ACCIDENT REPORT

MAIB

MARINE ACCIDENT INVESTIGATION BRANCH

Report on the investigation of two catastrophic engine failures, one resulting in a fire, on board the ro-ro passenger ferry *Wight Sky* at the entrance to Lymington River and before berthing at Lymington Pier on 26 August and 14 December 2018

SERIOUS MARINE CASUALTY

REPORT NO 4/2022

APRIL 2022

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2012 – Regulation 5:

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NOTE

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

°C	-	degrees centigrade
°dH	-	deutsche Härte, a German measurement of general water hardness, where 1°dH is equal to 17.848 mg/l calcium carbonate
μm	-	micron
ARGUS	-	Volvo Penta dealers' internal reporting system
Bar	-	metric unit of pressure (1bar = 100kPa)
CCTV	-	closed-circuit television
cSt	-	centistoke
DPA	-	Designated Person Ashore
ECU	-	engine control unit
EU	-	European Union
FRS	-	Fire and Rescue Service
HT	-	high temperature
ISM Code	-	International Safety Management Code
ISO	-	International Organization for Standardization
KPa	-	kilopascals
kW	-	kilowatt
kts	-	knots
LR	-	Lloyd's Register
LT	-	low temperature
m	-	metre
MCA	-	Maritime and Coastguard Agency
MCU	-	marine control unit
ME	-	main engine
mg/L	-	milligrams per litre
MMR	-	machinery monitoring room
nm	-	nautical miles
OBS	-	observation
pH	-	A scale used to specify how acid or alkaline a water-based solution is
ppm	-	parts per million
RKM	-	RK Marine Ltd

ro-ro	-	roll-on/roll-off
rpm	-	revolutions per minute
SCA	-	supplemental coolant additive
SEM	-	scanning electron microscope
STCW	-	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended
SMS	-	safety management system
TBN	-	Total Base Number
TTH	-	The Test House
UTC	-	universal time coordinated
VSP	-	Voith Schneider Propeller
Wightlink	-	Wightlink Ltd
W-Class	-	Wight Class

TIMES: all times used in this report are UTC unless otherwise stated.

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Wight Sky

SYNOPSIS

At 1835 on 26 August 2018, the roll-on/roll-off passenger ferry *Wight Sky* suffered a catastrophic main engine failure as it prepared to enter the Lymington River on its regular crossing from Yarmouth, Isle of Wight. This was the ferry's second catastrophic main engine failure in less than a year, the failed engine being the replacement for a previous catastrophic engine failure that had resulted in a fire and serious injuries to an engineer officer. On 14 December 2018, *Wight Sky* suffered a third catastrophic main engine failure. On this occasion, the failed engine had been in operation for just 389 hours.

Wight Sky was one of three sister ferries operating between Lymington and Yarmouth. Following the third engine failure the ferry owner, Wightlink Ltd, withdrew its Wight Class ferries from service. After discussions between the ferry owner, the Maritime and Coastguard Agency, Lloyd's Register, and the engine manufacturer Volvo Penta, a mitigation plan was put in place to enable the ferries to return to service. The initial mitigation measures included weather and engine load constraints, enhanced engine monitoring and shutdown procedures, and restrictions on personnel entering the engine rooms when the main engines were running.

This investigation found a history of engine failures across the Wight Class fleet while operating on the route, dating back to 2010. As a consequence, the scope of the investigation expanded to include all known failures, leading to a long and detailed technical investigation that comprised forensic examination and testing of five of the failed engines and their components, a full review of the vessels' system design and operation, and the safety management, planned maintenance and condition monitoring procedures, together with manning and technical oversight. In May 2019, the MAIB published an interim report of its initial findings.

Although *Wight Sky*'s catastrophic main engine failures had similar consequences, the complex circumstances that led to them differed. However, many of the underlying factors that contributed to the *Wight Sky* and other Wight Class engine failures were similar and included insufficient technical oversight of engine operating parameters, maintenance management, quality control and engine component and auxiliary system design. This was exacerbated by a lack of engine maintenance and condition monitoring ownership, which resulted in long-standing reliability issues that were either unidentified or unresolved.

Wightlink Ltd and other stakeholders have taken several actions following their internal investigations and in response to recommendations made in previous MAIB reports. Since December 2018, the ferries have successfully operated without any catastrophic engine failures. RK Marine Ltd, the local service centre contracted to undertake most of the Wight Class ferry engine overhauls, has had its authorisation as a Volvo Penta Centre dealer removed by the engine manufacturer.

Recommendations aimed at addressing specific issues that remain unresolved by the actions already taken have been made to Wightlink Ltd, Volvo Penta, Lloyd's Register and RK Marine Ltd.

SECTION 1 – FACTUAL INFORMATION

1.1 PARTICULARS OF *WIGHT SKY* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Wight Sky*
Flag	United Kingdom
Classification society	Lloyd's Register
IMO number	9446984
Type	Roll/on roll/off passenger ferry
Registered owner	Wightlink Ltd
Manager(s)	Wightlink Ltd
Construction	Steel
Year of build	2008
Length overall	62.40m
Gross tonnage	2546
Minimum safe manning	Dependent on passenger numbers
Authorised cargo	Passengers, private and commercial vehicles

VOYAGE PARTICULARS		
Port of departure	Yarmouth (Isle of Wight)	Yarmouth (Isle of Wight)
Port of arrival	Lymington	Lymington
Type of voyage	Internal waters	Internal waters
Cargo information	117 passengers, 33 vehicles	43 passengers, 17 vehicles
Manning	10	9

MARINE CASUALTY INFORMATION		
Date and time	26 August 2018 at 1841	14 December 2018 at 0655
Type of marine casualty or incident	Serious Marine Casualty	Serious Marine Casualty
Location of incident	50° 44' 41N 1° 30' 42W Lymington River entrance	50m from Lymington ferry berth
Place on board	Forward engine room	Aft engine room
Injuries/fatalities	None	None
Damage/environmental impact	No.2 main engine damaged beyond repair	No.4 main engine damaged beyond repair
Ship operation	In service	In service
Voyage segment	Arrival	Arrival
External & internal environment	Near gale; slight sea; moderate visibility	Gentle breeze; calm sea; good visibility
Persons on board	127	52

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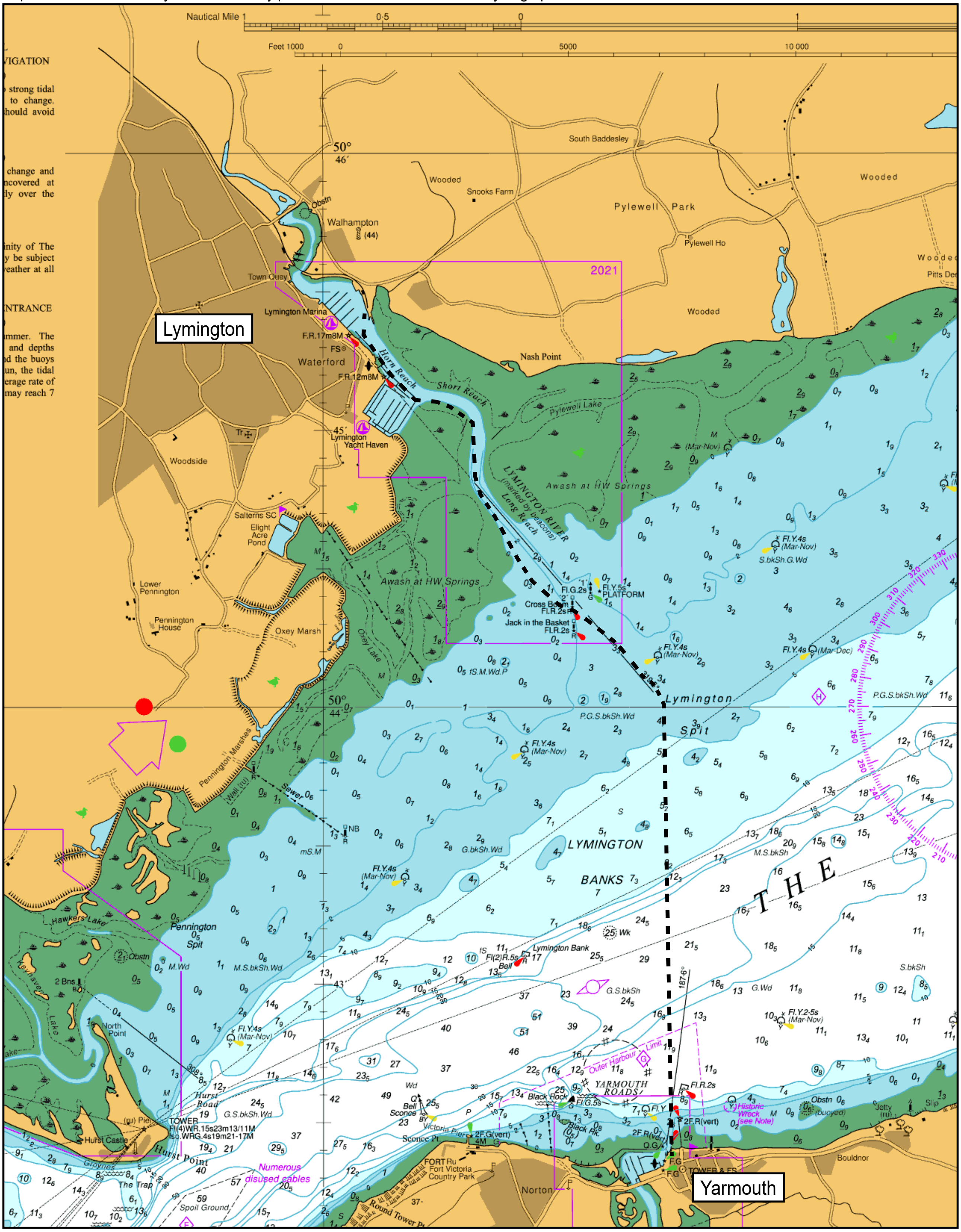

Figure 1: Lymington to Yarmouth route

1.2 BACKGROUND

Wight Sky was a UK registered roll-on/roll-off (ro-ro) passenger ferry, owned and managed by Wightlink Ltd (Wightlink). It was one of three Wight Class (W-Class) ferries operated between Lymington, Hampshire and Yarmouth, Isle of Wight **(Figure 1)**. The crossing took about 40 minutes.

Wight Sky was a double-ended vessel that could be driven in either direction. It had two engine rooms with identical layouts that were referred to as the forward and aft engine rooms. The ferry had four diesel-driven, variable speed Volvo Penta D16 MH main engines (ME): ME1 and ME2 in the forward engine room, and ME3 and ME4 in the aft engine room **(Figure 2)**. The ferry was propelled and steered by two five-blade Voith Schneider Propeller (VSP) units, one forward and one aft. Depending on the required power, one or two MEs could independently drive each propulsion unit.

In addition to the main engines, each engine room contained two electric generators driven by Volvo Penta D9 MG diesel engines. A central auxiliary machinery space contained the engine room water mist fire suppression system **(Figure 2)**.

On 12 September 2017, *Wight Sky*'s ME2 suffered a catastrophic[1] failure during the vessel's approach to Yarmouth, which resulted in an engine room fire and caused serious injuries to an engineer officer. RK Marine Ltd (RKM), a local Volvo Penta dealer, had recently overhauled the engine ashore, after which it was rebuilt in the vessel's engine room. The engine ran for less than 6 hours before it failed. Volvo Penta's investigation concluded that a big end bearing's lubrication supply had probably been blocked by debris that had been allowed to enter the engine's oil channels during its rebuild.

The MAIB's investigation (MAIB 14/2018)[2] concluded that:

> *Rebuilding the engine in a clean and controlled environment and transferring it complete into the engine room would have reduced the likelihood of debris ingress.*

Subsequently, fully assembled engines were shipped in and out of the W-Class ferries via the designated route.

A new-build engine replaced the failed ME2. It was delivered from Volvo Penta's factory in Sweden and installed by RKM.

1.3 NARRATIVE

1.3.1 Number two main engine failure August 2018

At 1823 on 26 August 2018, *Wight Sky* left Yarmouth on its regular route across the Solent to Lymington. On board were a range of commercial and private vehicles, 117 passengers and 10 crew. ME1 and ME2 drove the VSP at the bow and ME3 drove the VSP at the stern. All three MEs were operating at their 1800rpm full speed setting.

[1] A catastrophic engine failure means a sudden and total failure from which recovery is impossible.

[2] https://www.gov.uk/maib-reports/catastrophic-engine-failure-and-fire-on-board-ro-ro-passenger-ferry-wight-sky

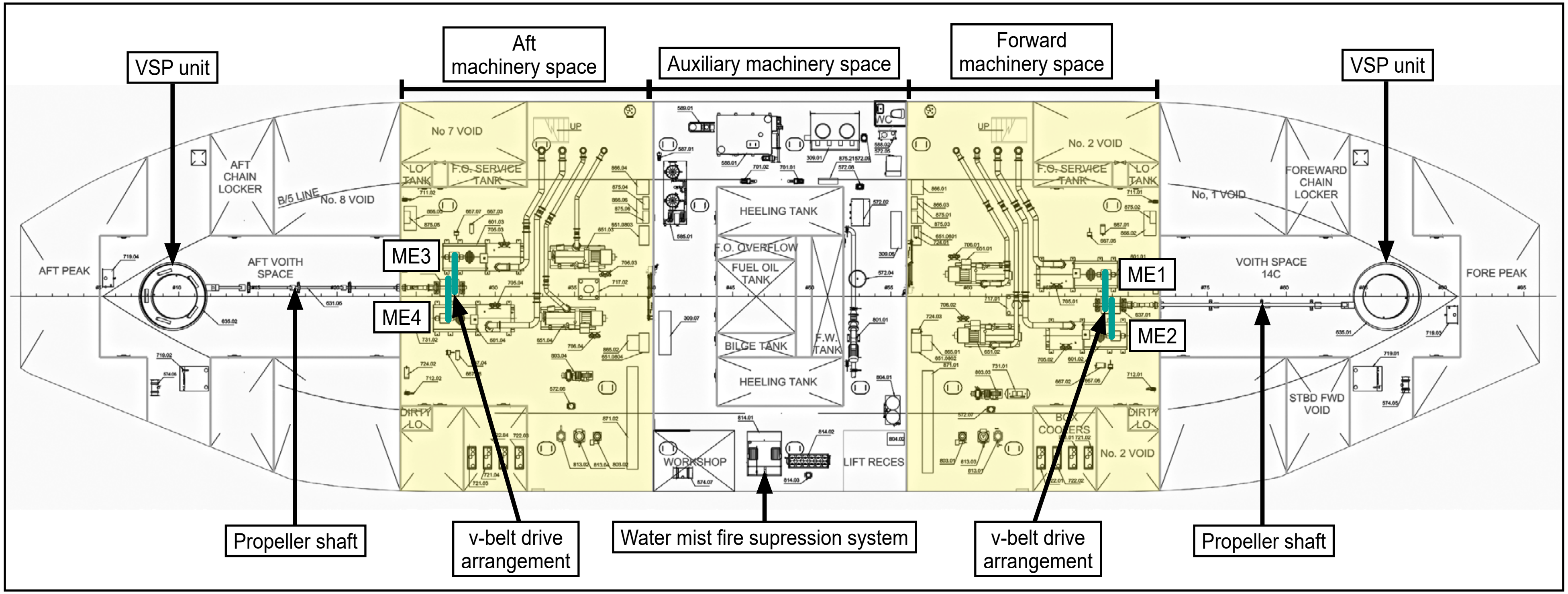

Figure 2: Layout of machinery spaces

As *Wight Sky* approached the entrance to Lymington River, it waited for the outbound ferry, *Wight Light*, to clear the river. The bridge team reduced the pitch on the VSPs and used them to hold position and stem the wind and tide.

At 1840:52, *Wight Sky*'s machinery monitoring system identified a loss of ME2 lubricating oil pressure and initiated an engine shutdown. Within 2 seconds, ME2's low piston cooling oil pressure and shutdown common alarms activated. At 1841:55, the engine failed catastrophically, causing internal engine components to be thrown through the engine crankcase into the engine room. The oil and vapours released from the crankcase into the engine room ignited and created a fireball around the engine **(Figure 3)** that activated the fire detection system alarm on the bridge. The master looked at the engine room's closed-circuit television (CCTV) monitor, saw the smoke and fire, took immediate action to ensure the engine had declutched and stopped, and activated the engine room's water mist fire suppression system, which extinguished the fire.

The crew were quickly mustered, the passengers assembled, and the coastguard alerted. The master informed the coastguard that the fire appeared to be out and that his intention was to continue into Lymington under the vessel's own power. He requested the attendance of the Fire and Rescue Service (FRS). The crew monitored the bulkhead and deck temperatures in the compartments around the forward engine room and rigged hoses for boundary cooling.

Figure 3: Engine room CCTV of ME2 engine fire

Shortly after the master made the decision to proceed to Lymington, black smoke began issuing from ME2's engine room funnel. The chief engineer advised the master to declutch and stop ME1 as a precaution because it was in the same engine room as ME2. The master followed the chief engineer's advice and decided to abort the entry and return to Yarmouth, where *Wight Sky* could use its one available VSP to safely berth without assistance.

In parallel with ME3, ME4 was started and clutched in and the vessel headed back across the Solent towards Yarmouth. At 1911, *Wight Sky* was berthed alongside the ferry terminal. The FRS boarded the ferry and the passengers were disembarked via the side door. The vehicles were disembarked once the FRS confirmed it was safe to do so.

The initial ME2 inspection identified that the engine's number four cylinder connecting rod had failed and been ejected through the side of the engine crankcase **(Figure 4)**, and that a localised fire had ensued. The engine had accumulated 2241 running hours since its installation and, as the failure mode appeared identical to the previous ME2 failure, the MAIB began a new investigation.

On 22 November 2018, *Wight Sky*'s ME2 was replaced with a new-build engine.

1.3.2 Number four main engine failure December 2018

At 0535 on 14 December 2018, *Wight Sky* departed Yarmouth and headed to Lymington. On board were 17 commercial and private vehicles, 43 passengers and 9 crew. ME1 and ME2 drove the VSP at the bow and ME4 drove the VSP at the stern.

At 0640, *Wight Sky* entered Lymington River with all three engines operating at the intermediate speed setting of 1360rpm. At 0655:48, with the ferry about 50m from its berth, an ME4 common alarm[3] sounded. The chief engineer, who was in the machinery monitoring room (MMR) on the main deck, acknowledged the alarm and checked the engine's operating status on the machinery monitoring system. The chief engineer noted that the lubricating oil pressure was lower than expected but was within its alarm limits.

At 0657:56, the ME4 sounded a 'DGU[4] MODBUS[5]' alarm. The chief engineer did not recognise this alarm, which coincided with the deck crew entering the MMR to report loud banging noises from the aft engine room and observations from the shore that smoke could be seen issuing from the vents. The chief engineer contacted the master on the bridge and advised him to activate the aft engine room's water mist fire suppression system; this was done at 0658:51. The chief engineer then went to the aft engine room entrance, where he activated the emergency stops for the space's vent fans and fuel pumps and tripped the aft fuel oil service tank quick closing valves.

The master raised the fire alarm and requested FRS attendance on berthing; the passengers were informed of the situation and kept updated. The vessel's fire party mustered on the main deck and rigged fire hoses for boundary cooling. On his

[3] Indicates an active alarm status.

[4] Distributed Generic Unit is a module designed to communicate with external equipment on a serial line or CAN for controlling and monitoring different engine applications, i.e. propulsion.

[5] MODBUS is a communication protocol where data is transmitted one bit at a time (i.e. 50kbps) providing alarms and system status.

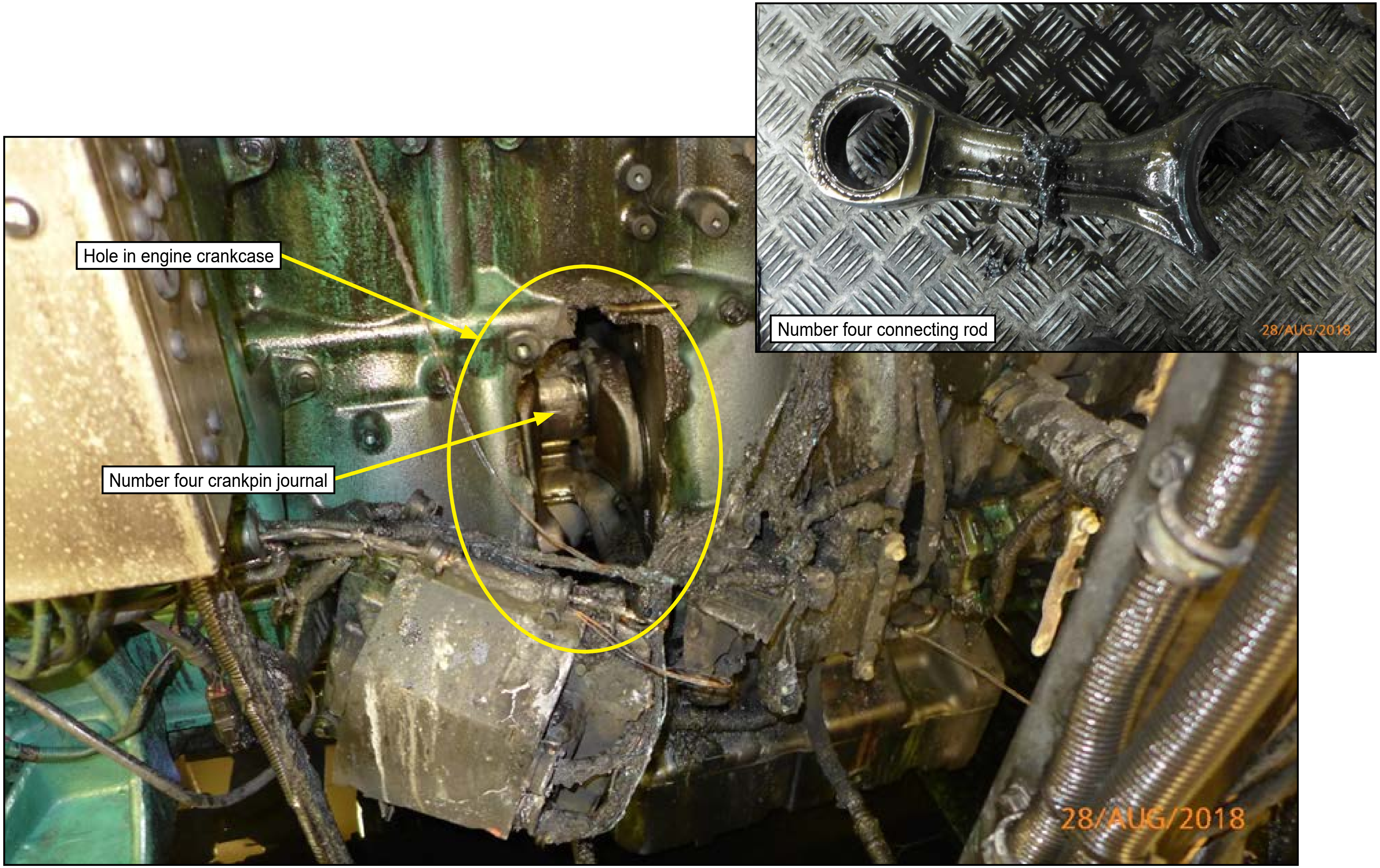

Figure 4: Hole in ME2 crankcase, showing number four crankpin journal, and inset, showing number four connecting rod on the engine room deck plate

return to the MMR, the chief engineer noted that ME4 was still running and asked the master to declutch and stop the engine from the bridge. He then transferred the electrical load onto the forward diesel generators and shutdown the aft generator.

The aft engine room remained sealed and crew monitored its boundary temperatures; the forward fire pump was started in preparation for boundary cooling. A few minutes later, the vessel successfully berthed at Lymington and its passengers and vehicles were quickly disembarked. The FRS boarded and confirmed there was no fire.

The initial inspection of the engine room identified that ME4 had failed catastrophically and that its number four connecting rod and gudgeon pin **(Figure 5)** had been ejected through the side of the engine crankcase **(Figure 6)** into the engine room. The engine room was unoccupied at the time and there was no evidence of a fire.

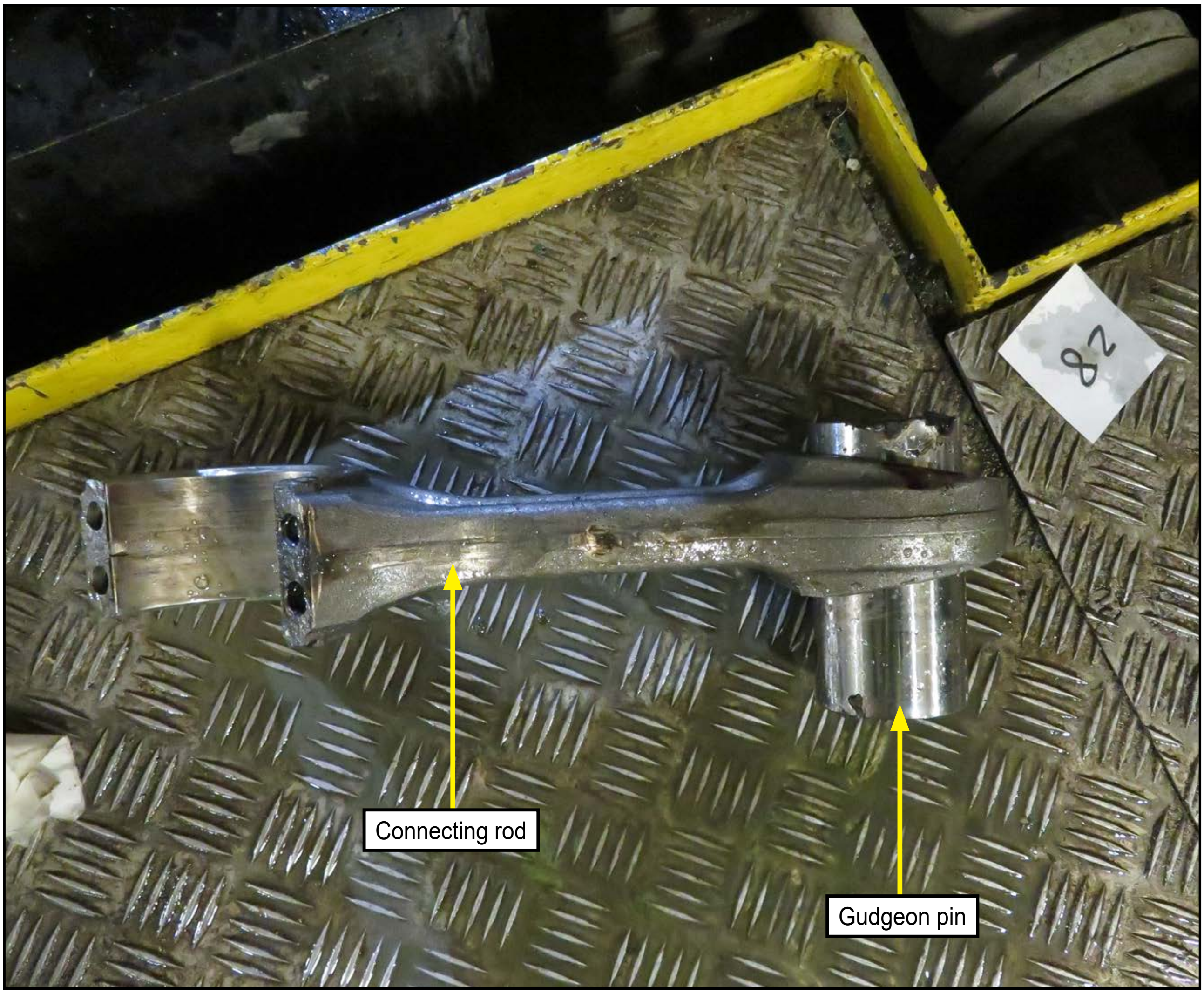

Figure 5: ME4 number four connecting rod and gudgeon pin

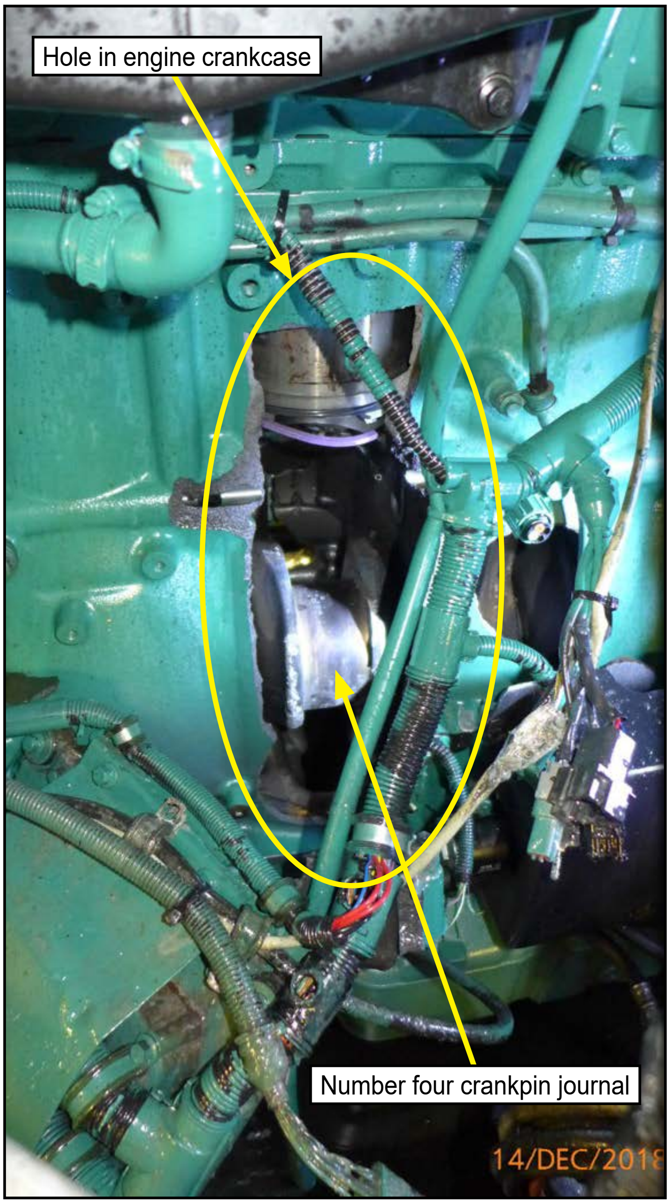

Figure 6: Hole in ME4 crankcase/engine block, showing number four crankpin journal

1.3.3 Post-accident actions

Following *Wight Sky*'s ME4 failure, Wightlink immediately withdrew its W-Class vessels from service. After discussions between Wightlink, the Maritime and Coastguard Agency (MCA), the vessels' classification society Lloyd's Register (LR), and Volvo Penta, a mitigation plan was introduced that enabled the ferries to return to service. Initial measures included: the introduction of more rigorous weather and engine load constraints; enhanced engine monitoring and shutdown procedures; and restrictions on personnel entering the machinery spaces when the MEs were running. Further precautionary steps were taken as the technical investigation progressed.

ME4 was a new-build engine that had accumulated 389 running hours before it failed. As this was *Wight Sky*'s third catastrophic engine failure in 15 months, and due to the apparent similarities, the MAIB widened the scope of its investigation to include the causes and circumstances of ME4's failure.

In May 2019, MAIB issued an interim report[6] on its initial findings and the actions taken by Wightlink, Volvo Penta, RKM, LR, and the MCA.

As the investigation progressed, it became apparent that similar and other types of ME failure were more common on the three Lymington to Yarmouth W-Class vessels than initially thought. The failures **(Tables 1**, **2** and **3)** started within two years of the vessels' 2009 introduction into service. No single causal factor had been identified by Wightlink, RKM, Volvo Penta or LR. As a result, the breadth of this investigation was further expanded to include all known ME failures across the three vessels.

Date	**Description of main engine failure**
July 2010	ME1 cylinder liner failure. Erosion at O-ring seal lands at 6027 running hours, resulting in engine rebuild that included new liners.
March 2011	ME3 cylinder liner failure. Erosion at O-ring seal lands at 8125 running hours, resulting in engine rebuild that included new liners and bearings.
November 2011	ME2 cylinder liner failure. Erosion at O-ring seal lands at 9394 running hours, resulting in engine rebuild that included new liners and bearings.
January 2012	ME4 cylinder liner failure. Erosion at O-ring seal lands at 7750 running hours, resulting in engine rebuild that included new liners and bearings.
01 May 2015	ME1 cylinder liner failure. Erosion at O-ring seal lands at 16412 running hours, resulting in engine rebuild that included new liners and bearings.
24 February 2017	ME4 idler gearwheel bearing failure. The engine was rebuilt in situ.
July 2017	ME2 coolant loss problem. The turbocharger and exhaust were replaced (without improvement).
04 August 2017	ME2 exhaust issued white smoke on starting. Turbo charger replacement followed by subsequent failure of a number five cylinder exhaust valve at 20907 running hours. Engine rebuild, using previously repaired engine block from *Wight Sun* ME4 and crankshaft from *Wight Light* ME1.
12 September 2017	**Catastrophic failure of ME2 5.5 running hours after rebuild. The engine was replaced with a factory supplied new build. MAIB Report 14/2018[7].**
26 August 2018	**Catastrophic failure of ME2 after 2241 running hours. The engine was replaced with a factory supplied new build.**
14 December 2018	**ME4 catastrophic failure after 389 running hours. The engine was replaced with a factory supplied new build.**

Table 1: *Wight Sky* main engine failures

[6] Interim report on the investigation into two catastrophic engine failures on board the ro-ro passenger ferry *Wight Sky* on 26 August 2018 and 14 December 2018.

[7] https://www.gov.uk/maib-reports/catastrophic-engine-failure-and-fire-on-board-ro-ro-passenger-ferry-wight-sky

Date	Description of main engine failure
15 October 2012	ME3 cylinder liner failure. Erosion at O-ring seal lands at 11373 running hours, resulting in engine rebuild that included new liners and bearings.
18 November 2014	ME2 cylinder liner/block failure at 13022 running hours, resulting in engine rebuild that included new engine block, liners, bearings, pistons and fuel injectors.
17 May 2016	ME4 cylinder liner failure. Erosion at O-ring seal lands at 17407 running hours, resulting in engine rebuild including new engine block, crankshaft, 5-off ex-*Wight Sun* ME3 connecting rods and one new connecting rod, liners and bearings.
20 July 2017	ME1 cylinder liner failure. Erosion at O-ring seal lands and five cracked pistons at unknown running hours. The major overhaul included a previously repaired engine block from *Wight Light* ME4, crankshaft, connecting rods and liners.
2 February 2018	**ME1 crankshaft bearing seizure at 23400 running hours. The engine was replaced with factory supplied new build.**
March 2018	ME3 seizure approximately 7500 running hours after major overhaul. New engine installed.
April 2018	ME4 suffered a bearing failure on the idler gearwheel. The engine was removed ashore for overhaul.
3 August 2018	**ME2 suffered melted piston/partial seizure about 8000 hours after major overhaul. The engine was replaced with factory supplied new build.**

Table 2: *Wight Light* main engine failures

Date	Description of main engine failure
01 October 2012	ME1 cylinder liner failure. Erosion at O-ring seal lands at 14860 running hours, resulting in engine rebuild that included new liners and bearings.
April 2013	ME3 clutch coupling failure at 8800 running hours, resulting in engine rebuild that included new liners and bearings.
03 March 2014	ME2 cylinder liner failure. Erosion at O-ring seal lands at 8200 running hours, resulting in engine rebuild that included new liners and bearings.
01 July 2015	ME2 cylinder liner failure. Erosion at O-ring seal lands at 12791 running hours, resulting in a new engine block, liners and bearings.
November 2015	ME3 suffered number 3 big end bearing seizure and crankcase explosion at 13295 running hours, resulting in engine rebuild with replacement short block.
March 2016	ME4 suffered a seizure due to rotation of a main bearing, resulting in engine rebuild.
06 July 2017	ME4 lubricating oil pressure failure, resulting in bearing shell rotation at unknown running hours. Engine rebuild with replacement short block from unknown spare engine.

Table 3: *Wight Sun* main engine failures

Two of the *Wight Light* failures were investigated in greater detail and included in the scope of the technical investigation. The failure events shown in bold in **Table 1** and **Table 2** were numbered as Events 1 to 5 **(Table 4)**.

Event number	Vessel/Main engine number	Date	Description of failure
Event 1	*Wight Sky* ME2	12 September 2017	Catastrophic failure
Event 2	*Wight Light* ME1	2 February 2018	Main bearing seizure
Event 3	*Wight Light* ME2	3 August 2018	Melted piston and partial seizure
Event 4	*Wight Sky* ME2	26 August 2018	Catastrophic failure
Event 5	*Wight Sky* ME4	14 December 2018	Catastrophic failure

Table 4: Engine failure - Events 1 to 5

1.4 CREW

1.4.1 Manning levels

The manning levels on board Wightlink's ferries varied according to the numbers of passengers carried. The company used a modal manning system designed to meet or exceed the MCA's minimum manning requirements based on passenger demand.

Wightlink's Lymington-based crew members worked to a roster system; they were not appointed to a particular vessel but typically spent four concurrent days on one of the W-Class ferries. Three Portsmouth-based masters were cross-route trained and could be tasked to work on the W-Class ferries.

1.4.2 Crew on 26 August 2018

On 26 August 2018, *Wight Sky*'s 10 crew comprised the master, mate, bosun, three deck ratings, chief engineer, mechanic and two stewards.

The master held an STCW[8] II/2 Certificate of Competency and had worked on Wightlink ferries since 2002. He retired in August 2015, but was regularly contracted by Wightlink on a self-employed basis. He had maintained his certification, familiarisation and safety drills and was employed on a shift-by-shift basis.

The chief engineer held an STCW III/2 Certificate of Competency. He had worked as a Wightlink chief engineer since March 2018 and previously served as chief engineer on deep-sea vessels. He had also worked for the MCA as an examiner of engineers.

8 STCW – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended.

1.4.3 Crew on 14 December 2018

On 14 December 2018, *Wight Sky*'s nine crew comprised the master, mate, bosun, three deck ratings, chief engineer, mechanic and one steward.

The master held an STCW II/2 Certificate of Competency. He had worked on Wightlink ferries since May 2015.

The chief engineer was the same engineer who had been on board during the incident on 26 August 2018.

1.5 WIGHTLINK LTD

1.5.1 General

Wightlink operated six ro-ro passenger ferries and two high-speed passenger ferries on three scheduled routes between the Isle of Wight, Lymington and Portsmouth. The W-Class ferries *Wight Sky*, *Wight Light* and *Wight Sun* were specifically commissioned for Wightlink's Lymington to Yarmouth route. The company's three other ro-ro ferries operated between Portsmouth and Fishbourne, and its high-speed ferries between Portsmouth and Ryde. *Wight Sun* was often used as a replacement for Portsmouth to Fishbourne ferries during their repair periods.

1.5.2 The introduction of the Wight Class ferries

The W-Class ferries were built between 2007 and 2008 in Kraljevica, Croatia. *Wight Light* was constructed first, followed by *Wight Sky* and *Wight Sun*. On 25 February 2009, *Wight Light* and *Wight Sky* entered service, followed by *Wight Sun* on 25 May 2009. The beam and draught of the W-Class ferries were similar to those they replaced on the Lymington to Yarmouth service, but they were 6m longer and their lateral windage area was greater.

1.6 MAIN ENGINES

1.6.1 Overview

Wight Sky's six cylinder in-line D16 MH engines had a rated power output of 478kW at 1800rpm and were manufactured by Volvo Penta in Sweden. The engines comprised a main block with a ladder frame and a one-piece cylinder head with four valves per cylinder. They had a high-pressure fuel injection system and a twin entry turbo charger with a charge air cooler. The engine met EU Stage II emission requirements for mobile machinery not used on roads and was LR type approved.

The Volvo Group's D16 engine was designed for use in heavy duty commercial road vehicles and over 120,000 had been built since its 2004 launch. Volvo Penta is the marine arm of the Volvo Group and builds diesel engines for leisure and commercial vessels. With power ratings between 368kW and 551kW, the marinized D16 MH engine was the most powerful in Volvo Penta's product range and over 3000 had been built since its 2005 release.

1.6.2 Engine build process

The D16 engine blocks and cylinder heads were produced by a silica sand[9] casting process. Most of the engines were destined for commercial road transport and assembled at a highly automated factory in Sweden, which used robotic machining and computer-controlled audit checks. Volvo Penta's marine engines were assembled by hand on a separate production line **(Figure 7)**.

The connecting rods were cast in one piece and then broken at the big end to separate the connecting rod from its big end bearing cap. This process provided a matched mating surface between the rod and cap that helped reduce the risk of fretting wear at the joint. It also reduced the torque force required to tighten the big end bolts.

Figure 7: D16 MH engine connecting rod installation

[9] Silica sand has a grain size of around 190μm.

During the assembly process, the engine build technicians had to unbolt the connecting rod caps and place them on a work surface adjacent to the engine block before lowering the piston and connecting rod assemblies into their cylinder liners. Once the connecting rods (with bearing shells) were positioned on their respective crankpin journals, the technicians refitted the big end bearing caps. The bearing cap bolts were tightened to the specified torque and the resistance of the rotating crankshaft checked to ensure it was within tolerance. To help reduce the risk of transposing the rods and caps, the matched parts were each stamped with the same serial number **(Figure 8)**.

1.6.3 Engine maintenance schedules

Volvo Penta's D16 MH engine maintenance requirements were set out in a service protocol **(Table 5)**. The intervals between the maintenance activities listed in the service protocol were given in years and engine running hours, e.g. every 12 months or 500 running hours, whichever occurred first. The annual accumulated running hours for the W-Class D16 MH engines was typically between 1500 and 2500.

The service protocol did not include fuel injector overhaul and replacement or major maintenance work, such as cylinder head and rotating assembly (crankshaft, connecting rods, pistons, etc.) overhauls **(Figure 9)**, which were based on engine operating conditions and condition monitoring results, including engine oil and coolant tests.

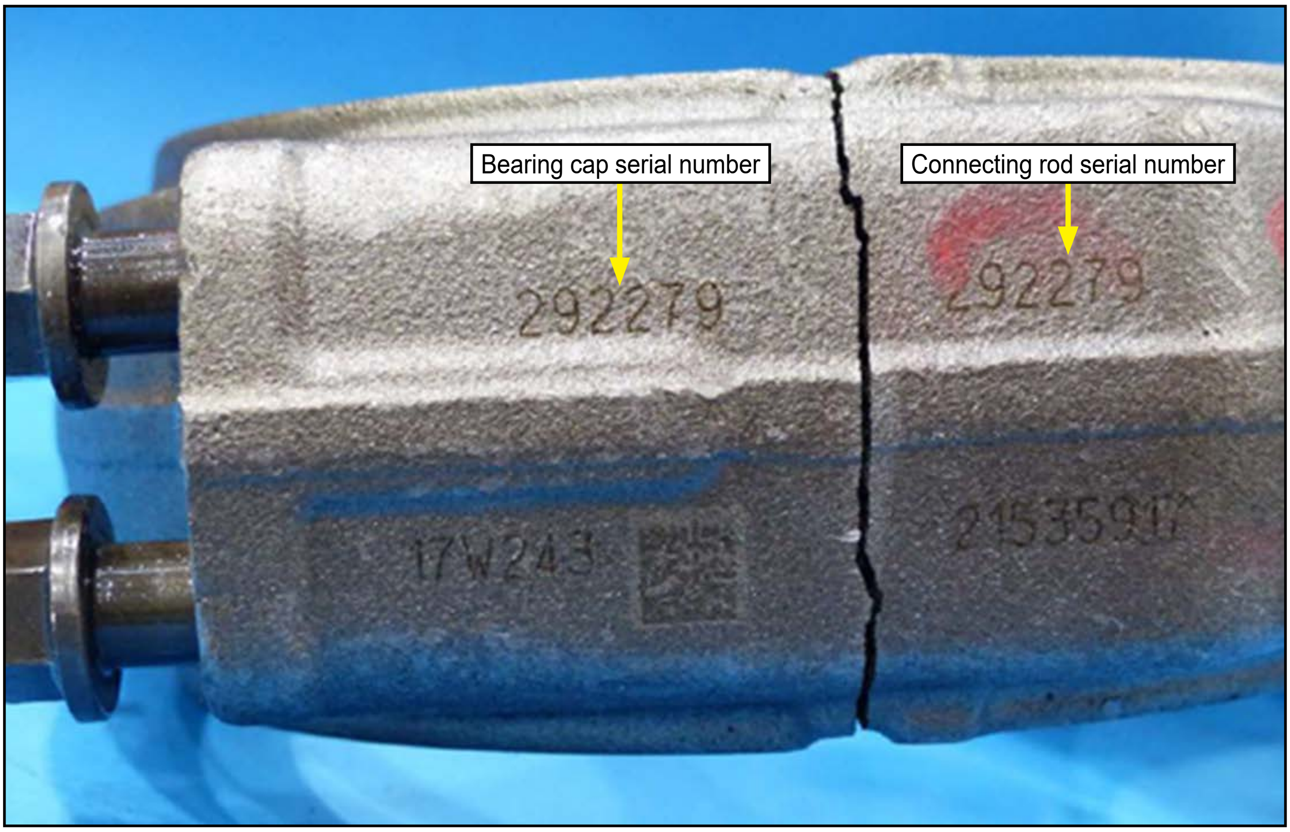

Figure 8: D16 MH bearing cap and connecting rod serial numbers

Service interval	Service activity	Action	
At 1000 hours	Valve clearance	Inspection	●
Every 12 months or 500 hours, whichever occurs first	Check software status Engine oil and oil filters replace Coolant level and antifreeze mixture Drive belts Fuel pre-filter, draining water / contamination Seawater filter Air filter Anode, protection system Impeller in seawater pump Transmission, according to manufacturer's recommendations	Inspection Replace Inspection Inspection Clean Clean Inspection Inspection Inspection Inspection	● ● ● ● / ○ ● ● / ○ ● ● / ○ ● / ○ ●
Every 12 months or 1000 hours, whichever occurs first	Fuel pre-filter, draining water / contamination Fuel fine filter Air filter Impeller in seawater pump	Replace Replace Replace Replace	● ● ● ●
Every 2000 hours	Valve clearance	Inspection	●
Every 48 months or 2000 hours, whichever occurs first	Drive belt	Replace	●
Every 3000 hours	Wear kit in seawater pump	Replace	●
Every 48 months or 8000 hours, whichever occurs first	Coolant	Replace	●
Key ● Service operation is recommended to be performed by an authorised Volvo Penta dealer ○ Service operation could be performed by owner/operator			

Table 5: Volvo Penta D16 MH service protocol

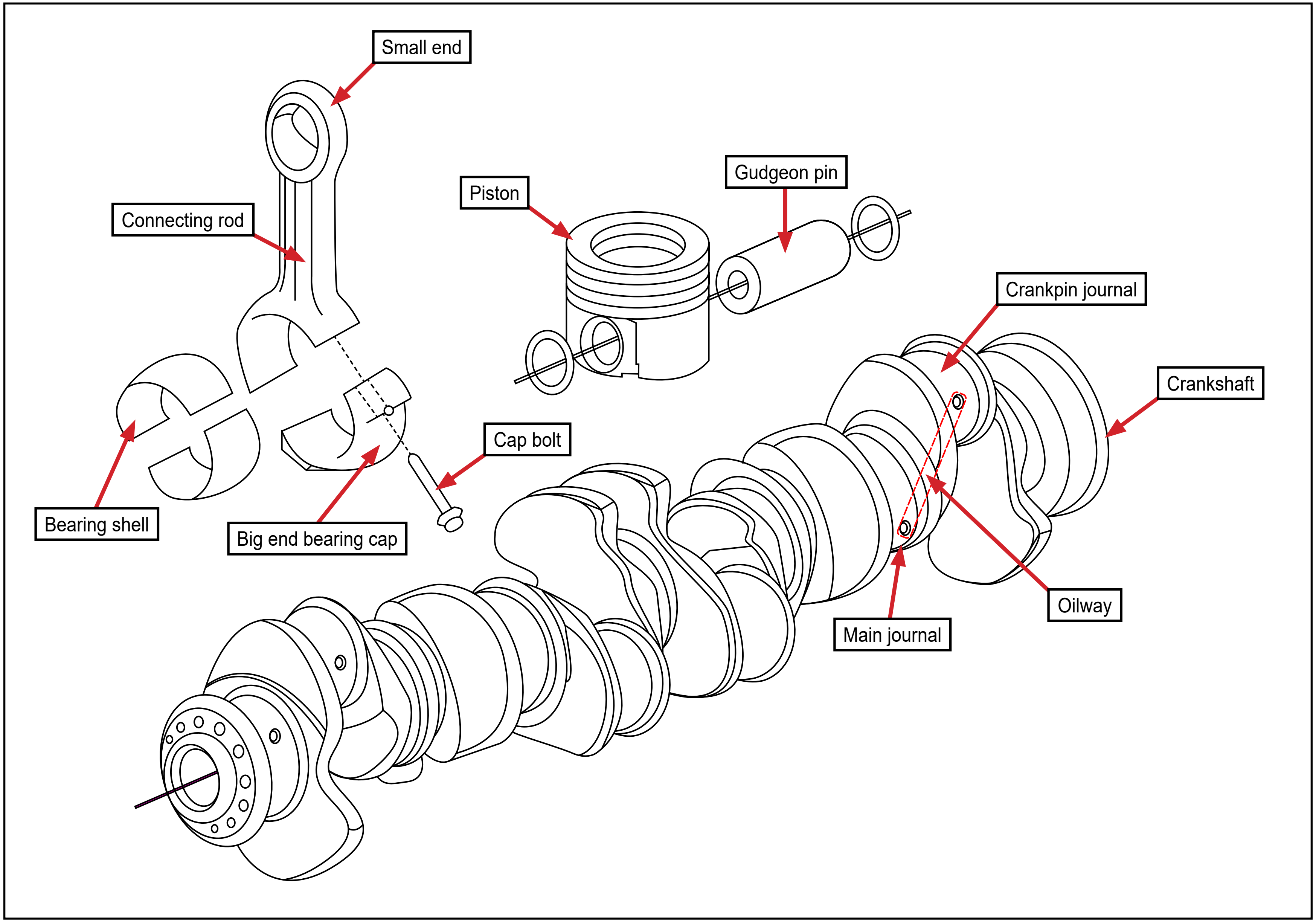

Figure 9: Schematic of rotating assembly

1.7 WIGHT CLASS PROPULSION SYSTEM

1.7.1 Overview

The D16 MH engines drove *Wight Sky*'s 21R5/135-2 VSP units via individual Transfluid KPTO drain-type fluid couplings and a shared v-belt drive arrangement **(Figures 10** and **11)**. The propulsion drive train included an ARCUSAFLEX AC7 WX torsional damper and a Rexnord Omega Elastomeric close-coupled E100 coupling[10] **(Figure 12)**.

The v-belt drive gearing reduced the 1800rpm full engine operating speed to 1000rpm, the input shaft speed of the VSP units. Internal gearing further reduced this to rotate the VSP at 92rpm.

The engine, torsional damper and fluid coupling were secured to their bedplates using flexible mounts designed to absorb vibration **(Figure 13)**.

Figure 10: Transfluid KPTO drain-type fluid coupling

[10] Elastomeric couplings are made from a flexible elastic material that transmits torque.

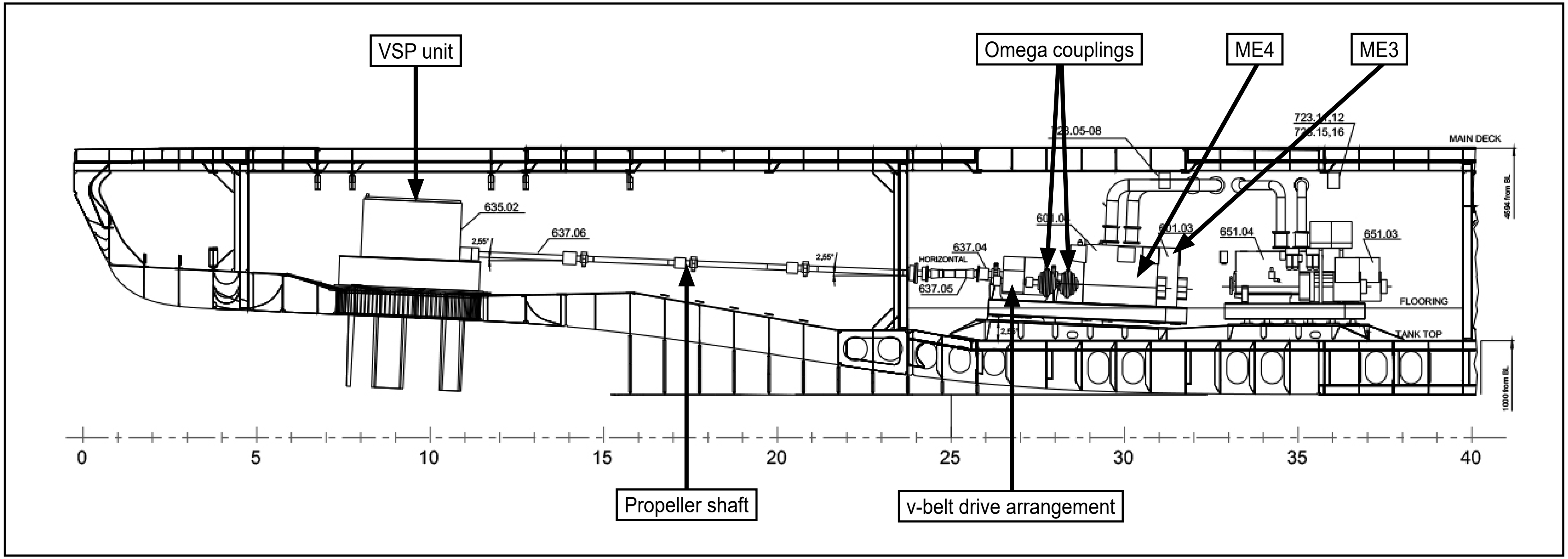

Figure 11: Propulsion system layout

Figure 12: Rexnord Omega elastomeric close-coupled E100 coupling

1.7.2 Vessel operating profile

The Lymington to Yarmouth ferries that operated before the W-Class vessels were also propelled by two VSP units in a similar fore and aft arrangement. The previous vessels' VSP units were each driven by a single direct-drive Mirrlees Blackstone medium-speed diesel engine that ran at a constant speed of 750rpm; there were no other engine speed settings.

The W-Class design concept aimed to provide a greater level of redundancy and a choice of engine configurations that best suited the propulsion system load demand while enabling lower exhaust emissions and better fuel consumption. To achieve this, the four smaller electronically controlled, high-performance, high-speed D16 MH engines were fitted.

During the W-Class ferry commissioning trials[11] conducted in 2008, it became apparent that the wash created by the VSPs, even at low pitch, was excessive for the confines of the river. To ensure compliance with the requirements of the Lymington Harbour Revision Order General Directions, Wightlink had already restricted the speed of its ferries to 4 knots (kts) on the Lymington River section of its route (the Lymington Harbour limit was 6kts). The commissioning trials identified that the engine running speeds needed to be reduced to minimise the wash and make the vessels more controllable.

The W-Class propulsion system was originally designed with an engine idle speed of 600rpm, a clutch in/out speed of 950rpm and an operating speed of 1800rpm. Wightlink's preferred option to resolve the wash issue was to provide variable engine

[11] W-Class ferry safety and environmental impact trials conducted by Wightlink for acceptance by Lymington Harbour Commissioners, not involving Lloyd's Register.

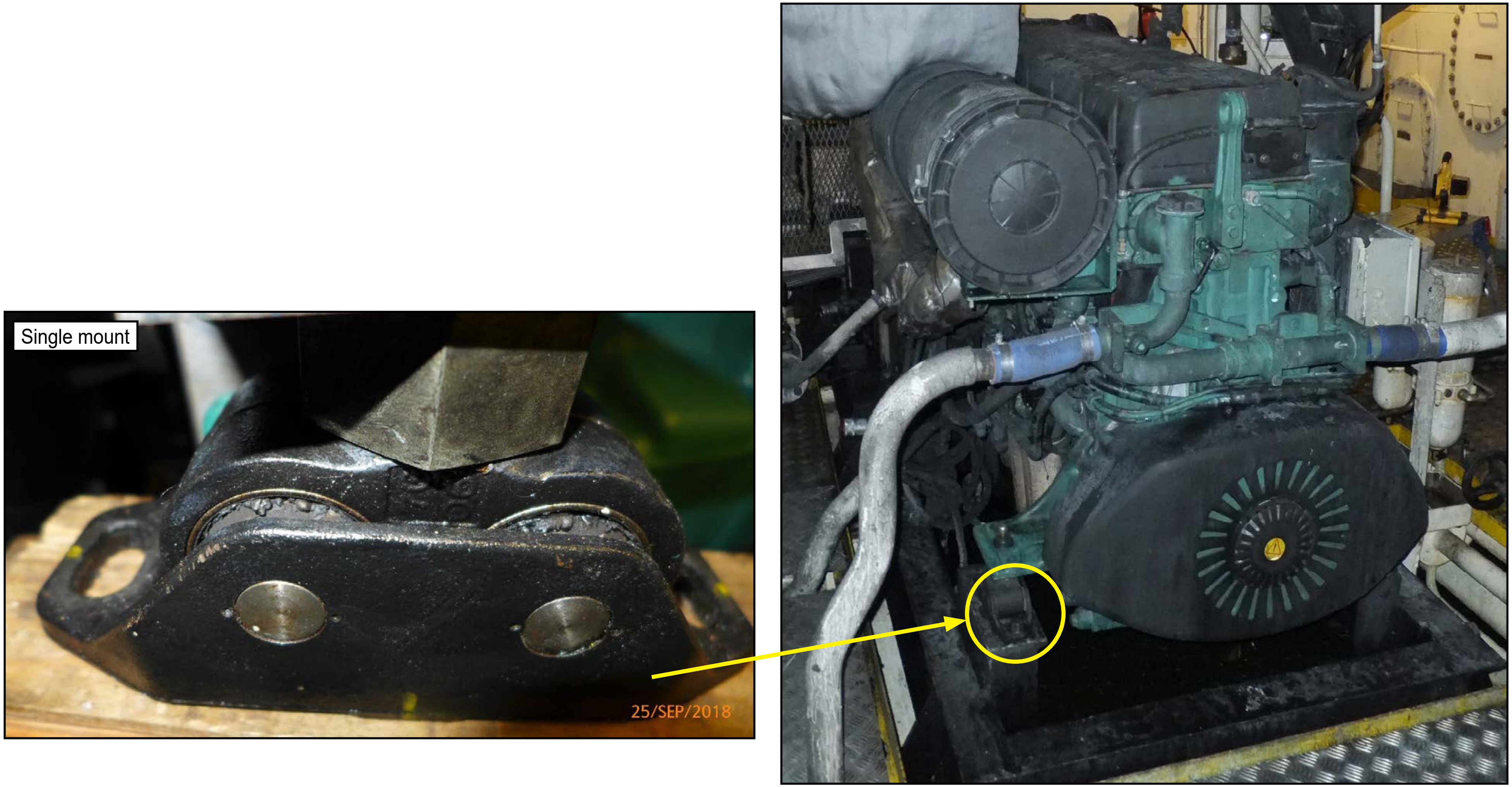

Figure 13: Flexible engine mounts

speed control between clutch in/out (950rpm) and full operating speed (1800rpm). This option was unsupported by Volvo Penta because the engines did not have full automatic shutdown protection below speeds of 1200rpm. Instead, an intermediate fixed speed setting of 1360rpm was introduced. This speed setting was chosen because it avoided the propulsion system's critical speed[12] range.

Wightlink contracted the Swedish electrical and automation company Callenberg Technology AB to develop the intermediate speed control capability and Volvo Penta provided the technical information needed to incorporate it into the engine's existing control system. *Wight Light* and *Wight Sky* both had the intermediate speed setting installed locally before they entered service. *Wight Sun* had the intermediate speed setting incorporated during its build in Croatia, which LR's local senior surveyor in charge had attended. The engine control system modifications were not subject to torsional vibration calculations.

Following the introduction of the intermediate speed, Wightlink chose to use three engine speed settings; slow (950rpm), medium (1360rpm) and full (1800rpm). This varied the power delivered to the VSP units.

Wightlink issued guidance on engine/VSP speed settings within Lymington Harbour in an annex to its W-Class operations manual titled *Lymington Harbour – Safe Operating Procedure* **(Annex A)**. The guidance stated that the aft steering VSP unit was to be operated at the slow speed setting in the river unless wind speeds exceeded 25kts, gusting to 30kts. The use of the medium speed setting was restricted to higher wind speeds and other specific conditions and was the maximum permissible engine speed for the aft VSP unit in the river during normal operations. The forward VSP provided most of the vessel's propulsion and acted as a tractor unit to pull the vessel forward, running at the full speed setting. This mode of operation resulted in minimum wash.

During the river transits, both VSP units could be driven by one engine but, concerned about the number of unexplained engine shutdowns and failures, some of the masters chose to use two engines to drive the forward VSP. This adopted precaution, intended to prevent loss of propulsion in the event of a sudden engine failure, meant the engines were running for prolonged periods at very low power.

During the approximate 10-minute section of the passage across the Solent, both of the ferries' VSPs could be operated at their full speed setting. When more power was required, such as to increase speed to make up for delays or to manage environmental conditions, a second engine would be clutched in to provide more power to the forward VSP.

The speed and power restrictions during the ferries' Lymington to Yarmouth arrivals and departures resulted in the engines operating at their maximum continuous rating for about 25 to 30% of each crossing.

[12] Critical speed is the rotational speed at which dynamic forces cause a machine component (such as a shaft) to vibrate at its natural frequency and can result in resonant vibrations throughout the entire assembly.

1.7.3 Fluid coupling power transmission

The engines were clutched in and out using the Transfluid KPTO drain-type fluid couplings. In addition to transmitting the engine power to the VSPs, the couplings provided torsional vibration damping and shock and overload protection for the engines.

The engines were clutched in and out by remote electrical solenoid valves that allowed the oil to be fed to the fluid coupling circuit when switched on (clutch in) and oil to drain through orifices located on the periphery of the fluid coupling when switched off (clutch out).

During the W-Class commissioning process, it became apparent that disengaging and stopping one of a pair of running engines was taking too long. This was because of the time it took for the coupling fluid to drain and was particularly evident when the engines ran at the lower speed settings. This led to the shutdown engine being driven by the onload engine via the common belt drive. Following the trials, the couplings were modified to increase the rate of oil drainage and allow the engines to stop when declutched. Coupling fluid drain times were not provided in the Transfluid data sheet and no records were kept of the drain system modifications.

Post-accident tests were conducted on 5 September 2018 to establish how long it took for the couplings to disengage when the engine protection system tried to stop an engine. With single engine drive, it took 15.1 seconds at the full speed setting and 17.4 seconds at the intermediate speed setting. When two engines were running in parallel at full operating speed, driving the same VSP unit, it took about 30 seconds for the coupling on the declutch engine to disengage. During this time, the onload engine drove the declutching engine.

1.8 ENGINE COOLING SYSTEM

1.8.1 Overview

Each ME had a low temperature (LT) and high temperature (HT) cooling circuit, each of which circulated the engine coolant through seawater box coolers fitted into the vessel's hull **(Figure 14)**. The LT coolant was circulated through the engine's charge air cooler and the fluid coupling oil cooler by an electric booster pump. The HT coolant was circulated through the engine's oil cooler, cylinder jacket space, cylinder head, exhaust manifold and turbo charger by an engine driven pump. Both cooling systems had a pressurised expansion tank.

The separation of the LT and HT circuits differed from standard D16 MH engine installations, which operated a single circuit to and from an engine mounted expansion tank (saddle tank) that was fitted with a pressure relief cap, like those fitted to road vehicles. In the W-Class installation, the saddle tanks were modified by replacing the pressure relief cap with a pipe running to a HT expansion/header tank approximately 1m above the engine, which was fitted with a 100kPa (1 bar) pressure relief cap. Due to the structural arrangements, the pipework between ME1 and ME4's saddle tanks and HT tanks was routed under the engines, creating a U-bend. This made the venting of air from these systems difficult.

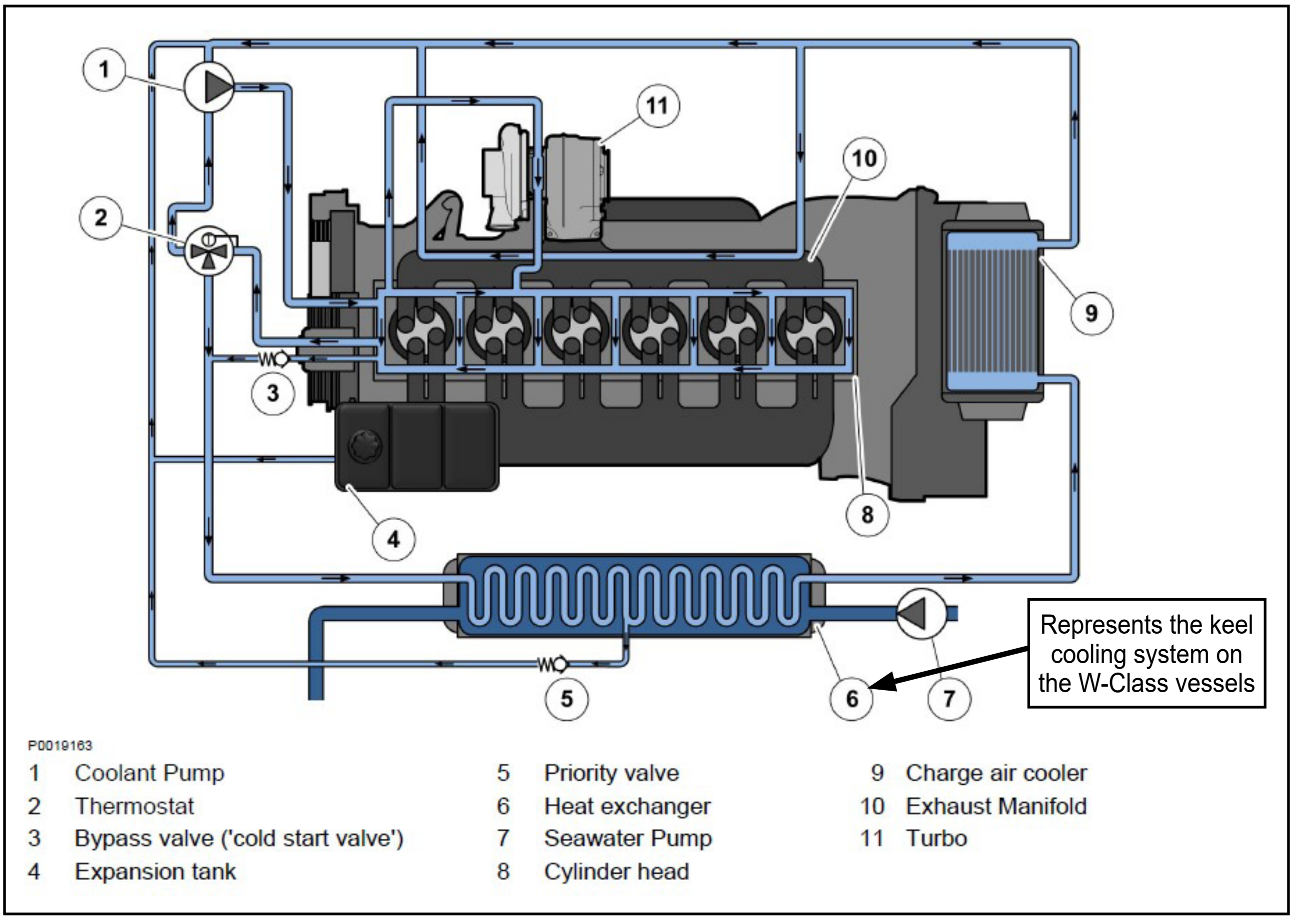

Figure 14: Engine cooling system

When the vessels were delivered from the shipbuilders, the pressure relief caps were found to be loosely fitted to the expansion tanks. Wightlink's engineering staff assumed that this was how the system was meant to operate and the caps were left loose. After the ferries had operated for several years, RKM service engineers noticed this practice and advised Wightlink that the caps should be tight as the engines were designed to operate with a pressurised cooling system.

After about 18 months' operation, the vessels started to suffer from cylinder liner failures. These were thought to be a result of difficulty in venting the HT cooling system and Volvo Penta advised the installation of a T-piece to aid effective venting of the engines' cooling water saddle tanks **(Figure 15)**. Following the two catastrophic engine failures in 2018, Volvo Penta was unable to determine the justification for the T-pieces and advised their removal, along with a revision to the pipework design to remove the U-bend in the systems and a change to pressure relief caps rated at 75kPa **(Figure 16)**.

Volvo Penta service bulletins relating to the coolant system included:

- *Quality Campaign 4380-2165, Q0003 – Improved Cooling*
- *Coolant Pump, Leakage (26-2 41 1).*

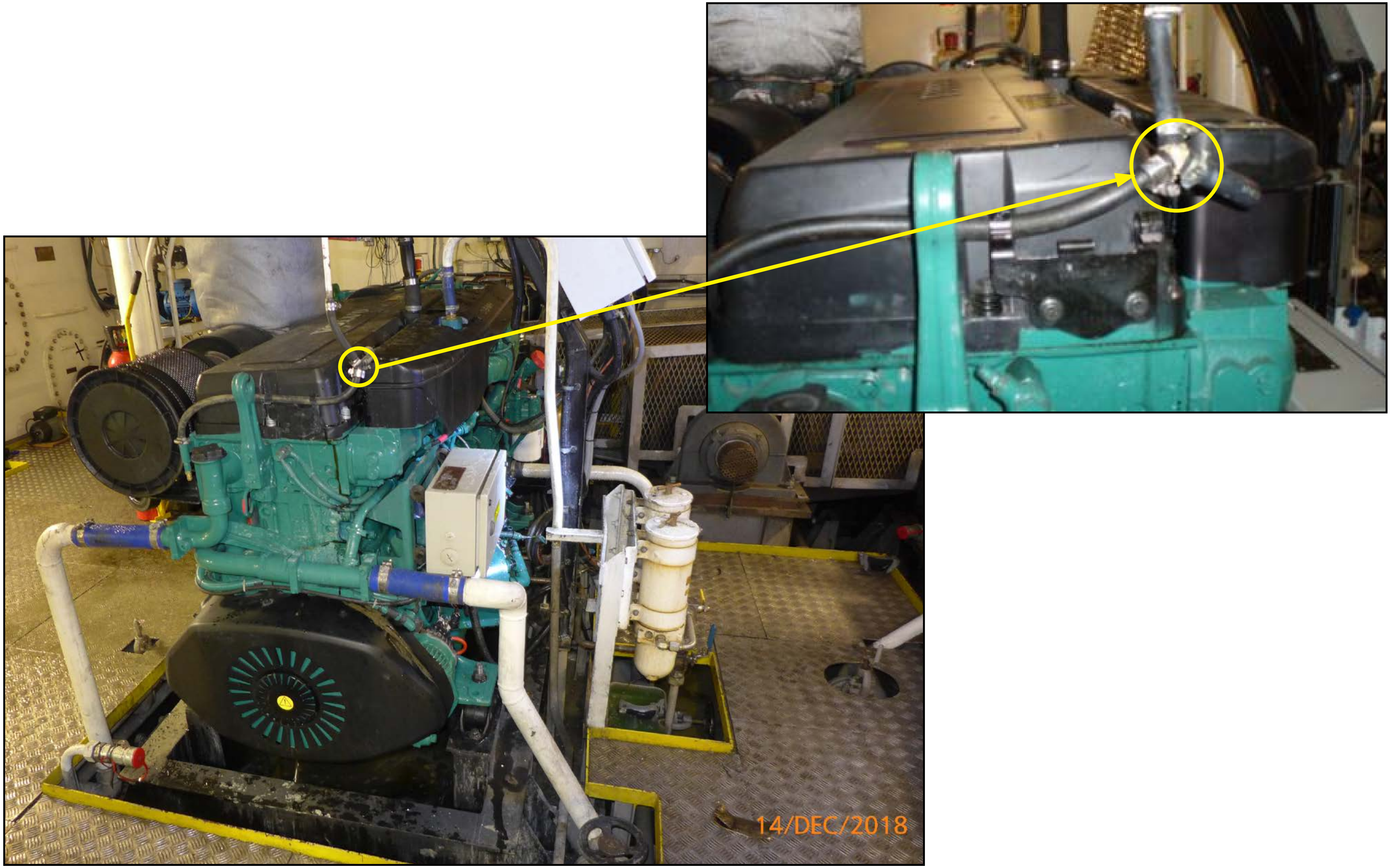

Figure 15: Coolant system T-piece

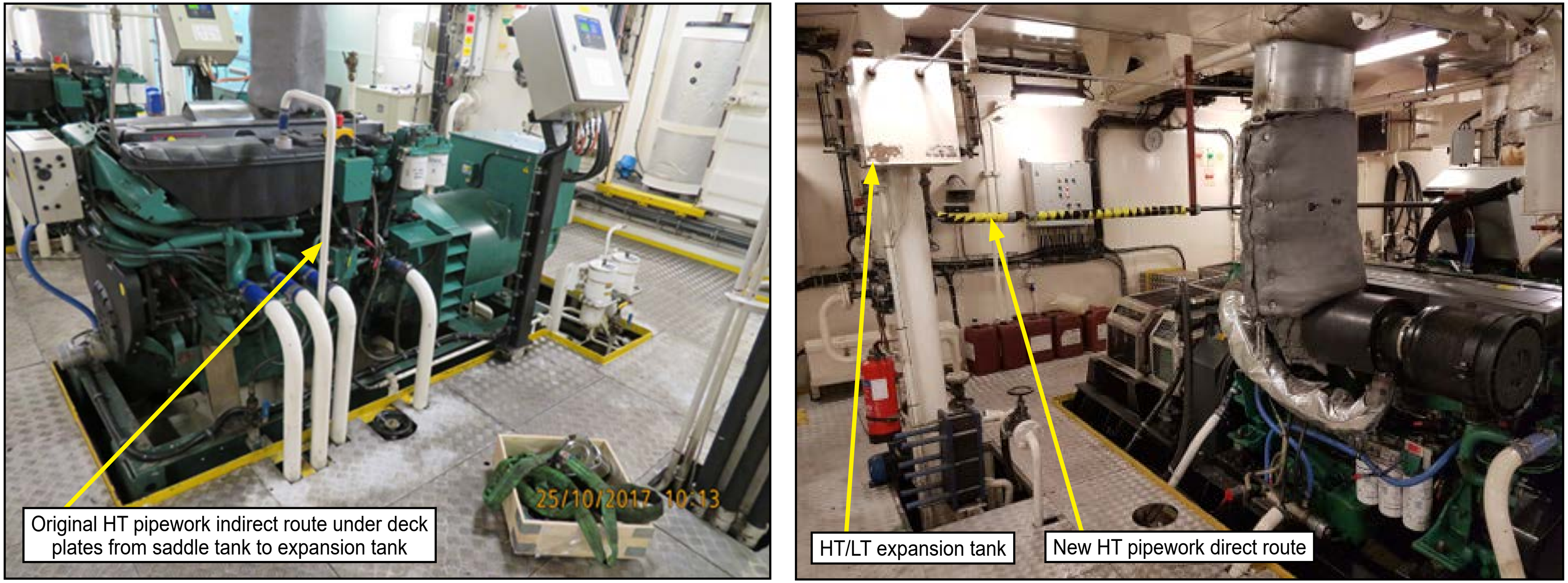

Figure 16: Modified cooling system high temperature circuit pipework

The aim of the Improved Cooling Quality Campaign was to improve the cooling system performance of engines using remote heat exchangers by increasing the venting capacity. It required a venting orifice in the air filter bracket to be enlarged to 5mm and the replacement of the HT coolant pump. Volvo Penta had determined that the original vent hole was too small and could easily clog.

The aim of the Coolant Pump Leakage bulletin was to alert service centre dealers to the number of warranty claims Volvo Penta had received about coolant pump leakages. It advised that a weep hole for draining a space behind the pump's mechanical seal could become blocked. It also stated that:

> *Pumps with burnt seal faces have been returned. It can be caused by air pockets in the coolant system, which have been trapped at the seal and led to dry-running. If the faces of the seal are burnt, that means that the seal temperature exceeds its admissible limit. This can happen if the boiling point of the coolant is lowered (ex: too much water compared to glycol). Engineering investigation also showed this can happen in case operating the engine with low coolant levels and/or incorrect water/glycol concentration.* [sic]

Wightlink was unaware of these bulletins. However, RKM carried out the necessary modifications in 2012 and 2013.

1.8.2 Engine coolant

Wightlink used the engine coolant specified by Volvo Penta. Known as green coolant, it was available either as a concentrated liquid that had to be mixed locally with water or as a pre-mixed 40 to 60 coolant liquid to water ratio. Wightlink ordered the coolant concentrate and mixed it on board the vessels with water supplied from ashore in Lymington.

The Volvo Penta *Operator's Manual* stated:

> *IMPORTANT! Coolant must be mixed with clean water, use distilled - de-ionized water. The water must comply with the requirements in ASTM D4985*[13]*, refer to "Water quality".*

The water quality section of the ASTM D4985 standard stated that the total hardness was to be less than 9.5°dH[14]. The water supply to the Lymington ferry terminal was moderately hard, with a total hardness of 14°dH.

In November 2014, Volvo Penta issued a service bulletin titled *Introduction of New Coolant*. This promoted the use of a new coolant (yellow) that contained inhibitors better suited to the materials used in more modern engines, including the D16 MH range. It also counteracted cavitation and galvanic corrosion and offered better protection against corrosion and the build-up of deposits. Its boiling point was 175°C compared to green coolant's 100°C. The bulletin stated:

> ***NOTE!*** *In the case of D13 Marine, D16 Marine and TWD1643GE engines delivered with Volvo Penta coolant (green) we recommend replacement with Volvo Penta coolant VCS (yellow). Before replacement, carry out cleaning using oxalic acid in accordance with Service bulletin 26-0-29.*

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[13] Standard Specification for Low Silicate Ethylene Glycol Base Engine Coolant for Heavy Duty Engines Requiring a Pre-Charge of Supplemental Coolant Additive (SCA).

[14] A degree of General Hardness °dH, (deutsche Härte) is equal to 17.848 mg/l calcium carbonate.

Wightlink was unaware of this service bulletin and no action was taken to change the coolant on the W-Class vessels. In March 2019, following discussions arising from this investigation, Volvo Penta informed Wightlink that, due to the difficulty in cleaning the cooling systems on board these vessels, Wightlink should continue to use the green coolant.

The engine maintenance schedule stated that the cooling system should be checked, cleaned and have the fluid replaced by an authorised Volvo Penta workshop every 2 years. There were no records of the coolant being tested or replaced on the W-Class. As part of the investigation, samples of the coolant in all 12 W-Class MEs were tested. The samples were a dark colour instead of clear and all showed signs of contamination, glycol degradation and precipitation[15].

1.8.3 Engine cylinder liner failures

In October 2012, an LR surveyor raised concern about the number of cylinder liner failures that had occurred on board Wightlink's W-Class ferries **(Tables 1**, **2** and **3)**. In response, RKM's technical manager opened a service request, informing Volvo Penta of the concern raised by the certifying authority and requesting guidance on how to resolve the issue. The technical manager identified six engines that had suffered liner failures over a 2-year period. The engine running hours at the time of failure ranged between 6027 and 14860; four of the engines had accumulated less than 10000 running hours.

RKM's technical manager attributed the problem to coolant leakage into the engine sump due to cavitation erosion in the liner at the annular groove seals located at the lower end of the liner/block interface. He suggested that long periods of off-load running might be causing the liner to oscillate in the engine block **(Annex B)**. The technical manager also advised Volvo Penta that the engines were operating on green coolant and it was his understanding that the coolant was checked daily and replaced every 2 years during vessel refit periods.

Volvo Penta's reply stated that it had not received any similar reports and agreed that liner oscillation might be a possible cause, but advised that low cooling system pressure could cause similar problems. Volvo Penta also expressed hope that the next inspection would show an improvement as Wightlink was now aware of the problem and would not run the engines off-load for extended periods.

RKM provided no further feedback and Volvo Penta closed the service request on 14 January 2013. Unaware of this, and awaiting further guidance, after amending the periodicity of engine overhauls as discussed in section 1.13.3 below, Wightlink and LR also took no further action.

In July 2015, the W-Class superintendent told an LR surveyor that he had held discussions with RKM about three engine blocks that had all suffered from pitting, and that he had asked RKM to consult with Volvo Penta. The *Wight Sky* ME2 that failed catastrophically on 12 September 2017 (Event 1) was a rebuilt engine that had been assembled using a repaired engine block from a *Wight Sun* engine and a crankshaft from a *Wight Light* engine. The engine block had suffered pitting erosion and was repaired using the epoxy coating product *Belzona 1391T*[16] (Belzona). On 18 August 2017, RKM staff made the repair, which was sanctioned by Wightlink

[15] Glycol reacts with oil additives, causing precipitation.

[16] *Belzona 1391T* is a two-part ceramic filled epoxy coating that provides erosion and corrosion resistance to high temperature equipment operating under immersion up to 120°C (248°F).

following discussions with an LR surveyor. Similar Belzona repairs had been undertaken by another engine repair company and the LR surveyor assumed that RKM staff were following a Volvo Penta agreed repair method. Volvo Penta did not approve Belzona repairs and no records could be found of any engine block repair service requests raised by RKM or received by Volvo Penta.

1.9 ENGINE LUBRICATION SYSTEM

1.9.1 Overview

The D16 engine was pressure lubricated by an engine-driven gear pump that, at full speed, supplied oil at a pressure of about 4 to 5bar to the engine's bearings and moving parts via two full-flow filters and one bypass filter **(Figure 17)**. Oil temperature was maintained by an engine mounted cooler.

Two lubricating oil galleries were drilled along the engine block; one fed the crankshaft bearings and the other was the piston cooling oil duct, which provided oil for both piston cooling and lubrication **(Figure 18)**. The following seven valves controlled the oil flow:

- **Bypass filter overflow valve** – this valve opened at pressures greater than 1.1 bar if the bypass filter started to become blocked and secured the oil supply to the turbocharger.
- **Full-flow filter bypass valve** – the valve opened at pressures above 2.1 bar if the full-flow filter became blocked and thereby secured lubrication.
- **Oil cooler bypass valve** – this valve opened when the oil temperature was low i.e. after start-up. When oil temperature rose the valve closed and forced the oil through the cooler.
- **Piston cooling valve** – this valve opened and provided oil to the piston cooling channel when engine speed was increased above idle.
- **Piston cooling oil control valve** – this valve maintained the piston cooling pressure at a constant level once the piston cooling valve had opened.
- **Lubricating oil pressure reduction valve** – the valve controlled the oil pressure by feeding excess oil back to the engine's oil sump.
- **Safety valve** – this valve opened and returned oil back to the sump when oil pressure was too high.

1.9.2 Oil filters

The full-flow oil filters had a 40-micron (μm) mesh size and gave 99% throughput to the main oil circuit at 38μm filtration and 50% throughput at 14μm. The bypass filter had low flow and a high degree of filtration capabilities using a 10μm mesh and gave 99% throughput to the turbo charger at 11μm filtration and 50% throughput at 4μm.

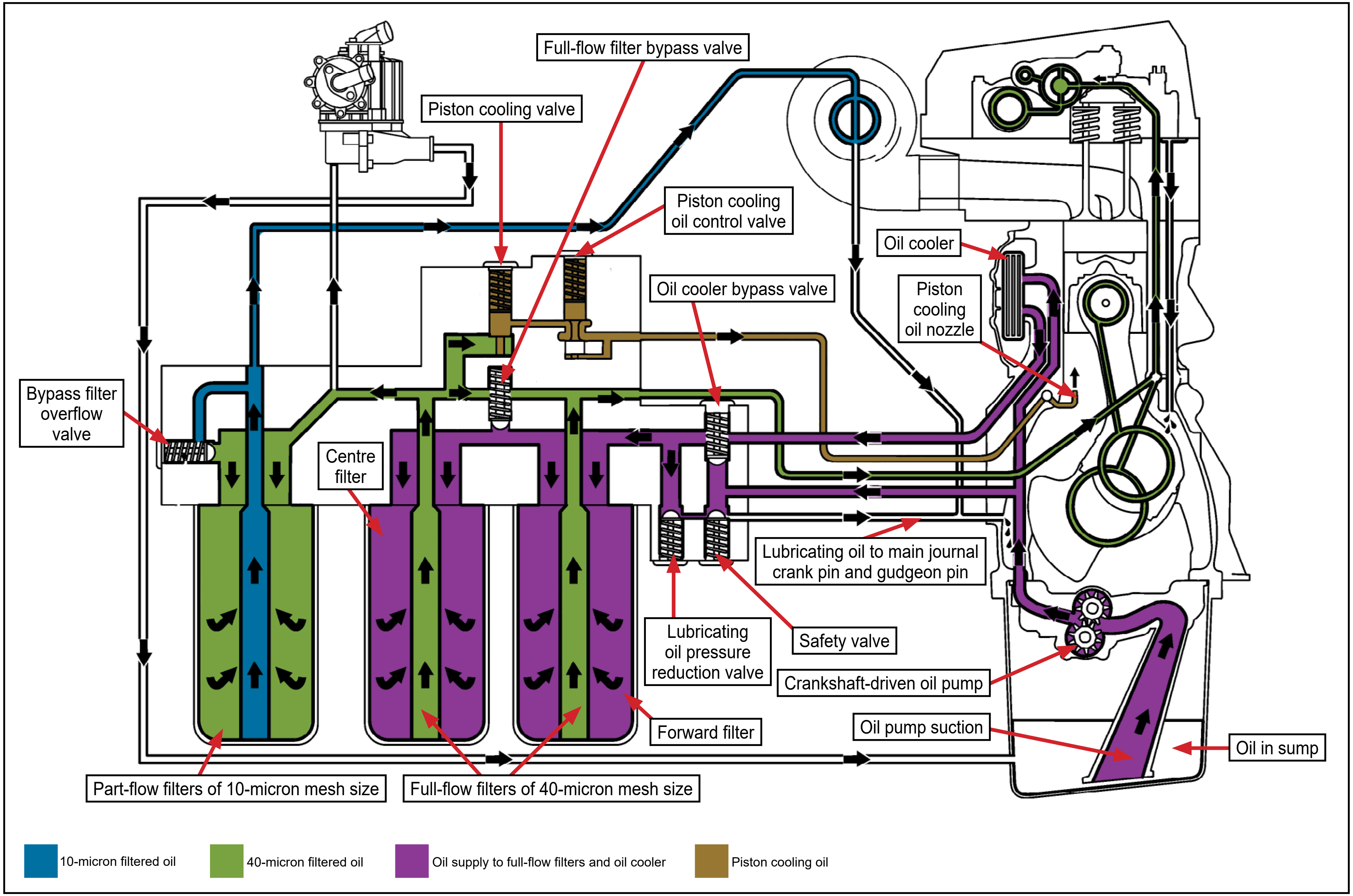

Figure 17: Engine lubricating oil system

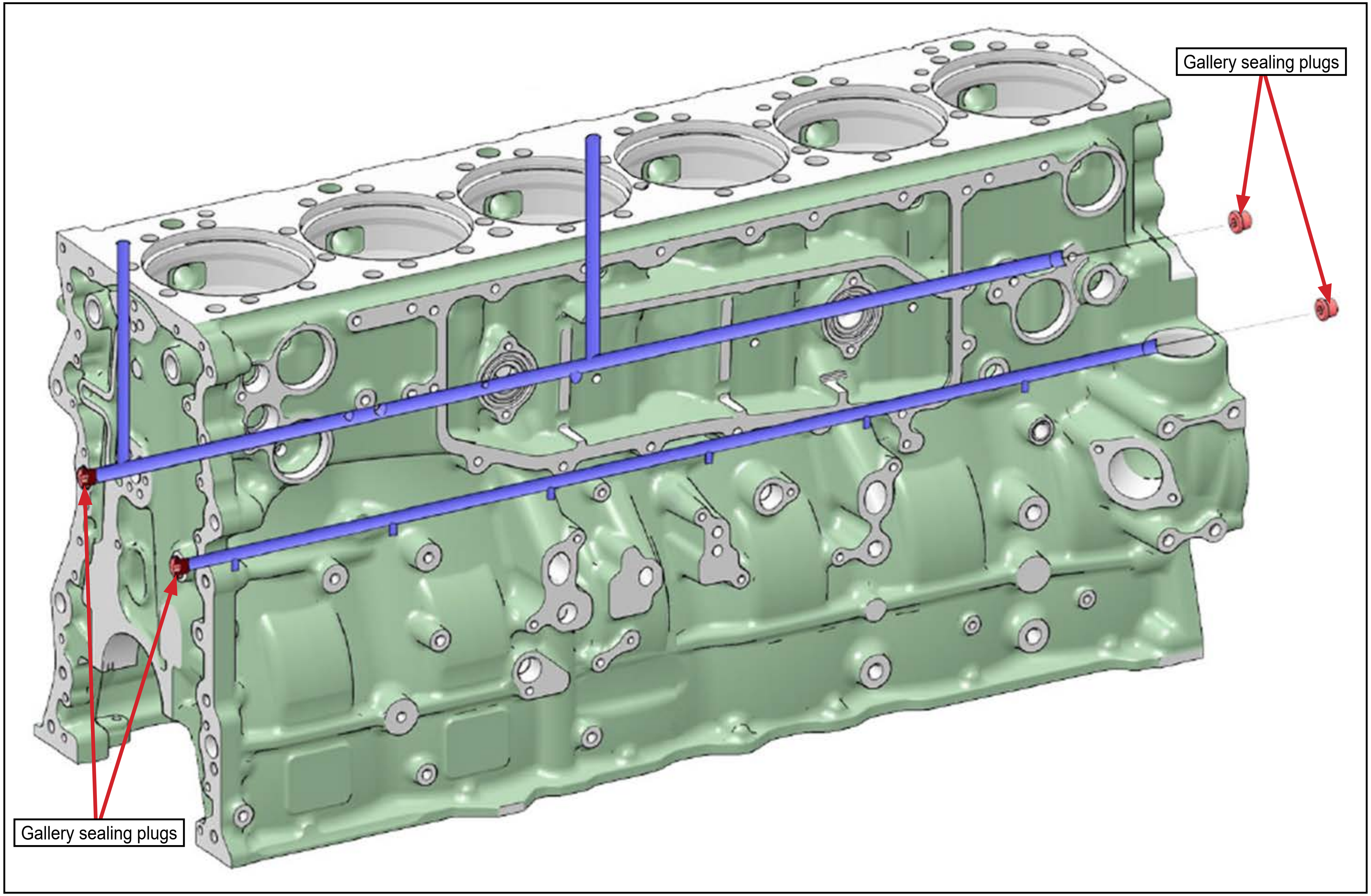

Figure 18: Engine block lubricating oil galleries

Up until 2015, classification society rules required the use of a switchable oil filter arrangement (duplex filter) that allowed the main oil filters to be changed individually while the engine was running. To meet this requirement the D16 MH engine full-flow oil filter had a central changeover cock **(Figure 19)**.

A Service Bulletin Recall Campaign (R0001), dated 1 August 2011, required an adaptor change within the duplex filter changeover cock mechanism. On the W-Class ferries, the modification resulted in an approximate 1.0 bar pressure drop in the lubricating oil system at full speed to between 3 and 4 bar. The bulletin did not explain the reason for the modification.

During Volvo Penta's investigations into the causes of the Wightlink engine failures, a design error was identified with the oil filter arrangement. It was discovered that, at full engine speed, the full-flow filters' bypass valve opened slightly and allowed 10 to 20% of unfiltered oil to flow through the circuit. The overflow valve for the main filters was affected by the pressure drop caused by the changeover cock. In April 2019, Volvo Penta informed Wightlink and subsequently issued a D16MH/MG service bulletin for the overflow valve spring replacement. In Wightlink's case, as the changeover cock was no longer required to meet classification society requirements, Volvo Penta advised its removal from the oil filter block. This work was completed on the W-Class vessels **(Figure 20)**.

1.9.3 Oil testing

Volvo Penta's service protocol recommended that the engine lubricating oil be replaced every 12 months or 500 running hours, whichever came first. Volvo Penta explained that the replacement interval might need to be reduced dependent on the oil quality and the sulphur content of the fuel in use. The W-Class ferries operated on low sulphur fuel and Wightlink intended to manage the oil change interval through a regular regime of oil condition monitoring, enabling them to both maximise the life of the oil and maintain an awareness of engine degradation. The oil renewal period could then be varied dependent on the test results of the samples taken.

Wightlink started with an oil sampling and replacement interval of 400 running hours. Samples of the old oil were sent to a laboratory for testing and analysis against Volvo Penta's specification; the results were usually received a few days later. When a sample result indicated an issue with the oil quality, Wightlink's standard practice was to test samples of the new oil after 50 to 100 hours. The aim of the retest was to rule out spurious results and possible contamination when the first sample was taken.

The laboratories relied upon accurate labelling of test samples to ensure that the results were assessed against the correct criteria for the engine and oil being tested. Each engine had a unique identification number for lubricating oil test purposes, which linked the sample to all previous samples for that engine. The unique identification number was regularly missed from the documentation provided by ship's staff, leading to samples being identified as fit for use against a standard set of criteria rather than the more stringent criteria developed by Volvo Penta to suit the high-performance nature of the D16 MH engines.

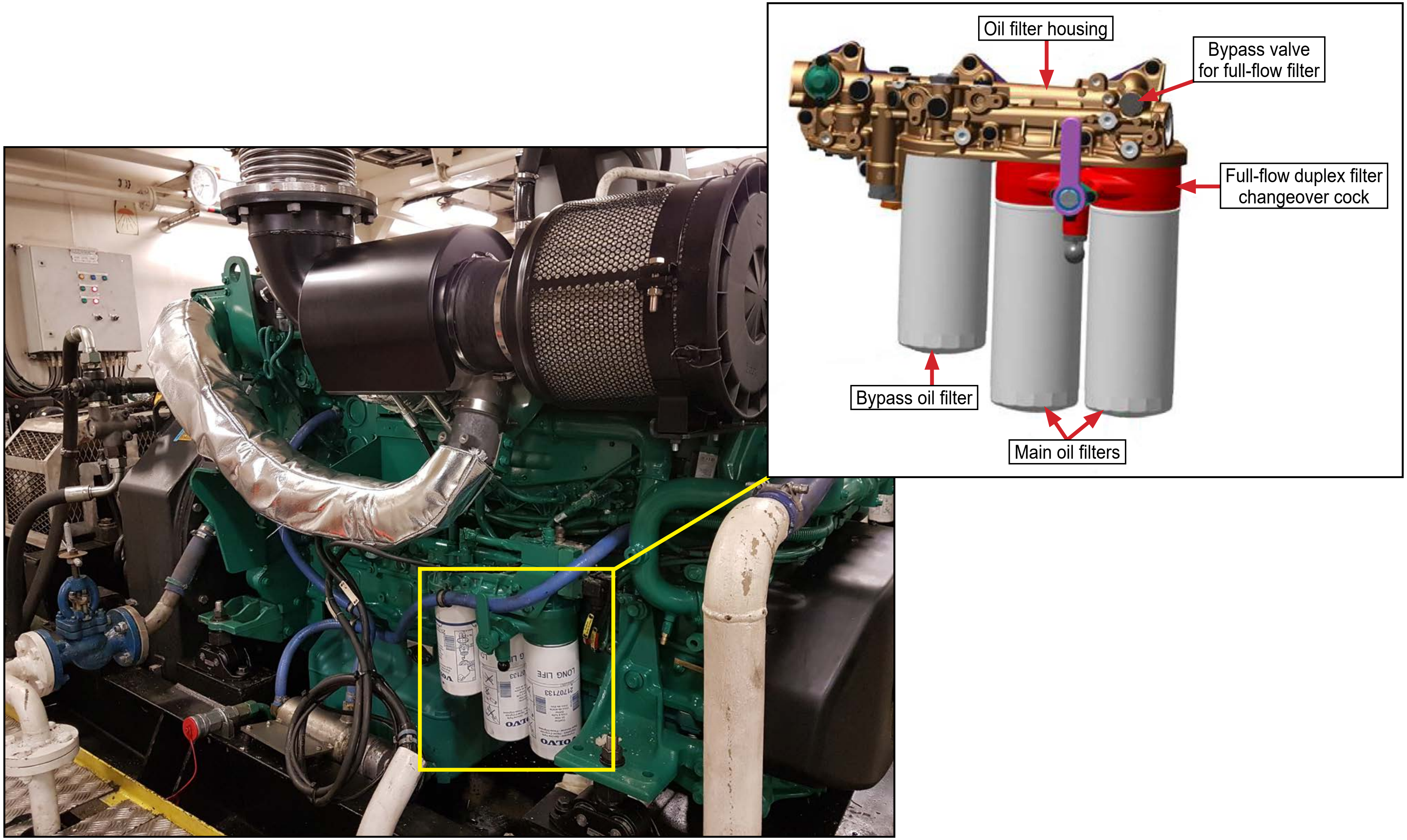

Figure 19: D16 MH lubricating oil filters (with changeover cock)

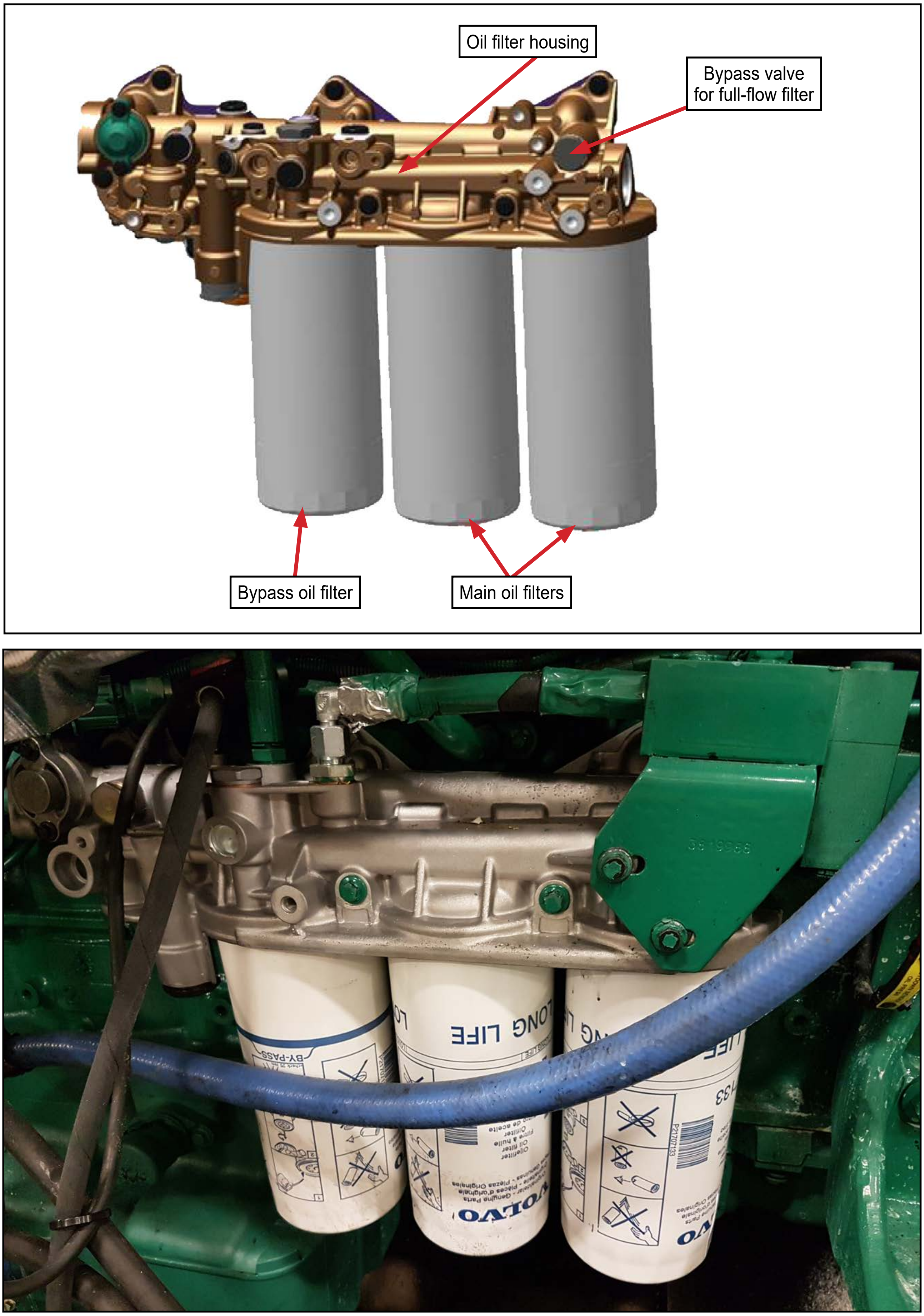

Figure 20: Replacement lubricating oil filters without changeover cock

The early oil sample analysis returned mixed results across the 12 engines. Some identified higher than normal levels of wear elements, contamination and low levels in the oil's residual Total Base Number (TBN[17]). Even so, in discussion with RKM, Wightlink technical staff decided that the results were good enough to extend the oil replacement hours. These were raised in two stages, first to 600 hours during 2013 and then to 800 hours about 12 months later. However, record-keeping was sporadic and the running hours between renewals varied considerably.

As part of the risk mitigation plan put in place after the catastrophic failure of *Wight Sky*'s ME4 on 14 December 2018 (Event 5), the oil replacement schedule was reduced back to 400 running hours. The intervals between oil sample testing were also reduced. The new regime required oil samples to be tested after the first 10 running hours and subsequently every 100 running hours. Volvo Penta's designated testing laboratory analysed the samples and the results were promulgated to the service centre dealer contracted to maintain the engines.

1.9.4 Lubricating oil analysis service bulletin

In April 2015, Volvo Penta issued Service Bulletin 17-0 23 - *Engine Oil & Oil Analysis*. The Bulletin referred to industrial engines and marine diesel engines. It described the different additives and the various oil types and their suitability for various engines and operating profiles.

The bulletin specified the oil parameter limits **(Table 6)** within the oil sample report analysis and the respective oil change intervals. The oil used by Wightlink allowed a 500 running hour change when used with fuel containing less than 0.5% sulphur content by weight.

The bulletin did not provide guidance on the frequency of normal oil sampling, but stated:

> *In cases where oil analysis shows high PPM content, carry out:*
>
> 1. *Oil change and filter replacement.*
>
> 2. *Further oil analyses:*
>
>   a. *At a few number of running hours, after the oil change and filter replacement.*
>   b. *And then three oil analyses at intervals of 100 hours.*

And,

> *These oil analyses provides an answer to the tendency (after oil & filter replacement). It may turn out as follows:*
>
> 1. *PPM content drops. Wear is normal.*
>
> 2. *PPM content remains at a high but stable level. Wear is normal.*
>
> 3. *PPM content continues to rise. This indicates abnormal wear and the customer should be informed.*

[17] TBN is a measurement of basicity expressed in mg KOH/g. TBN for marine grade lubricants is typically 15-80 mg KOH/g, to increase their operating period before the lubricant requires replacement.

4. *PPM content varies greatly up and down. This indicates presence of foreign particles caused by working environment, storage of oil etc.*

It is important to note that iron content rises with faulty air cleaner system before it is possible to note rising silicon content, …

On fuel dilution of the oil, the bulletin stated:

Low load or cold application?

- *Collect info regarding drive cycle, engine history.*
- *Try to change running cycle and increase load.*

NOTICE! *Frequent starts of an engine, excessive idling and cold running.*

Parameter	Possible Origin/Cause	Limit	Unit
Sodium, Na	Coolant leak	≤ 10	ppm
Silicon, Si	Sand, dirt etc	≤ 30	ppm
Aluminium, Al[18]	Pistons, charge air cooler, dirt	≤ 15	ppm
Chrome, Cr	Piston rings, valve stems	≤ 15	ppm
Copper, Cu[19]	Bid-end and main bearing shells, gudgeon pin bushes, oil cooler, heat exchanger	≤ 30	ppm
Iron, Fe	Crankshaft, cylinder liner, camshaft, cam follower, valve guides	≤ 100	ppm
Lead, Pb	Big-end and main bearing shells	≤ 30	ppm
Tin, Sn	Outer surface of sliding bearings	≤ 15	ppm
Nickel, Ni	Layer between surface and copper layer on sliding bearings, rocker arm bushes	≤ 15	ppm
Molybdenum, Mo	Piston ring	≤ 15	ppm
Soot	Incomplete combustion	≤ 3	%
TBN	TBN indicates remaining alkalinity after acid neutralisation	≥ 4	-
Water	Coolant, condensation	≤ 0.2	%
Fuel[20]	Incomplete combustion, internal leak on fuel system etc	≤ 6	%
Viscosity	Reduction: fuel dilution, oil shearing. Increase: oxidation, contamination by soot.	Min: 9	cSt

Table 6: Oil analysis parameter limits

[18] Can be considerably higher during running-in.

[19] Several 100ppm copper levels can be found during the early life of the engine. This copper is flushed out from the oil cooler and is not harmful to the engine.

[20] If fuel dilution is > 6% and viscosity is > 9cSt then engine is okay. If fuel dilution is > 6% and viscosity is < 9cSt continue with “Fault Tracing: Fuel Dilution”.

1.10 ENGINE CONTROL, MONITORING AND PROTECTION SYSTEM

Each W-Class ME was fitted with a Volvo Penta Engine Control Unit (ECU)[21]. The ECUs were supplied at build and mounted to the engine. The ECU monitored and logged the engine status and managed all speed, torque, fuel injection and emission controls through a series of connected sensors. The sensor readings were logged by the ECU but not time stamped. Each ECU provided outputs to local alarm panels and the ferries' Kongsberg machinery monitoring system panels in the MMR and on the bridge. The Kongsberg system provided time-stamped alarm information.

The ECU also provided emergency shutdown and power reduction protection. Emergency shutdowns involved the immediate declutching of the engine and removal of fuel and could be triggered by:

- high coolant temperature (120°C);
- low gearbox oil pressure (400kPa);
- low lubrication oil pressure (150kPa);
- low coolant pressure (30kPa); and
- engine overspeed.

The power reduction function, referred to as '*derating*' in the electrical section of Volvo Penta's *Workshop Manual*, provided protection in response to certain less critical high temperature and low/high pressure readings, e.g. high coolant (101°C) and oil (128°C) temperatures, low piston cooling pressure (150 ± 20kPa) and rapid increase in crankcase pressure. The derate functions were inactive at engine speeds below 1200rpm and the percentage of load shedding differed according to alarm type, sensor readings and engine speed.

Parameters that could result in an automatic engine derate were grouped under a common alarm on the Kongsberg system. To identify the specific cause of the common alarm, the shipboard engineer had to inspect the relevant local alarm panel in the engine room. The *Workshop Manual* included fault-finding guidance on the electrical systems but did not provide instructions on how to test the common alarms and their respective derate functions. Wightlink's technical staff were aware of the ECU derate functionality but had never tested its operation or noticed the engines being derated automatically.

Following the catastrophic engine failures in 2018, Volvo Penta, with the agreement of Wightlink, LR and MCA, changed the piston cooling oil pressure protection from '*alarm and derate*' to '*alarm and shutdown*'.

In March 2019, during a routine software upgrade to its engine range, Volvo Penta identified that the 478kW rated D16 MH engines were not supplied with the derating software. Further analysis identified that, as a result, the derating function of these engines did not work and, in the case of the Wightlink engines, never had.

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[21] Engine Control Unit is used in this report as a generic term for Volvo Penta's *Marine Commercial Control* system, which includes a standalone hard-wired engine shutdown unit.

1.11 WIGHTLINK TECHNICAL AND MAINTENANCE MANAGEMENT

1.11.1 Technical management team

Wightlink's Maintenance and Repair Organisation was responsible for the day-to-day technical management of the ferry fleet and the planning and delivery of maintenance periods, refits and dry dockings. Each Wightlink vessel had a nominated senior master and a survey chief engineer. The survey chief engineers were responsible for ensuring the consistent maintenance of engine rooms, machinery spaces, deck machinery and auxiliary equipment. They also oversaw the maintenance and repair work conducted during refits and dry-docks.

The onboard engineers, many of whom had worked on Wightlink ferries for many years, operated and monitored the machinery, undertook routine planned maintenance tasks, including oil and filter changes and tappet adjustments, and carried out minor breakdown repairs. Major planned maintenance tasks and complex breakdown repairs were typically performed by shore contractors.

The technical management team structure had been subject to significant change over several years, particularly between 2016 and 2018, when:

- The Head of Maintenance and Repair position was changed twice.
- The W-Class technical superintendent was required, for a short period of time, to take on the role of technical superintendent for Wightlink's entire fleet. During this period he was provided with support from the office-based chief engineer.
- The Portsmouth fleet technical superintendents changed three times.

In 2017, Wightlink introduced an electronic computer-based integrated management system designed to provide both crew and office staff with a one-stop shop for the management of safety, maintenance, and purchase requests. The integrated system replaced a largely paper-based maintenance management system that had fallen into abeyance. The computer-based system's roll out was problematic, with initially low uptake by the on board engineering teams.

Volvo Penta recommended that one of its authorised dealers performed all maintenance tasks listed in its maintenance protocol **(Table 5)**. In 2008/09 it identified four minor inspection tasks that the engine owner or operator could perform. Wightlink asked RKM, on an ad hoc basis, to undertake most of the ME maintenance work.

1.12 VOLVO PENTA

1.12.1 Volvo Penta dealers

Volvo Penta operated as a business partner to its network of independent Volvo Penta Centre dealers and smaller Volvo Penta Service dealers. The dealers sold and serviced Volvo Penta products based on the markets they served.

Volvo Penta contacted its dealers twice a year. The discussions covered areas such as warranty, training reviews, dealer assessment, tooling inspections and new products.

1.12.2 Service requests and service bulletins

Volvo Penta dealers raised service requests through the engine manufacturer's internal reporting system (ARGUS), which facilitated communication between dealers, Volvo Penta Sweden and its UK headquarters. The system was monitored for recurrent problems to enable an effective response. Where updates were no longer provided from dealers on a particular issue, the respective Volvo Penta product team perceived the issue as resolved locally and closed out the service request on ARGUS.

Volvo Penta issued service bulletins to its dealers to promulgate information about engine modifications, servicing improvements and equipment design changes. The dealers were expected to contact their customers and either provide them with advice to help update their planned maintenance systems or arrange for necessary work to be completed.

1.13 RK MARINE LTD

1.13.1 Overview

RKM was based in Swanwick, England, about 20 miles from Portsmouth and 30 miles from Lymington. It was an authorised Volvo Penta Centre dealer and had sold, serviced and overhauled Volvo Penta engines and associated equipment for more than 40 years. It also supported a network of Volvo Penta Service dealers.

RKM split its engine maintenance work between leisure (about 80%) and commercial (about 20%) vessels. Wightlink was RKM's only customer operating D16 MH engines.

1.13.2 Maintenance of Wightlink's D16 MH engines

Volvo Penta's installation engineers proposed RKM as the dealer for Wightlink's D16 MH engines during the W-Class vessel commissioning process. Three RKM engine technicians were trained to service the D16 MH engine, one of which was the technical manager, who also deployed to a ferry when required by Wightlink. The technicians operated a duty callout arrangement. The various stages of a typical engine overhaul were often undertaken by different engine technicians.

Wightlink awarded RKM short-term contracts for its engine work; it was not tasked to provide any form of maintenance management or engine condition monitoring service. No calibration data or other measurements were provided and no written maintenance or operational advice was given to Wightlink in light of any findings from engine maintenance or repair.

Where an engine problem necessitated an overhaul, RKM provided an estimated cost for the work based on a standard set of overhaul kits available from Volvo Penta. Once stripped down, RKM and Wightlink technical staff and, when informed, an LR surveyor, would assess the full scope of work and RKM would quote for completing the overhaul. Volvo Penta had no input into the commercial arrangements between Wightlink and RKM.

Engine overhauls were performed ashore at RKM's workshops and its engine technicians reinstalled the overhauled engines on the vessels. RKM did not have a dynamometer to load test the engines, but used the dynamometer services of another Volvo Penta Centre post-Event 1. The production plant in Sweden used dynamometers to test new engines.

1.13.3 Operational guidance

Volvo Penta's service protocol did not include major maintenance work such as cylinder head, rotating assembly and fuel injector overhauls or replacement. These were dependent on local engine operating conditions and the results of through-life condition monitoring.

RKM discussed the major overhaul arrangements for the W-Class engines with Wightlink, which decided that the cylinder heads would be overhauled at 10000 running hours and the rotating assembly at 20000. These arbitrary figures were based on limited experience of the D16 MH engines and did not account for factors such as lubricating oil and coolant condition monitoring.

During 2012 and 2013, when cylinder liner and engine block cavitation erosion problems arose in W-Class engines, Wightlink, in discussion with RKM and LR, agreed to perform major overhauls after 15,000 running hours. This included cylinder liner and engine block inspections.

In December 2017, Volvo Penta issued a safety bulletin providing updated fuel quality requirements for commercially operated engines. For those running on marine distillate fuels, it stated that the *Fuel injection equipment replacement intervals shall be halved.* No service interval for injectors had been stated by Volvo Penta for these engines and RKM continued replacing them when the cylinder heads were overhauled.

RKM provided operational advice verbally to Wightlink staff and LR surveyors during face-to-face meetings. This included the need to ensure that the pressure relief caps on cooling system header tanks for the engines were tight and that the coolant was changed in accordance with the maintenance schedule.

1.13.4 Application of service bulletins

RKM received all Volvo Penta service bulletins and recall campaigns and promulgated relevant information from bulletins to the customers it had long-term through-life support contracts with. Wightlink was not such a customer and therefore did not benefit from this service. In the course of its contracted work on the W-Class ferries, RKM completed maintenance tasks in accordance with the guidance contained in the service bulletins without specifically informing Wightlink of the service bulletins' details. Furthermore, Volvo Penta service bulletins relating to maintenance tasks not performed by RKM, were not brought to Wightlink's attention by the engine manufacturer or RKM and so were not captured within Wightlink's planned maintenance system.

1.13.5 Quality management system audits

RKM's quality management system was ISO 9001[22] accredited and was audited annually by an external assessor. The audit was wide-ranging and covered all aspects of the business, including parts supply, training, technical publications, risk assessments and lifting equipment. The audits included interviews with the managing director and selected staff across the company. No specific customer complaints were noted in the audit reports between 2009 and 2018. The comments in RKM's December 2013 audit report included:

> *NCRs[23] are logged, investigated with appropriate corrective and preventive measures applied. Records maintained, although very few.*
>
> *Complaints are very low - virtually non-existent. It is very rare for a Volvo part to fail inside its warranty period.*
>
> *Returned items are generally due to the wrong part being ordered (by customer) and parts being ordered and then not used.*

About continual improvement, the report stated:

> *Company is pro-active and uses the data collected from analysis and audits to refine its processes to continually try and improve its service to customers.*

On control of monitoring and measuring equipment, RKM's 2014 audit report, stated:

> *Company uses some measuring equipment i.e. gauges but not end product critical.*
>
> *No calibration log.*

And for the same item, the 2017 audit report stated:

> *Company uses torque wrenches that are calibrated against a Check Line … Torque Tester. Evidence of tester having been calibrated in Oct 2014. It is unclear as to what the calibration regime is for this piece of equipment.*
>
> *OBS[24] – Unclear as to the calibration regime for Check Line torque tester.*

RKM was also subject to audit by Volvo Penta. These audits primarily focused on sales targets, the company's management style and its impact on the rate of staff changes, staff attitude and cooperation. Volvo Penta took no steps to address these concerns.

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[22] ISO 9001 is a quality management standard established by the International Organization for Standardization (ISO).

[23] A non-conformance report (NCR) is a note or document that addresses a specific issue that fails to meet quality standards.

[24] An observation (OBS) is a statement of fact made during an audit, often used to highlight an area for future review.

1.14 EXAMINATION OF THE FAILED ENGINES

1.14.1 Overview

The engines listed in **Table 4** (failure Events 1 to 5) were inspected by Volvo Penta engineers during this investigation. *Wight Sky*'s Event 1 engine was examined at Volvo Penta's Europe Office in Warwick, UK; Event 2, 3, 4 and 5 engines were sent to Volvo Penta's factory in Gothenburg, Sweden for closer examination.

1.14.2 *Wight Sky* main engine number two failure 12 September 2017 (Event 1)

Volvo Penta identified the debris in the oilways that led to the engine's catastrophic failure during its initial examinations in the UK immediately after the accident. The debris had reduced the oil supply and caused the crankshaft's number five main journal bearing shells to turn; this blocked the lubricating oil supply to the journal and number four crankpin. The presence of the debris was attributed to poor engine hygiene practices during rebuild.

The re-examination of the engine in Sweden focused on the condition of the liners, pistons, engine block, various oilways and reciprocating components **(Figure 21)**. The examination identified piston and liner scuffing on all units, scoring within the oil pump, and scoring to main bearings. It was also noted that a Belzona repair had been made to the block in way of the liner landing face.

Figure 21: Event 1 – engine block re-examination

The engine's number six piston and connecting rod assembly were sent to Exponent International Limited for the extraction and examination of debris seen within the connecting rod oilway. Exponent International Limited's report **(Annex C)** stated that the debris extracted from the oilways included two carbon particles, approximately 1mm^3, surrounded by wear metal material. Since the oil supply to the oilway came via the crankshaft, and the crankpin bearing clearances were much smaller (127μm) than the debris, it must have been present in the oilway before the engine was started.

Separate examination of debris found embedded in the main bearing shells identified particles of silicon dioxide (silica sand), cadmium oxide and aluminium oxide.

1.14.3 *Wight Light* main engine number one main bearing seizure 2 February 2018 (Event 2)

On 2 February 2018, *Wight Light*'s ME1's ECU shutdown automatically due to low lubricating oil pressure. The engine had accumulated a total of 23400 running hours from build and RKM had overhauled it 7 months earlier at 22700 running hours. The initial engine inspections identified that the crankshaft had seized and that one of its main journal bearing shells had turned. During its overhaul, RKM fitted a new engine block[25] and a spare cylinder head.

Volvo Penta's December 2018 examination identified that the crankshaft main journal bearing caps numbers one and seven had been transposed **(Figure 22)** during RKM's engine overhaul 700 hours earlier.

1.14.4 *Wight Light* main engine number two melted piston and partial seizure 3 August 2018 (Event 3)

Wight Light's ME2 was an original engine fitted during build. In August 2017, RKM replaced the engine's fuel injector sleeves having been contracted to investigate an unspecified issue with the engine. On 29 July 2018, the engine oil was replaced after 448 running hours due to fuel contamination.

On 3 August 2018, with approximately 21000 running hours, the engine suffered a high exhaust temperature alarm and white smoke was seen coming from the funnel. Having quickly determined that it was running on five cylinders the engine was declutched and stopped. On 14 August, RKM attended and installed an overhauled set of injectors but within 5 minutes of starting the engine began to generate excessive amounts of white smoke and made abnormal noises. When the engine's cylinder head was removed the RKM technician discovered the crown of number six piston had melted and found liner scoring to several other units **(Figure 23)**.

When the engine was stripped down at Volvo Penta's Gothenburg facility, the initial examinations identified that:

- The engine was last overhauled at approximately 13000 hours.
- Pistons one, five and six were seized in their liners.
- Cylinder liners one, three, five and six were badly scuffed.

[25] A short block is an engine sub-assembly comprising the portion of the cylinder block below the head gasket but above the oil pan.

- Numerous lubricating oil samples from 2017 and 2018 noted that fuel contamination was present.

- Between April and July 2018, there was no evidence of investigation and correction of the fuel contamination cause by the engine operators.

Figure 22: Event 2 – main journal bearing cap number seven

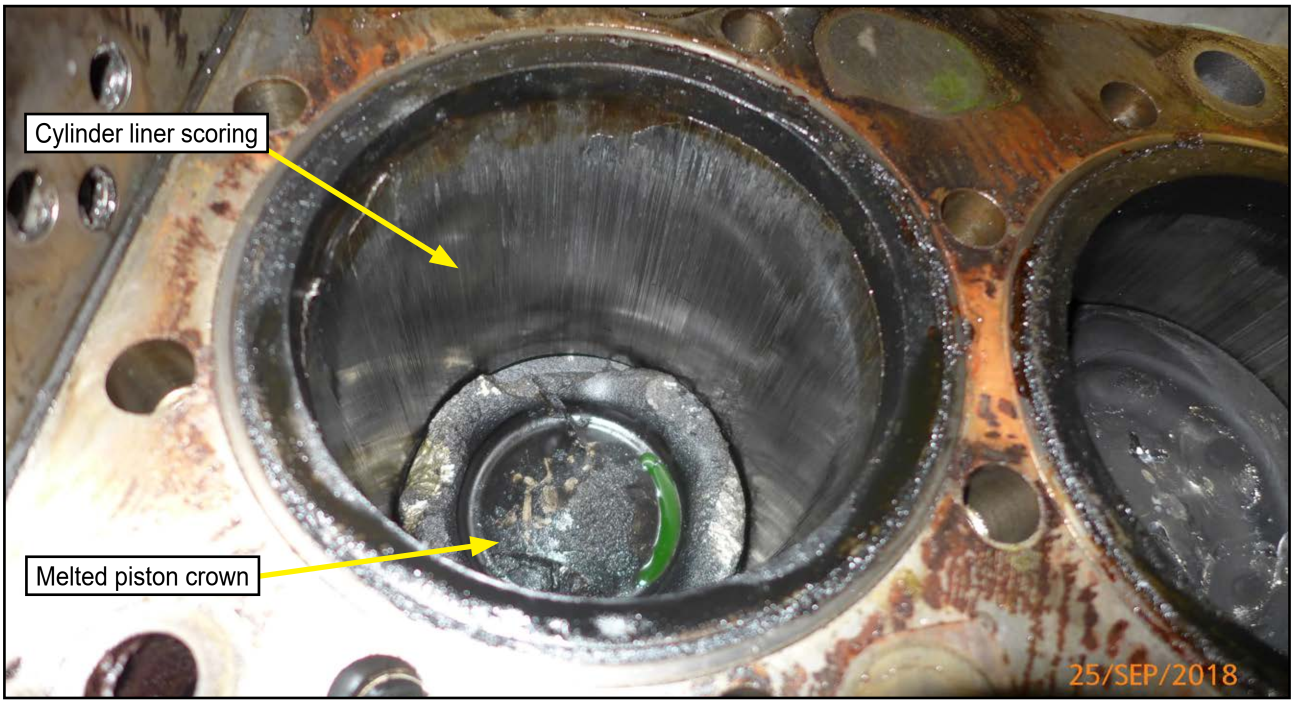

Figure 23: Event 3 – number six cylinder scoring and melted piston crown

- The ECU was not original to the engine, having been transferred from the replacement engine.

- Number seven crankshaft main journal bearing was more worn than the others, probably caused by seizure on number six piston.

- The upper piston rings showed discolouration in the contact surface towards the liner.

- There were high levels of carbon build-up above the second piston ring.

Volvo Penta sent the engine's liners, pistons and piston rings to their respective manufacturers for more detailed examination.

The pistons were manufactured by MAHLE GbmH and its examination report included the following observations and conclusions for the piston and liner scuffing:

- The scuffing marks to the rear of number three liner most likely started at the top piston ring.

- The scuffing damage to the pistons was most likely secondary to the scuffing of the top piston rings.

- The melted crown of number six piston was clearly indicative of abnormal combustion. However, this could also be linked to oil carry over resulting from ring damage.

- The scuffing damage could be linked to lack of lubrication between the top ring and the cylinder liner. This could have been the result of over spraying or abnormal injection but the remarkable cleanliness of the pistons, after so many running hours and a seizure, was indicative of oil dilution.

It should be noted that the piston manufacturer did not have access to the oil test results.

The report also identified that:

- Number four piston had suffered from graphite delamination at the piston skirt. This was subsequently clarified as being due to contact with coolant.

- Number one cylinder liner had suffered from sporadic corrosion/erosion attack of the outer face in way of the water jacket.

The piston ring manufacturer Federal-Mogul Powertrain's examination report did not identify any clear underlying issues involving the piston rings. The summary of its investigation report included:

- *A drift of the injectors which could cause fuel over-spraying/wash-off of the oil film from the cylinder wall and overrating* [overloading] *should be investigated as a possible contributor.*

- *The engine oil used should be analysed to check for a possible cooling water ingress, fuel in oil, foreign particles etc.*

1.14.5 *Wight Sky* main engine number two catastrophic failure 26 August 2018 (Event 4)

In October 2017, *Wight Sky*'s new-build ME2 was installed onto the same flexible mounts as the previous engine, which were the original mounts fitted at build. Alignment of the Event 1 engine had been problematic and the flexible mounts at the free end of the engine had been bolted to the engine bedplate using new bolt holes drilled by RKM. The replacement engine had also been installed using these new bolt holes.

On 8 January 2018, the engine oil and the oil and fuel filter elements were renewed after 801 running hours. A further oil and filter change was carried out 4 months later; the running hours were not recorded.

In March 2018, about 1400 running hours after installation, ME2 began to suffer increasing levels of vibration, causing the failure of steel brackets for the air cooler. To reduce the vibration, new engine mounts were fitted using the original bedplate boltholes. During this period, the engine's flexible coupling was reported to have failed three times, twice prior to the replacement of the engine mounts and once after. There was no documentary evidence of these repairs.

Volvo Penta's examination of the engine at its Gothenburg factory identified the following:

- Heavy carbon deposits on the fuel injector nozzles, cylinder head inlet valves **(Figure 24)** and number four piston.
- Number four piston had suffered impact damage with the cylinder head and had a fracture at 90° to its gudgeon pin that extended approximately 75% across piston crown. Its gudgeon pin had failed and its connecting rod was bent.
- Water marks on the bore of number four cylinder liner.
- Crankshaft:
    - Heat damage to number four crankpin journal **(Figure 25)**.
    - Plastic deformation and impact damage to number five main journal.
    - Number five main journal bearing shells had rotated 180°; they had suffered a loss of white metal and were heavily scored and deformed. Volvo Penta perceived this to be the primary locus of the failure with number four unit suffering progressive damage as a result of oil loss.
- Heavy scoring to all main journal bearing shells **(Figure 26)**.
- ECU not original to the engine, having been transferred from the replacement engine.

The engine's fuel injectors were examined and tested in the UK by their manufacturer, Delphi Technologies. A series of tests to assess injection performance under a range of conditions were performed using an automated test rig, which the injectors passed. A comparison with the injector's original test results showed that there had been minimal degradation during the engine's 2241 running hours.

Following Volvo Penta's examinations, MAIB transported the engine to The Test House (TTH) laboratory in Cambridge for metallurgical testing. Section 8 of TTH's examination report, *Conclusions, Discussion and Opinion*, included the following:

- *Carbonaceous deposits were identified on the inlet valves indicating poor combustion.*

- *Fractured cylinder liner No.4 showed graphitisation on the bore surface. Graphitisation is a corrosion mechanism in cast irons and occurs when the cast iron surface is exposed to medium acids or soft water. This graphitisation indicates an ingress of water into cylinder No.4* **(Figure 27)***.*

- *The SEM*[26] *examination identified the brittle nature of the fracture surface and suggests that the crankcase, cylinder liner and piston failed due to a sudden, impact type loading.*

- *The microstructural examination of the cap end shell bearings did identify regions of scoring.*

Figure 24: Event 4 – carbon deposits on cylinder head valves

[26] Scanning electron microscope (SEM).

Figure 25: Event 4 – heat damage to number four crankpin journal

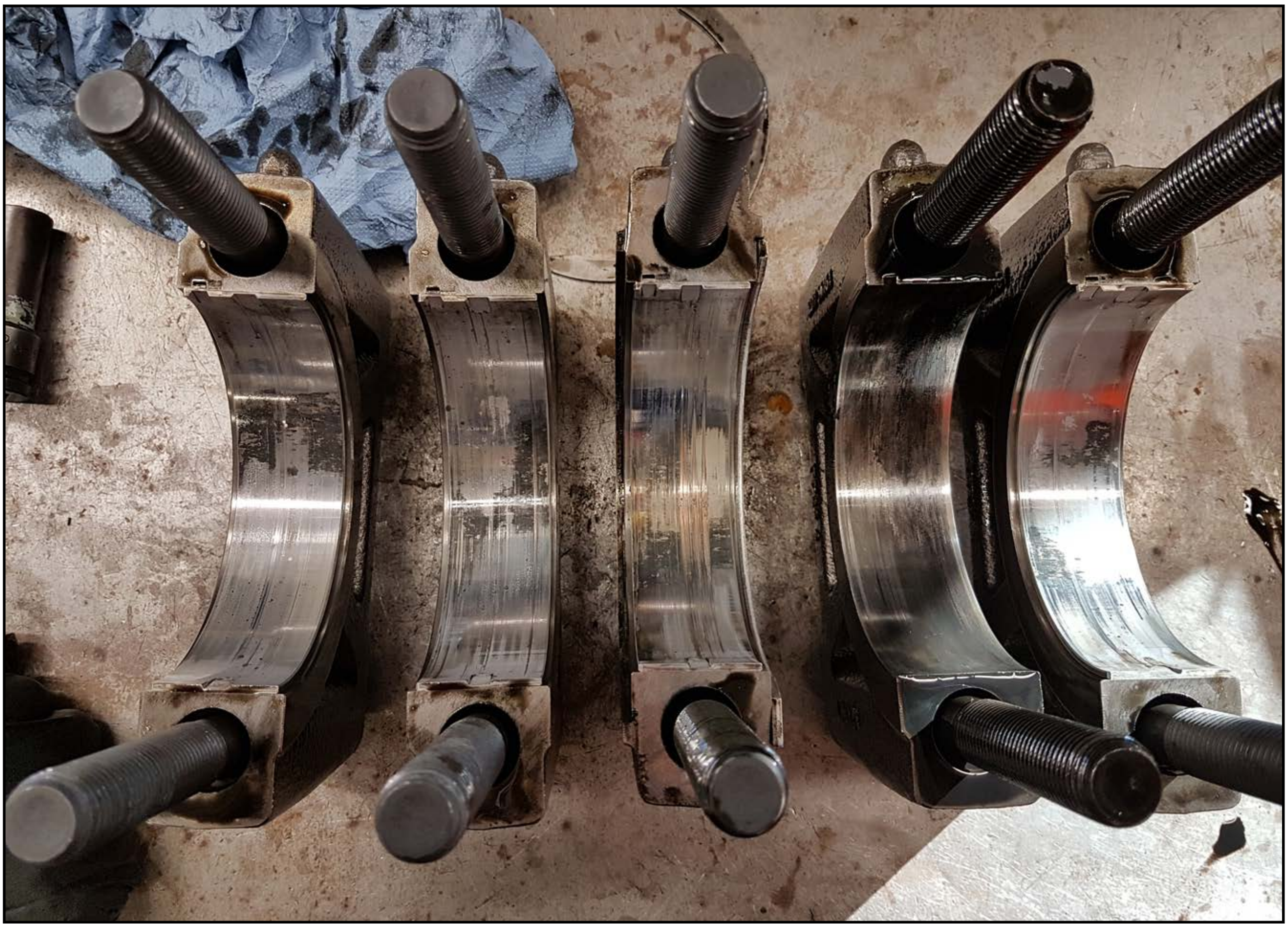

Figure 26: Event 4 – scoring of main journal bearing shells

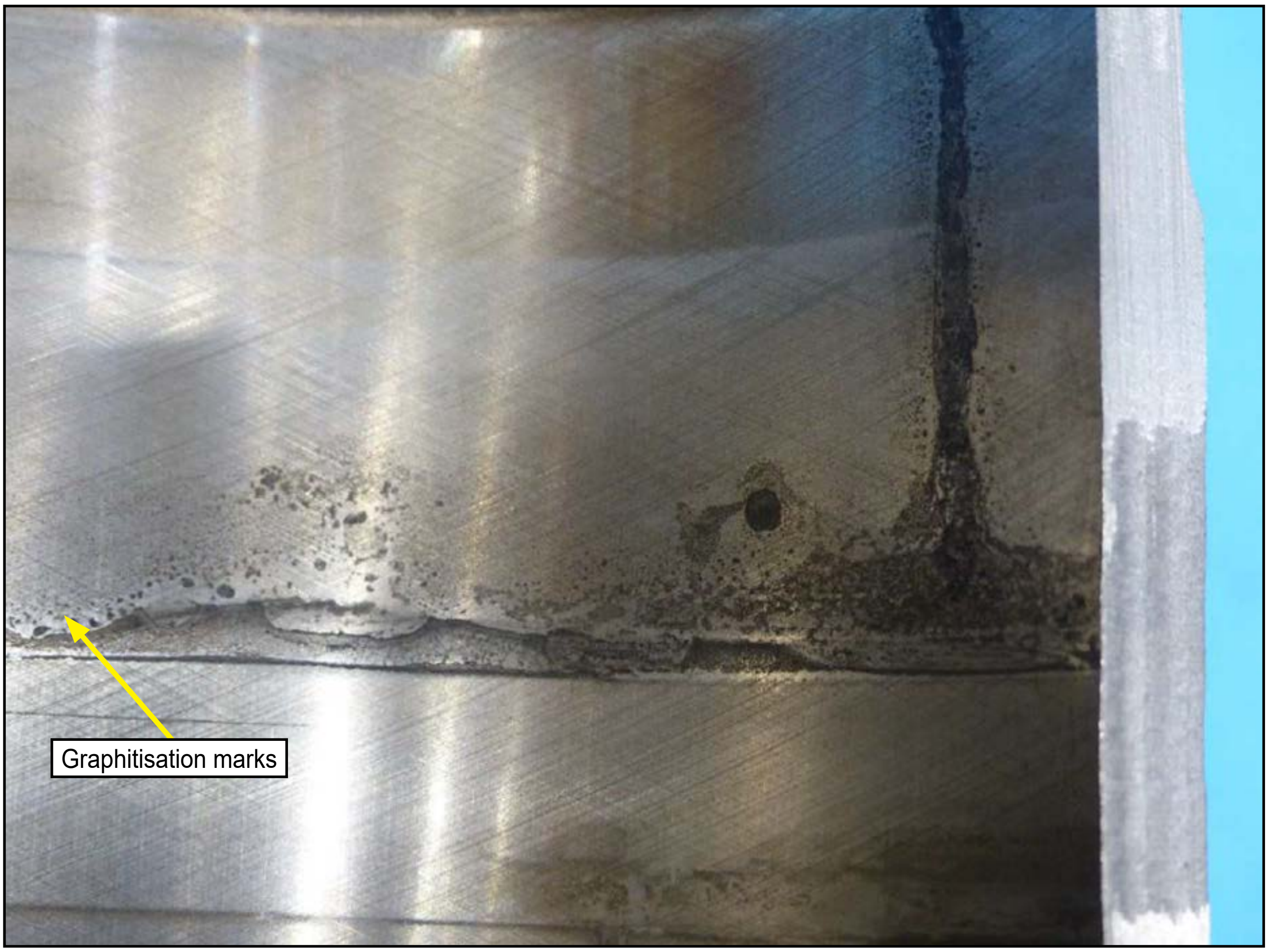

Figure 27: Event 4 – graphitisation marks on number four cylinder liner

Based on TTH's examination results, various engine components, including the number four liner with graphitisation marks, main bearings with ingrained debris and the oil filter, were re-examined by Volvo Penta in Gothenburg. The results included:

- The liner graphitisation was identified as corrosion caused by an unidentified liquid corrosive media, which included a small sulphur peak in the energy dispersive x-ray spectroscopy analysis.
- The main bearings ingrained debris particles included main bearing material but also some unexplained elements, including silicon, calcium, aluminium, zinc and phosphorus, and a silicon oxide considered likely to be sand.

Volvo Penta's concluding summary stated that:

- *It is currently being considered that oil contamination also contributed to the gradual breakdown of the main bearings as indicated in the oil analysis from May 2018, leading to #5 main bearing turning.*
- *The SEM analysis of the bearing shells and the oil filter contents confirms that wear particles were present. Additionally, there are some contaminant particles which are not related to the engine were found embedded within the main bearing shells.* [sic]

1.14.6 *Wight Sky* main engine number four catastrophic failure 14 December 2018 (Event 5)

On 22 November 2018, *Wight Sky*'s new-build ME4 was installed using new flexible mounts. Volvo Penta's examination of the engine at its facility in Gothenburg identified that the big end bearing caps on number four and number five connecting rods had been transposed during assembly at Volvo Penta's factory.

This procedural error was identified by comparing the connecting rod serial numbers. Other engines, built at around the same time and by the same technician, were examined and no further assembly errors were found.

Other observations made by Volvo Penta during its examination of the engine included:

- There was minimal heat damage sustained to the crankpin journal and the bearing shells.
- Number four piston had made hard contact with the cylinder head and valves, thus causing rocker gear damage.
- Number four big end cap bolts had failed under tension.
- Number five big end cap bolts torque was below the specified range.
- Number five big end connecting rod and cap mating faces showed clear signs of fretting.
- Carbon build-up behind the inlet valves.
- ECU not original, and had been transferred from the replaced engine.
- Injector codes in the ECU not updated to the new codes for the new injectors.

1.15 OTHER TESTS AND EXAMINATIONS

1.15.1 Engine alignment and vibration analysis

In December 2018, Volvo Penta conducted vibration measurements on board *Wight Sky*. This involved attaching sensors on ME2 and ME3 and conducting five return trips to the Isle of Wight during normal ferry operations. For each engine, a controlled torque increase from low to high over a 30-second period was completed at the three engine propulsion power speeds: 960, 1360 and 1800rpm. Torsional vibration measurements were noted for each in lieu of engine loads, which could not be measured. The trials team analysed the vibration data and concluded that, outside of the critical range, they indicated potential engine misalignment or uneven belt tensions in the belt drive assembly.

RKM used a straight edge and dial gauge indicator to check engine alignment after the installation of new and overhauled engines. Checks carried out by the same method during the December 2018 trials showed that both angular and axial displacements were well within the limits on the flexible couplings on all engines.

1.15.2 Flexible mounts and testing

The engines were installed on four flexible mounts **(Figure 13)**; a further two mounts were used to secure the fluid clutch couplings. Volvo Penta's installation manual for its D5 to D16 engine range contained drawings that illustrated the correct order of installation. The manual stated:

> *Before adjustments can be made, the engine must rest on the rubber mounts for at least twelve hours but preferably more than two days.*

Overhauled or replacement engines on board the Wightlink vessels were commonly installed and connected over a period of several days.

Volvo Penta did not provide any guidance on when engine mounts should be changed. In March 2019, MAIB contracted Element Materials Technology Hitchin Limited to test and analyse several engine mounts of different ages. These included:

- The original mounts for *Wight Sky*'s ME2, which had been in place for about 10 years and had accumulated about 22500 running hours;
- The new mounts fitted to *Wight Sky*'s ME2 in March 2018, which had accumulated about 800 running hours; and
- A new unused mount.

The laboratory examination and testing involved:

- Mechanical stiffness characterisation;
- Sectioning and flaw/damage characterisation; and
- Assessment of the extent of environmental elastomer ageing.

The examinations identified that one of ME2's new mounts (800 running hours) was assembled incorrectly during manufacture. The mount's rubber element void spaces had not been correctly aligned **(Figure 28)**. This resulted in increased vertical loading being applied to solid sections of the rubber element, causing a 60% increase in stiffness. The laboratory test report concluded that the other mounts were undamaged and serviceable.

1.15.3 Subsequent planned maintenance engine examinations

In 2019, Wightlink contracted a different Volvo Penta Centre dealer to manage and perform its planned maintenance work on the W-Class D16 MH engines. During the new dealer's initial examination of three engines it identified a number of issues, including:

- Two engines with debri s in the sump pan and one with debris in the lubricating oil pump strainer. The debris included old cable ties **(Figure 29)**.

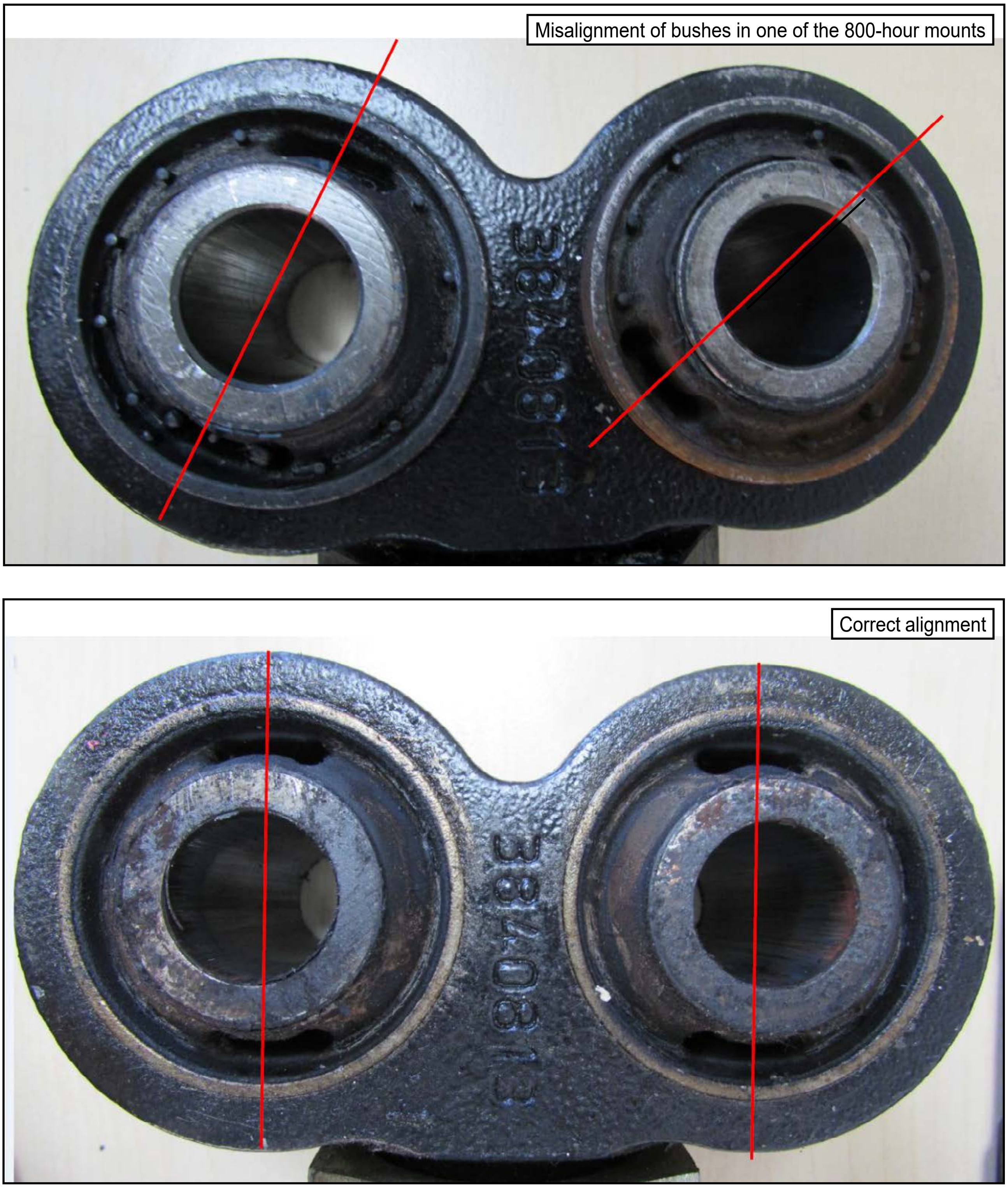

Figure 28: Engine flexible mount rubber bush misalignment

Figure 29: Debris found in engine sump pan and lubricating oil strainer

- Liner sealing ring hardening, resulting in the seal not making contact for the full circumference of the liner; block erosion/corrosion in an area that should be dry **(Figure 30)** and pitting/erosion of the liner at the liner seal groove.

- Two engines with cavitation erosion to the HT coolant circulation pump, considered to be because of low system pressure and/or incorrect coolant concentrations **(Figure 31)**.

- Two engines with pockets of corrosion in cylinder heads **(Figure 32)** thought to indicate airlocks and a failure of deaeration system pipework.

1.16 CLASSIFICATION SOCIETY OVERSIGHT

Classification societies establish and maintain technical standards for the design, construction and survey of marine vessels and offshore structures. Classification society surveyors inspect ships at all stages of their development and operation to make sure the design, components and machinery are developed and maintained in accordance with the classification society's rules. The process includes inspection of engines, shipboard pumps and other critical machinery.

The D16 MH engine was type approved by LR and many of the engine's components were listed as specific items on which the classification was based (class items). These included the cylinders, pistons, connecting rods, bearings and turbochargers.

Figure 30: Erosion to engine block in line with and below the upper of the two lower cylinder liner seals

Figure 31: Cavitation erosion of high temperature cooling water pump

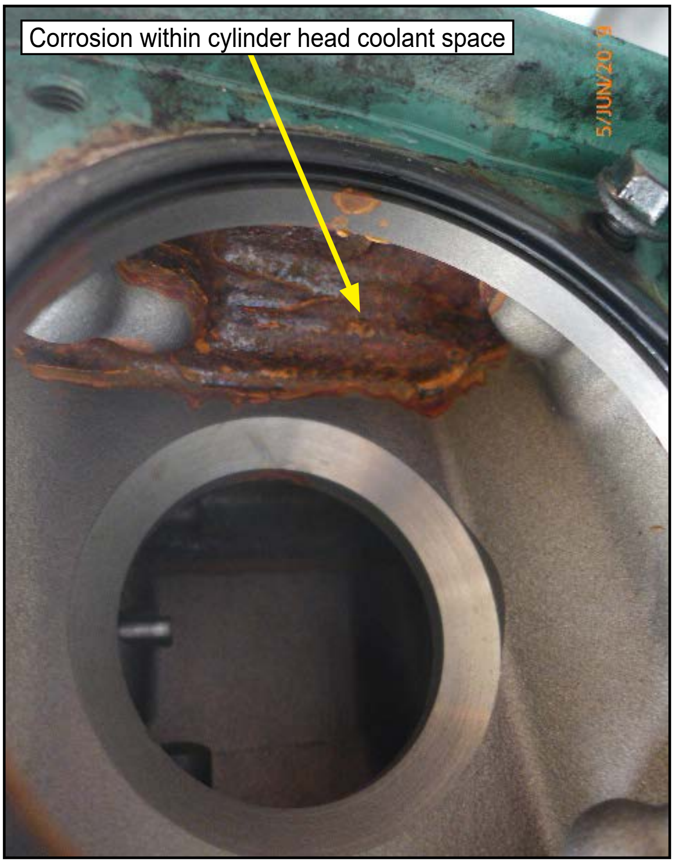

Figure 32: Corrosion in upper cylinder head from air pocket

LR's *Rules and Regulations for the Classification of Ships Part 1 – Regulations, Chapter 2 Classification Regulations, Section 1 Conditions for Classification* stated that damage or breakdown of a vessel's main engine could invalidate the conditions of class and so should be reported to LR without delay.

It became evident during the investigation that eight incidents requiring the removal of W-Class MEs for repair and overhaul ashore were not reported to LR by Wightlink. These incidents were primarily related to liner failures but also included other issues such as turbocharger replacement.

The alarm and shutdown devices fitted to the W-Class D16 MH engines were also LR approved. They were tested as required by ship's staff and RKM technicians and the tests were witnessed by an LR surveyor as required. The derate function was not verified during these checks.

The propulsion drive train was assessed and torsional vibration calculations on the shafts submitted to LR as part of the approval process. The calculations were based on one engine driving the propeller shaft via the belt drive at the design operating speed of 1800rpm.

1.17 SAFETY MANAGEMENT

Wightlink's ferry operations were limited to UK internal waters. This meant that Wightlink was required to operate its W-Class ferries in accordance with the Safety Management Code for Domestic Passenger Vessels[27]. Despite this, Wightlink voluntarily undertook to comply with the more stringent requirements set out in the International Safety Management Code (ISM Code).

The purpose of the ISM Code is to provide an international standard for the safe management and operation of ships, and for pollution prevention. The ISM Code requires the company to establish and maintain a safety management system (SMS). It defines the necessary organisational structure, responsibilities, procedures, processes and resources. As required under the ISM Code, the MCA conducted audits of Wightlink's SMS.

Section 1.2 of the ISM Code states that the company should:

- *Provide for safe practices in ship operation and a safe working environment;*
- *Assess all identified risks to its ships, personnel and the environment and establish appropriate safeguards; and*
- *Continuously improve safety management skills of personnel ashore and aboard ships, including preparing for emergencies related both to safety and environmental protection.*

Section 10 of the ISM Code sets out the maintenance management requirements for vessels and their equipment. It requires vessel owners and operators to establish procedures to ensure that the vessel is maintained in conformity with the provisions of any relevant rules and regulations and with any additional requirements it might set. In meeting these requirements, the company should ensure that:

- *Inspections are held at appropriate intervals;*
- *Any non-conformity is reported, with its possible cause, if known;*
- *Appropriate corrective action is taken; and*
- *Records of these activities are maintained.*

Wightlink's electronic integrated management system provided the platform for its safety and maintenance management systems.

Wightlink managed a programme of internal audits to verify that its safety and environmental protection practices complied with the company's SMS. These audits were conducted by trained personnel at intervals of not more than 12 months, with the possibility of further audits as necessary.

[27] The Merchant Shipping (Domestic Passenger Ships) (Safety Management Code) Regulations came into force on 1 November 2001. The Regulations apply to all domestic passenger ships, except those domestic operators required to comply with the ISM Code.

The Volvo Penta's operating instructions, maintenance manuals and safety bulletins had not been incorporated into Wightlink's maintenance management system. And Wightlink's operating procedures and maintenance records had not been audited against the engine manufacturer's requirements.

1.17.1 Company meetings

Board of Directors meetings were held about once a month and the agenda included: reviews of identified safety, health and environmental issues; outcomes of audits undertaken by the MCA; and accident and incident reports submitted to MAIB or the Health and Safety Executive. In addition, Health, Safety and Environmental committee meetings were held at 6-monthly intervals, at which the company's overall health, safety and environmental management performance was discussed.

No discussions about the longer term ongoing ME maintenance management issues on board the W-Class ferries were recorded in the minutes for either the Board of Directors or Health, Safety and Environmental Committee meetings held between 2017 and 2019. One item recorded in the July 2018 Board of Directors meeting referred to a *Wight Sky* engine failure as being due to *…a similar lubrication issue on another of our Volvo engines…*, with a resolution via an insurance claim. Other items relating to the engines focused on the catastrophic failures, the associated injury to the engineer, the subsequent revised operating procedures implemented by Wightlink and the respective external investigations. No reference was made to any internal investigations to understand and resolve any underlying engine problems that had caused these failures.

1.18 PREVIOUS ACCIDENTS

1.18.1 *Windcat 8* – catastrophic engine failure

On 7 September 2017, the 15.87m crew transfer vessel, *Windcat 8*, was on passage to Grimsby, UK, from the Lynn Wind Farm in the North Sea with two crew and eight windfarm technicians on board. Shortly after setting off, the vessel's port Volvo Penta D16 MH engine suffered catastrophic failure and caught fire (MAIB report 1/2018[28]). The fire was quickly extinguished and the passengers transferred onto another crew transfer vessel, *Windcat 31*. *Windcat 8* was towed back to port; there was no pollution and no injuries.

The MAIB's investigation identified that the catastrophic damage to *Windcat 8*'s engine was caused by the overheating and failure of a connecting rod big end bearing shell, which resulted in the connecting rod assembly releasing and penetrating the engine crankcase. The crankshaft crankpin suffered plastic deformation, which clearly indicated a loss of lubrication oil supply.

1.18.2 *St Helen* – mezzanine deck collapse

On 18 July 2014, the starboard forward mezzanine deck on board Wightlink's ro-ro passenger ferry *St Helen* partially collapsed (MAIB report 1/2016[29]). *St Helen* was berthed at the Fishbourne ferry terminal, Isle of Wight and the mezzanine deck

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[28] https://www.gov.uk/maib-reports/catastrophic-engine-failure-resulting-in-a-fire-on-crew-transfer-vessel-windcat-8

[29] https://www.gov.uk/maib-reports/collapse-of-a-mezzanine-deck-on-board-ro-ro-passenger-ferry-st-helen

was being lowered in preparation for the disembarkation of the cars parked on it. One crewman and several passengers were injured but none remained in hospital overnight.

The MAIB investigation identified weaknesses in the way that Wightlink had managed the day-to-day maintenance of its vessels and, in particular, its mezzanine decks. The investigation report included recommendations to Wightlink to:

- *Review and, as necessary, improve its safety management system to ensure the company:*
  - *Acts promptly in response to nonconformities affecting important and critical equipment on board its vessels.*
  - *Applies a proactive response to the management of observations and deficiencies identified during the thorough examination of its vessels' lifting equipment.*
  - *Notifies the relevant authority in the event of damage to a vessel that requires structural repair.*

The MCA was recommended to:

- *Ensure its audit inspections of Wightlink vessels provide specific focus on the effectiveness of the company's maintenance procedures.*

These recommendations were closed after the MCA reported Wightlink as having implemented the appropriate actions. These actions included the introduction of a company-wide database that monitored non-conformities and sent warnings to the company's designated person ashore and senior managers if the due date was about to expire.

SECTION 2 – ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.2 OVERVIEW

This investigation was opened on 26 August 2018, when *Wight Sky*'s ME2 suffered a catastrophic failure. The engine was a new build and replaced an engine that had suffered a similar failure 11 months earlier. On the 14 December 2018, *Wight Sky*'s ME4, another new-build engine that had been installed a month earlier, suffered what appeared to be a similar catastrophic failure. The scope of the investigation was widened to cover both accidents.

In this section of the report, the causes of *Wight Sky*'s ME2 and ME4 failures will be analysed and the underlying factors that contributed to them, and a series of other main engine failures on board Wightlink's W-Class ferries, will be discussed. These include maintenance management, engine condition monitoring, maintenance standards and quality control, main propulsion system configuration and vessel operating profile.

2.3 *WIGHT SKY* CATASTROPHIC ENGINE FAILURES

2.3.1 Number two main engine failure August 2018 (Event 4)

On 26 August 2018, *Wight Sky*'s ME2 failed catastrophically as the ferry was about to enter the Lymington River. The engine was running at full speed (1800rpm) and was driving the forward VSP unit in parallel with ME1 when its ECU detected a loss of lubricating oil pressure and initiated an engine shutdown. 63 seconds later, the engine's number four connecting rod and piston assembly was thrown out of the crankcase into the engine room. The engine had accumulated 2241 running hours and had been installed 11 months earlier as a new build replacement for an engine that had suffered a similar catastrophic failure (Event 1).

Evidence was found of water ingress and impact loading damage in number four cylinder. The damage could potentially have been the result of coolant leakage leading to the cylinder becoming hydraulically locked at the time of failure. However, like *Wight Sky*'s previous ME2 failure, the engine's number five main journal bearing shells were found to have turned in their housing. This would have blocked the lubricating oil supply to the main journal bearing and number four connecting rod crankpin. Coupled with the extent of the heat and wear damage caused to the crankshaft journals, this clearly indicated that the engine failed due to a sudden loss of lubricating oil.

The circumstances that led to the main journal bearing shells turning through 180° were less clear and several factors that could have contributed to this were examined. These included:

- The sudden or gradual loss of lubrication oil supply;

- High operating loads due to poor combustion and engine operating profile;

- Excessive heat due to engine misalignment; and
- Vibration.

No material defects that could have caused a sudden loss of lubricating oil pressure were found with the engine's lubricating oil pump, filter arrangements and supply circuit. Wear particles were found embedded in the bearing shells and filter elements.

The investigation report (MAIB Report 14/2018) into the previous ME2 failure concluded that the most likely cause was a loss of lubricating oil supply due to the presence of debris in the engine's oil channels. The debris was attributed to poor hygiene standards being applied when the engine was rebuilt in RKM's workshop. However, the replacement engine was a new build and therefore the likelihood of debris being introduced locally was extremely low.

Further analysis of debris found in the oilways and bearing shells of both failed ME2 engines (Events 1 and 4) identified the presence of silicon dioxide (silica sand) and oxides of cadmium and aluminium. Silica sand is commonly used in the engine component casting process and further examination of the particles found indicated that they were consistent in size (approximately 190μm) with casting sand. The oxides of cadmium and aluminium are abrasive components commonly used in crankshaft polishing and their presence in the case of Event 1 was probably the result of ineffective cleaning of the oilways after polishing. It is possible that the build-up of silica sand and other particles embedded in the bearing material caused the shell bearings to turn.

It is also possible that poor fuel combustion, engine misalignment and high levels of vibration could have contributed to the eventual failure of the engine. Heavy carbon deposits were found on the injector nozzles, cylinder head inlet valves and number four piston crown, and the engine mounts had been misaligned. However, oil sample test results and wear particles found in the oil filters and embedded in the shell bearing surfaces suggested that contaminated lubricating oil was a significant factor and could have caused the gradual breakdown of the main bearings and sudden failure of the engine.

2.3.2 Number four main engine failure December 2018 (Event 5)

On 14 December 2018, *Wight Sky*'s ME4 failed catastrophically after 389 running hours. The ferry was about to berth alongside at Wightlink's Lymington Harbour ferry terminal and the engine was running at its intermediate speed setting of 1360rpm and independently driving the aft VSP unit. Like *Wight Sky*'s ME2 failures, the engine's number four connecting rod was thrown from the crankcase into the engine room.

Although the consequences of the ME4 failure had similarities with *Wight Sky*'s previous ME2 failures, the event was found to be the direct result of an assembly error at Volvo Penta's factory in Sweden. The engine's number four and five connecting rod big end bearing caps had been inadvertently transposed during the engine's assembly. This meant that the mating surface between the connecting rod and its cap **(Figure 8)** did not match. This would have significantly reduced the amount of metal-to-metal contact and increased the risk of fretting wear due to the oscillating forces imposed during engine running. This in turn would have progressively reduced the tension in the big end bolts and rapidly accelerated both the securing arrangement loosening and fatigue failure processes.

The engine build technician that assembled *Wight Sky*'s ME4 was an experienced Volvo Penta technician who had performed the task of installing the piston and connecting rod assemblies many times. It was evident that he must have made a simple skill-based error, probably due to a lapse in concentration or some form of distraction. Volvo Penta's internal investigation was unable to determine why the technician made such a basic error. However, the engine manufacturer's investigation identified that the serial numbers on the connecting rods and caps were not routinely checked to ensure that they matched following assembly. To mitigate the risk of similar errors, Volvo Penta introduced an improved method of identifying and matching the connecting rods into its production process.

2.4 OTHER WIGHT CLASS ENGINE FAILURES

2.4.1 General failure rate

The W-Class vessels began to suffer cylinder liner and engine block cavitation erosion problems within a year of being brought into service in 2009. Of the 26 engine failures between 2010 and 2018 listed in **Tables 1**, **2**, and **3**, 12 were attributed to cylinder liner failures due to pitting. Between 2015 and 2018, 12 engines suffered catastrophic failures or required rebuilds due to mechanical issues. The three catastrophic failures on board *Wight Sky* and two on board *Wight Light* detailed in this report all occurred within a 15-month period and were indicative of escalating maintenance and management shortcomings.

Catastrophic engine failures present a real danger to vessels, those on board and the environment because they can cause loss of propulsion control, major engine room fires and serious injuries. These types of failures are typically the direct result of inadequate lubrication, overheating, abnormal combustion or component failure.

Inadequate lubrication was identified as the direct cause for four of the five failed engines examined during the investigation. However, the individual circumstances that led to the loss of lubricating oil supply differed in each case. Nevertheless, it was clear that weaknesses in the management of maintenance, standards of overhaul, quality control, technical oversight, propulsion system design and configuration, and the vessels' operating profile all contributed to the high engine failure rate seen on Wightlink's W-Class ferries.

2.4.2 *Wight Light* number one main engine failure February 2018 (Event 2)

On 2 February 2018, *Wight Light*'s ME1 suffered a crankshaft main journal bearing seizure 700 running hours after RKM had overhauled the engine. Subsequent examination by Volvo Penta engineers identified that the crankshaft's main journal bearing cap numbers one and seven had been transposed during overhaul.

During manufacture, the engines are line-bored to ensure alignment of the crankshaft and bearings and, like the connecting rod big end bearing caps, the main journal bearing caps are matched and should not be interchanged. Volvo Penta concluded that the transposition of the number one and number seven bearing caps resulted in a misalignment, which led to overheating and eventual rotation of number seven journal bearing shell. The rotation of the shell would have blocked the oil feed to the crankshaft's main journal and number six crankpin journal, causing the engine to seize.

2.4.3 *Wight Light* number two main engine failure August 2018 (Event 3)

On 3 August 2018, *Wight Light*'s ME2 was stopped because it was emitting excessive amounts of white smoke from its exhaust and generating abnormal levels of noise. On 14 August, the engine was returning to service after RKM had fitted an overhauled set of injectors and had been running for less than 5 minutes before the problems were detected. When the engine's cylinder head block was removed, the RKM service engineer discovered a melted number six piston crown and liner scoring to several other units **(Figure 23)**.

High exhaust temperatures and similar levels of white exhaust smoke earlier in the month had alerted the ferry's engineers to the fact that the engine had been running on only five cylinders; a fuel injector failure was thought to be the cause of the problem. The engine had suffered fuel injection issues a year earlier and its lubricating oil was replaced due to fuel contamination 6 days before the accident. The symptoms observed at the beginning of the month could have been the result of injector issues, but there were other possible causes. The piston manufacturer concluded that the melted crown was clearly indicative of abnormal combustion, but explained that the abnormal combustion could have been linked to oil carry over resulting from piston ring damage.

Contamination of the engine's lubricating oil by both diesel fuel and coolant was probably the most significant underlying factor that contributed to the engine failure. Contaminated oil would have led to piston ring wear, allowing oil carry over with subsequent poor combustion followed by piston overheating and melting. This was supported by the damage noted in Volvo Penta's examination report and the reports from both the piston and piston ring manufacturers. A thorough investigation into the earlier problems and the consequences of the oil contamination would have reduced the risk of major damage to the engine and the dangers associated with a catastrophic failure.

2.5 MANAGEMENT OF MAINTENANCE

2.5.1 Wightlink maintenance management system

Wightlink's SMS complied with the requirements of the ISM Code and was approved and audited by the MCA. Maintenance management is not only an essential aspect of engineering good practice, but also a requirement of the ISM Code. Under the ISM Code, machinery had to be inspected at regular intervals and any non-conformities had to be reported and investigated. Subsequent maintenance and repairs also had to be recorded.

Wightlink used an integrated computer-based platform to help manage and record planned maintenance tasks and defect repairs. The system had recently been introduced to address the ferry operator's problems with its previous, largely paper-based, system (see 1.18.2). The roll out of the new electronic system had been problematic and it was apparent that ME maintenance was not being managed effectively. Of note:

- Maintenance schedules and guidance provided in service bulletins were not always fully followed.

- Some repairs were not performed in accordance with the engine manufacturer's instructions.

- Maintenance and repair activities were not being properly recorded.
- Oil and coolant condition monitoring was ineffective.
- Communication with RKM, Volvo Penta and LR was inconsistent.

High-performance, high-speed engines such as Volvo Penta's D16 MH engine require deep technical knowledge and special tooling to be maintained effectively. Volvo Penta recommended that all but the most basic of inspection tasks be undertaken by its approved dealers. The routine planned maintenance schedules for the engines was set out by Volvo Penta in its service protocol **(Table 5)**. The intervals between intrusive maintenance work such as injector, cylinder head, piston and main bearing overhauls were largely dependent on through-life condition monitoring results and local engine operating conditions.

Many of Wightlink's engineers were experienced and had worked for the company for many years. Their primary role was to operate and monitor the vessels' machinery. Most engineers moved at regular intervals from vessel to vessel and, although these were identical, it could result in a loss of vessel ownership for maintenance management responsibilities. Wightlink understood this and its introduction of survey chief engineers was intended to provide a degree of vessel-specific continuity and ownership. Unfortunately, the rapid changes of Wightlink's shore-based technical staff between 2016 and 2018, coupled with the demands of commissioning a new-build vessel, adversely affected the proactive impact of the new role. Consequently, an increasingly reactive approach was taken towards the management of routine maintenance and defect rectification. Furthermore, the engineers' lack of understanding and application of the company's new electronic integrated management system meant that many maintenance tasks were not properly recorded.

2.5.2 Service bulletins

Volvo Penta issued service bulletins to promulgate information about various technical issues, engine modifications, software upgrades or maintenance management improvements. These were issued to the dealer network but not the engine owners as owners were not expected to maintain their engines beyond conducting basic inspections and monitoring operating conditions.

RKM incorporated the guidance contained in relevant service bulletins into any work it completed on Wightlink's engines. However, as it was not contracted to provide through-life support to Wightlink, RKM did not pass on relevant bulletins or make recommendations to Wightlink based on their content. As a result, Wightlink was not aware of several relevant bulletins, particularly those containing maintenance or inspection advice for dealers.

An example of an issue raised in service bulletins that was not actioned includes the requirement to halve the fuel injector replacement intervals on vessels using marine distillate fuels.

2.5.3 Through-life maintenance support

Volvo Penta recommended Wightlink to use RKM for its maintenance, repair, and warranty work. Wightlink followed the engine manufacturer's recommendation, but chose to contract the Volvo Penta Centre on a job-by-job basis rather than putting in place a long-term service agreement.

It was evident that communication between Wightlink, RKM and Volvo Penta was sporadic and this adversely affected the ferry operator's understanding of how best to operate and maintain its engines. This was apparent when an early opportunity to address cylinder liner erosion issues was lost because a Volvo Penta service request was closed out before ensuring the problem had been resolved. Had RKM been awarded a long-term contract, the authorised Volvo Penta Centre could have provided a higher level of support to Wightlink and taken a more proactive approach to the overall maintenance management of its engines.

A long-term agreement for the through-life maintenance and support of the D16 MH engines would undoubtedly have resulted in increased levels of communication, better record-keeping, improved condition monitoring and more effective trend analysis and defect diagnostics; all of which would have improved engine performance and reduced the risk of catastrophic engine failures.

2.5.4 Safety management system non-conformities

The ISM Code set out the maintenance management requirements for vessels and their equipment. Vessel owners and operators were required to establish procedures to ensure that the vessel is maintained in conformity with the provisions of any relevant rules and regulations. To help achieve this Wightlink undertook regular internal audits and raised non-conformities if the SMS requirements were unmet.

The W-Class propulsion units could each be driven by one of two MEs and therefore had a high degree of redundancy, enabling the vessels to operate on three engines, or two in an emergency. Because of this, Wightlink did not consider the loss of a single ME to be critical to the retention of propulsion control and did not raise a loss of critical equipment or SMS non-conformities for such events. This meant that many of the engine failures were not brought to the attention of the company's board of directors or properly scrutinised by the safety management team. Instead, engines were repaired or replaced and the vessels resumed operation without a clear understanding of why the failure had occurred or what actions might be introduced to prevent a recurrence.

The series of earlier engine failures did not initially lead to any serious negative outcomes. However, they were precursors to the highly dangerous, catastrophic failures that followed. Had the early failures been investigated under the SMS, it is possible that the subsequent catastrophic failures could have been avoided, along with the associated fires and injury to a crew member.

2.6 ENGINE CONDITION MONITORING

2.6.1 Engine performance diagnostics

Each W-Class D16 MH engine was supplied with a Volvo Penta ECU that monitored and logged the engine status and provided automatic shutdown protection. The ECUs also provided engine performance readings and engine sensor signals to local alarm panels in the engine rooms and to data logging and machinery monitoring systems in the MMR and on the bridge. The Kongsberg machinery data logging system provided time-stamped alarm information.

The ECUs were mounted on the engines at build and were intended to remain paired with the engine throughout its lifecycle. RKM had found that the time taken to download software upgrades received from Volvo Penta had a knock-on effect to the reinstatement of the new engines. To mitigate this, it had become RKM's practice to remove the ECU from the new engine and replace it with one taken from the old engine. This practice saved time but meant that the ECU did not have the most recent software updates and, because the recorded alarms were not time stamped, it was not possible to distinguish between alarms logged for the old and the new engine. This adversely affected the ability to interrogate an engine's alarm history and diagnose technical problems.

2.6.2 Lubricating oil quality and testing

Volvo Penta's service protocol recommended the replacement of engine lubricating oil at 500 running hours or after 12 months, whichever occurred first. Volvo Penta also advised that the replacement intervals might need to be significantly reduced based on the fuel burnt and recommended that the task be carried out by its service centre technicians. Initially, Wightlink replaced the engine oil after 400 running hours but had gradually extended this to 800 running hours based on the results of periodic oil sample testing.

Regular testing of an engine's oil condition is vital to identify if the oil is still serviceable and to enable the early identification and resolution of engine problems. Engine manufacturers will usually advise a condition monitoring schedule, but this can be amended by the vessel operator dependent on operational and other circumstances. The more regular the testing, the more accurate the trend analysis, enabling a better understanding of rate of deterioration of the oil and wear on the engine components. The oil renewal and maintenance schedules can then be adapted accordingly.

The early oil sample test results for the W-Class D16 MH engines provided a mixed picture. Some showed good oil quality while others identified a variety of problems normally associated with contamination and wear. Nevertheless, in discussion with RKM, Wightlink technical staff decided that the results were good enough to extend the oil replacement hours. These were raised in two stages during 2013: first to 600 hours and then 800 hours. However, there was no in-service oil sampling before the oil changes, record-keeping was sporadic and the running hours between renewals varied considerably.

While the oil replacement running hours were being increased, the engines were failing due to liner corrosion leading to coolant ingress into the engine sump. Had the frequency of testing been increased at this time it would have been possible to identify engines that were suffering from internal coolant leakage, potentially before the resultant contamination of the lubricating oil caused major damage. Wightlink did not increase the frequency of sampling during this period and relied on the samples taken at the increased oil replacement hours. In the event of a poor test result, a further sample of the now freshly renewed oil would be taken to confirm the first result. Invariably, as the oil and oil filter had only recently been changed it returned a better result and no further investigation into the cause of the previous poor result took place. This practice continued after the issue of a service bulletin in 2015, which clearly stated that where oil analysis showed contamination further analysis should be performed at intervals of 100 running hours.

Another factor likely to have reduced the effectiveness of the oil analysis process was poor labelling of the oil sample bottles by ships' engineers. The testing process required accurate labelling to ensure that the results were assessed against the correct criteria for the engine and oil being tested. Insufficient information on the labels led to samples being assessed against a standard criterion as opposed to the more stringent criteria developed by Volvo Penta to suit the high-performance nature of these engines. Consequently, some test results indicated that oil quality was satisfactory when they did not meet the more stringent criteria set by Volvo Penta. Despite this issue being recognised by Wightlink's technical staff ashore, poor labelling still occurred during the later engine failure incidents, showing a lack of understanding of the value of oil condition monitoring throughout Wightlink.

The condition of the engine oil, which can provide crucial early indication of engine problems, was improperly monitored. The intervals between oil and filter changes had been extended but the periodicity of oil sample analysis was not increased and many samples were tested against an inferior standard to that stipulated by the engine manufacturer. This meant lost opportunities to identify and diagnose engine problems early and therefore avoid catastrophic failures.

2.6.3 Engine coolant

High-performance, high-speed engines, such as those fitted to the W-Class vessels, place considerable demands on the cooling system to ensure heat is removed efficiently and erosion and corrosion of the engines' internal metal surfaces is prevented. Consequently, the need to comply with the engine manufacturer's specification and closely monitor the condition of the coolant is essential to the health of an engine.

The ME coolant on board the W-Class ferries was outside the required specification from the outset because the water used to formulate the coolant did not meet Volvo Penta's prescribed standard. In 2014, Volvo Penta recommended that D16 MH engines using its old green coolant change to its new yellow coolant. The new coolant provided improved protection against cavitation erosion and corrosion because it contained extra additives and had a higher boiling point. However, due to the extended cooling system and the difficulties in cleaning it, Volvo Penta recommended the green coolant remained in place and so it was not changed on the W-Class ferries.

Volvo Penta's service protocol recommended that the condition of the engine coolant be checked at 500 running hours or after 12 months, whichever occurred first. It also recommended that the coolant be replaced at 8000 running hours or after 48 months, whichever occurred first. The engine manufacturer also recommended that both tasks be carried out by its service centre technicians.

There were no records of the coolant on the W-Class vessels having been tested or replaced. As part of the investigation, samples of the coolant in all 12 W-Class MEs were tested and all showed signs of contamination, glycol degradation and precipitation.

The failure to follow Volvo Penta's engine coolant guidance was probably the result of a lack of knowledge due to poor communication. Had Wightlink chosen to use pre-mixed coolant from the outset, changed to the new coolant when recommended, and monitored the condition of the coolant more closely, the risk of liner failure would have reduced and the opportunity to identify underlying engine problems would have increased.

2.7 MAINTENANCE STANDARDS AND QUALITY CONTROL

2.7.1 General maintenance standards

Much of the maintenance work carried out by RKM did not meet the standards set by Volvo Penta and those expected by Wightlink. Assembly errors were made during overhauls, basic levels of workshop cleanliness were not always met, engines had not been properly aligned, unapproved repairs were carried out and components were regularly switched from engine to engine. Separately, an assembly error at Volvo Penta's factory in Sweden and the presence of casting sand particles within oilways was not identified before delivery of new engines.

2.7.2 Assembly errors

Basic errors were made during the assembly of two of the five engines examined during this investigation. In both cases, these errors were considered causal to the engines' failure.

The circumstances that led to main bearing caps being transposed during the rebuild of *Wight Sky*'s ME1 (Event 2) at RKM's workshop are unknown. It is also unclear why a similar assembly error occurred during *Wight Sky*'s ME4 build (Event 5) when the big end caps were transposed at Volvo Penta's factory in Sweden. However, it is apparent that for both events the checks in place to ensure the identification and correction of such errors were insufficient.

2.7.3 Debris in the rotating assembly

During the close examinations of the three *Wight Sky* and two *Wight Light* failed engines, and other engines overhauled by RKM, various types of debris were discovered in oilways, bearings, filters and sumps. These ranged from cable ties to sand particles.

The particles that made up the debris found within the engines' oil galleries included materials such as cadmium oxide and aluminium oxide. These are not compounds associated with engine operation, they are the main abrasive components used in crankshaft polishing. Therefore, it was apparent that proper mechanical cleaning of the oilways was not completed prior to installation.

Other particles discovered within the rotating assembly, including casting sand and carbon, were significantly larger than the crankshaft big end bearing clearances through which the oil in the rotating assembly must pass. Therefore, they cannot have entered the assembly with the engine oil during operation and must have been present at build (sand) and/or introduced during overhaul (carbon).

2.7.4 Engine alignment and vibration

The new engine fitted on board *Wight Sky* to replace the ME2 that failed in September 2017 (Event 1) suffered significant levels of vibration during its initial 1400 running hours. The levels of vibration were sufficient to cause the engine's air cooler steel brackets to fail. Both failed ME2 engines had been installed on old flexible mounts, two of which had been bolted to newly drilled holes in the engine bedplate. The vibration was arrested when the engine mounts were renewed and bolted to the original holes.

Wightlink did not routinely renew its flexible engine mounts during major overhauls and the mounts used for ME2 were the same age and had accumulated similar running hours to those fitted to other W-Class engines. It is therefore unlikely that the condition of the flexible mounts was the main cause of the sudden and progressive increase in vibration.

Excessive vibration is often caused by engine misalignment and it is likely that the repositioning of two of the mounts introduced a degree of misalignment. RKM had drilled new holes for the flexible mounts in ME2's bedplate to help facilitate alignment at the free end of the engine. It is unclear why this had to be done, but such action should not have been undertaken without consulting with Wightlink, Volvo Penta and LR.

Engine misalignment can also cause bearing temperature increases and premature bearing, coupling, or driveshaft failures. Although the excessive vibration stopped when the flexible mounts were renewed and the original bolt holes used, the extent of any internal damage caused during the engine's first 1400 running hours is unknown. However, given the extent of the external damage caused, it is likely that misalignment and vibration contributed in some way to the eventual failure. Vibration was less likely to have been a factor in the first ME2 failure as the engine had only run for 5.5 hours and no reports of excessive vibration were made.

2.7.5 Reuse of engine components and unauthorised repairs

The reuse of components between engines was predominantly done at the behest of Wightlink's technical department for cost saving reasons and to expedite repairs. However, few records exist regarding these changes and the W-Class chief engineers were not made aware of them.

RKM, with the agreement of Wightlink and LR, performed one of the two Belzona repairs to the engine blocks. As the engine was out of warranty, it was Wightlink's decision as to whether a damaged block be repaired or replaced. However, Volvo Penta were not consulted and therefore remained unaware of the continued issues with erosion at the liner/block interface.

If consulted, Volvo Penta would not have approved the routine reuse of old and/ or repaired engine components during major engine overhauls; similarly, it would not have sanctioned the Belzona repairs carried out on the W-Class engine blocks. If the engine manufacturer had been consulted about the engine block repairs, it would have had a greater understanding of the ongoing cooling system issues and this would almost certainly have prompted higher level technical investigations.

2.7.6 Quality management

RKM's quality management system was ISO 9001 accredited and subject to annual external audits. RKM was also audited by Volvo Penta and its work on board the W-Class ferries was overseen by Wightlink's technical staff and, where appropriate, approved by LR.

It was apparent that the internal and external audit processes and the technical oversight of the work undertaken by RKM did not deliver the required level of quality assurance. The investigation also identified assembly line quality control issues at Volvo Penta's factory in Sweden.

Many of the shortcomings discussed in this section of the report should have been identified during RKM's internal audit process and some could have been identified during Volvo Penta's authorised dealership audits and inspections; had they been, the likelihood of catastrophic engine failures would have been significantly reduced.

2.8 ENGINE CONTROL, MONITORING AND PROTECTION SYSTEM

The ECU included a standalone hard-wired shutdown unit that was designed to declutch and stop the engine during critical alarm conditions. An engine shutdown sequence was initiated at least 1 minute prior to both *Wight Sky* ME2 catastrophic engine failures (Events 1 and 4). Both engines were running in parallel with ME1 when the shutdown signal was given.

Tests conducted after the second ME2 failure indicated that the stoppage of an engine, when clutched in and running in parallel with a second engine following an 'emergency stop' shutdown, was relatively slow as the engine was driven by the running engine for up to a minute before declutching was completed. The delay in declutching the shutdown engine was governed by the time taken for oil to drain from its fluid coupling. The shutdown engine was driven by the other engine because its fuel supply had been cut off as part of the shutdown sequence. The inability to immediately declutch, and therefore stop an engine that is running in parallel with another engine when a shutdown signal is given, significantly increased the severity of engine damage and the likelihood of explosions and fires.

The ECU could be programmed to provide an automatic derate function that protects the engine by reducing its power output. This function was intended to arrest gradual changes in temperature and pressure, and allow the ferry engineers time to investigate their causes, while still delivering some propulsion power to the bridge. However, due to an internal Volvo Penta process error, the ECU software for the 478kW D16 MH engine had never been upgraded to provide derate protection.

Given the circumstances of the catastrophic engine failures, it is unlikely that the provision of a derate function would have prevented the accidents on board *Wight Sky*. However, the load shedding function would have provided another layer of safety critical protection and might have acted as a barrier for some of the other engine failures that previously occurred on the W-Class ferries.

2.9 COOLING WATER SYSTEM AND LINER FAILURES

Cylinder liner pitting and engine block erosion issues were first diagnosed in 2010 when coolant began to seep into the engine crankcases. By 2012, half of the engines in operation had suffered from this issue.

Pitting is often found in diesel engines on the exterior walls of wet cylinder liners and is a direct result of cavitation erosion. Cavitation erosion of the cylinder wall begins when vapour bubbles, generated in the coolant by liner vibration during the normal combustion cycle, form on or close to the liner wall and implode. The repeated implosion of the vapour bubbles creates enough energy to physically attack the metal surface of the liner and create pitting. If not addressed, coolant may eventually penetrate the cylinder and contaminate the oil or oil may be introduced to the coolant. The resulting oil contamination can interfere with piston ring and bearing performance, significantly elevating wear rates and increasing the risk of engine seizure.

Poor fuel combustion, loose-fitting liners and failure to follow the engine manufacturer's operating parameters can all increase the risk of cylinder liner cavitation erosion **(Annex B)**. The use of coolant additives and pressurised cooling systems are common methods of avoiding cavitation erosion in high-speed engines. Coolant additives can form a protective coating on the metal surfaces exposed to the coolant to reduce cavitation erosion. Pressurised systems raise the boiling temperature of the coolant and therefore reduce the rate of vapour bubble formation.

The D16 MH engine was designed to operate with a pressurised cooling system. However, the pressure relief caps fitted to the cooling system expansion tanks (header tanks) on board the W-Class ferries were left loose for several years. This reduced the cooling system operating pressure and therefore lowered the temperature at which the coolant would boil. This increased the likelihood of cavitation erosion.

Modifications to the HT cooling pipework, such as the fitting of the T-piece and the later removal of a U-bend, were intended to resolve the perceived issues with gassing up and venting. However, no assessment of the cooling system design, components, system temperatures or flow calculations were undertaken, and the modifications were not done in a coordinated manner or assessed for their effectiveness. The modifications probably increased the risk of hot spots developing in the jacket spaces between the liners and engine block, which again would have accelerated the cavitation erosion process.

The cavitation erosion problems that were clearly visible at the interface between the cylinder liners and engine blocks on board the W-Class ferries led to coolant leakage into the crankcase and contamination of the lubricating oil. This was likely to have been a major contributing factor to some of the bearing-related engine failures.

2.10 LUBRICATING OIL FILTER DESIGN

When Volvo Penta closely examined the performance of the full-flow duplex oil filter, it discovered that at full engine speed the filter bypass valve opened slightly and allowed 10 to 20% of unfiltered oil to flow through the circuit. To resolve this, Volvo Penta issued a service bulletin advising the removal of the duplex filter changeover cock.

Volvo Penta did not link any of the engine failures to the oil filter bypass valve issue. However, the circulation of up to 20% unfiltered lubricating oil significantly increased the risk of bearing wear and engine damage due to oil contamination. The arrangement also failed to meet LR rules on oil supply and 100% filtration.

2.11 FERRY OPERATING PROFILE

The provision of four main propulsion engines was designed to accommodate varying propulsion system load demands and provide redundancy in case of engine failure. The W-Class D16 MH engines were originally intended to be operated at their full running speed of 1800rpm. However, this caused serious wake wash issues within the confines of the Lymington River, which was resolved by the introduction of slow (950rpm) and medium (1360rpm) speed engine settings. Volvo Penta and LR were not fully aware of the revised operating profiles.

LR's approval of the W-Class drive train was based upon the torsional vibration calculations for one engine driving the VSP unit via the belt drive at 1800rpm. Volvo Penta was aware of, and had approved, the use of the 1360rpm intermediate speed on the basis that further torsional vibration calculations be completed and provided to LR for approval. Such calculations were not performed and therefore the potential impact of the operating profile changes on the longevity of the engines or drivetrains was unknown.

Volvo Penta had not approved the on-load operation of its engines at speeds below 1360rpm because the ECU automatic shutdown or derate protections were not fully active at speeds below 1200rpm. Therefore, the use of the engines on-load at 950rpm as recommended by Wightlink was contrary to Volvo Penta's guidance and had not been approved by LR.

The engine load profile for the route resulted in the engines operating at their maximum continuous rating for about 25 to 30% of each crossing. In addition, to mitigate the consequences of an engine failure, Wightlink's masters routinely operated with two engines in parallel driving the same VSP when entering and leaving Lymington and Yarmouth. These prolonged periods of low load running introduced several potentially detrimental conditions, including reduced coolant and lubricating oil pressures and carbon build-up from poor combustion.

2.12 CLASSIFICATION SOCIETY OVERSIGHT

Wight Sky and the rest of the Wightlink fleet were classed by LR. The loss or breakdown of the MEs on board the W-Class ferries should have been reported to LR without delay as such events could invalidate LR's approvals. However, not all engine failures were reported to LR and the classification society was not fully aware of the magnitude of the problems on board the W-Class ferries.

Most of the engine failures discussed in this report were reported to LR; however, the investigation did identify eight that were not. This meant that on at least eight occasions LR surveyors were denied the opportunity to investigate the circumstances of an engine breakdown and provide technical oversight. The failure to report also affected the amount of historical data recorded by LR, which could have been used for trend analysis and to identify recurring issues.

The D16 MH engine was type approved by LR and the provision and testing of its emergency shutdown and power reduction functions formed an integral part of the type approval process. The derate function is described in several sections of LR's Rules, including those relating to sea trials. Therefore, it is surprising that the lack of derate protection on the W-Class engines was not identified by LR during the ferries' new construction commissioning trials, refits and engine rebuilds. Wightlink staff did appear to be aware of the lack of derating, but this information was not passed on to LR or identified when engine shutdowns and associated safety systems were demonstrated to LR surveyors.

LR's delivery of robust classification and statutory services, as well as its ability to offer sound technical advice to Wightlink, was impacted by weak levels of communication between the engine manufacturer, its authorised service centre, and the ferry operator. Again, the weak communication was indicative of poor maintenance management.

2.13 EMERGENCY RESPONSE

Wight Sky's crew were quick to respond to both ME2 and ME4 engine failures, and their response was effective. During both incidents, the alarm was raised immediately, and the engine room water mist fire suppression systems were activated swiftly and effectively. On the ferry's return to port, the emergency services were waiting to come on board and the passengers and their vehicles were quickly landed ashore.

Engine explosions and engine room fires often result in significant damage and loss of life. The effectiveness of the response to such incidents is largely dependent to the crew's level of emergency preparedness. The actions of crew to isolate the affected machinery spaces, activate the fixed fire suppression system and monitor the boundaries of the engine rooms, helped limit the consequences of *Wight Sky*'s catastrophic engine failures to mechanical damage and ferry service delays.

SECTION 3 – CONCLUSIONS

3.1 SAFETY ISSUES DIRECTLY CONTRIBUTING TO THE ACCIDENTS THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. *Wight Sky*'s ME2 failed catastrophically due to a sudden loss of lubricating oil supply to its number five main journal bearing and number four crankpin. [2.3.1]

2. The oilway to the main journal and crankpin was blocked off when the bearing shells turned in their housing. Poor fuel combustion, the presence of silica sand and other abrasive particles embedded in the main bearing shells, engine misalignment, high levels of vibration, and contaminated lubricating oil might all have contributed to the event failure. [2.3.1]

3. *Wight Sky*'s ME4 failed catastrophically because of an assembly error during build at Volvo Penta's factory in Sweden. Two of the engine's matched connecting rod big end bearing caps had been transposed during the engine assembly process. [2.3.2]

4. The transposition of the bearing caps reduced the metal-to-metal contact between surfaces of the connecting rods and their bearing caps. This would have caused fretting wear between the mating faces, which would have led to loosening and rapid failure of the end cap securing bolts. [2.3.2]

5. Four of the five catastrophic engine failures discussed in detail in this report failed suddenly because of a loss of lubrication supply to the engines' crankshaft journal bearings and crankpins. [2.4.1]

6. The operation and maintenance of Wightlink's main engines was not being managed effectively, and many of its engineering crew were not recording tasks they had performed, or engine fluid test results on the company's electronic integrated management system. [2.5.1]

7. The ability to interrogate the alarm history of an engine and the level of protections against abnormal changes in running temperatures and pressures was reduced because engine control units were moved from engine to engine and were not subject to manufacturer's software upgrades. [2.6.1]

8. Opportunities to identify and diagnose engine problems early, and therefore avoid catastrophic failures, were missed because the condition of the engine lubricating oil and coolant was not closely monitored. [2.6.2] [2.6.3]

9. Some aspects of the maintenance work carried out by RKM did not meet the standards set by Volvo Penta and those expected by Wightlink. Assembly errors had been made during overhauls, basic levels of workshop cleanliness were not always met, engines had not been properly aligned, unapproved repairs were carried out and used components were regularly switched from engine to engine. [2.7.1]

10. The checks in place at both RKM's workshop and Volvo Penta's factory were not robust enough to identify the basic assembly errors. [2.7.2]

11. The debris and sand particles found in the engine sumps, oilways and bearing faces were either introduced during maintenance or not removed at build. [2.7.3]

12. Engine misalignment due to assembly error, incorrect location of engine mounts and condition of flexible mounts was likely to be a significant factor in some of the engine failures. [2.7.4]

13. Volvo Penta were not fully aware of the extent to which major engine components were being repaired, reused, and switched from engine to engine. [2.7.5]

14. Many of the sub-standard working practices discussed in this report should have been identified during RKM's internal audit process and some could have been identified during Volvo Penta's audits and inspections of its authorised dealerships. [2.7.6]

15. The emergency shutdown protection provided by the engines' ECUs was ineffective, particularly when two engines were driving one VSP unit in parallel, because of the time it took the fluid couplings to declutch the shutdown engine. [2.8]

16. The inability to immediately declutch and therefore stop an engine when a shutdown signal was given significantly increased the severity of engine damage and the likelihood of explosions and fires. [2.8]

17. The long history of cavitation erosion and cylinder liner and engine block seal failures was likely to have been a contributory factor in some of the engine bearing failures. [2.9]

18. Up to 20% of the lubricating oil circulating through the engine was unfiltered because of a duplex filter bypass valve design fault. This significantly increased the risk of bearing wear and engine damage due to oil contamination. [2.10]

19. The standard of oversight provided by LR was adversely affected by lack of communication from Wightlink, RKM and Volvo Penta. LR were not made aware of all engine failures; it accepted repairs that had not been approved by the engine manufacturer; and had not identified the engine shutdown and protection system problems discovered following *Wight Sky*'s ME2 and ME4 catastrophic failures. [2.12]

20. The emergency response by *Wight Sky*'s crew was swift and effective and helped minimise the consequences of the engine failures and subsequent fires. [2.13]

3.2 SAFETY ISSUES NOT DIRECTLY CONTRIBUTING TO THE ACCIDENTS THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. The engines on board the W-Class ferries had suffered cylinder liner erosion problems since their introduction in 2009, but the increasing number of catastrophic engine failure events between 2015 and 2018 was indicative of major maintenance management shortcomings. [2.4.1]

2. The *Wight Light* number one main engine seizure on 2 February 2018, 700 running hours after the engine had been overhauled, was probably the consequence of shell bearing rotation due to overheating caused by crankshaft misalignment. The misalignment would have been introduced when two of the crankshaft's main journal bearing caps were transposed during overhaul. [2.4.2]

3. Another *Wight Light* main engine failure in August 2018 could have been avoided had earlier problems been investigated and diagnosed. [2.4.3]

4. Initiatives taken to address the maintenance management issues highlighted in previous MAIB reports were adversely affected by high staff turnover and the technical demands associated with the build and commissioning of a new vessel. [2.5.1]

5. The performance of the W-Class main engines would have been improved and the risk of failures significantly reduced had Wightlink put in place a long-term through-life maintenance and support contract with an authorised Volvo Penta Centre. Levels of communication, record-keeping, condition monitoring and technical knowledge would all have been improved. [2.5.3]

6. Many of the engine failures were not brought to the attention of the senior management team because the loss of one engine was not considered critical to the maintenance of propulsion control and therefore did not constitute a safety management system non-conformity. [2.5.4]

7. The risk of liner failure would have been decreased had Volvo Penta's coolant standard been met and the switch to its new coolant been implemented. [2.6.3]

8. The engine ECUs had not been set up to provide derate or load shedding protection. This omission by Volvo Penta was identified during the investigation and was not restricted to Wightlink engines. [2.8]

9. Given the circumstances of the catastrophic engine failures, it is unlikely that the provision of a derate function would have prevented the accidents on board *Wight Sky*. [2.8]

10. Some aspects of the design and operation of the engines' HT cooling systems increased the likelihood of cavitation erosion and therefore cylinder liner failure and oil contamination. [2.9]

11. The engine operating profiles introduced to meet the wake restrictions in the Lymington River and to mitigate the risk of losing an engine resulted in long periods of low power running, which probably had a detrimental effect on engine condition. [2.11]

SECTION 4 – ACTION TAKEN

4.1 MAIB ACTIONS

The **MAIB** has issued an interim report in May 2019, informing the maritime sector of its initial findings and advising the public of the immediate safety measures imposed by Wightlink, Volvo Penta, MCA and LR to mitigate the risks of future engine failures.

4.2 ACTIONS TAKEN BY OTHER ORGANISATIONS

Following this investigation Wightlink, Volvo Penta, LR and the MCA have agreed and introduced a range of measures aimed at improving the safety and reliability of the W-Class engines and propulsion system. Since December 2018, the ferries have successfully operated without any further catastrophic engine failures.

Wightlink Ltd has:

- Implemented a mitigation plan, in cooperation with Volvo Penta, LR and the MCA, which enabled the W-Class ferries to continue operating while the underlying causes of the failures were resolved.
- Checked the alignment of all engines with the shaft output coupling.
- Employed a new marine superintendent and a new engineering superintendent for the Wightlink fleet, totalling three technical superintendents, and are to undergo class-approved additional professional development.
- Raised the role profile of its Director of Safety, Health and Environment with support from a deputy DPA and five Safety, Health and Environment professionals.
- Produced and promulgated a Maintenance Procedure Manual that includes reporting processes, escalation and prioritisation.
- Rewritten the process for identifying and escalating technical issues within the company SMS, including a fair and just safety culture.
- Instigated a weekly engineering and operations meeting that details incident reports, defect reports and outstanding non-conformances to members of the senior management team.
- Initiated an engineering and estates monthly company board report on major failures and technical issues and remedial action taken.
- Developed a process for individual vessels to submit end of month technical reports to the DPA for challenge and sign off.
- Contracted a different Volvo Penta Centre to undertake maintenance.

Lloyd’s Register has:

- Engaged with and instructed Wightlink on measures required to maintain the W-Class ferry certification through:
    - Sea trials to update class certification.
    - Review and revision of the planned maintenance system.
    - Reiterating classification society and flag reporting requirements.
- Observed a full torsional vibration assessment of the propulsion drivetrain and recommended:
    - Adjustments to the power absorbed by VSP units.
    - The implementation of a barred speed range between 970-1155rpm.
    - Further investigation into the flexible coupling angular displacement characteristics.
- Requested that Volvo Penta review the vibration amplitudes in comparison with those in the ISO10816-6 standard.

Volvo Penta has:

- Conducted full strip down and inspection of the engines involved in failure events 1 to 5.
- Conducted a review of the engine production and assembly process and provided additional instructions and training.
- Initiated a review of maintenance manuals and following this will consider making further improvements.
- Carried out a review of the engine software release program and developed improvements in this process.
- Initiated a review and improvement of the entirety of its dealership operating standards to include additional controls, monitoring and best practice to further enhance operational standards. This will be monitored by future dealership audits and measured against key performance indicators.
- Identified the technical root cause of the oil filter bypass anomaly and undertaken to develop an improvement for release when available.
- Modified the engine alarm system to provide earlier warning of potential major failure.
- Worked with Wightlink to help implement:
    - Onboard vibration testing.
    - An oil replacement schedule of 400 hours.

    - Increased oil sampling to at first 10 running hours and subsequently every 100 running hours.
    - The use of Volvo Penta's designated oil testing laboratory.
    - A process to follow in response to poor oil test results.
    - A coolant sample testing and analysis schedule.
    - A remote alarm monitoring capability to enable Wightlink shore management and Volvo Penta oversight of engine faults.
    - The installation of load measuring equipment to correlate engine load requirements against VSP pitch demand.
- Removed RK Marine as an authorised service provider.

RK Marine Ltd has:

Reviewed and revised its internal procedures for engine stripping and rebuilding in response to the failure of the engine in Event 2.

SECTION 5 – RECOMMENDATIONS

Wightlink Ltd is recommended to:

2022/109 Ensure competent technical oversight of maintenance on board its vessels, through resourced procedures, so that technical issues are identified and escalated to senior management as necessary.

Volvo Penta AB is recommended to:

2022/110 Identify all affected D16 MH customers to inform and resolve the identified oil filter bypass anomaly.

Lloyd's Register is recommended to:

2022/111 Assess the need to introduce within its rules and regulations the time taken to declutch a main propulsion engine from the drive shaft in the event of an emergency shutdown, to prevent the engine from being driven and increasing the risk of serious injury and damage.

RK Marine Ltd is recommended to:

2022/112 Provide its customers with all manufacturers' safety bulletins applicable to the engines in use.

Safety recommendations shall in no case create a presumption of blame or liability

Marine Accident Report

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