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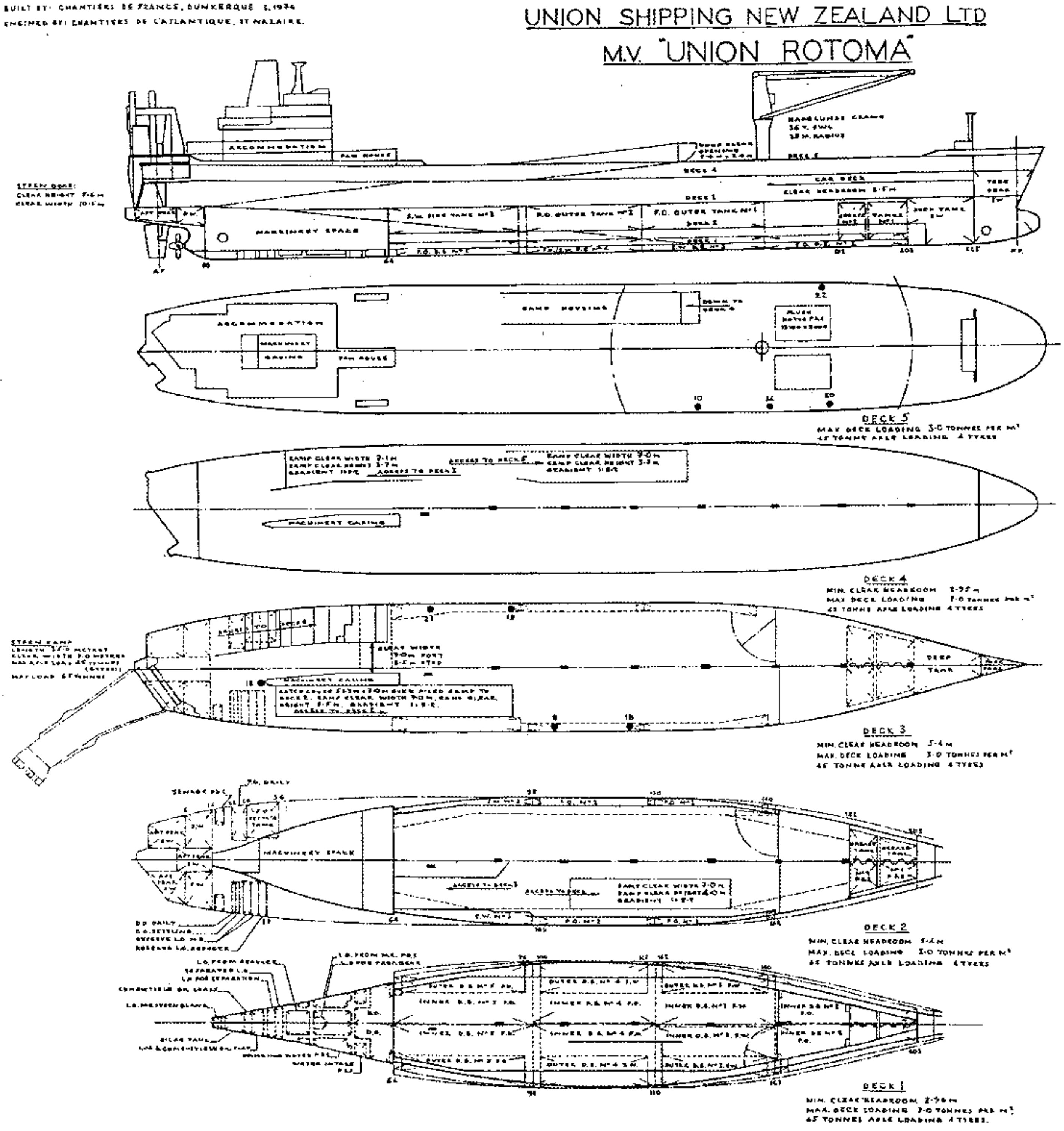

General arrangement UNION ROTOMA

Summary

On 19 April 1994 the New Zealand flag ro-ro vessel Union Rotoma was on passage from Nelson in New Zealand to Port Botany in NSW when, at 1835, alarms were sounded by the vessel's automatic fire detection system indicating a fire in the engine room. The duty engineer quickly reported that the aft end of the port main engine was on fire. The fire was spreading very rapidly and the decision was taken to evacuate the engine room and to flood it with the ship's fixed carbon dioxide extinguishing system. A "Mayday" message was transmitted by Inmarsat C and was acknowledged by the Maritime Rescue Coordination Centre in Canberra.

While the crew were shutting down the engine room, the bulk CO_2 was released. The main engines had been stopped from the bridge. Shortly after the release, the running generator stopped, indicating that it had been stifled by the CO_2. Approximately one and a half hours after the release of CO_2, two engineers wearing breathing apparatus made an inspection of the engine room and reported that the fire had been extinguished and there were no remaining hot spots.

The engine room was purged of CO_2 before a further inspection was made and the generators were started to restore full electrical power.

The inspection revealed that oil, spraying from a fractured pipe on the starboard engine, had ignited on the hot exhaust manifolds of the port engine. The pipe, carrying lubricating oil to the engine's overspeed trip mechanism and to the camshaft bearings, had been fractured by the movement of the camshaft anchor bearing housing moving out of the entablature, into which it had been secured by eight 20mm diameter set bolts, all of which had sheared or worked loose.

Damage caused by the fire was slight, involving mainly instrumentation and wiring. The ship was able to proceed on its voyage to Port Botany using only the port main engine.

The incident was investigated by the Marine Incident Investigation Unit under the provisions of the Navigation (Marine Casualty) Regulations.

Information Sources

The Master and officers, MV Union Rotoma

Materials Evaluation Facility, Civil Aviation Authority

SEMT Pielstick, Saint Nazaire, France

Union Shipping New Zealand Ltd.

Union Rotoma

Union Rotoma is a New Zealand flag ro-ro vessel of 13,978 gross tonnes with an overall length of 207.38m and a beam of 29.57m. The ship was built in 1976 at Dunkerque, France, originally for French owners. It underwent a succession of name changes - Rostand, CGM Rostand, PAD Australia, Kagoro and Rost before it was acquired by its present owners, Union Shipping New Zealand, in January 1991 and named Union Rotoma under the New Zealand flag.

The ship operates a regular service between the ports of Auckland, Wellington, Lyttleton, Dunedin, and Brisbane, Sydney, Melbourne and Adelaide at a service speed of up to 19 knots.

The vessel's complement consists of the Master, three mates, four engineers and 11 ratings. Two of the engineers are designated as Third Engineer, but one, the Extra Third, is an electrician by trade and carries out the duties both of an engineer and the ship's electrician. The machinery spaces are classified as UMS (Unmanned Machinery Spaces) and the four engineers carry out the tasks of the duty engineer, rotating on a daily basis.

Electrical power is provided, at sea, by two 2200kVA shaft-driven generators and in port, by two 990 kVA diesel generators, all of which generate power at 440 volts, 60 Hz, 3 phase.

The vessel is fitted with bow and stern thruster units.

Main machinery

Union Rotoma is powered by two SEMT Pielstick type 16PC3V-480 non-reversing engines, connected, via a gearbox, to a single shaft and controllable-pitch propeller. The engines have a 16 cylinder, Vee-configuration, of 480mm bore and 520mm stroke producing an output of 13428 kW* at the shaft.

Each bank of cylinders has a separate camshaft. The camshaft is constrained in the longitudinal direction by an "anchor bearing" assembly containing two axial-thrust ball bearings (see illustration on next page). The complete anchor bearing housing is secured in position in the engine entablature by means of eight 20mm diameter set bolts and is located by means of two dowel pins.

Passing just over, and bolted to, the anchor bearing housing on the outside of the entablature, is a 30mm diameter pipe carrying lubricating oil, under pressure, to the camshaft bearings and the engine's overspeed trip mechanism (See photograph of arrangement on port engine, page 7).

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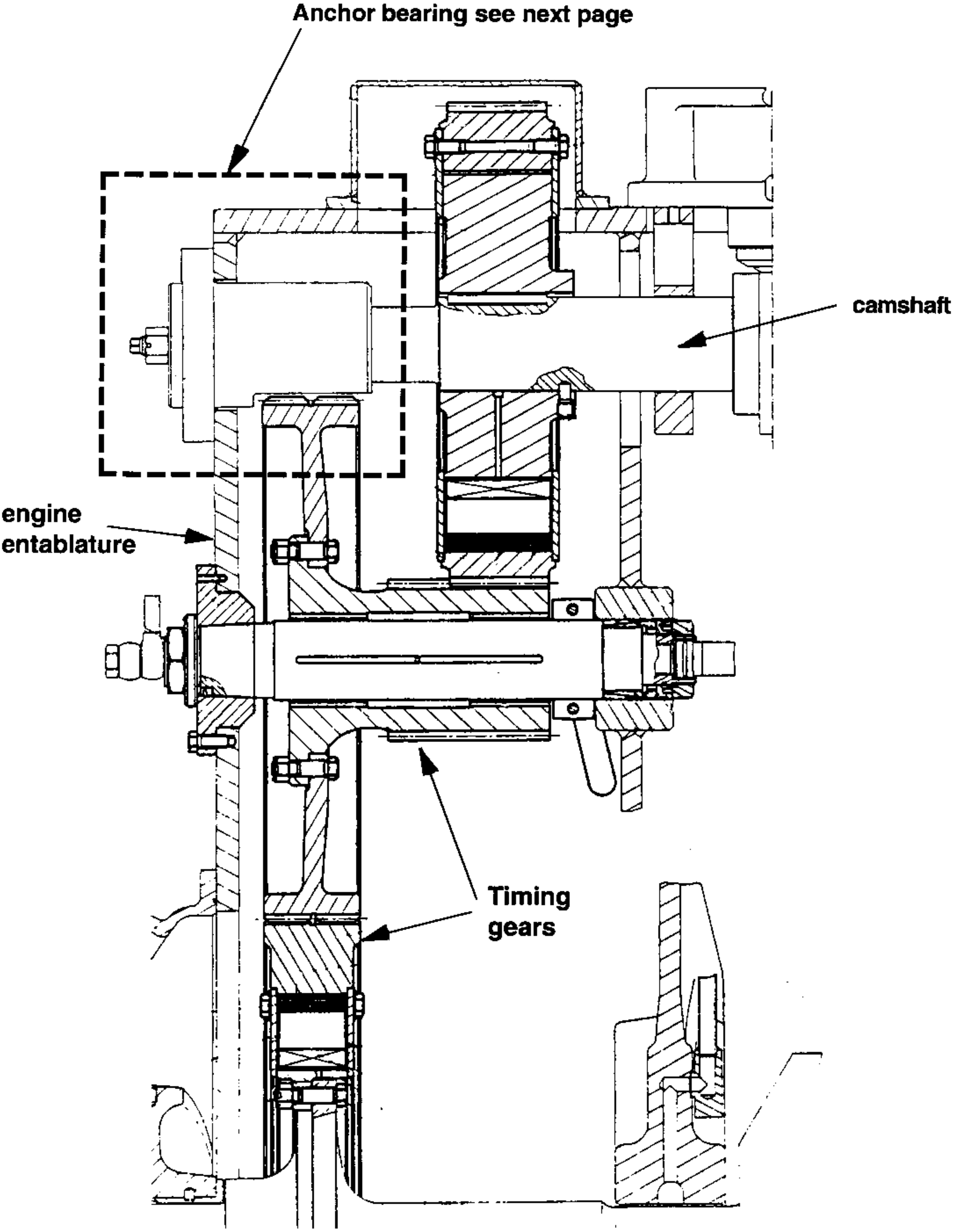
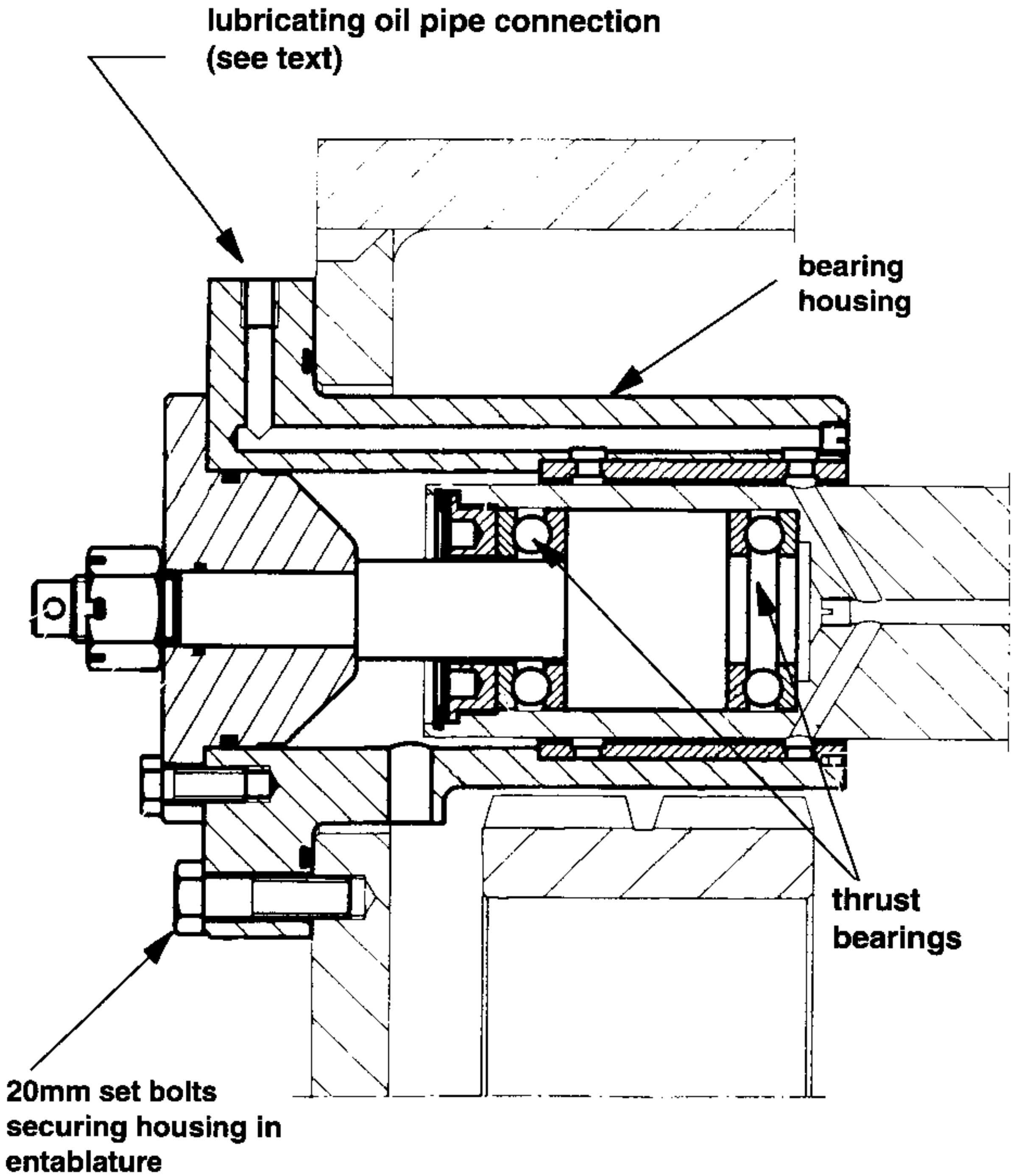
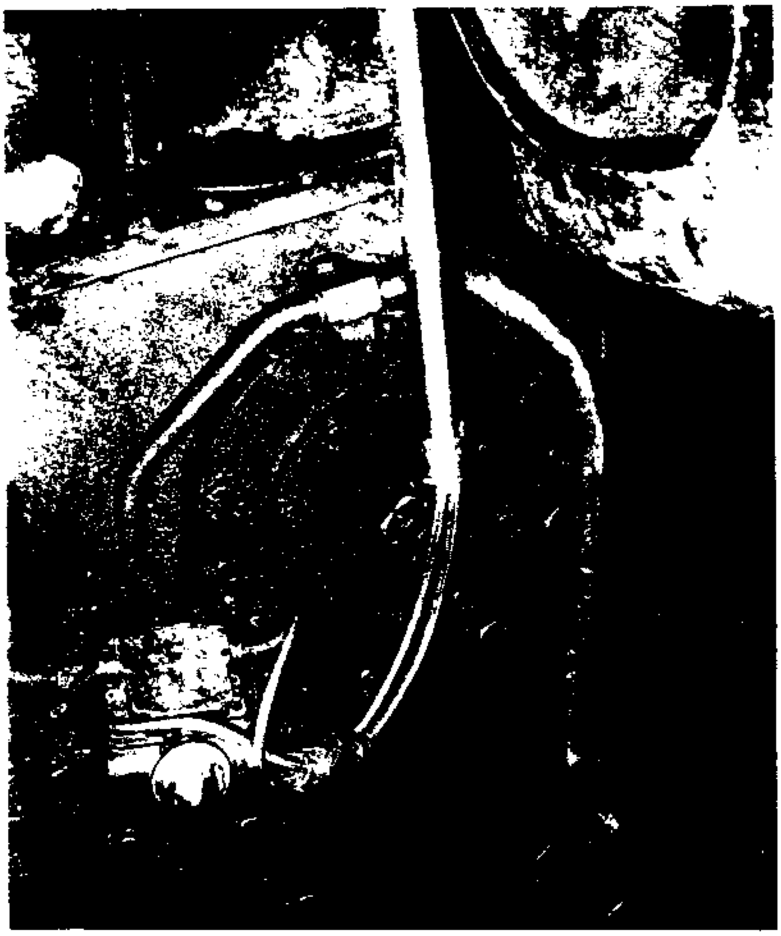
* Main engine power output listed in Lloyd's Register as 22,362 kW (30,401 bhp).



Sectioned elevation of timing gear showing position of camshaft anchor bearing in entablature

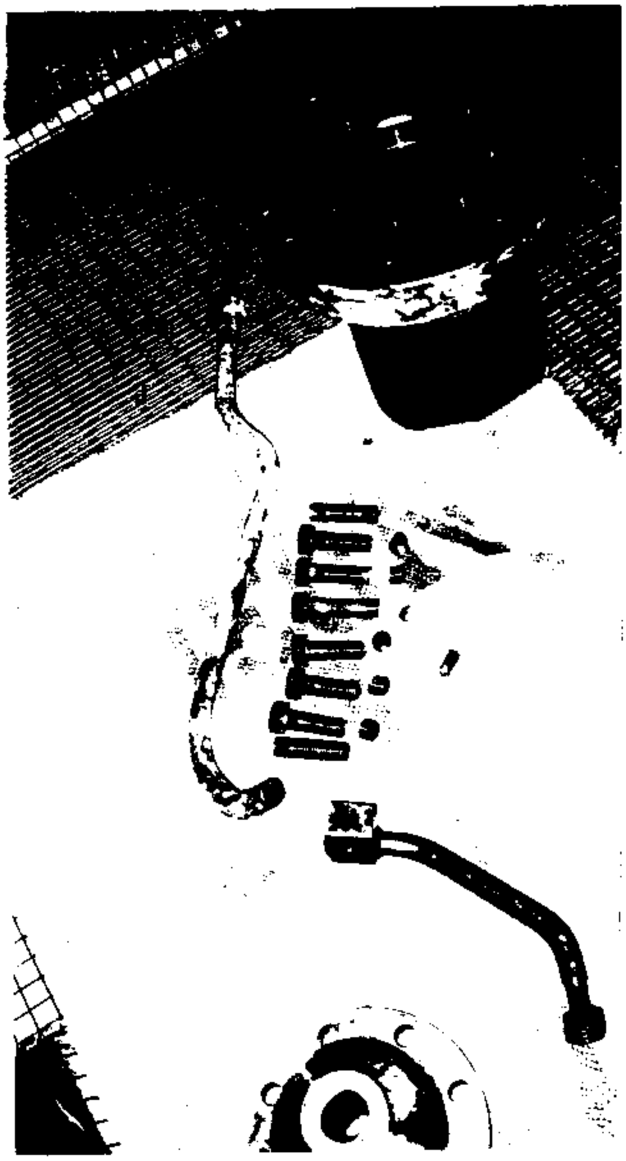


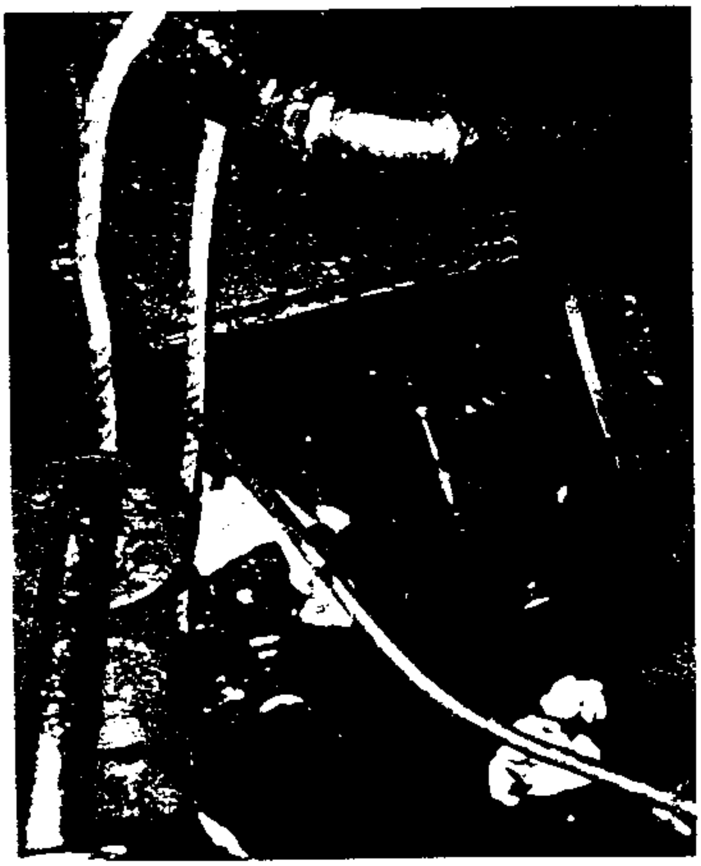
Section of chamshaft anchor bearing assembly



Camshaft anchor bearing housing in entablature of port engine
(Note lubricating oil pipe bolted to top of bearing housing)

Camshaft anchor bearing housing from starboard engine with fractured lubricating oil pipe and sheared securing bolts





Starboard engine entablature with camshaft anchor bearing housing removed

Narrative

On Tuesday 19 April 1994, Union Rotoma was on passage from the New Zealand port of Nelson bound for Port Botany, NSW. The Mate was on watch on the bridge in fine weather when, at 1835 Eastern Australian standard time, (2035 New Zealand standard time) the vessel's fire alarms sounded, indicating a fire in the ship's engine room. The vessel's position was 35°14.5'S 155°16.0'E.

Initially, the alarm indicated a fire in zone 3 in the engine room, but very shortly afterwards most of the other zones within the engine room were in the alarm condition, the sensors all being triggered by the spreading smoke.

The Third Engineer, who was the duty engineer for that day, went directly to the engine room to investigate the cause of the alarm. The Second Engineer, who was in the officers' television room at the time the alarm sounded, went to his cabin, put on overalls and collected his UHF radio. There was a slight smell of smoke in the alleyways. After leaving his cabin, he encountered the Extra Third Engineer and the Chief Engineer in the alleyway where they heard the Third Engineer reporting over the radio that there was a fire on top of the port main engine, at the aft end. At that time, the flames were less than a metre high, licking out from between the two air manifolds.

It was quickly agreed that two engineers would enter the engine room through the escape trunk which leads from the engine control room to the main deck. While the Second and Extra Third engineers did this, the Chief Engineer made his way to the fire muster station at the same time using his radio to ask the bridge to re-activate the alarms, which had by this time been stopped, and to make a broadcast on the PA system informing all on board that the fire was genuine.

The Second and Extra Third Engineers, meanwhile, reached the engine control room by which time the flames from the fire were reaching the engine room deckhead and the intensity of the fire was rapidly increasing. Burning cinders were falling from the deckhead onto the main engines. They decided that the fire was not going to be easily brought under control and the Second Engineer advised the Chief Engineer of this by radio. All officers were in radio contact and this message was also picked up on the bridge.

At the fire muster station a head count was taken and sets of breathing apparatus were being prepared for making an engine room entry. The Chief Engineer briefly discussed the situation with the Second Mate and asked him to organise a shut down of the engine room, quickly, in preparation for CO_2 flooding. As the Chief Engineer was leaving the muster station, he received the Second Engineer's message whereupon he ordered the three engineers to evacuate the engine room.

The ship's electrical power was, until this time, being supplied by the shaft alternator driven by the main engines, and the Third Engineer, who had initially discovered the fire, was busy preparing to start up the diesel alternators in preparation for changing over the source of electrical power and shutting down the main engines. He had one diesel alternator connected to the switchboard when he had to leave the engine room on account of the smoke and heat.

The three engineers had begun to evacuate the engine room, by way of the control room escape trunk, when they heard the Chief Engineer's instruction to leave. The Extra Third Engineer was the last out and, in the process, suffered from some smoke inhalation. The Second Engineer confirmed, by radio, that all the engineers had evacuated the space.

The Chief Engineer and the Second Officer made their way to the CO_2 room, on the next deck up, where the Chief Engineer opened the lid of the CO_2 release box which automatically operated the CO_2 alarms. Having received the Second Engineer's report that the engineers had left the engine room and were on No.5 deck, the Chief Engineer operated the CO_2 release lever. He gave the Second Mate the CO_2 check list and asked him to begin organising the shut down of all the engine room vent flaps and doors. The Bosun, with a radio and two able seamen (AB), first shut down No.5 deck while the Second Mate and another AB moved down to Nos.4 and 3 decks. On reaching No.3 deck, however, they abandoned the task as smoke was, by this time, coming into the cargo deck areas. They returned to the aft mooring deck to await the arrival of men in breathing apparatus. The Third Mate, having been advised that two men in breathing apparatus were required to close down the lower hold (3 deck) areas, arrived shortly afterwards together with the Mate.

While the Second Mate continued to work through the check-off list of vent flaps, the Mate and an AB donned breathing apparatus (BA) and entered No.4 deck from the after end. A back-up man waited on the outside. Smoke, escaping into the hold from the engine room was reducing visibility to less than two metres as they made their way down to the lower hold on No.3 deck. Making their way between the vehicles, they found an open engine room stores and escape hatch through which the smoke was issuing. Having closed that, they progressively checked the other engine room apertures all of which were found shut.

The Second Engineer made his way to the bridge where he remotely operated the quick-closing fuel shut-off valves. The Master already had operated the remote stops for the ship's engines from the bridge having been requested to do so by the Chief Engineer. The running generator stopped when it was starved of air by the discharge of CO_2 into the engine room and there was a short blackout before the emergency generator automatically started and came on line.

At 1845, while these events were taking place, the Master, who had gone to the bridge on the initial fire alarm, transmitted a distress alert on the ship's Inmarsat Standard-C. This message was received and acknowledged by the Maritime Rescue Coordination Centre in Canberra.

The Chief Engineer was watching the CO_2 contents gauge as the bulk system discharged into the engine room. He was aware that the required amount for flooding the engine room was 7 tonnes, but intentionally gave it some extra, discharging approximately 10 tonnes before shutting off the discharge. While the discharge was under way, the Chief Engineer received a report that the engine room shut down had been successfully completed.

Having been reassured by the fact that the running generator had stopped, indicating that the CO_2 was effectively blanketing the engine room, the engineers felt sufficiently confident to make their way to the duty mess for a coffee and to take stock of the situation. After a period of rather more than an hour, plans to re-enter the engine room were put into operation.

It was decided to start the emergency fire pump before making any attempt to re-enter the engine room but, because of the limited capacity of the emergency generator, this required that as much electrical load as possible should be shed from the main switchboard. The emergency generator provides the full accommodation lighting, but when it is running much of the hold lighting is switched off automatically, the remainder then becoming the "emergency" lighting. The Extra Third Engineer (the electrician) and the Chief Steward went around the accommodation switching off power points and unnecessary lighting. This action reduced the load sufficiently for the emergency fire pump to be started and the firemain pressurised.

The fire party assembled at the top of the control room escape hatch on No.5 deck where a BA control point was established and preparations were made for a re-entry using breathing apparatus. At 2010, the Second and Third Engineers, wearing BA sets entered the engine room via the escape hatch. They took radios with them and reported their progress back to the Chief Engineer as they searched for any sign of fire or hot spots. They found the fire was out, but the area where it had been was saturated with lubricating oil.

When they had approximately ten minutes of air left and the Chief Engineer had been advised that there was no sign of fire and no hot spots, they were instructed to return to the control point. At 2030 a situation report was passed to the Master who, shortly afterwards, cancelled the "Mayday" call transmitted earlier.

The emergency fire pump was stopped and the CO_2 extraction fan, also fed from the emergency circuit, was started. There was some discussion about, and difficulty encountered with, finding a suitable point from which the state of the engine room could be monitored. The top of the engine room was still full of smoke. It was found, however, that the engine room could be viewed quite well after making an entry into the boiler flat. Here it was possible to feel the air rushing down. By opening the funnel flaps and the engine control room escape hatch and running the CO_2 extraction fan, the engine room was effectively ventilated. Following discussions with the Master, a further plan was formulated which was for the Second and Third Engineers to enter the engine room again and gather up all the small emergency escape breathing sets, three of which were deployed around the engine room, and to put them in the control room. This they did, and at the same time reported that they could feel air passing through the control room from No.5 deck. The engineers, still wearing BA sets, then prepared to start one of the main generators, using the emergency starting air bottle and, once it was connected to the switchboard, started the vent fans.

At about this time, the warning whistles on their BA sets started to sound, indicating that they were getting low on air. The Chief Engineer, feeling confident that the engine room was by then well ventilated, instructed them to take off their BA sets. From that point on, when moving around the engine room to start other items of machinery, they each carried an emergency escape breathing set.

The fire parties were stood down at 2232 and by 2310, when the second diesel generator was started, full electrical power was restored to the vessel.

The cause of the fire still had not been established. One by one, fuel and lubricating oil pumps were started, from the control room. When the lubricating oil pump for the starboard main engine was started, oil sprayed from a fractured pipe at the aft end of the engine, above the inboard camshaft anchor bearing housing. It was found that all the securing set bolts and one of the locating dowels for this bearing housing had failed, allowing the housing to move out of the entablature thus fracturing the oil pipe which had been secured to it. Oil, under pressure, had then sprayed over the aft end of the port engine, igniting on the hot exhaust trunking adjacent to the turbo-charger.

Fire damage sustained by the vessel was found to be minor. A number of sensors for jacket cooling water temperature, together with their associated wiring above the port engine, were damaged, as were fire alarm sensors and wiring in the general vicinity of the fire. Instrumentation, installed by the previous owners and designed to facilitate economical running on only one engine, was also damaged.

The port engine was washed down with a high pressure water blaster and the damaged temperature alarms and trips were by-passed. After a normal start on the port engine, it was clutched in at 0042 on 20 April, and the ship proceeded on passage to Sydney, running on the port engine only. The engine was run at low power for a period of time to dry out the oil-soaked lagging and the engineer officers reverted from a daywork routine to one of watch-keeping.

Comments

Maintenance

Union Rotoma was acquired by Union Shipping New Zealand from its English owners three years before this incident. When the vessel was handed over, no documentation or records of maintenance were supplied and it was not possible for the investigation to establish either the quality or the extent of maintenance carried out on board prior to that time.

The manufacturer's maintenance schedule for the main engines makes reference to checking, for local wear, under the camshaft journal bearings every 3000 hours and a full inspection of the bearings with a view to replacement, every 24,000 running hours. It makes no reference, however, to any specific checks or inspections to be carried out on the anchor bearing and its housing although it could be taken that the inspection after 24,000 running hours would include this item. It would be considered good engineering practice, however, to consider the expected life of the ball bearings as defined by the manufacturers of the particular brand of bearings fitted within the assembly.

This bearing housing had not been opened up for inspection during the three years that Union Rotoma had been in the hands of Union Shipping and, with the lack of documentation relating to the ship's previous history, there was no indication of when, if ever, an inspection had been carried out.

Although no specific maintenance or checks were required on this part of the engine, it was usually sighted by the duty engineer officer during the course of his daily rounds. These rounds are carried out three times a day, once in the morning, once in the afternoon and again in the evening. The log sheets are completed during the morning rounds.

None of the engineers on board the vessel at the time of the incident had noticed anything amiss during their rounds on the day of the fire or the days leading up to it.

Set bolts

When first inspected after the fire, the bearing housing was found to be sitting 2 to 3mm out of the entablature with seven of the eight bolts, which had been securing it in the entablature, sheared. The other set bolt had vibrated free in intact condition. One of the locating dowel pins had been sheared by the movement of the housing.

The 20mm diameter set bolts were manufactured from high tensile steel (marked 8.8) and the remains of the bolts were submitted by the Marine Incident Investigation Unit to the metallurgy laboratory of the Civil Aviation Authority in Canberra for examination and comment.

The CAA laboratory found that the bolts had failed due to fatigue crack growth caused by alternating loads in the axial direction. The wear on the thread of the remaining intact bolt indicated that it had been loose. The most likely cause of the fatigue failure of the bolts appears to be that insufficient preload (torque) was applied when they were last tightened.

The CAA report is reproduced as Attachment 1 of this report.

The set bolts securing the housing in the entablature were not fitted with any locking arrangements such as lock-washers or laced with locking wire.

Although not actually shown in the assembly drawings, the engine parts list has "locking wire" as item 29 on the page referring to the camshaft thrust bearing. Advice from the manufacturer has confirmed that the heads of the set bolts should be cross-drilled and that they should be laced with locking wire.

It is not known when the original bolts were replaced with those fitted at the time of the incident, although it is evident that they had been replaced at some time in the vessel's past as, although made of the correct material, the heads of those fitted were not cross-drilled for lacing wire. The metallurgical evidence indicates in addition, that when they were fitted, the bolts were probably not tightened up to the specified torque of 180 Newton-metres to give the required preload. These factors, together with the fact that the engines in Union Rotoma were renowned among the ship's staff for high levels of vibration, appear to have combined to cause the failure and the resulting fire.

Fire fighting

The fire was first sensed, and the alarms sounded, by the ship's automatic fire detection system which indicated a fire in zone 3, one of the engine room zones. Within a very short space of time, the various zones on the bridge alarm panel which monitor the engine room were all in the alarm state indicating a serious fire.

The muster of the ship's company at the fire station at the aft end of "D" deck was completed without delay.

As is the practice on Union Rotoma, all officers switched their UHF walkie-talkie radios to channel 1 upon hearing the fire alarm. The Inspector has little doubt that the speedy and efficient manner in which the fire was extinguished was due in large measure to the fact that all officers had a personal radio and excellent communications were maintained, by all involved, throughout the incident.

During fire drills held before this incident, using a walkie-talkie radio while wearing a BA set was specifically practiced and it had been found that by holding the radio against the speech diaphragm, drawing a breath, speaking, then exhaling, one could be clearly understood by the receiving station. This technique was used to good effect during the process of fighting the engine room fire and enabled the BA control point to maintain effective communications with those crew members wearing BA sets.

The monthly fire drill held the previous month, although with different crew members, had involved the same officers and the scenario used was that of an engine-room fire requiring the discharge of bulk CO_2, a drill which stood them in good stead for the real incident which followed.

The moment it was realised that the fire was beyond being easily controlled and the decision had been taken to flood the space with CO_2, the efforts of the crew were concentrated on sealing off the engine room and therefore hoses were not rigged. The main fire pumps were not available, although the emergency fire pump could have been used if necessary. In the event it was not required, although hoses could have been rigged during the lull while the CO_2 was taking effect should it have been found, upon re-entry, that the fire had not been fully extinguished.

Re-entry

Once the CO_2 had been released, a period of one hour and twenty-five minutes elapsed before a re-entry was made into the engine room. After this time, the fire having been confirmed as having been put out, ventilation was commenced to clear the CO_2. An hour later, a second entry was made during which it was ascertained that a good air flow was established through the space. Approximately 30 minutes after that, it was considered safe for personnel to enter and work in the engine room with no life support equipment.

In the event, these times all proved sufficient. The vessel, however, carried no portable oxygen analysers and the decision on whether or not the atmosphere within the engine room was fit to breathe, was largely guesswork. A portable oxygen analyser, although not a statutory requirement, would have given a more definitive answer in this respect.

In addition to the usefulness of an oxygen analyser following this incident, a recent spate of accidents on ships around the globe, involving hazardous atmospheres, has indicated that such an instrument could be considered an essential piece of equipment to be used both under similar circumstances and before entering ship's tanks and void spaces.

Conclusions

These conclusions identify the different factors contributing to the accident and should not be read as apportioning blame or liability to any particular organisation or individual.

1. The fire in the engine room was caused by a spray of lubricating oil, from a fractured pipe on the starboard main engine, being ignited by the hot exhaust manifolds on the port engine.

2. The lubricating oil pipe was fractured when the housing for the camshaft anchor bearing worked its way out of the entablature, consequent upon the failure of the eight securing set bolts.

3. The set bolts which secured the bearing housing in the entablature had no form of locking and should have had cross-drilled heads and been laced with locking wire.

4. It was not possible to ascertain when the securing set bolts had been fitted, but it appears that they must have been fitted when the vessel was in the hands of previous owners. At the time that they were fitted, they were probably not pre-loaded to the required torque.

5. Engine vibration would have contributed to the failure of the bolts.

6. The response of the vessel's firefighting organisation was both fast and effective. This was due in large part to the fact that all officers and key personnel had personal UHF radios and excellent communications were maintained between all those involved throughout the incident.

7. Realistic fire drills carried out on a regular basis, incorporating such techniques as using radios while wearing breathing apparatus and scenarios such as engine room fires requiring CO_2 flooding, contributed to the efficiency with which the fire was extinguished.

8. No portable oxygen analysers were available on board with which to test the atmosphere in the engine room after it had been vented to clear the CO_2. Although not a statutory requirement, had one of these been available it would have minimised the risk to personnel when re-entering a space which had been flooded with CO_2.

Submissions

Under sub-regulation 16(3) of the Navigation (Marine Casualty) Regulations, if a report, or part of a report, relates to a person's affairs to a material extent, the Inspector must, if it is reasonable to do so, give the person a copy of the report or the relevant part of the report. Sub-regulation 16(4) provides that any such person may provide written comments or information relating to the report.

The report was sent to Union Shipping New Zealand, the Master and the Chief Engineer of Union Rotoma.

The comments submitted by Union Shipping New Zealand have been incorporated into the body of the report.

Details of vessel

Name	Union Rotoma (Previous Names: Rostand, CGM Rostand, PAD Australia, Kagoro and Rost)
Flag	New Zealand
Lloyd's Number	7359711
Owners	Union Shipping New Zealand Ltd
Type	Roll-on/roll-off cargo
Builder	Chantiers de France, Dunkerque
Classification Society	Bureau Veritas
Length overall	207.38m
Beam	29.57m
Gross tonnage	11,680
Nett tonnage	4 403
Summer deadweight	12,967 tonnes
Summer draught	9.560 metres
Capacity	646 TEUs
Main engines	Two, SEMT Pielstick type 16PC3V-480
Engine power	13,428kW
Crew	19

Attachment 1

SPECIALIST REPORT 30-94

CAMSHAFT END BEARING HOUSING (THRUST BEARING) ASSEMBLY BOLT FAILURES

SEMT PIELSTICK PC3V-480 MEDIUM SPEED MARINE DIESEL

UNION ROTOMA

DR A. ROMEYN Materials/Failure Analysis Specialist

CIVIL AVIATION AUTHORITY AUSTRALIA

MATERIALS EVALUATION FACILITY
DIRECTORATE OF AVIATION SAFETY REGULATION

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CAMSHAFT THRUST BEARING ASSEMBLY BOLT FAILURES, UNION ROTOMA

1. Introduction

In the course of the investigation an engine room fire on the "UNION ROTOMA" the bolts employed to secure the camshaft end bearing housing (thrust bearing) into the engine entablature and one dowel pin were found fractured. The Marine Investigation Unit of the Department of Transport requested that the fractured bolts be analysed.

Engine History

The camshaft end bearing housing assembly had not been removed for inspection or overhaul for at least 3 years prior to the engine room fire. The SEMT Pielstick PC3V-480 medium speed marine diesel has 16 cylinders arranged in a V configuration and is rated at 11,181 kW (15,200 BHP).

2. Failure Analysis

A total of eight bolts, nominal diameter 20mm, from the camshaft end bearing housing were examined. Of the eight bolts, one bolt was intact, two had fractured under the head of the bolt, and the remaining five had fractured at a location approximately between 12 to 15 mm from the end of the bolt (at a point which appears to coincide with the extent of thread engagement into the engine entablature), see figures 1 and 2.

Figure 1. Bolt from the camshaft end bearing housing, as received.

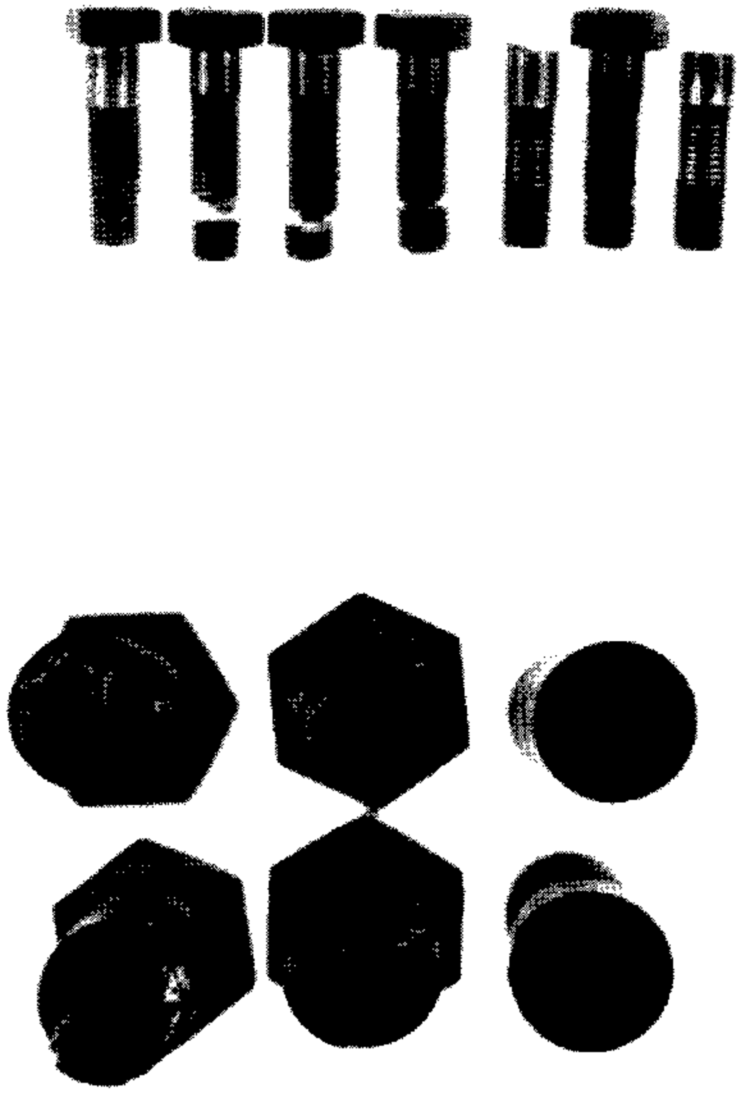

Figure 2. The remainder of the bolts from the camshaft end bearing housing, as received.

In each case bolt fracture was caused by fatigue. The location of the fatigue fractures coincides with sites of stress concentration, under the head of the bolt and at the limit of thread engagement in the entablature.

The orientation of the plane of crack growth with respect to the axis of the bolt indicates that alternating axial loads were responsible for fatigue crack initiation and growth.

The resistance of bolts to fatigue cracking depends on the level of preload established in the bolt during assembly and maintained during operation. Generally, if the applied load does not exceed the bolt preload, then the bolt will experience only a small proportion of the applied alternating load (the precise amount depends on the ratio of the stiffness of the bolt to the joint).

Bolt preloads are established during assembly. The action of applying a specified torque to a bolt head creates a preload in the body of the bolt. It was reported that the manufacturers recommended assembly torque was 180 N-m.

Hardness testing indicated that the bolts were manufactured from a steel with a tensile strength of approximately 1000 MPa.

The fractured dowel pin exhibited evidence of extensive fretting wear (wear created as a result of relative movement between two contacting surfaces), see figure 3. The fracture of the pin was caused by excessive load.

Figure 3. Fractured dowell pin. Magnification 2.7X

3. Conclusions

Eight bolts from the camshaft end bearing were examined. Seven of the eight bolts had fractured. In each case fracture was caused by fatigue crack growth. The orientation of the plane of crack growth indicated that the alternating loads responsible for fatigue were aligned with the axes of the bolts. The region of thread wear on the remaining intact bolt indicated that it had been loose.

Resistance to fatigue cracking depends on the creation of the correct level of preload, with respect to the magnitude of the applied alternating loading condition, in the body of the bolts. The application of a torque lower than that recommended by the manufacturer, during assembly, may result in the development of fatigue cracks in the bolts.

Recommendations regarding corrective action should also consider the following alternatives. If the bolts had been tightened according to specification and the magnitude of the alternating loading condition imposed on the bolts is associated with "normal " operation, then consideration should be given to increasing the torque applied to the bolts during assembly in order to prevent further failures. Or, if the loading condition is associated with "abnormal" operation, then action should be taken to address the cause of the loading condition in order to prevent further failures.

Materials/Failure Analysis Specialist 31-5-94