INTERNAL COMBUSTION ENGINES

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1.0 SCOPE

This data sheet applies to the inspection and maintenance of gaseous- or liquid fueled reciprocating internal combustion engines (ICEs) greater or equal to 500 hp (373 kW). While guidance is provided for size-sensitive recommendations, it is not possible to address all engine installations. Therefore, engineering judgment is to be used in the application of the recommendations for smaller engines under 500 hp (373 kW).

This data sheet deals only with internal combustion engines and integral engine-compressor units. Separately driven equipment (generators, pumps, compressors, etc.) are beyond the scope of this document.

Recommendations contained in this data sheet are not applicable to engines used to drive fire pumps or emergency electric power generators. Recommendations for these engines can be found in Data Sheet 3-7, *Fire Protection Pumps*, and Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*, respectively.

For integral engine-compressor units, additional guidance for fire and explosion perils can be found in Data Sheet 7-95, *Compressors*.

Reference to other data sheets may be necessary to ensure appropriate loss control measures have been taken. Such data sheets include the following:

Data Sheet 9-0/17-0, *Asset Integrity*
Data Sheet 9-18/17-18, *Prevention of Freeze-ups*
Data Sheet 13-18, *Industrial Clutches and Clutch Couplings*
Data Sheet 13-7, *Gears*

1.1 Changes

July 2020. Interim revision. Updated contingency planning and sparing guidance.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

All recommendations made in this data sheet pertaining to maintenance of reciprocating components and cylinders of internal combustion engines apply to integral compressors as well (for example, clearance checks of bearings and crossheads, NDE of connecting rods).

2.2 Equipment and Processes

2.2.1 General

Check and prepare all engines as described below prior to operation.

2.2.1.1 Ensure wiring and tubing are adequately protected from the heat and vibrations emitted by reciprocating machinery. Use harnesses as specified by the original equipment manufacturer (OEM) to protect wire and tubing bundles from mechanical wear and thermal degradation.

2.2.1.2 Route harnesses to prevent accidental damage from personnel. Place harnesses 6 to 12 inches from connectors to prevent excessive stress or deflection. Support wires and tube bundles so that engine mechanical vibration does not cause excitation of bundles. Resonant frequencies or mechanical wear can result in wire and tubing failure within a short period of time.

2.2.1.3 Ensure new and overhauled units are given a break-in period during which the engine is operated at reduced load. Refer to the OEM’s guidelines for specific instructions.

2.2.1.4 Pre-heat and circulate lubricating oil through the bearings prior to unit startup to prevent excessive wear. Arrange the pre-lube pumps to start automatically prior to rolling the engine over for blow-down or starting the engine. In addition, design pre-lube pumps to start automatically when the engine is being shut down. This applies to large medium-speed or slow-speed engines that may only have engine-driven lube-oil pumps.

Provide a lube-oil pressure permissive for engines with electrically driven lube-oil pumps so the engines cannot be rolled over until the lube-oil pressure permissive is satisfied. Do not rotate large engine crankshafts at any speed without pressure lubrication to the bearings.

2.2.1.5 Install mechanical crankcase ventilation on large engines. Decreasing differential pressure (increased crankcase pressure) can be caused by worn, stuck, or broken piston rings, worn cylinder liners, or loss of mechanical ventilation.

2.2.2 Protective Devices

2.2.2.1 Equip all IC engines with protective devices listed in Table 1. Provide separate alarm and trip settings as indicated in the table. Do not use time delays for ICE protective service.

Use protective devices that either shut down the engine or prevent startup if there is a failure (electric or pneumatic) in the shutdown circuitry (i.e., all protective devices will ‘‘fail-safe’’).

Table 1. Protective Devices for Internal Combustion Engines

Device	*Alarm*	*Trip*
High cooling water jacket temperature	X	X
Low engine lube-oil pressure	X	X
High lube-oil temperature	X	X
High bearing temperature (apply only to main bearing thermocouple embedded in the bearings)	X	X
Power cylinder lubrication, no flow[1]		X
Excess engine vibration		X
Engine overspeed detection system[2]		X
Turbocharger: — Thrust bearing failure detector — Low oil pressure Overspeed trip actuator[3] — High lube oil temperature	X X X	X X X X
‘‘Engine running’’ indicator (for all emergency engines that start automatically)	X	
Auxiliary oil pump running	X	
Crankcase overpressure[4]		X

1. Power Cylinder lube oil no-flow most likely will apply only to slow speed engines with a cross head arrangement.

2. Overspeed shutdown devices are the type that operates totally independent of other engine control functions to protect against runaway and subsequent damages.

3. If recommended by engine manufacturer.

4. Can be caused by overpressure from compressor rod seal leaks on integral engine-compressor units, cracked or worn power piston rings, cracked engine block, and crankcase explosion.

2.2.2.2 Equip all diesel engines of more than 1000 hp (745 kW) with both inlet air and fuel shutoff valves to prevent engines from continuing to run when volatile fumes are present following a unit trip. Spark ignition engines need only be equipped with a fuel shut-off valve.

2.2.2.3 Transmit all actual control instrumentation values and protective device signals for unattended operating engines to monitors at constantly attended location.

2.2.2.4 Provide adequate FM approved crankcase explosion vents. Small engines typically do not have explosion vents.

2.2.3 Monitoring Devices

2.2.3.1 Provide temperature probes embedded in the thrust bearings and monitor lubricant drain temperature.

2.2.3.2 Where vibration monitoring is available, provide trend data collection to operators for further vibration evaluation.

2.2.3.3 Monitor crankcase pressure, increased pressure (or decreased differential pressure, depending on the installation) as piston rings and cylinder liners wear or are damaged. Crankcase pressure will also show an increase as crankcase ventilation fans or blowers lose performance or are otherwise damaged or restricted.

The crankcase pressure on large engines is usually measured as a differential pressure, referenced to atmosphere. It is typically slightly negative if the crankcase ventilation system is operating properly and there are no adverse mechanical conditions with the engine.

2.2.3.4 Install the following monitoring devices: Installation of these devices is optional, though strongly advised if the loss potential is large enough to warrant the cost of their installation.

- Lube-oil metal particle monitor
- Crankcase oil mist detector
- Crankcase overpressure
- High and low crankcase oil level
- High oil pressure
- Low coolant level
- Low coolant flow
- High exhaust gas temperature

2.3 Operation and Maintenance

Viable inspection, testing and maintenance programs, record keeping, and data evaluation are essential tools to properly evaluate mechanical condition and engine performance to ensure engine reliability. Record and evaluate performance data so trends can be easily detected. Establish and implement an internal combustion engine inspection, testing, and maintenance program. See Data Sheet 9-0, *Asset Integrity, for guidance on developing an asset integrity program.*

Note: ″Mechanical condition″ refers to the physical condition of a machine. Good mechanical condition means that an engine's parts are all in new or nearly new condition, and deteriorating mechanical condition implies that a certain amount of physical damage (including wear) has occurred to one or more components.

Performance has to do with how a machine is carrying load. It is concerned largely with horsepower and fuel efficiency. An engine can be in good mechanical condition and be performing poorly. The opposite, however, is not true because an engine has to be in good mechanical condition to be able to perform to specification. Performance can be affected by items such as air/fuel ratio, ignition timing, and cam timing.

2.3.1 Predictive Maintenance Program

2.3.1.1 Establish a machinery monitoring and analysis program (MMAP) in accordance with the manufacturer's recommendations and as determined by operating experience. See Table 2.

Table 2. Predictive Maintenance Summary

Daily	*Weekly*	*Monthly*	*Quarterly*	*Semi-Annually*	*Annually*
Observe exhaust gas condition (diesels only). Check cylinder exhaust temperatures. Check water temperature differential to and from cooler. Check pressure drop across lube-oil filter.* Check pressure drop across fuel filter. Observe engine sound(s). Record any unusual observations. Visually inspect engine. Check crankcase pressure.* Check lube-oil temperature. Check Governor oil. Check jacket water temperature.	Emergency or standby engines: Start and run not less than 30 minutes (loaded if possible). Check operation of auxiliary oil pump. Check intake manifold pressure.* Check jacket cooling water composition.	Check cylinder compression pressures.* Check fuel consumption.* Check lube-oil consumption.* Submit lube-oil sample for analysis. Check ignition timing. Check power cylinder load balance (not to exceed 200 operating hr). Note and correct any variations >5% of engine avg. in peak firing pressures (PFP's) between cylinders.*	Check all unit safety devices for operation. Check crankshaft counterweight bolt indexing. On integral engine-compressor units, NDE all compressor valve cap studs.	Check valve clearances. Check foundation and grouting for cracking, breaking and excessive oil. Check and tighten all engine mounting bolts/ nuts; if tightening is required, redo web deflections. Check coupling for axial movement.	Measure web deflection at all crank throws at 4 angular positions (0°, 90°, 180°, 270° of crank rotation) Check main and connecting rod bearing clearances. Remove water temperature and oil pressure sensors from engine and test to ensure proper operation. Test and calibrate all pressure, temperature, and flow devices. Test all engine protective devices. Test overspeed trip (by actual overspeeding, if possible).
		Bi-Monthly			*Biennially*
		Analyze engine condition (not to exceed 1500 operating hours).*			NDE flywheel, counterweight, and crankcase mating bolts.

Refer to manufacturer's manuals for additional maintenance activities and their frequencies.
Engine dismantle/overhaul should be based on engine condition. Where engine condition analysis is not performed, engine dismantle/ overhaul should be done at 24000 operating hour intervals.
All quantities for items marked with an asterisk (*) should be recorded and trended to check for changes in engine condition.

2.3.1.2 Blow down engines prior to start to eliminate water that may have collected in the cylinders through leaks in the heads or liners. Confirm adequate starting capacity for air starting systems.

2.3.1.3 Check fuel rack hardware periodically as required by the OEM for binding linkages and loose hardware. There are cases where bolts fall out of fuel racks while running; this can lead to heavily imbalanced operation, especially in ″V″ configured engines.

2.3.1.4 Do not reuse cotter pins and tab locking washers.

2.3.1.5 Avoid wet stacking (wet stacking occurs when an engine runs unloaded or with too light a load). Sludge and carbon deposits can accumulate on valves, fuel injectors, piston rings, and turbocharger, resulting in decreased engine performance, fouled fuel injectors, and leaking valves.

2.3.1.6 To prevent crankcase explosions, equip large diesel engines with main bearing temperature monitoring devices. Oil-mist detection can also be used to detect mist in the crankcase and can be useful in preventing the development of an explosive atmosphere. See Figure 1.

An explosion can develop within a diesel engine crankcase when excessive blow-by past the piston rings allows an accumulation of fuel and oil mist to develop, or when crankcase ventilation is inadequate. The ignition source for crankcase explosions is often a hot bearing, which can develop as the result of engine overloading or inadequate lubrication.

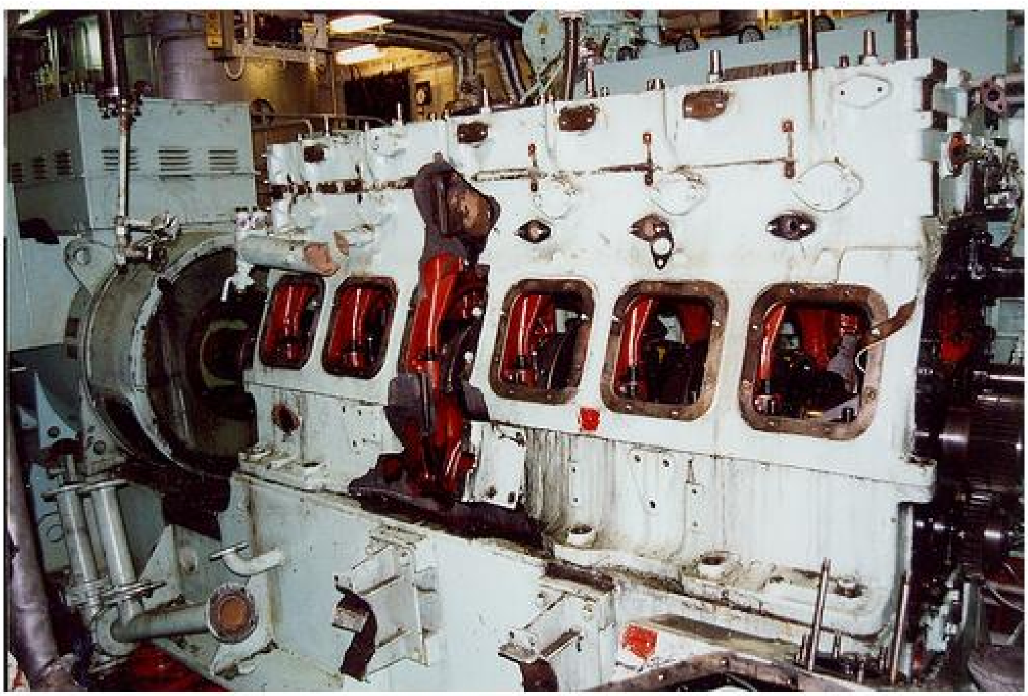

Fig. 1. The results of a crankcase explosion. (Used with permission)

2.3.1.7 The following items will have the most significant effect in reducing the possibility of an engine failure:

2.3.1.7.1 *Crankshaft web deflections*. Misalignment is one of the primary causes of crankshaft failures; it is therefore essential that crankshaft deflection be within acceptable limits. To ensure proper alignment, check crankshaft web deflections annually, or at any time maintenance activities could affect alignment. Measure deflection on every crank throw at as close to normal operating temperature as possible. Engines $<$ 1000 hp (745 kW) need only have deflection readings taken at the front and rear crank throws. Employ alternative means of alignment inspection for engines $<$ 1000 hp (745 kW) that do not have easy access to the crankshaft to take web deflection readings. In these cases, check alignment at each dismantle or as often as reasonably possible. Ensure deflection limits conform to manufacturer's specifications.

Check the main bearings when crankshaft web deflections exceed manufacturer's limits for wear and clearance. If clearances are satisfactory and all temperature detectors are in working order, no disassembly is required. If bearing condition is determined to be acceptable, realign the engine crankshaft to correct the deflection by adding or removing shims from under the bearing keeps.

2.3.1.7.2 *Engine condition*. Monitor engine condition as indicated in Section 2.3.2.

2.3.1.7.3. *Protective devices.* Install, test and calibrate all engine protective devices listed in Table 1.

2.3.1.7.4. *Connecting rod and main bearings (see Figure 2).* Check bearing conditions and clearances at the intervals recommended by the manufacture. It is not recommended that main or connecting rod bearings be disassembled for their annual clearance check if they have been operating satisfactorily up to that time. Many bearing failures can be attributed to the introduction of dirt during dismantle or reassembly, or possible human errors, such as misalignment, during reassembly. During the bearing check, verify that connecting rod bolts and nuts are secured. Measure and NDE connecting rods during engine dismantles and maintain a log of component measurements.

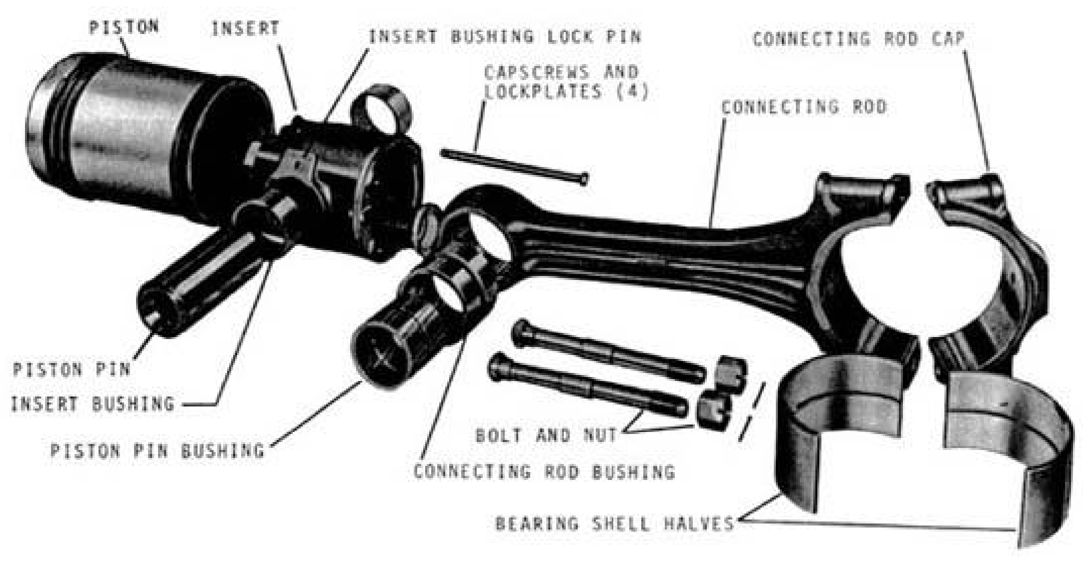

Fig. 2. Connecting rod components (Courtesy of Wartsila Corp.).

2.3.1.7.5. *Power cylinder load balancing*. Check power cylinder load balance weekly (200 hr max) at rated load and speed with all temperatures and pressures stabilized. This will minimize the effects of unbalanced cylinder loading on critical engine parts (crankshaft, bearings, connecting rods, pistons, etc.).

Rebalance cylinder load in accordance with the manufacturer's specifications or any time there is a differential in peak firing pressure of 30 psi (207 kPa) or more between cylinders or a maximum deviation of 5% cylinder to cylinder or 5% of the average of all cylinders.

When individual cylinders are overloaded or underloaded, they do not operate at peak efficiency. Fuel consumption increases and operating pressures and temperatures rise, increasing wear on critical engine components such as bearings and rings.

2.3.2 Engine Condition Monitoring

2.3.2.1 Perform engine condition monitoring (e.g., engine analysis, performance monitoring, etc.) ***on*** each engine after not ***more than*** 1500 hours of operation. Take and trend the following data to determine the condition of the engine. To ensure consistency of data, engine load and speed must be at specified conditions at the time of data collection.

1. Ignition system — primary and secondary voltages, pulses and timing

2. Power cylinder load balance

3. Power cylinder vibration

- Conventional (5 kHz 28 kHz)
- Ultrasonic (15 kHz 70 kHz)

4. Oil analysis

5. Spectrum analysis (vibration)

- Turbocharger
- Oil and water pump
- Accessory drives
- Frame and foundation

6. Critical process variables

- Lube oil and coolant pressure and temperature
- Air and fuel manifold pressure and temperature
- Lubrication system data
- Exhaust temperature
- Turbo speed
- Fuel measurement data consumption and fuel analysis)
- Waste gate valve and bypass positions
- Ambient pressure and temperature

In addition, take and trend the following as applicable:

7. Crankshaft deflection readings

8. Main and connecting rod bearing and wrist pin clearance and condition

The following observations warrant an immediate shutdown of the engine to determine cause:

- An increase in *crankcase pressure* of 25% or more above the baseline
- A decrease in *compression pressure* of 10% or more below the baseline
- An increase in lube-*oil consumption* of 20% or more above the baseline
- An increase in *specific fuel consumption* of 10% or more above the baseline
- An increase or decrease in peak *firing pressure* of 10% or more above or below the baseline

If a trend is observed where all or many of the above variables are approaching their respective limits, schedule overhaul activity to correct the adverse conditions, since a gradual deterioration of all variables indicates overall wear.

2.3.3 Testing of Protective Devices

2.3.3.1 Do the following at least once per year:

A. Test the overspeed trip by actually overspeeding the engine. Follow the manufacturer's recommended procedures. Record the speed at which the engine trips. The trip limit is 110% of rated speed unless specified otherwise by the manufacturer. During the test, verify that the governor and overspeed protection system functions to shut off the fuel supply to the engine, as well as close the air intake (see Figure 3).

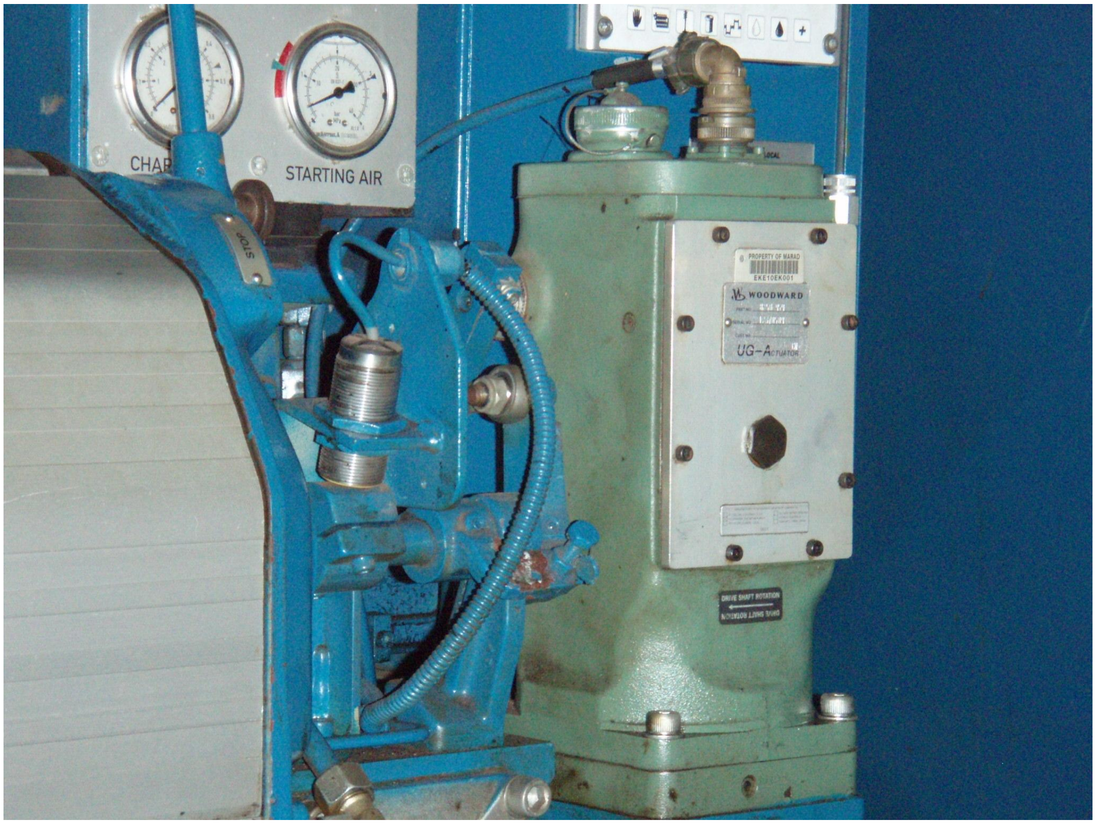

Fig. 3. Governor/overspeed system (courtesy Wartsila Corp.).

This will test the reliability of the overspeed trip actuator, the signal transmission system, and the engine air and fuel shutoff valves. If overspeeding is not possible, a simulation method can be used, provided it tests all of the above mechanisms.

B. Cooling systems. Jacket water temperature sensing devices are highly susceptible to corrosion and the effects of additives and impurities. Carbon in engine oil can foul oil pressure sending units. While an engine is shut down, remove the jacket water temperature and oil pressure trip sending units, visually inspect them, and test them using suitable external methods to ensure that they actuate the alarm and trip mechanisms. See Figure 4.

C. Compare the levels of water temperature and oil pressure at which alarms and trips occur to their design set points, and recalibrate the switches if they do not actuate at the proper settings.

D. Inspect, test and maintain all remaining protective devices via simulation methods during convenient shutdown periods. Remove and disassemble the devices (where applicable), and thoroughly clean and inspect for corrosion or other visual defects.

2.3.4 Lube-Oil Analysis

2.3.4.1 Monthly, take lube-oil samples from each engine and have them analyzed for water, acid, solids, etc. (including percentage of each). The presence of lacquer, oxidation, moisture, sludge, etc., will result in decreased engine life; metals in the oil are indicators of wear problems, etc. Such analysis in conjunction with a suitable MMAP will provide an accurate picture of engine condition. In addition, take oil samples from each bulk delivery for analysis to confirm proper oil and additives, and absence of contaminants (see Figure 5).

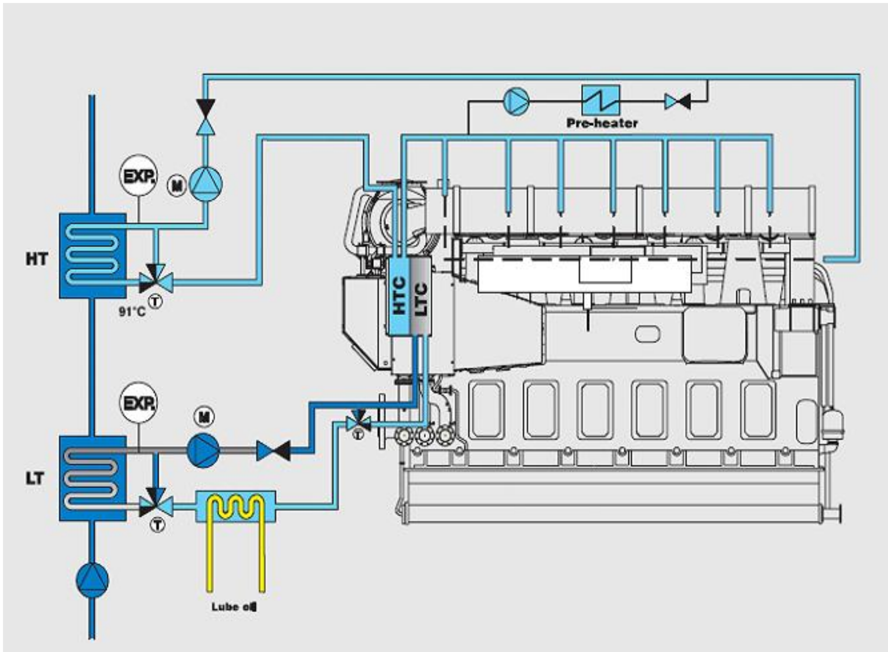

Fig. 4. Cooling system (courtesy Wartsila Corp.)

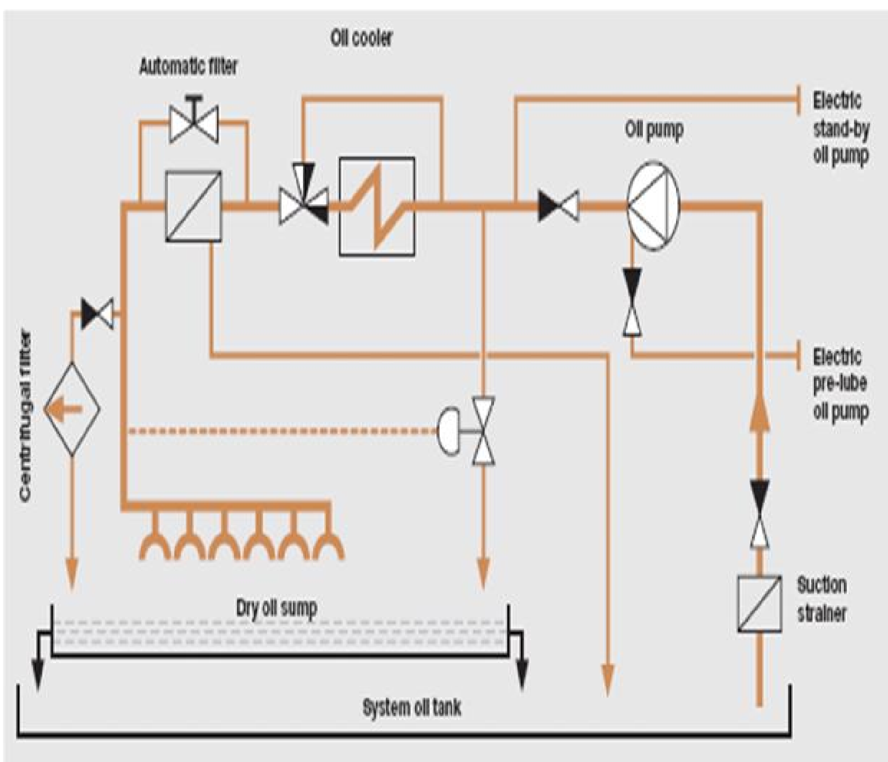

Fig. 5. Lube-oil system (courtesy of Wartsila Corp.).

2.3.5 Fuel System and Fuel-Oil Analysis

2.3.5.1 Conduct fuel-oil analyses on a regular basis. Ensure the quality of fuel oil used is in accordance with the manufacturer requirements. Extensive damage can be attributed to poor fuel quality. High-temperature corrosion of valves and piston crowns can be accelerated when sulfur and vanadium limits in fuel are exceeded. (See Figures 6 and 7.)

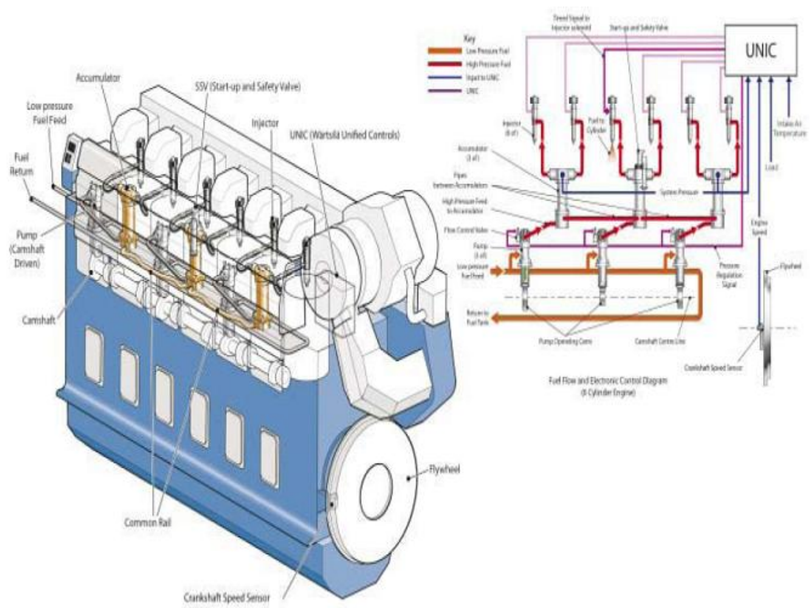

Fig. 6. Electronic fuel injection system (courtesy Wartsila Corp.)

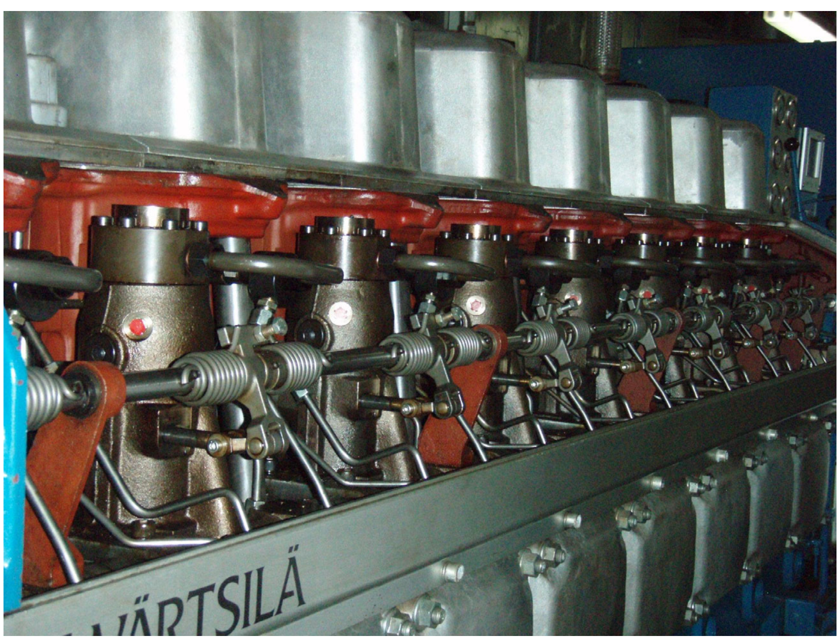

Fig. 7. Mechanical fuel injection system (courtesy Wartsila Corp.)

2.3.6 Engine Component Inspection

2.3.6.1 Overhaul/Dismantle Activity (All)

2.3.5.1.1 In addition to annual crankshaft deflection readings, take main bearing offset deflection readings on any engine that has had a history of crankshaft failures to detect and correct any main bearing offset, which could lead to torsion fatigue failures of crankshaft journals. Also, during overhaul or extended shutdown periods, nondestructively examine the crankshaft. For engines >1000 hp (745 kW), the crankshaft is usually accessible for in-place examination by the ultrasonic method, with the explosion vent panels removed.

2.3.6.1.2 At intervals not exceeding two years, ultrasonically examine the following highly stressed fasteners to ensure their integrity: flywheel bolts, counterweight bolts, crankshaft mating bolts, and connecting rod pin bolts.

In addition, index counterweight bolts such that a change in position of any part can be visually determined. For engines in continuous service, check the indexing during any routine maintenance period, not to exceed annually. For engines in intermittent service, check indexing after every 2000 hours of operation.

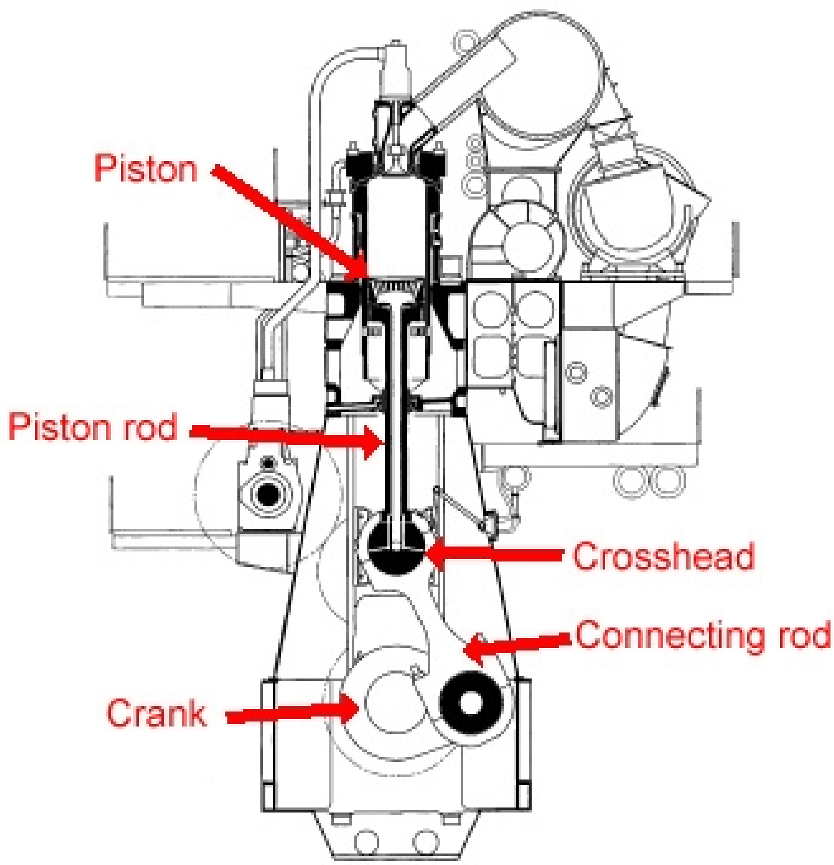

Fig. 8. Engine components

2.3.7 Repair of Internal Combustion Engines

2.3.7.1 Crankshafts

2.3.7.1.1 Make a complete engineering analysis prior to performing any crankshaft repairs. (See Figure 9.) Include in this analysis measurements and hardness testing of damaged journals. Compare the results with the limits set by the manufacturer to determine if a repair of the crankshaft is feasible.

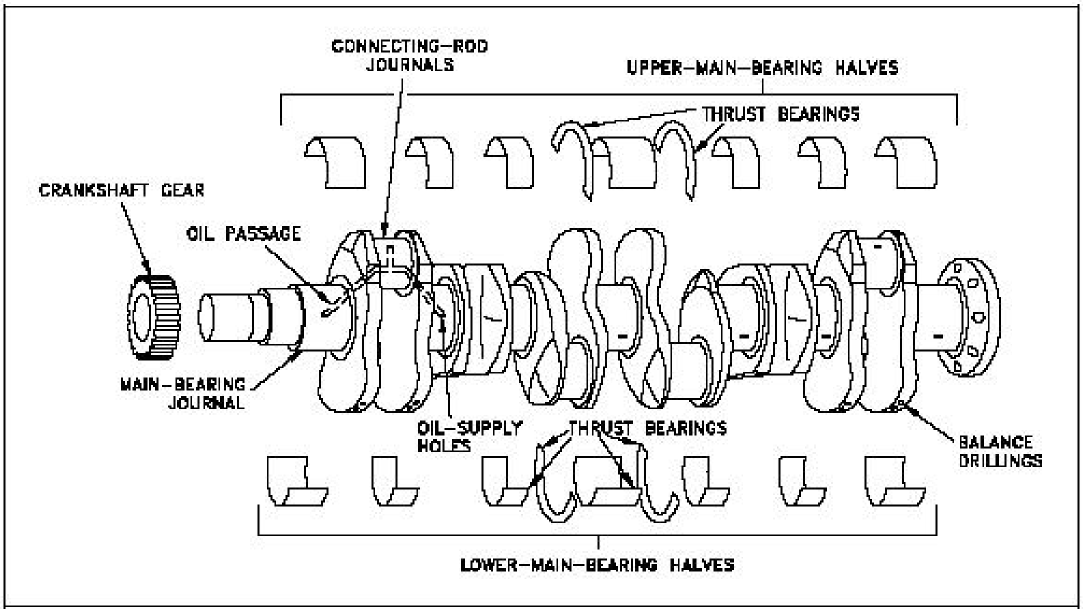

Fig. 9. Crankshaft components (courtesy of Wartsila Corp.).

2.3.7.1.2 Ensure machining of crankshafts that have sustained surface damage such as scoring or pitting does not exceed the manufacturer's specifications.

2.3.7.1.3 Some crankshafts can be surface-repaired by adding new metal to the undersized journal(s). This is normally followed by an outer layer of wear-resistant material that is ground and polished to meet surface quality and dimensional requirements. Apply this process only if recommended by the engine manufacturer or as a result of an independent, detailed, and documented engineering study.

2.3.7.1.4 Do not repair cracked crankshaft journals or webs by welding. The stress(es) that caused the initial crack will cause the weld-repair to crack even faster, since weld repairing invariably reduces the crankshaft's fatigue strength.

2.3.7.1.5 Any time a crankshaft has cracked (or broken), determine and correct the cause of the failure before a replacement crankshaft is placed into service.

2.3.7.1.6 Confirm proper main bearing alignment before installing a replacement crankshaft. If the main bearings are aligned, analyze the system for resonances, and correct before returning the engine to service. If the crankshaft failure was a diagonal crack across the connecting rod journal (see Figure 10), torsion vibration may exist. Where the crack was through the crank web, offset bearing misalignment is the most likely cause.

2.3.7.1.7 Other items that could contribute to crankshaft overloading and subsequent failure are cylinder load imbalance, operating in an overloaded condition, and excess bearing clearance.

2.3.7.1.8 When a new engine system is installed or whenever modifications have been made to the shaft's mass elastic system, analyze the crankshaft and driven object shafting system for resonances to ensure the unit will not be operated at or near a critical speed. Set the engine vibration trip device(s) at the time of installation or modification.

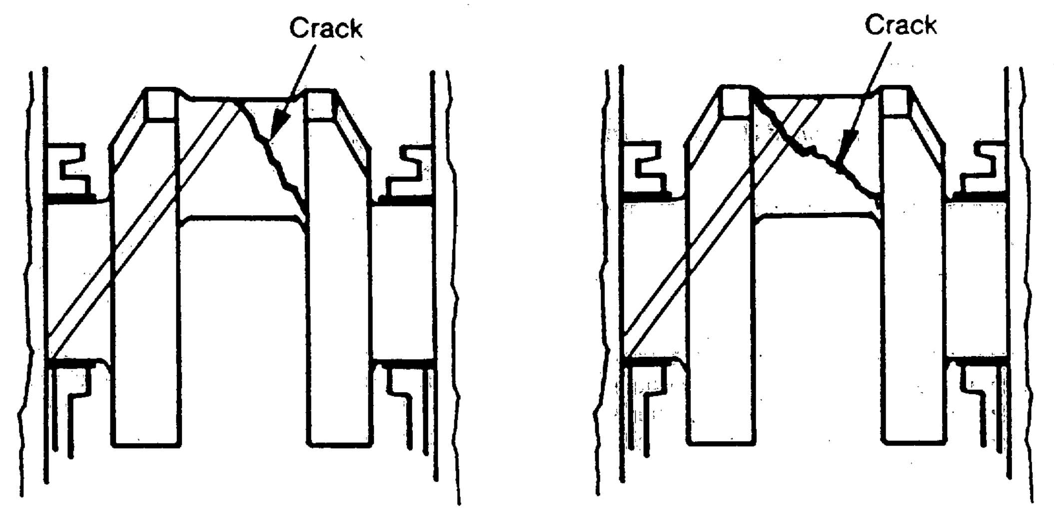

Fig. 10. Torsional stress cracks caused by offset main bearing misalignment.

2.3.8 Pistons

2.3.8.1 Thoroughly inspect the fasteners that secure the crown to the skirt and the locking devices of new or remanufactured pistons, to ensure they are properly torqued and the locking devices are properly installed. Also verify that all piston oil cooling holes are free of any blockage, and that any protective packaging plugs the manufacturer had installed are removed before piston installation.

2.3.9 Engines in Standby Service

2.3.9.1 Infrequently used engines may not run enough hours to fit the maintenance schedule outlined for frequently or continuously operated engines (Table 2). However, inspection, testing and maintenance is required for these engines to ensure that they will start and run properly when needed. The following activities, in addition to those proposed by the engine manufacturer, will have the most significant effect in reducing the probability of serious engine problems:

1. Once a week, blow down engines with wet liners to remove moisture from the cylinders. Adjust the frequency to a shorter interval (two to three times a week) if local conditions show that a lot of moisture accumulates in the cylinders. If there's a lot of moisture consistently, investigate for leakage or damage.

2. Check the jacket water and lube-oil ″keep warm″ or pre-heater systems daily to make sure the engine is maintained at a ready-to-start temperature.

3. Ensure large diesel engines receive a blow down prior to start.

4. Check fuel rack hardware for binding linkages and loose hardware at intervals as specified by the OEM. There are cases where bolts fall out of fuel racks while running. This can lead to heavily imbalanced operation, especially in ″V″ configured engines.

5. Test start/run systems monthly. Prior to starting the engine, verify that that lube-oil jacket water and pre-lube pumps are set up for proper operation in auto-start. Run engine for at least 30 minutes to raise engine heat sufficiently to drive off any moisture entrained in engine systems (primarily in lube-oil systems).

6. Analyze lube oil (primarily for moisture content) monthly. Take samples from lube oil system.

7. Check power cylinder load balance, monitor engine condition (refer to Section 2.3.2), test overspeed trip device, and check crankshaft deflection annually.

2.3.10 General

2.3.10.1 Check and prepare all equipment subject to freezing or cold weather malfunctioning or damage for cold weather operation or lay-up before the advent of freezing weather.

2.3.10.2 Properly store replacement crankshafts to ensure they are in serviceable condition when needed. Mount the shaft in a rigidly constructed fixture that firmly clamps the shaft on the journal bearing areas and store the assembly on a flat, solid surface to ensure fixture and, consequently, shaft alignment. See Figure 11.

2.3.10.3 Oil the shaft bearing areas periodically to minimize the effects of corrosion. Where high humidity is a factor, store the shaft and fixture in containment with either a desiccant or heater.

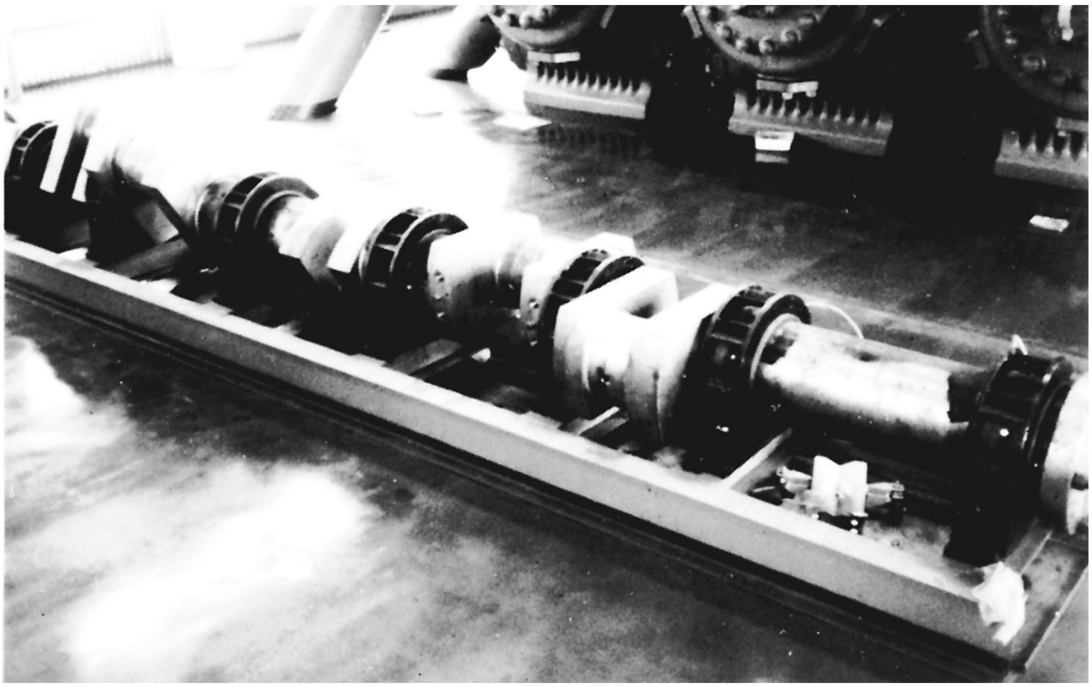

Fig. 11. Crankshaft stored in rigid support fixture

2.4 Contingency Planning

2.4.1 Equipment Contingency Planning

When an internal combustion engine breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable internal combustion engine equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

In addition, include the following elements in the contingency planning process specific to internal combustion engines:

A. Engine components repair/replacement options, lead times and availability, focusing on crankshafts and turbocharger rotors.

B. Engine component storage and handling considerations.

2.4.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by an internal combustion engine breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.4.2.1 Routine Spares

Routine internal combustion engine spares are spares that are considered to be consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the internal combustion engine, but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer. See Section 3.3 for routine spare guidance.

3.0 SUPPORT FOR RECOMMENDATIONS

Overspeed failures in internal combustion engines are usually the result of:

- Load disconnect/rejection
- Control system failure
- Fuel injection problems
- External fuel source/turbocharger lube-oil seal failure
- Failure of safety systems

3.1 Routine Spares

The following are common routine spares for an internal combustion engine. Store and maintain the routine spares per original equipment manufacturer recommendations to maintain viability. Refer to Data Sheet 9-0 for additional guidance.

- Seals/gaskets
- Bearings
- Pistons/rods
- Valves
- Fuel injectors and filters

3.2 Loss History

Loss experience with IC engines has shown that a lack of adequate condition monitoring is a major contributing factor.

4.0 REFERENCES

4.1 FM

Data Sheet 3-7, *Fire Protection Pumps*
Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*
Data Sheet 7-95, *Compressors*
Data Sheet 9-0/17-0, *Asset Integrity*
Data Sheet 9-18/17-18, *Prevention of Freeze-ups*
Data Sheet 13-18, *Industrial Clutches and Clutch Couplings*
Data Sheet 13-7, *Gears*

APPENDIX A GLOSSARY OF TERMS

High speed: For European-manufactured engines, “high speed“ means over 750 rpm; for American-manufactured engines, “high speed“ means over 900 rpm.

Medium speed: For European-manufactured engines, “medium speed“ means 350-750 rpm; for American-manufactured engines, “medium speed“ means up to 300-900 rpm.

Slow speed: For European-manufactured engines, “slow speed“ means up to 350 rpm; for American-manufactured engines, “slow speed“ means up to 300 rpm.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

July 2020. Interim revision. Updated contingency planning and sparing guidance.

Janaury 2011. This data sheet has been revised to reflect current technology and best practices. Changes include the following:

- Added information on additional monitoring devices.
- Added new recommendations for engine operation and maintenance
- Modified information on crankshaft explosions.
- Added recommendations regarding fuel and oil analysis.
- Modified guidance related to engine overhaul, repair, and dismantle activity.
- Updated guidance on contingency planning and spare equipment.
- Added terms to Appendix A, Glossary of Terms.

May 2010. Minor editorial changes were made for this revision.

May 2001. Minor editorial changes were made for this revision.

September 2000. This revision of the document has been reorganized to provide a consistent format.

November 1994. Fist published.