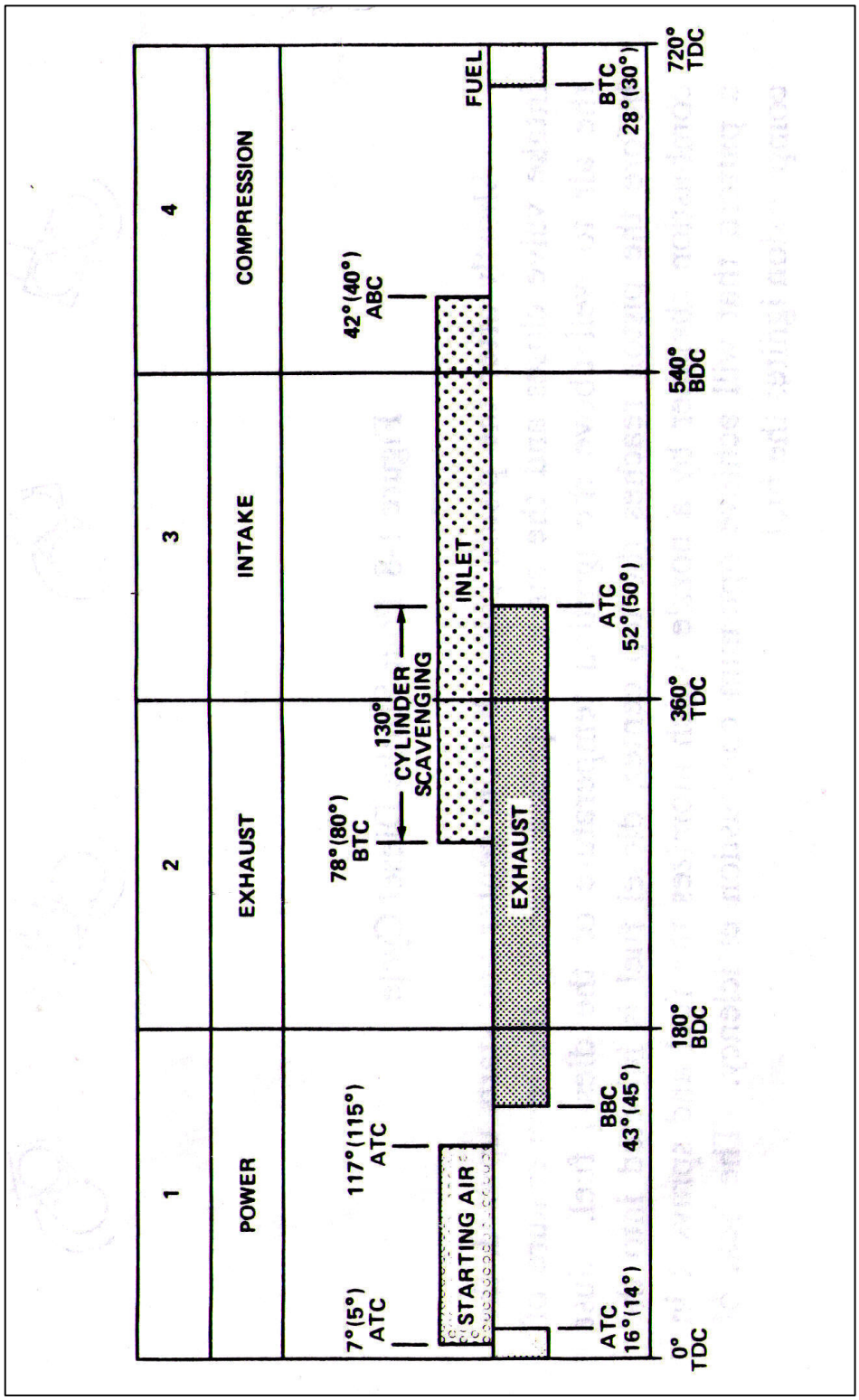


Figure 14-7 Cooper Engine Timing Bar Graph

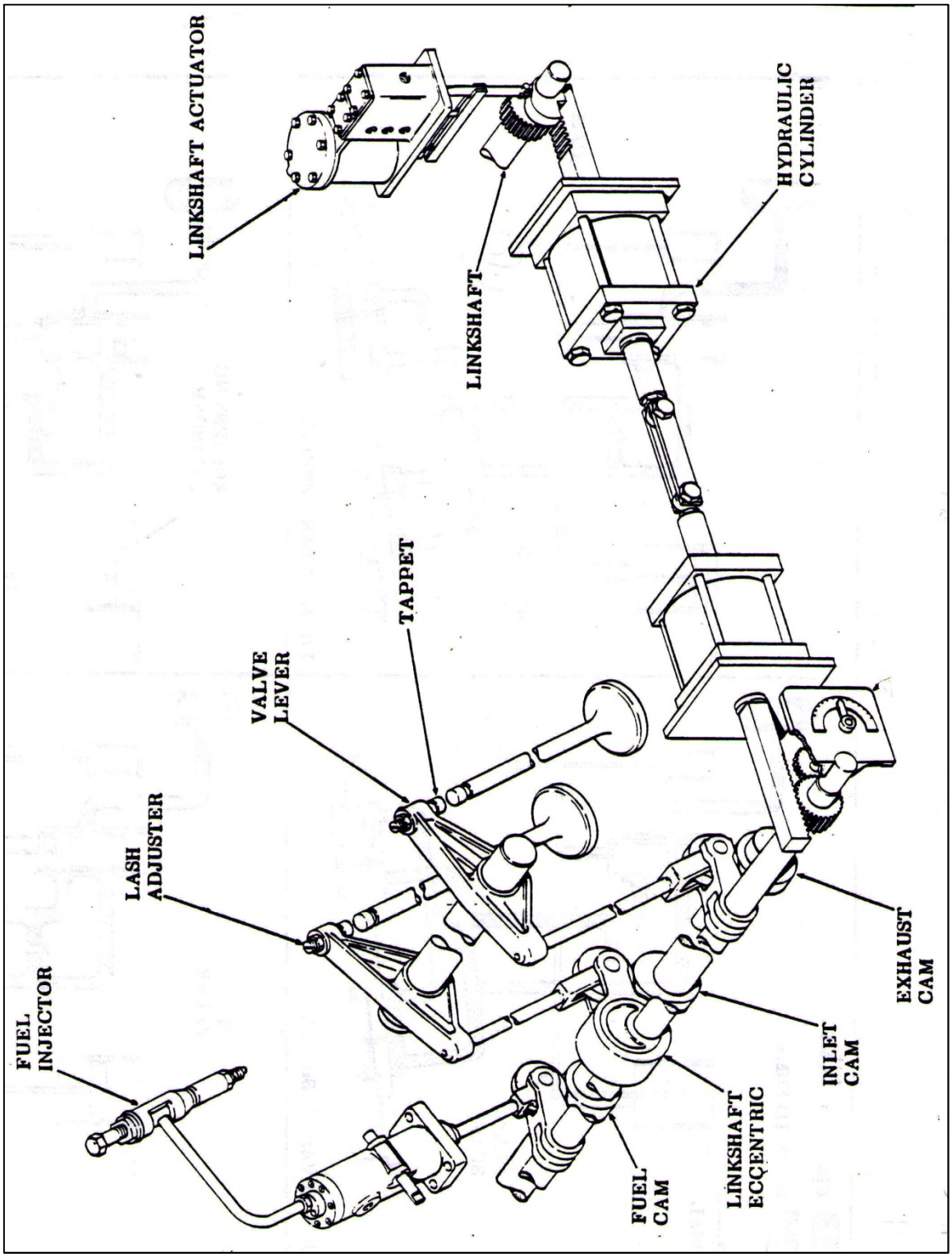


Figure 14-8 Nordberg Engine Linkshaft

NORDBERG ENGINES

GENERAL DATA

Engine Type	Four-Stroke Cycle, Vee
Rated and Idling Speed	514 RF
Number of Cylinders	16
Bore	13 ½ inches
Stroke	16 ½ inches
Rated Horsepower	4900 BHP
Rotation	Counterclockwise
Firing Order	1r-8l-6r-2r-7l-5r-4l-8r-1l-3r-6l-7r-2l-4r-5l
Electrical Ratings	4812 KVA at 0.8 Power Factor 3850 KW
Flywheel Markings	One Degree Equals 0.593 inch

Note: A torsional critical speed analysis has been made for this engine. This analysis shows the engine to be free from harmful torsional criticals throughout normal operation. Engine idle speed should be at 514 rpm.

Should it become necessary for minor repairs of maintenance work to operate the engine with the fuel is out from any given cylinder, this may be done provided the fuel out from no more than one cylinder at a time.

Figure 14-9 Nordberg Engine Service Data Sheet

NORDBERG ENGINES
Recommended Operating Temperatures and Pressures
for Straight Oil Engines Rated at 200 BMEP

Temperatures (Degrees Fahrenheit)	Minimum	Maximum
Inlet Manifold Air	120	150
Jacket Water from Engine	165	175
Lubricating Oil from Engine	160	170
Cooling Water from Turbocharger		190
Exhaust (Pre-turbine)	940	1020
Exhaust (Individual)	675	775
Pressures (psi)		
Compression	830	880
Maximum Firing	1200	1250
Lubricating Oil to Engine	36	42
Fuel to Header	36	42
Jacket Water to Engine	**	35
Starting Air	150	250

** As required to maintain normal 10 to 12° temperature rise across the engine.

Pressures (Inches of Water)		
Crankcase Vacuum	0.2	1.0
Suction before Turbocharger		8
Exhaust Back Pressure		10
Air Inlet Manifold Pressure at 514 rpm (psig) Approximate		
100 percent load		23.5
75 percent load		13.5
50 percent load		7.8

Figure 14-10 Nordberg Engine Operating Pressures & Temperatures

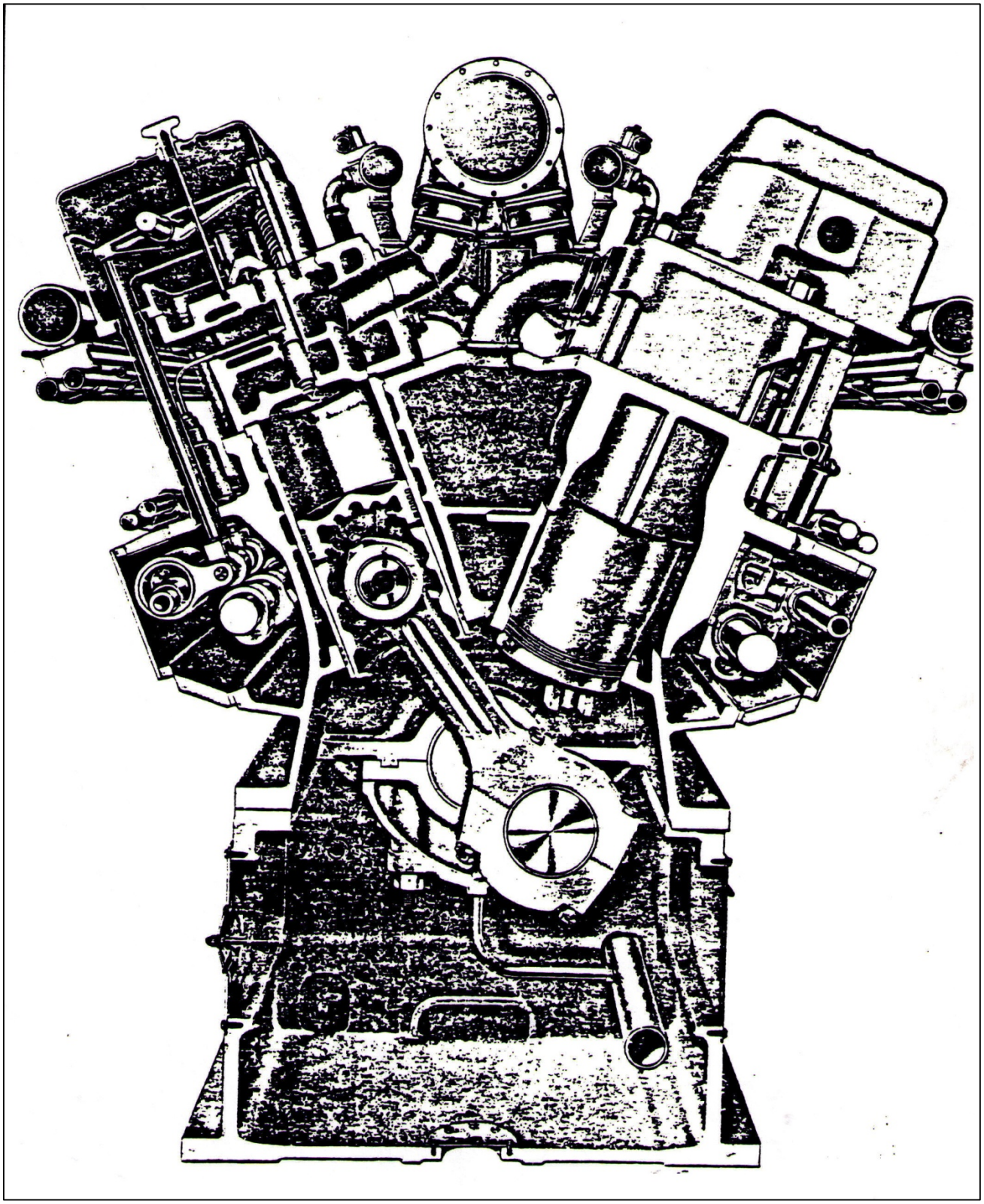


Figure 14-11 Nordberg Engine Cross Section

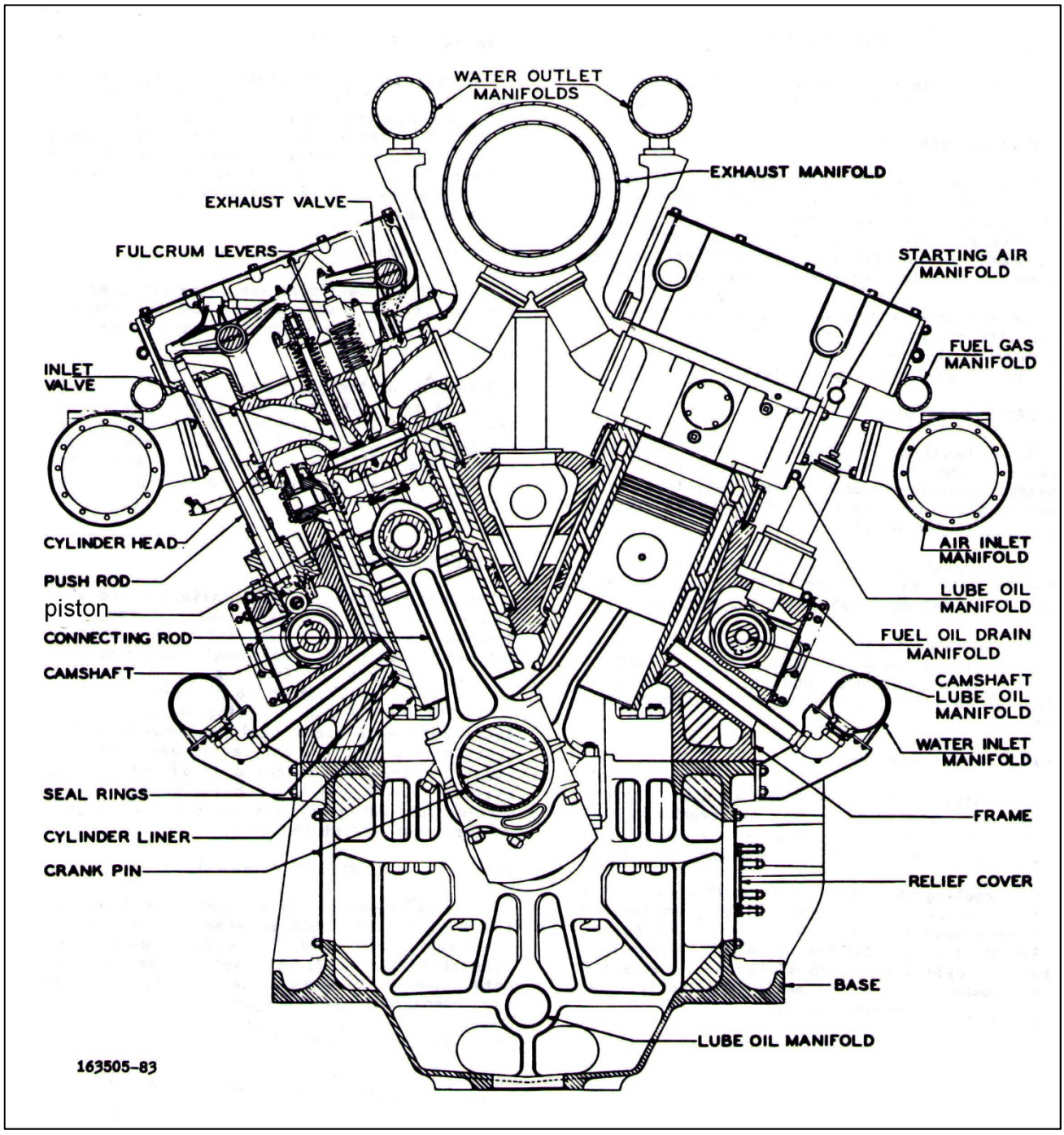
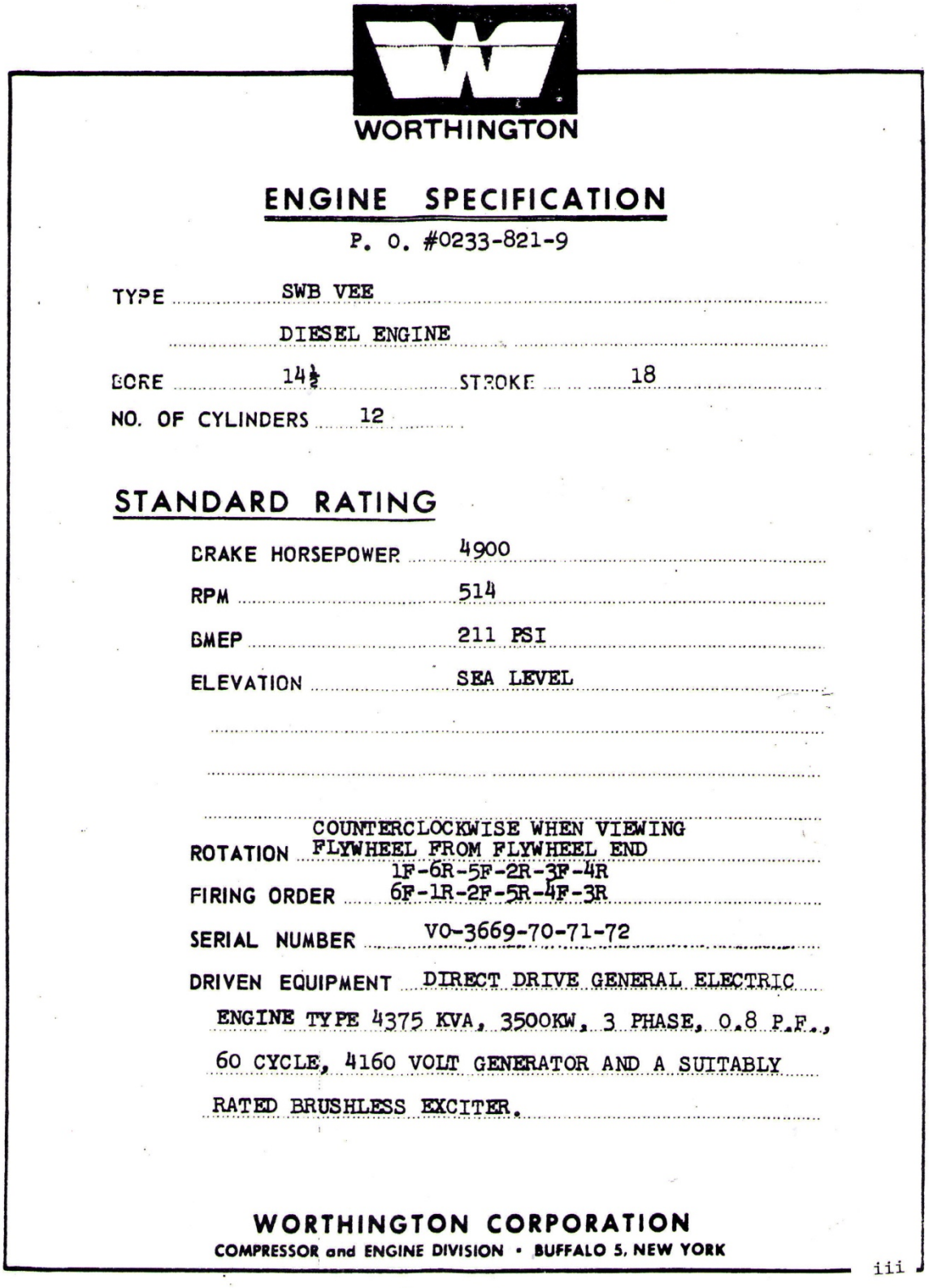


Figure 14-12 Worthington Engine Cross Section



WORTHINGTON

ENGINE SPECIFICATION

P. O. #0233-821-9

TYPE SWB VEE DIESEL ENGINE

BORE 14½ STROKE 18

NO. OF CYLINDERS 12

STANDARD RATING

BRAKE HORSEPOWER 4900

RPM 514

BMEP 211 PSI

ELEVATION SEA LEVEL

ROTATION COUNTERCLOCKWISE WHEN VIEWING FLYWHEEL FROM FLYWHEEL END

FIRING ORDER 1F-6R-5F-2R-3F-4R
6F-1R-2F-5R-4F-3R

SERIAL NUMBER VO-3669-70-71-72

DRIVEN EQUIPMENT DIRECT DRIVE GENERAL ELECTRIC ENGINE TYPE 4375 KVA, 3500KW, 3 PHASE, 0.8 P.F., 60 CYCLE, 4160 VOLT GENERATOR AND A SUITABLY RATED BRUSHLESS EXCITER.

WORTHINGTON CORPORATION
COMPRESSOR and ENGINE DIVISION • BUFFALO 5, NEW YORK

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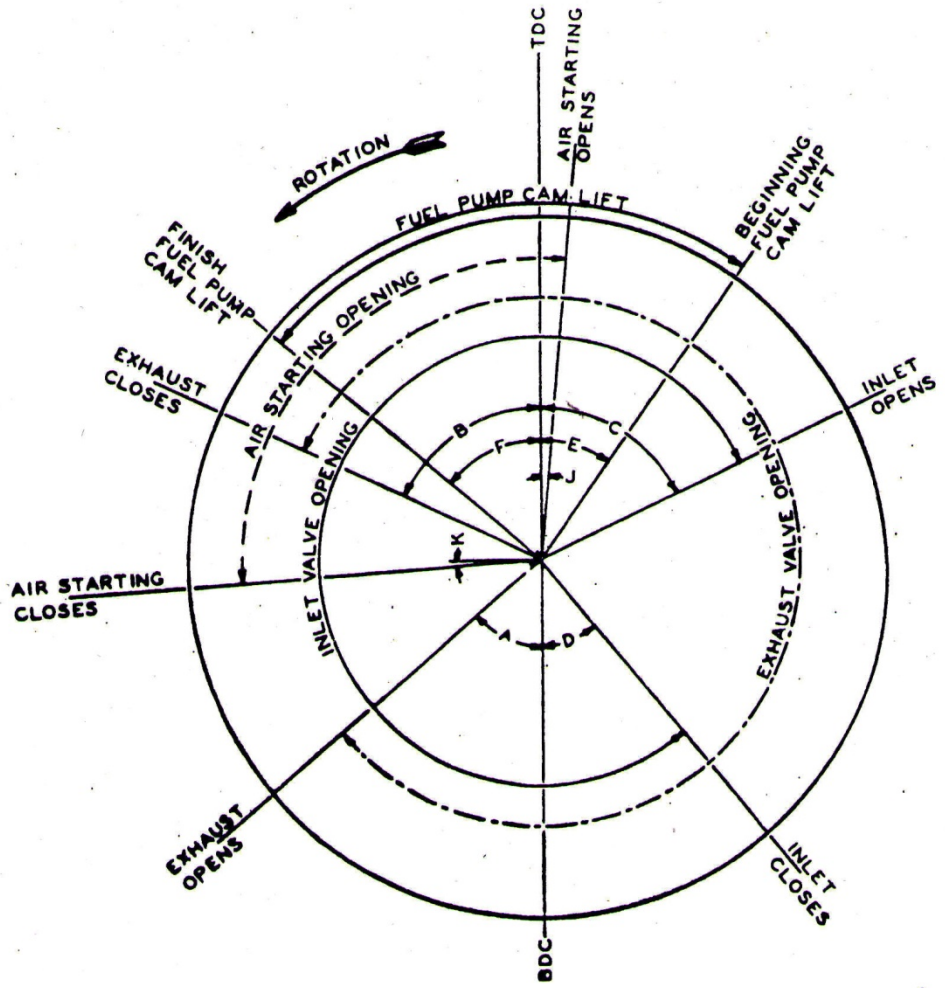
Figure 14-13 Worthington Engine Service Data



TIMING DIAGRAM

A.	Exhaust Valve opens	50	Deg. B.B.D.C.
B.	Exhaust Valve closes	65	Deg. A.T.D.C.
C.	Inlet Valve opens	65	Deg. B.T.D.C.
D.	Inlet Valve closes	40	Deg. A.B.D.C.
E.	Fuel Pump Lift begins	35° - 30'	Deg. B.T.D.C.
F.	Fuel Pump Lift ends	50° - 04'	Deg. A.T.D.C.
J.	Starting Air opens	6° - 30'	Deg. B.T.D.C.
K.	Starting Air closes	116° - 30'	Deg. A.T.D.C.
	Fuel Pump Port Closing	16.5	Deg. B.T.D.C.

Figure 14-14 Worthington Timing Diagram

EMERGENCY DIESEL GENERATOR DESIGN DATA

DIESEL ENGINE

MANUFACTURER	SACM DIESEL
MODEL/TYPE	UD 45 V16 S5D
QUANTITY	TWO PER GENERATOR SET
CYCLE	FOUR
CONTINUOUS FULL-LOAD RATING	2,785 kW PER ENGINE (GROSS LOADS)
SHORT-TIME RATING	3,064 kW PER ENGINE (GROSS LOADS)
RATED ENGINE SPEED	1,200 RPM
CYLINDER ARRANGEMENT	VEE AT 50°
NUMBER OF CYLINDERS	16

Figure 14-15 SACM Engine Service Data Sheet

EMERGENCY DIESEL GENERATOR DESIGN DATA

DIESEL GENERATOR

MANUFACTURER	JEUMONT-SCHNEIDER
TYPE	SAT 100/100/6
CONTINUOUS FULL-LOAD RATING	5,400 kW (NET ELECTRICAL OUTPUT)
SHORT-TIME RATING	5,940 kW (NET ELECTRICAL OUTPUT)
POWER FACTOR (AT CONTINUOUS RATING)	0.8
RATED VOLTAGE	4,160 V
FREQUENCY	60 Hz
kVA (AT CONTINUOUS RATING)	6,750
LINE CURRENT (AT CONTINUOUS RATING)	938 AMPS

Figure 14-16 SACM Generator Service Data Sheet

DELAVAL ENGINES

GENERAL DATA

Engine Type . . . . . Four-Stroke Cycle, Enterprise DRS Vee

Rated Speed . . . . . 450 RPM

Number of Cylinders . . . . . 16 (2 banks of 8 cylinders in a Vee)

Bore . . . . . 17 inches

Stroke . . . . . 21 inches

Piston Speed . . . . . 575 fpm

Rated Horsepower . . . . . 667 BHP per cylinder (515 kw)

BMEP . . . . . 250 psig

Engine Peak Firing Temperature (rated load) . . . . . 1750^{O} F.

Engine Peak Firing Pressure (rated load) . . . . . 1500 psig*

*This 1500 psi peak firing pressure acting on the pistons top surface area loads the piston with 340,000 pounds 225 times each minute.

Figure 14-17 DeLaval Engine Service Data Sheet

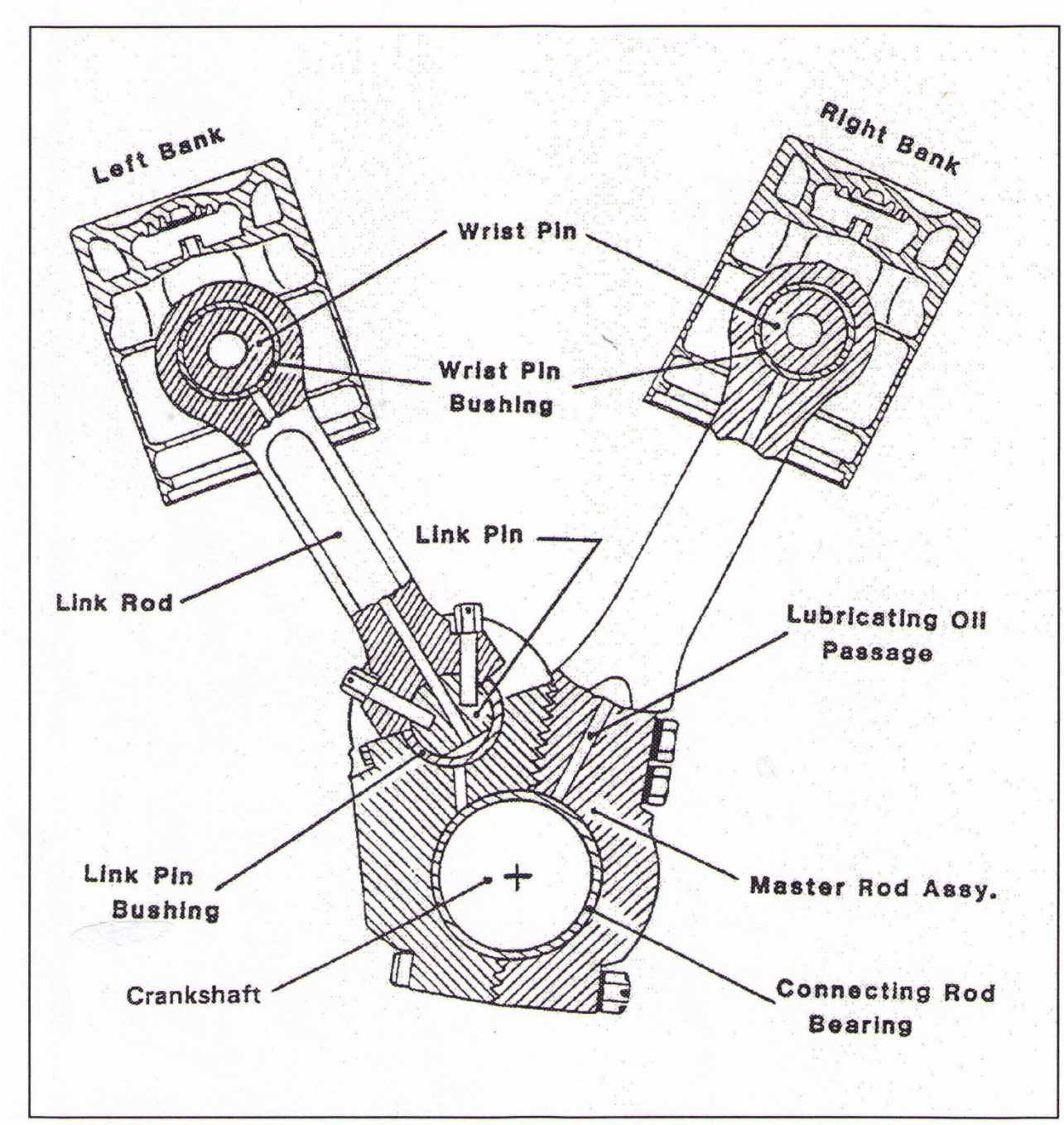


Figure 14-18 DeLaval Engine Articulating Connecting Rod Assembly