



Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation
Federal Higher Authority subordinated to the Ministry of Transport
and Digital Infrastructure

Investigation Report 431/15

Serious Marine Casualty

**Serious engine damage
followed by fire
on board the cargo vessel THETIS D
on 26 October 2015
in the Kiel Bight**

14 June 2018

The investigation was conducted in conformity with the Law to improve safety of shipping by investigating marine casualties and other incidents (Maritime Safety Investigation Law – SUG). According to said Law, the sole objective of this investigation is to prevent future accidents. This investigation does not serve to ascertain fault, liability or claims (Article 9(2) SUG).

This report should not be used in court proceedings or proceedings of the Maritime Board. Reference is made to Article 34(4) SUG.

The German text shall prevail in the interpretation of this investigation report.

Issued by:
Bundesstelle für Seeunfalluntersuchung – BSU
(Federal Bureau of Maritime Casualty Investigation)
Bernhard-Nocht-Str. 78
20359 Hamburg
Germany



Director: Ulf Kaspera
Phone: +49 40 31908300
posteingang-bsu@bsh.de

Fax: +49 40 31908340
www.bsu-bund.de

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1 Summary

The container ship THETIS D, flying the flag of Liberia, was en route from Gdynia, Poland, to Bremerhaven, Germany, when serious damage to the main engine became apparent in the engine room on the morning of 26 October 2015. The main engine was stopped automatically. One cylinder's drive unit was completely destroyed. A large amount of lubricating oil escaped, which ignited. This was followed by a fire in the engine room.

At this point, the THETIS D was on the Kiel-Baltic Sea route about 5.6 nm north-east of Kiel Lighthouse. The fire in the engine room extinguished automatically after airtight integrity was established. The THETIS D was towed not under command (NUC) to the port of Kiel Ostuferhafen with the support of two tugs.

Nobody came to physical harm due to the accident, nor was there any environmental pollution.

2 FACTUAL INFORMATION

2.1 Photo



Figure 1: Photo of the ship

2.2 Ship particulars

Name of ship:	THETIS D
Type of ship:	Container ship
Nationality/Flag:	Liberia
Port of registry:	Monrovia
IMO number:	9372274
Call sign:	D5BV6
Owner:	Drevin Bereederungs-GmbH & Co. KG
Year built:	2009
Shipyard/Yard number:	J. J. Sietas/1262
Classification society:	DNV GL
Length overall:	168.11 m
Breadth overall:	27.04 m
Gross tonnage:	17,488
Deadweight:	16,950 t
Draught (max.):	9.60 m
Engine rating:	11,200 kW
Main engine:	MAN 58/64 CD
(Service) Speed:	19.0 kts
Hull material:	Steel
Minimum safe manning:	11

2.3 Voyage particulars

Port of departure:	Gdynia, Poland
Port of call:	Bremerhaven, Germany
Type of voyage:	Merchant shipping, international
Cargo information:	Containers
Manning:	14
Draught at time of accident:	8.70 m
Pilot on board:	No
Canal helmsman:	No
Number of passengers:	None

2.4 Marine casualty information

Type of marine casualty:	Serious marine casualty
Date, time:	26 October 2015, 0829 ¹
Location:	Bay of Kiel
Latitude/Longitude:	φ 54°31.92' N λ 010°25.43' E
Ship operation and voyage segment:	High seas
Place on board:	Engine room
Consequences (for people, ship, cargo, environment, other):	Serious damage to the main engine and inside the engine room. Nobody came to physical harm, nor was there any environmental pollution

Extract from Navigational Chart 54,
Federal Maritime and Hydrographic Agency (BSH)

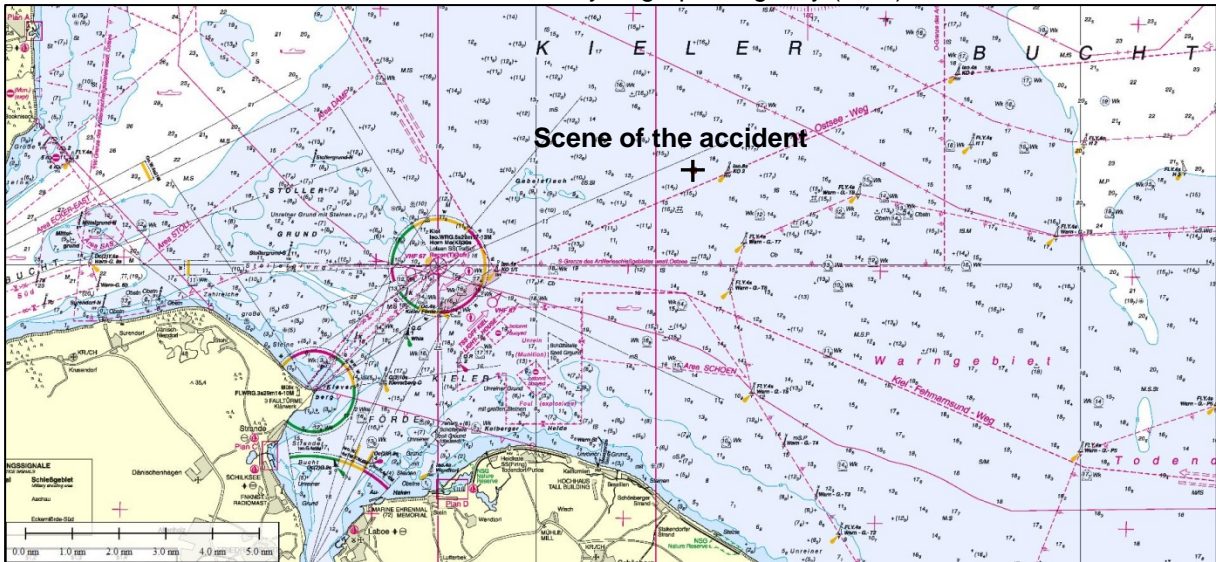


Figure 2: Navigational chart

¹ All times shown in this report are local = UTC + 1.

2.5 Shore authority involvement and emergency response

Agencies involved: Vessel Traffic Service (VTS) Travemünde,
Waterway Police (WSP) Kiel

Resources used: Tugs KIEL and KITZEBERG

Actions taken: Watertight integrity established in the engine room;
ship towed to the port of Kiel

Results achieved: Fire extinguished automatically; ship towed to the
port of Kiel safely

3 COURSE OF THE ACCIDENT AND INVESTIGATION

3.1 Course of the accident

The container ship THETIS D, flying the flag of Liberia, was en route from Gdynia, Poland, to Bremerhaven, Germany, on 26 October 2015. The weather at sea was good. A force 3 south-easterly wind prevailed and visibility stood at 10 nm. The chief officer (on watch) and master manned the THETIS D's bridge from 0800 onwards. The second engineer (on watch) was in the separator room and the oiler was painting in the steering gear compartment. At about 0830, there was a loud bang and violent shuddering in the engine room. The ship then vibrated severely. Both the engine room personnel and the bridge crew then noticed the development of thick smoke. The main engine stopped automatically. At this point, the THETIS D was on the Kiel-Baltic Sea route about 5.6 nm north-east of Kiel Lighthouse.

One cylinder's drive unit was completely destroyed. A large amount of lubricating oil escaped, which ignited. The fire in the engine room extinguished automatically within 20 minutes due to the establishment of airtight integrity. The crew survived the accident unharmed.

A towing connection was established with the NUC THETIS D at 1100. The tugs KIEL and KITZEBERG towed her to the port of Kiel Ostuferhafen, where she made fast at 1702.

At the beginning of November 2015, the THETIS D was towed to Hamburg, where her cargo was discharged. Following that, the THETIS D was repaired at the Norderwerft shipyard in Hamburg.

3.2 Investigation

VTS Travemünde and WSP Kiel notified the Federal Bureau of Maritime Casualty Investigation (BSU) of the accident on board the THETIS D on the morning of 26 October 2015. The accident was initially reported as engine damage in accordance with the information given by the THETIS D's command. Only in the later stages of the day did it transpire that the accident went beyond the scope of ordinary engine damage. This prompted the BSU to start an investigation on the evening of 26 October 2015. The flag State of the THETIS D, Liberia, was notified and also started an investigation of the marine casualty.

3.2.1 Surveys

The BSU's investigation team carried out an initial survey on board in the port of Kiel Ostuferhafen on 27 October 2015. At this point, the engine room only had makeshift lighting because the fire had destroyed most of the lights (see Fig. 3).



Figure 3: View of the main engine (taken on 27 October 2015)

It was found during a visual inspection of the main engine that the drive unit openings on both sides of cylinder 7 exhibited considerable damage. The maintenance cover had been blasted off on both sides and large fragments of the engine frame had broken away (see Fig. 4).

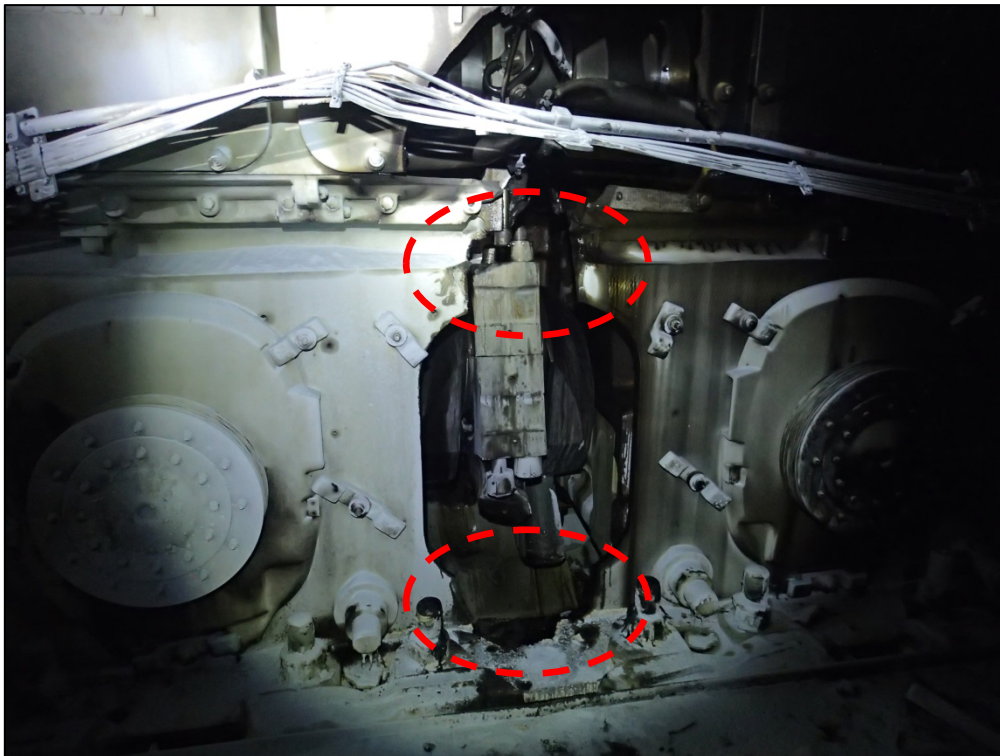


Figure 4: Cylinder 7's drive unit opening (taken on 27 October 2015)

The BSU's investigation team documented the damage pattern found in the engine room (see section 3.2.3). The master and the chief engineer officer were interviewed with regard to the course of the accident. Moreover, the manoeuvre log printouts and data from the engine alarm system and engine safety system were secured.

It was found as the survey progressed that the data on the voyage data recorder (VDR) had not been backed up by the ship's command (see section 3.2.8).

The BSU commissioned an expert with a detailed investigation of the engine damage and carried out another survey of the THETIS D with him on 3 November 2015. The THETIS D's engine room personnel were interviewed during this survey. In the meantime, a certain amount of cleaning and clearing work had already taken place in the engine room. The debris had been divided into groups of individual components (see. Fig. 5).

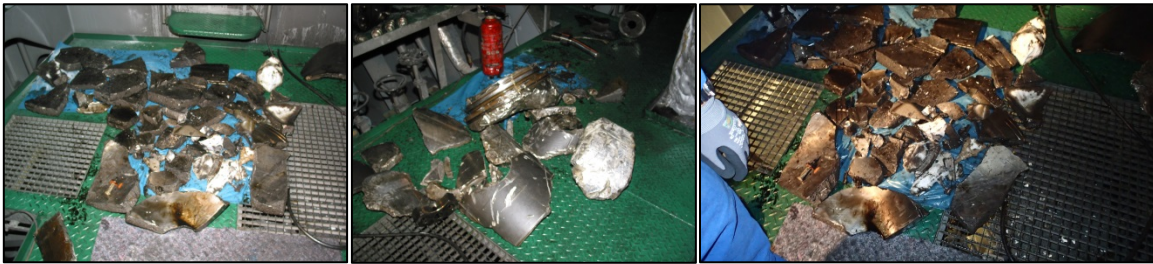


Figure 5: Sorted debris (taken on 3 November 2015)

The BSU's investigation team arranged for the seizure of two threaded ends from the mounting bolts on cylinder 7's forward counterweight to verify whether the accident may have been caused by a loose counterweight on the crankshaft.

Further surveys of the THETIS D in the Norderwerft shipyard in Hamburg took place together with the expert on 9 November, 24 November, and 15 December 2015. Inter alia, a filter cartridge was taken from the automatic lubricating oil filter and a lubricating oil sample from the indicator filter.

3.2.2 Witness interviews

The BSU's investigation team interviewed the German master and the German chief engineer officer to begin with. The latter has been employed by the THETIS D's operator for seven years and qualified as a chief engineer officer on 4 May 2015. The team from the BSU also interviewed the Ukrainian second engineer and the Philippine oiler. The crew members described the course of the accident as follows:

The chief officer (on watch; Philippine national) and the master manned the THETIS D's bridge on the morning of 26 October 2015. It was reported that violent shuddering and severe vibration occurred suddenly at 0824. The main engine stopped immediately. Shortly after, smoke rising from the engine room's ventilation fans was noticed on the bridge. The general alarm was sounded and a check made to verify that all the crew members were unharmed. Watertight integrity was established in the engine room. Following that, the fire extinguished automatically after about 20 minutes. Therefore, there was reportedly no need to flood the engine room with CO₂. It was claimed that the engine room's crew did not notice any irregularities on the main engine before the accident. The second engineer was in the separator room at the time of the accident, which is only accessible via the engine room, and the oiler was in the steering gear compartment. The second engineer hurried toward the engine room after a loud bang. From the entrance to the engine room, he observed how the main engine was moving violently in all directions.

Flames were visible in the area of the turbocharger. Black smoke blocked the route to the engine control room (ECR), meaning it was not possible to carry out an emergency shutdown of the main engine from there. The second engineer was able to escape through the forward emergency exit and the oiler found refuge in the aft manoeuvring station, which he reached via another emergency exit.

3.2.3 Main engine

The THETIS D is fitted with a MAN B&W 8L58/64 CD medium-speed main engine built in 2009.

Engine design	4-stroke
Number of cylinders	8
Maximum continuous power rating	11,200 kW
Nominal speed	428 min ⁻¹
Direction of rotation	Right-hand
Firing order	1 – 4 – 7 – 6 – 8 – 5 – 2 – 3
Approved for marine fuel	DM ² and RMK ³ according to ISO 8217

The main engine had been in service for about 32,840 hours when the damage occurred.

The THETIS D sustained heavy drive unit damage on the main engine. In addition to fractured drive unit parts on cylinder station 7, the engine frame was destroyed and parts of the unit had been ejected.

The maintenance cover on cylinder 7's drive unit openings had been blasted off on both sides (see Fig. 4). Debris was spread over an extensive area and a 50-kg powder extinguisher had triggered after being hit by debris (see Fig. 6).

² Marine diesel oil.

³ Heavy fuel oil/residual marine oil.

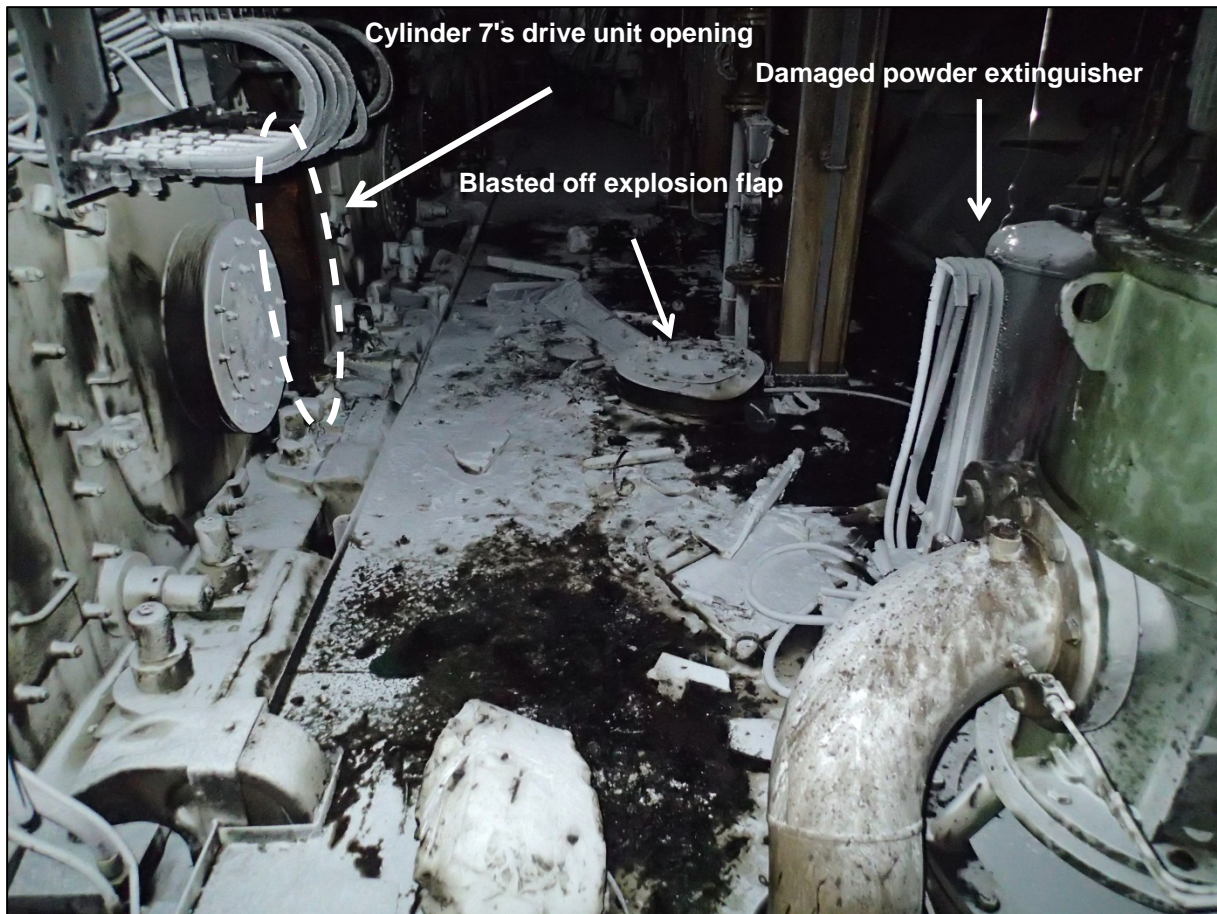


Figure 6: Debris in front of a drive unit opening belonging to cylinder 7
(taken on 27 October 2015)

Parts of the connecting rod were 7 m away. A large amount of lubricating oil had escaped.

The entire engine room exhibited heavy fire damage (soot build-up, melted overhead lighting – see Fig. 7).



Figure 7: Traces of fire in the engine room

No traces of fire were visible in the ECR, where only a part of the ceiling lining had loosened (see Fig. 8).



Figure 8: ECR with detached ceiling lining

3.2.4 Inspection of the connecting rod bearing before the accident

According to information given by the owner, the former chief engineer officer had opened and then closed cylinder unit 7's connecting rod bearing on 25 March 2015 to carry out a routine inspection after 30,400 service hours. At that time, the current chief engineer officer was serving on the THETIS D as second engineer and present during the inspection of the connecting rod bearing in March 2015.

The THETIS D had technical work cards and a manual from the engine's manufacturer on board for works on the engine. It was not possible to clarify whether or to what extent they were used for the inspection of the connecting rod bearing retrospectively.

A replacement connecting rod was carried on the THETIS D (see Fig. 9), meaning exchanging it would have been possible if necessary.



Figure 9: Replacement connecting rod in the THETIS D's engine room

3.2.5 Opinion of the MAN materials testing laboratory

The manufacturer of the main engine, MAN Diesel Turbo SE, arranged for parts of the THETIS D's dismantled engine to be assessed in an accredited MAN testing laboratory. The findings of the examination and photographic documentation of each step of the examination were provided to the BSU.

Part of the assessment included a visual inspection of the crankshaft on 7 December 2015. Furthermore, a surface crack test and a hardness test were carried out in the area of the crankshaft bearing pin 7. A protruding upper shell belonging to the connecting rod bearing was found during the examination, among other things. A further assessment of the connecting rod on 10 December 2015 revealed extremely pronounced signs of fretting⁴ on the connecting rod shank's mating surfaces and on the connecting rod bearing cap. The materials laboratory suggested that these findings were indicative of a pre-stress loss in the corresponding bolt connection at the connecting rod's bearing bore.

3.2.6 Technical opinion on behalf of the BSU

Prof. Dipl.-Ing. Hark Ocke Diederichs assisted the BSU's investigation team in this safety investigation. The assessment centred on the examination of cylinder station 7's damaged connecting rod (see Figure 10).

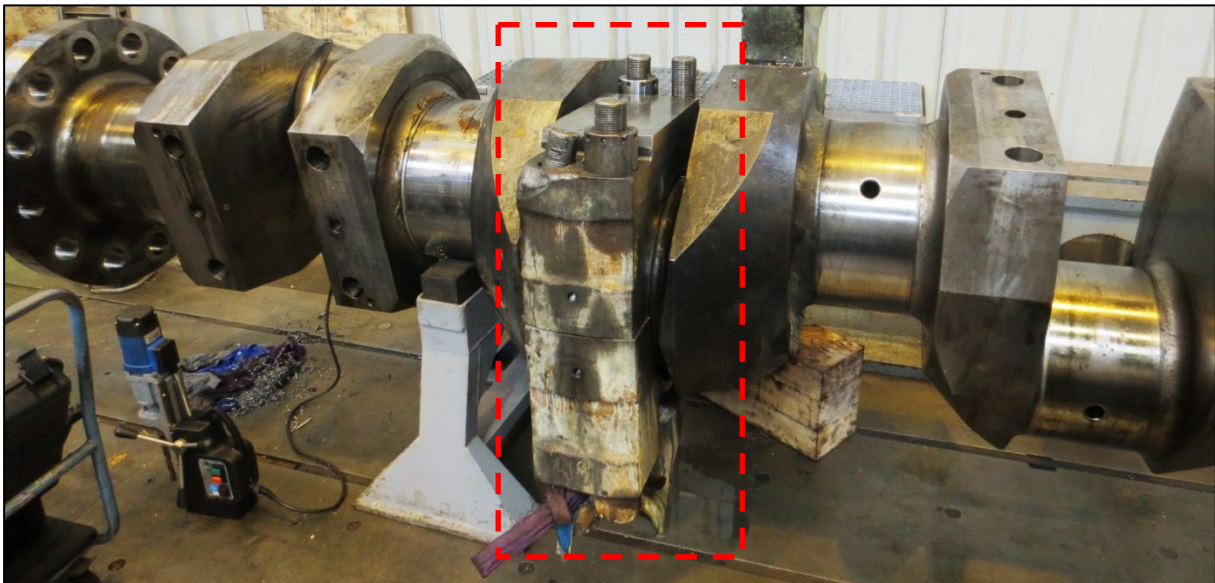


Figure 10: Damaged connecting rod bearing after the removal of the crankshaft

Extracts from the examinations carried out by Professor Diederichs and the corresponding findings from his opinion of 31 October 2016 are reproduced below.

⁴ Signs of seizure as a result of dry friction.

3.2.6.1 Connecting rod

The expert states the following with regard to the connecting rod:

"The split connecting rod consists of the upper part with a connecting rod eye and the lower part with the connecting rod bearing. Both parts are connected to each other on the split shank with six necked-down bolts."

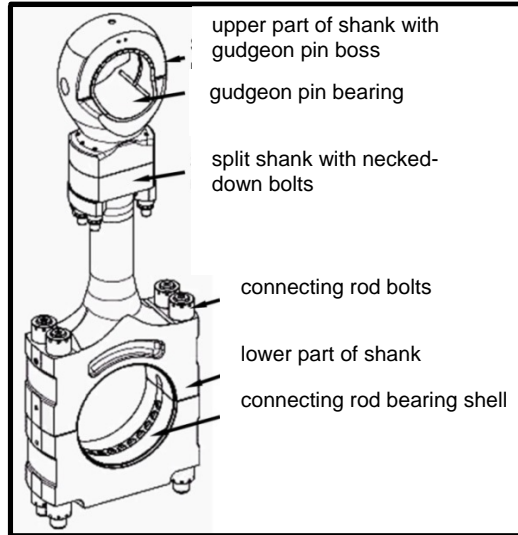


Figure 11: Technical drawing of the connecting rod

[The small end bearing] is a single piece and pressed into the gudgeon-pin boss. The connecting rod bearing is in two parts with an upper and a lower shell, which is clamped in the bearing housing with four bolts. [...] The [THETIS D's] connecting rod has broken apart at the split shank and broken just above the connecting rod bearing.

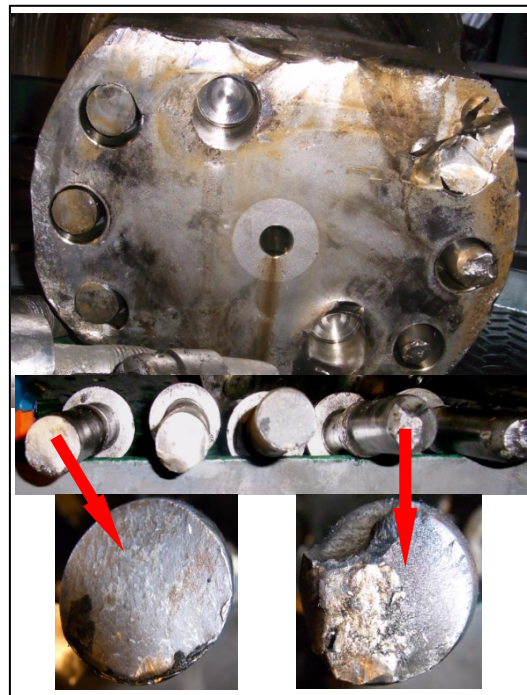


Figure 12: Broken bolts for the split shank

Three of the six connecting bolts for the split shank exhibit typical characteristics of a ductile shear stress break, the other three bolts a ductile bending forced fracture with lateral contraction. This suggests that the connecting rod was first kinked (bending forced fracture), and afterwards the separation surfaces shifted (sliding) and "cut" the other bolts as a result.



Figure 13: Connecting rod eye with breakage and laterally shifted bearing bush

Large pieces were broken out from the bearing bush in the connecting rod eye and the bush was pushed approx. 50 mm out of the bore. The connecting rod eye and bearing bush exhibit heat tones. [...]

The lower part of the connecting rod broke off directly at the transition to the bearing body and the broken piece exited the crankcase.

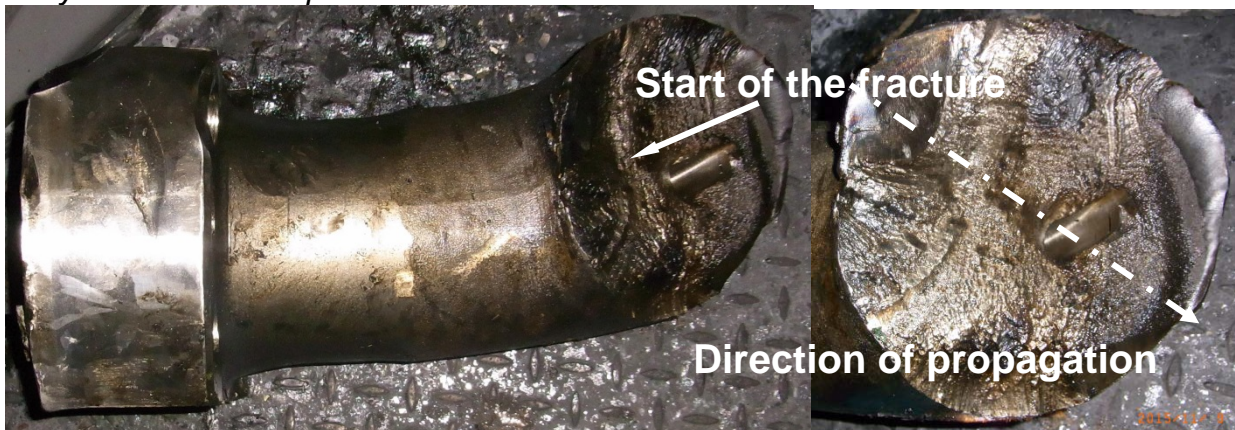


Figure 14: Broken connecting rod with detailed enlargement of the broken surface

The broken surface exhibits the typical characteristics of a ductile forced fracture. It is noticeable that the fracture begins in the middle and then continues in a curve. This suggests that a compressive force and torsional force must have been applied at the same time."

After assessing the fracture patterns on the bolts, the expert arrives at the conclusion that the connecting rod fractured under great force due to buckling. This is reportedly only possible if the piston is blocked while moving upward.

3.2.6.2 Connecting rod bearing

As regards the connecting rod bearing, the expert states:

"The connecting rod bearing was fixed and would not rotate around the crank pin. It was not possible to measure the bearing play, but it could be felt to be large. The visible external damage is shown in [Figure 15; label ES = exhaust side, CS = control side]."

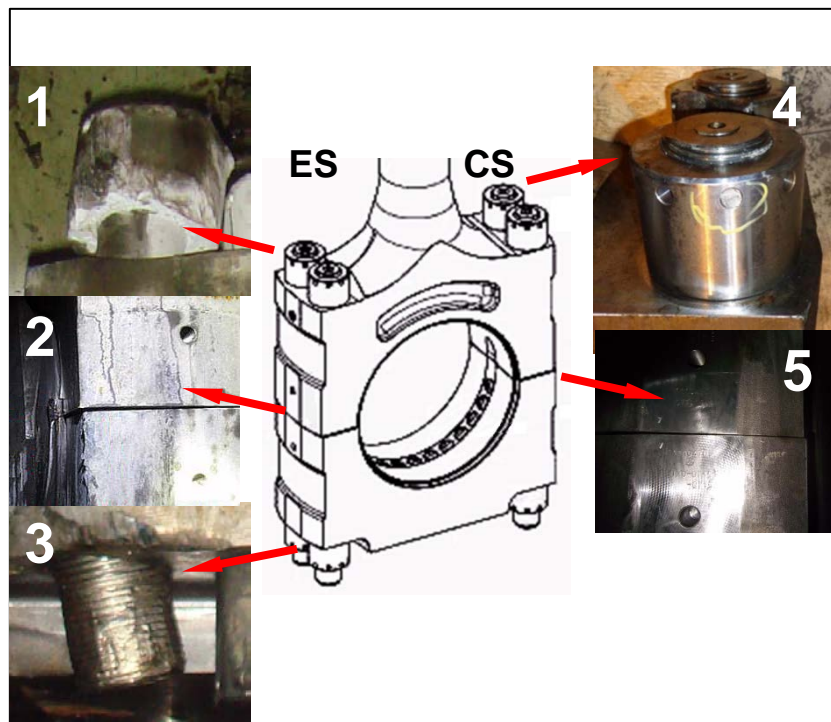


Figure 15: Visible external damage on the connecting rod bearing

- 1 *Ring nut fragmented and free end of thread bent.*
- 2 *Bearing shell squeezed out sideways, gap between bearing housing halves and shift of the housing halves*
- 3 *Bolt exited out of bearing housing*
- 4 *Broken rotating pin in the upper ring nut*
- 5 *Wedge-shaped gap between bearing housing halves*

"The inspection of the bearing shells, the shell seating and the seating surfaces between the two bearing halves was carried out after opening the connecting rod bearing."

The expert was unable to find any scoring or other signs that were indicative of rotating bearings on the bearing seats or on the back of the bearing shells. According to his diagnosis, both bearing shells had been driven out of the bearing bore laterally and exhibited localised, blue discolouration. The bores in the lower shell exhibited oval deformation (see Figure 16), which permits the conclusion that misalignment had occurred.



Figure 16: Rear side of the bearing shells

"Concomitant rotation of the bearing shells due to friction between the bearing journal and the bearing shells must be prevented by static friction between bearing shell and bearing housing. To achieve this, elastic tension is applied to the bearing bolts after the bearing shells are seated in the bearing housing halves by tightening the nuts, and the resultant bolt forces are transferred as compressive forces to the end faces of the bearing shells, so that these are pressed [...] onto the seats of the bearing housing halves firmly. [...]"

Even deformation of the bearing shells and thus even distribution of the compressive stress in the bearing shells are guaranteed only if the bearings are protruding evenly on both sides and all bearing shells are pre-stressed. Deviations from these two conditions can lead to unintended elastic/plastic deformation of the bearing shells during operation.

A hydraulic device is used to tighten the bearing bolts." (See section 4.3 for the procedure for installing the connecting rod bearing bolts properly.)

3.2.6.3 Alarm and safety system

The expert's examination also included the alarm and safety system on board the THETIS D. The opinion stated:

"All the relevant operating parameters of the engine (temperatures, pressures, flow resistances) and the remaining operation of other machinery are continuously tracked by a monitoring and safety system. Depending on their extent, deviations from the set values trigger audible (sirens) and visual (flashing light, colour change) alarm signals. The audible and visual alarm signal can be recognised throughout the

engine room, but are acknowledged only in the ECR. After acknowledgement, the visual alarm persists until the fault is eliminated.

Depending on the risk potential of a deviation, important operating parameters defined by the classification society or engine manufacturer cause the safety system to automatically initiate a power reduction (AUTO-LOAD REDUCTION) or shutdown (SHUT DOWN) of the engine. After acknowledgement of the alarm signal, automatic intervention of the system can be suppressed during operation by pressing the override button on the bridge or in the ECR (ship before machine principle), except in cases of engine overspeed. [...]

Criteria for a reduction in power include excessive operating media temperatures (cooling water, lubricating oil); for engine shutdown, overspeed, insufficient lubricating oil pressure, excessive bearing temperatures or oil mist in the drive chamber."

3.2.6.4 Findings

The opinion yielded the following findings, *inter alia*:

- the serious engine damage was caused by low pre-stressing on the connecting rod bearing bolts;
- excessive wear on the connecting rod bearing occurred, subsequently resulting in deformation. This caused a reduction in bolt force, among other things;
- the engine's loss of power worsened due to increased friction in cylinder 7 (piston seizure), whereupon the automatic load governor had to increase the fuel supply to compensate for the reduced revolution rate, and
- the expert thinks it unlikely that previous damage to the bearing shells would have caused the present damage to the bearing.

3.2.7 AIS and VHF recordings of the VTS

VTS Travemünde provided the BSU with the following data for the investigation:

- AIS data of 26 October 2015 (000000 to 235959 UTC) and
- VHF recordings for channel 67 (080016 to 120000 LT = UTC + 1).

The following data on the course of the THETIS D's voyage were exported from the VTS's database (see Spreadsheet 1; display: per minute; colours added by the BSU):

Time ⁵	SOG ⁶	COG ⁷	HDG ⁸
082206	15.5	245.0	246
082306	15.6	245.0	246
082405	15.5	246.0	246
082505	15.5	245.0	246
082605	15.5	245.0	246
082705	15.7	246.0	246
082805	15.7	245.0	246
082905	15.5	246.0	246
083005	12.4	245.0	245
083105	10.5	242.0	239
083205	9.0	234.0	229
083305	7.7	222.0	216
083405	6.5	210.0	204
083505	5.7	200.0	197
083601	5.1	196.0	194
083702	4.7	195.0	194
083802	4.4	195.0	197
083902	3.9	199.0	202
084002	3.8	200.0	209
084102	3.3	207.0	217
084202	3.2	217.0	225
084302	3.1	226.0	231
084401	2.8	233.0	235
084501	2.8	236.0	238
084601	2.6	241.0	240
084701	2.6	242.0	240
084801	2.5	239.0	238

Spreadsheet 1: AIS data on the course of the THETIS D's voyage

This indicates that there was a reduction in speed combined with a deviating course to port as from 0830.

Using the THETIS D's AIS position data, which were also exported, the following course was reconstructed for the period relevant to the accident (see Figure 17).

⁵ The times in the AIS database were adjusted from UTC to local time (UTC + 1) to improve comparability.

⁶ Speed over ground (shown in knots).

⁷ Course over ground.

⁸ Heading.

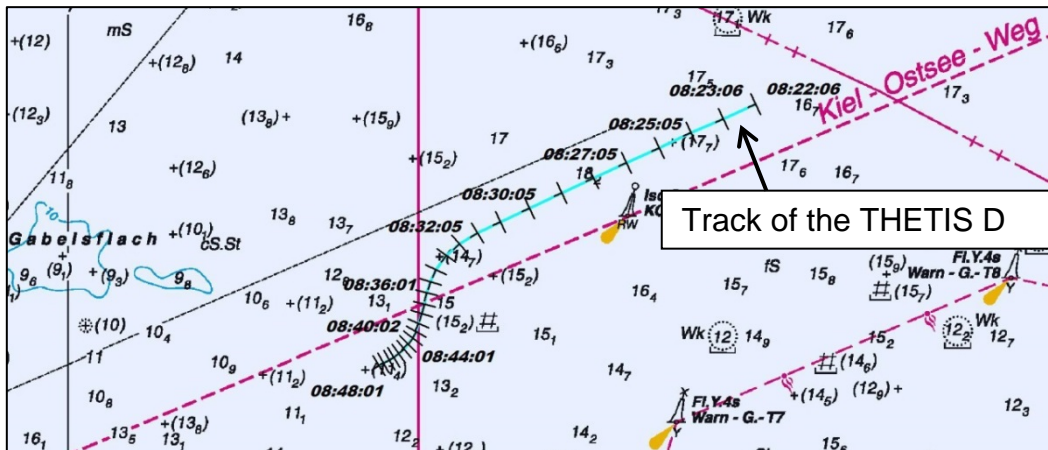


Figure 17: Course of the voyage taken by the THETIS D

The course of the voyage shows that the THETIS D started to cross the Kiel-Baltic Sea route separation line at 0837 and then drifted NUC against the recommended direction of the Kiel-Baltic Sea route in the German Exclusive Economic Zone of the Baltic Sea.

The following voice traffic could be reproduced in respect of the THETIS D using the VHF radio recordings for channel 67 (blue font indicating the translation from German):

Time	Speaker	Message
085114	Master THETIS D	Kiel Traffic, THETIS D.
	Kiel Traffic	<i>Yes, Kiel Traffic receiving.</i>
	Master THETIS D	Kiel Traffic, THETIS D. Hello. This is to inform you that we have engine damage and are drifting just off of Kiel Lighthouse, east of Kiel Lighthouse that is.
	Kiel Traffic	<i>Yes, I can see you on the screen. Yes, I have understood. Please let me know when you get underway.</i>
	Master THETIS D	<i>Yes, okay.</i>
[...]		
085802	Pilot	Kiel Traffic, [name of ship].
	Kiel Traffic	<i>Yes, Kiel Traffic receiving.</i>
	Pilot	Kiel Traffic, [name of ship] outbound at Kiel Lighthouse.
	Kiel Traffic	<i>Kiel Traffic, for anyone outbound at Kiel Lighthouse, the THETIS D, you probably have her on your screen, is not under command and on the wrong side of the fairway. Just to inform you.</i>
	Pilot	I have already told my master that he should leave her on the starboard side, for now. Seems to be okay.
	Kiel Traffic	<i>All right.</i>

Time	Speaker	Message
(Continued) [...]		
091020	Kiel Traffic	<p>All stations, all stations, good morning. This is Kiel Traffic with information service for the Kiel Bight and Kiel Fjord from today, zero – nine – zero – zero.</p> <p>Weather information: wind direction Kiel Lighthouse south-easterly force four, visibility is good. Actual water level Kiel Lighthouse: five – zero – five constant. No wind or gale warning.</p> <p>And further information for the shipping: We have a vessel THETIS D approximately four miles north-easterly of Kiel Lighthouse not under command. Please pass this ship with caution.</p> <p>For the traffic situation please listen to the reporting calls and information service. Next information service in one hour from now.</p>
091101	Kiel Traffic	<p>All maritime radio stations, good morning. This is Kiel Traffic with the situation report for the Kiel Bight and the Kiel Fjord of today, now zero nine one zero.</p> <p>Weather information: South-easterly force four winds at the lighthouse; visibility good. The current water level at the lighthouse is five metres five. No wind or storm warnings.</p> <p>Special instructions for shipping: The vessel THETIS D is not under command about four miles, four and a half miles north-east of Kiel Lighthouse. Please pass this vessel with caution.</p> <p>Refer to the ongoing individual reports for the traffic situation. End of the situation report. The next situation report will be sent at 1000. Kiel traffic is listening in on VHF channels 67 and 16. All maritime radio stations: Have a good voyage.</p>
[...]		
092757	Tug KIEL	Kiel Traffic, tug KIEL.
	Kiel Traffic	<i>Yes, Kiel Traffic receiving.</i>
	Tug KIEL	Yes, hello, KIEL and KITZEBERG, we are making ready and will then proceed to the THETIS D.
	Kiel Traffic	<i>All right, thank you very much.</i>
[...]		
110110	Master THETIS D	Kiel Traffic, THETIS D.
	Kiel Traffic	<i>Kiel Traffic receiving.</i>
	Master THETIS D	Yes, hello again, THETIS D now ready with tugs – now continuing our voyage to Kiel.
	Kiel Traffic	<i>Yes. Super, master. I have a question, who is the broker?</i>
	Master THETIS D	The broker is [company name].
	Kiel Traffic	<i>[Company name], all right, I wish you every success.</i>

Spreadsheet 2: Kiel Traffic's VHF log, channel 67

The situation reports at 1010 and 1100 contained similar references with regard to the THETIS D's situation to that of the 0910 report.

3.2.8 VDR

The THETIS D is equipped with a 100-G2 VDR made by Rutter. Storage of the data on the VDR was not triggered until 2220, i.e. nearly 13.5 hours after the accident, however. The system had overwritten the recordings for the period relevant to the accident automatically in the meantime. Consequently, the only recordings that could be analysed for the investigation started at 102054. The VDR worked properly.

4 ANALYSIS

The BSU's investigation took place at the same time as that of the THETIS D's flag State, Liberia. Communication with the manufacturer of the main engine and the classification societies ran smoothly. During the round of comments on the first draft investigation report, the BSU was provided with new technical documentation, which necessitated a reassessment of the course of events leading up to and during the accident.

The owner and the engine room's crew withheld or only forwarded to a limited extent numerous items of information, in particular with regard to the inspection of the connecting rod bearing in March 2015, safety management and the measures taken after the accident.

The numerous surveys of the THETIS D, the recordings of VTS Kiel Traffic, and the technical exchanges with the engine manufacturer and the classification society already discussed made it possible to close the investigation despite the complications.

4.1 Course of the accident

The bridge was manned sufficiently on the day of the accident by the master and chief officer (on watch). The engine room's crew stated they were occupied with routine work. The voyage from Gdynia to Bremerhaven was reportedly uneventful up until the accident. In particular, they were reportedly not aware of any acute technical faults.

There were some problems with cooling water on the THETIS D in the days prior to the accident. This concerned the high-temperature system, which is connected to the systems for cooling the cylinders and injectors, *inter alia*, as well as the low-temperature system, which is connected to the lubricating oil cooler, *inter alia*. According to the chief engineer officer, excessive lubricating oil temperature caused an automatic reduction in power two days before the accident, which was remedied by flushing the seawater system. The expert consulted by the BSU included the cooling water system in his assessment and concluded that the problems were caused by sea water-induced contamination of the high-temperature cooler. The engine monitoring system did not record a fault of this nature on the actual day of the accident, however. Consequently, it is reasonable to assume that the fresh water cooling system worked properly on the day of the accident.

Shortly before the accident, the crew noticed the ship vibrate heavily in the superstructure and in the engine room. The damage to the drive unit occurred at about 0830 when engine components from cylinder unit 7 penetrated the housing. The main engine stopped automatically. The ship's command noticed smoke rising from the engine room's ventilation fans and then established airtight integrity. The master sounded the general alarm.

The fire that had broken out in the engine room was controlled and ultimately extinguished within about 20 minutes without the use of CO₂ after airtight integrity was established. The ship's command made sure that no crew members were injured during this period. The second engineer and the oiler, who had both been working in the engine room at the time of the accident, moved to safety via emergency exits. That the accident arising from the failure of the propulsion plant did not pose a risk to other shipping, too, is thanks only to the fortuitous circumstance that the THETIS D was still outside the more heavily used Kiel Fjord at the time of the accident.

4.2 Reconstruction of the chronological sequence

Reconstructing the course of the accident using alarm records from the THETIS D's ECR proved difficult. Some of the recordings of the various safety systems were only partially available and their entries differed from one another significantly. For example, the engine safety system recorded a splash-oil alarm for cylinder unit 7 26 minutes⁹ before the accident (see Figure 18¹⁰).

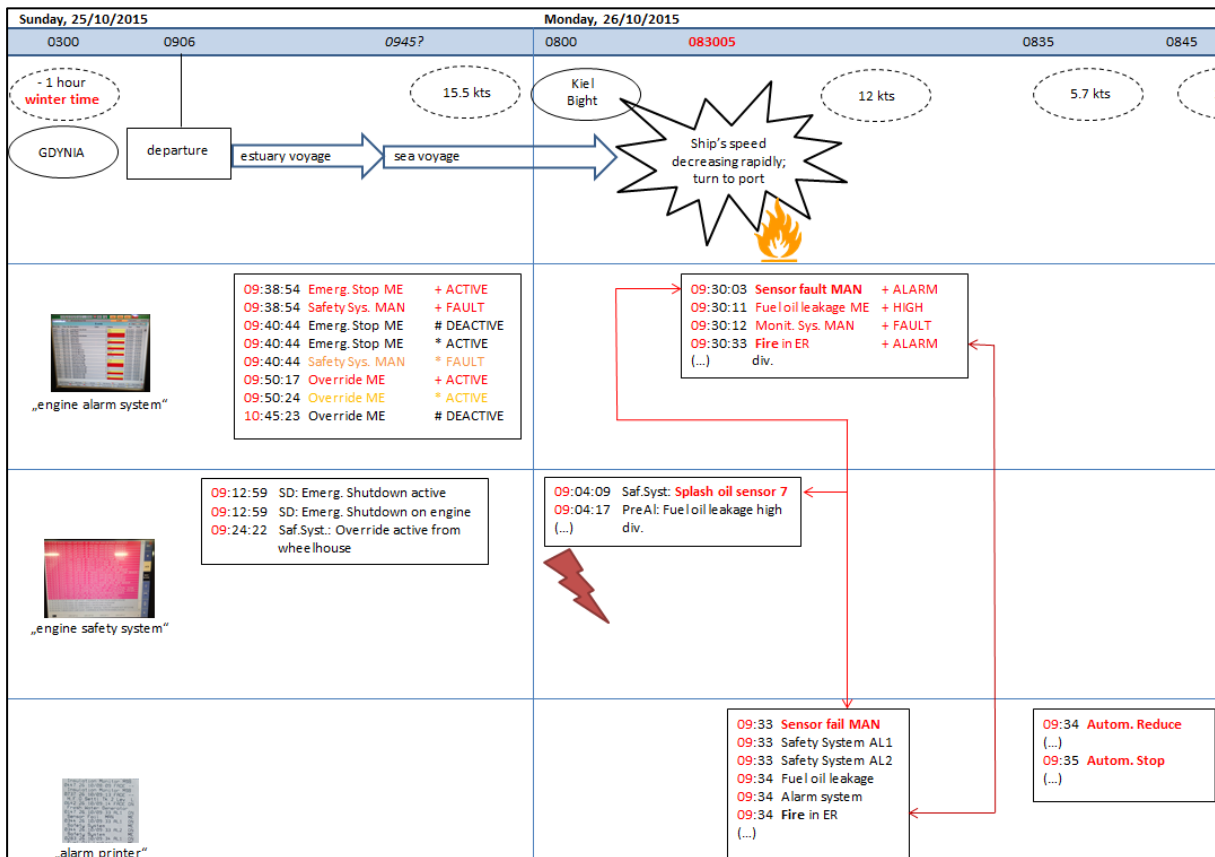


Figure 18: Engine alarms occurring at the time of the accident, extract from the BSU's graphical presentation

⁹ The crew stated that the accident occurred at 0824. The AIS recordings indicate that the accident occurred between 0829 and 0830. VDR recordings, which could have verified the timing, are not available for the period in which the accident occurred.

¹⁰ Recordings on board made at UTC + 2 hours.

Based on this pool of data, the investigators from the BSU and the expert consulted initially assumed that the main engine continued to run for more than 20 minutes before the serious engine damage occurred. This assessment was revised during the first round of comments on the draft report. The manufacturer of the splash-oil monitoring system demonstrated a system configuration on the THETIS D, which would have caused the engine to stop automatically within less than two seconds if the shutdown criteria were met (see Spreadsheet 3).

No	Measuring Point	Description	Drawing	Measuring Range	Nominal	Setpoint	Function	Location	Connected to	Signal Type	Supplier	Status
850	18TE2880	temp sensor splashoil temp rod bearing 8	11.99411-0391	0-120°C			splash oil supervision	engine	safety system	PT100	MAN	
	1TAH2880	limit value of 18TE2880				80°C,H hyst: -1K delay: 1.7s	alarm splashoil temp high			software setpoint	MAN	
	2TZH2880	limit value of 18TE2880				85°C,H hyst: -1K delay: 1.7s	auto shutdown splashoil temp high			software setpoint	MAN	
	1TDAH2880	limit value of 18TE2880				+2K,H hyst: -1 K delay: 1.7s	alarm splashoil temp mean value deviation			software setpoint	MAN	
	2TDZH2880	limit value of 18TE2880				+3K,H hyst: -1 K delay: 1.7s	auto shutdown splashoil temp mean value deviation			software setpoint	MAN	

Spreadsheet 3: Extract from the configuration of the splash-oil monitoring system on the THETIS D.

The oil lubricates each connecting rod bearing after passing through the crankshaft. Part of the oil is pumped further through the connecting rod and the remainder exits laterally after passing through the connecting rod bearings. It is propelled by the drive unit and then drips into the oil sump. The splash-oil sensors measure the temperature of this splash oil. By measuring and comparing the splash-oil temperature for each connecting rod bearing tap, the splash-oil monitoring system makes it possible to monitor the serviceability of the drive units.

It is evident from the configuration that two criteria existed, which could trigger an alarm or in the final instance an automated engine shutdown independently of each other:

- exceeding a measured splash-oil temperature (80°C → alarm, 85°C → engine shutdown), and
- a difference in splash-oil temperature in the various cylinders detected by the sensors (one sensor per cylinder in each case; deviation +2 Kelvin → alarm, +3 Kelvin → engine shutdown).

According to the configuration, the splash-oil monitoring system would have stopped the main engine with a delay of only 1.7 seconds if one of the two critical criteria had been met. This means that the main engine could not continue to run for several minutes after the damage occurred if the splash-oil monitoring system was functioning as it should. To prove serviceability, the BSU was submitted an extract from the manufacturer's own diagnostic system for the main engine in November 2016 (see Figures 19 and 20). The system time in the recordings deviates from local time by + 5 hours (13xx instead of 08xx). According to the recordings, the sensor in cylinder 7 failed initially. This was followed by a simultaneous increase in splash-oil temperature from 66°C to 73°C in the other sensors, before the sensors from cylinders 3, 6 and 8 also failed. The automated shutdown of the main engine

Ref.: 431/15

was triggered by insufficient lubricating oil pressure in the turbocharger before other safety systems were able to have any affect.

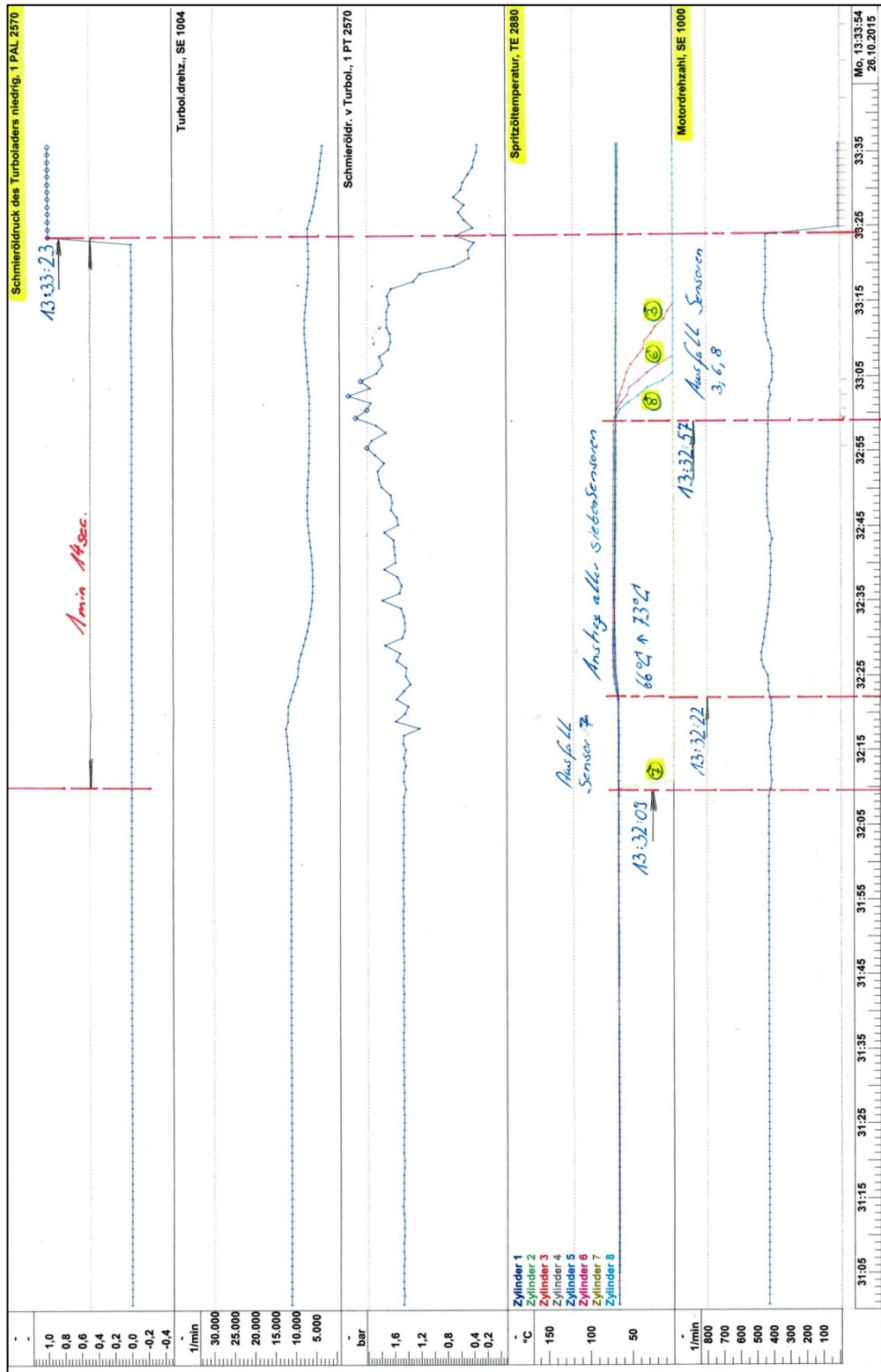


Figure 19: Extract from the manufacturer's diagnostic system for the main engine (splash-oil temperature and lubricating oil pressure in the turbocharger)

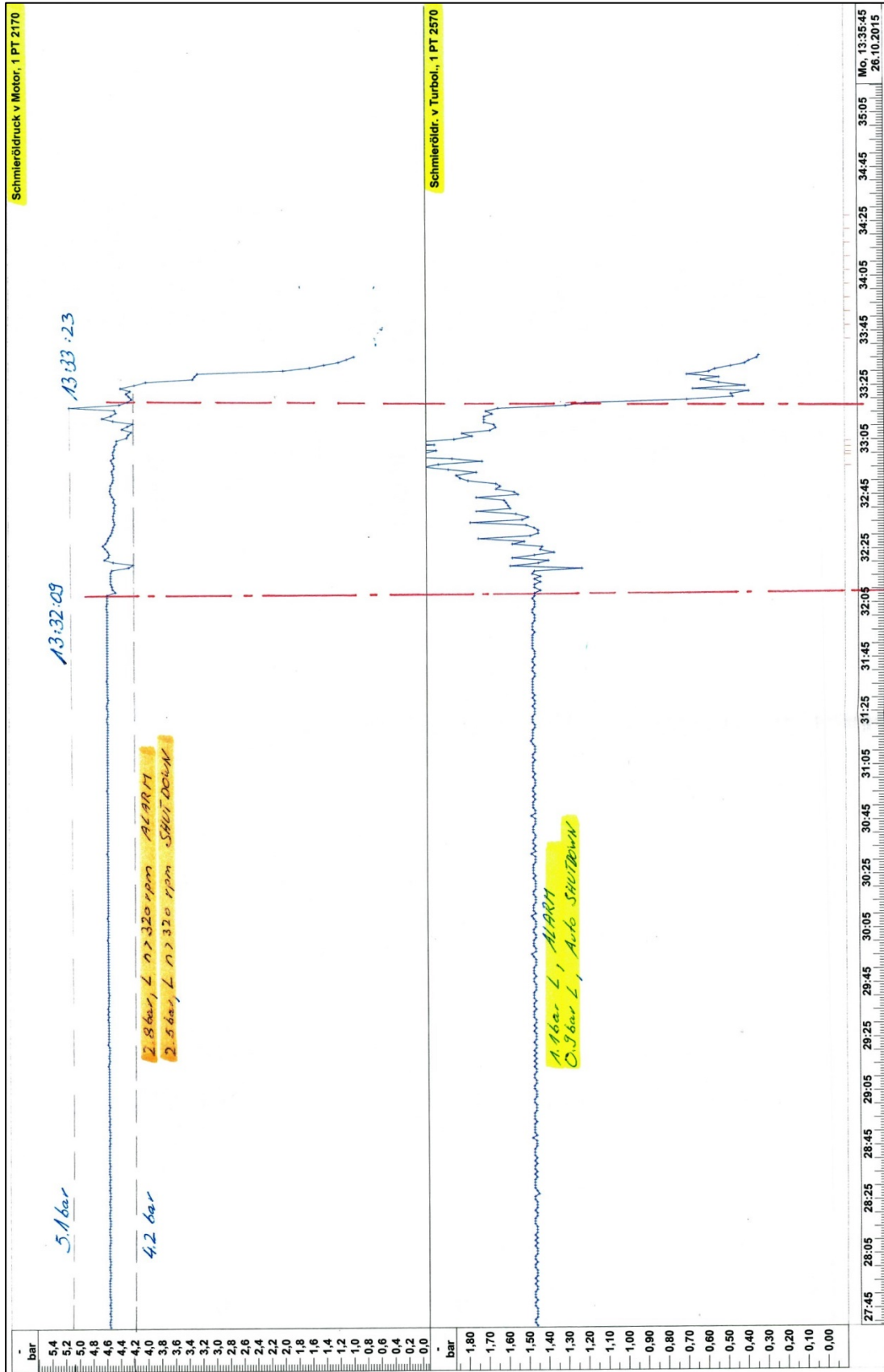


Figure 20: Extract from the manufacturer's diagnostic system for the main engine (lubricating oil pressure in the turbocharger, continued)

The documents show that at the time of the automated engine shutdown, neither of the two conditions (temperature 80°C or temperature difference +3 K) that would have prompted the splash-oil monitoring system to trigger the engine shutdown were met. The monitoring system for the turbocharger lubricating oil pressure was calibrated so that a drop in pressure to 0.9 bar would cause an automated engine shutdown. According to the recordings of the diagnostic system, this criterion was met at 083323, therefore causing the engine shutdown. Taking into account the time difference of + 5 hours, the documented time is consistent with the recordings on board (engine alarm system and alarm printer, recorded in UTC + 2 h) and the shore-based AIS recordings of the VTS (including SOG, recorded in UTC + 1 h) – see Spreadsheet 4 with synchronised times for ease of reference; all information in UTC + 1 h = local time.

VTS Travemünde SOG of the THETIS D	THETIS D					
	Engine alarm system		Alarm printer		MAN diagnostic system	
082905 15.5 kts	083003	Sensor fault MAN	0833	Sensor fail MAN	083209	Sensor 7 failure
	083011	Fuel oil leakage ME	0833	Fuel oil leakage		
	083012	Monitoring syst. MAN	0833	Safety system AL1 + AL2	083222	Temperature increase of 7 splash-oil sensors 66°C ↑ 73°C.
	083033	Fire in ER	0834	Fire in ER	083257	Sensor failure 3, 6, 8
083005 12.4 kts				083323	Low lubricating oil pressure in turbocharger → Autom. SHUTDOWN	

Spreadsheet 4: Synchronisation of the various recordings to explain the course of the accident

A comparison of the recordings from the various sources shows a consistency in respect of the main processes in the THETIS D's engine room. The timing differences of 1-3.5 minutes between the various data sources are essentially not unusual and can be explained by the setting of system times manually.

On the other hand, explaining the timing differences of the alarms recorded by the engine safety system was not so easy (see Fig. 18 on p. 29; synchronised to local time below):

- 080409 – Safety system: Splash-oil sensor 7 and
- 080417 – Pre-alarm: Fuel oil leakage high.

The timing differences between the engine safety system and the other systems, which are set on board, were a constant

- 25 minutes and 54 seconds to the engine alarm system and
- 29 minutes to the alarm printer.

Since the documents submitted subsequently by the engine manufacturer made it possible to rule out a malfunction in the splash-oil monitoring sensors, but the safety system ultimately triggered the engine shutdown within 1.25 minutes of the first sensor failure, only an isolated incorrect system time setting in the engine safety system is open to consideration as an explanation for the substantial time difference. The BSU's investigators reviewed this assumption with the classification society (DNV GL) based on the earlier recordings of the three shipboard systems for which system time is set manually by the crew (engine alarm system, engine safety system and alarm printer). At the same time, recordings made before the accident were compared. Although the three systems use different names for some of the alarms, four other alarms were identified that were recorded by both the engine alarm system and the engine safety system. All four exhibited a constant time difference of 25 minutes and 54 seconds.

With regard to system time setting, it was not possible to explain why a time that deviated from the other system times by just under 26 minutes or 29 minutes was set for a safety system in the ECR. The only certainty is that the chief engineer officer entered the following in the engine room log for 24 October 2015, i.e. one day before the accident:

"Set clock one hour back to wintertime during night to Sunday."

The time recorded by the THETIS D's safety systems corresponded to UTC + 2 hours and thus to Eastern European wintertime. The BSU has no further information on the criteria used to determine ship's time. Since this does not affect the difference in the various safety system times of almost 26 or 29 minutes, it is of no relevance to the investigation, either. The difference is severe.

On seagoing ships, engineers generally set safety system times in the ECR. This standard procedure was not carried out with the required precision on the THETIS D.

4.3 Inspection of the connecting rod bearing before the accident

Seven months (or 2,440 service hours¹¹) before the accident, the former chief engineer opened, visually inspected, and then re-tightened cylinder unit 7's connecting rod bearing. The damage to the upper and lower shells of the connecting rod bearing (fretting, deformation and discolouration) recorded after the accident by both the MAN test laboratory and the BSU's expert indicates that the bolted connection of the bearing halves was not tightened in accordance with the torque value in the manufacturer's instructions (1000 bar; see Spreadsheet 5).

(C11.00160-0183)		Seite page 3	Stand current level 4	Öldruck bar Längung Δl mm oil pressure elongation	Rück- drehwin- kel beim Lösen angle when slaciening	Einzugs- moment Nm screw-in moment	Anzugsdrehmoment Nm und Drehwinkel lightening torque and torsion angle		Arbeits- karte beachten observe work care
Gruppe group	Schraubverbindung screw connection						1. Stufe 1. step	2. Stufe 2. step	
030 Pleuelstange		connecting rod							
030-1	Pleuelschaft/Pleuelkopt connecting rod shank/connecting rod head ball			1000	200 =6L	200-M			030.01
				0.55 ÷ 0.65 = Schraubenlänge bei abgelassenem Öldruck Bolt elongation with oil pressure released					
030-2	Pleuelschaft/Pleuellagerdeckel connecting rod shank/connecting bearing cover			(500) 1000	300 =9L				030.02
				1.5 ÷ 2.1 = Schraubenlänge bei abgelassenem Öldruck Bolt elongation with oil pressure released					

Spreadsheet 5: Torque values for the connecting rod's bolted connection
(extract from the manufacturer's manual)

The 'Tightening of Bolted Connections – General remarks' chapter of the manufacturer's manual indicates that the above values are for bolted connections of primary significance that ensure operational safety.

The tightening of connecting rod bearing bolts as per the manufacturer's instructions required the use of hydraulic tensioning tools connected to a high-pressure pump (see Figure 21). The manual states the following with regard to functioning:

"The high pressure pump feeds a relatively small volume of liquid (if required, at a pressure of up to 1,500 bar) through the pluggable hose lines to one or more tensioning tools. If the piston of the tensioning tool is screwed onto the thread of the screw, the liquid raises the piston in the casing and extends the screw, whilst the tensioning tool is supported by the surrounding parts of the screw. The high pressure pump is operated by compressed air. The air is directed through control elements to a piston. This piston can be pressurized from both sides and is equipped with pistons of smaller diameter on both sides which draw in hydraulic oil from the surrounding reservoir, or which feed it to the distributor on the opposite side. As soon as the piston reaches an end position, the air flow is directed to the other side of the piston by a pilot valve, and the pumping and suction action is repeated. The effective pressure of the air is normally reduced in order to produce a pressure of 1,500 bar on the hydraulic side. An outlet pressure of 1,500 bar must not be exceeded."

¹¹ The inspection of the connecting rod bearing was made when the main engine had been in operation for 30,400 service hours. The accident happened after 32,840 service hours.

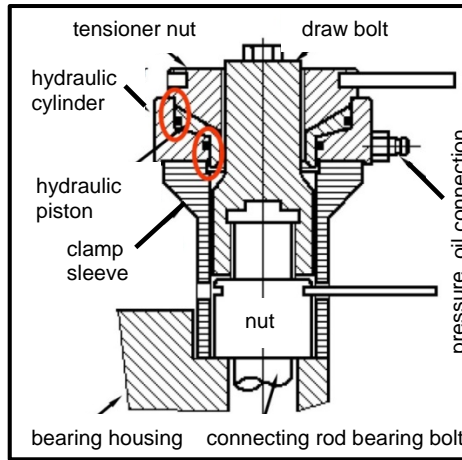


Figure 21: Hydraulic tensioning tool (schematic drawing)

A work card listing the various work steps exists for the tightening of connecting rod bearing bolts (see Figure 21).

Work sequence 3 - Tightening the connecting rod bearing bolts		L58/64
Starting position	Connecting rod bearing is pre-assembled so that only a small gap remains between the loose bearing shells at the join.	
6619 030.02-01 EN		
030.02		MAN Diesel
Connecting rod/Connecting rod bearing	NOTICE	The tightening process is performed in several steps. Ensure correct order of tightening!
	Working steps	<ol style="list-style-type: none"> 1. Determine the bolt length (L) of all bolts with the Vernier gauge (009.039 or 009.069) and note them down. This measurement will be required as the basis for the extension of the bolt Δl after tightening (check). 2. Mount two tensioning bolts (030.166), sleeves (030.165) and tensioners (009.301) with tensioning nuts (020.018) diagonally on the connecting rod bearing bolts and connect to the high pressure pump (see Figure 1). 3. Connect the tensioners to the high pressure pump and pump up to pre-pressure 500 bar. Tighten the nuts (9) hand-tight. 4. Release pressure, remove tensioners and fit onto the remaining two bolts. 5. Bring the tensioners to the final pressure (see Work Card 000.30). Tighten the nuts (9) hand-tight. 6. Release pressure, remove tensioners again and fit onto the two bolts pre-tightened first. 7. Pump the tensioners up to the end pressure. Tighten the nuts (9) hand-tight. 8. Release pressure, remove tensioners. 9. Measure the bolt length (L) again, calculate the bolt elongation Δl and compare with the prescribed value (see Work Card 000.30).
ily groups	NOTICE	The bolts must be tightened with the prescribed tensioning pressure, not according to the extension. Elongation specifications serve only for checking purposes. Repeat tensioning process in the case of great deviations or check the pressure gauge. If they are over-extended, the bolts may have a permanent elongation. 1 mm over the nominal measurement is permitted as the maximum dimension. If this value is exceeded the bolt must be replaced.

Figure 22: Work card for the tightening of connecting rod bearing bolts

After the bolted connection is tightened, which the manual explains step-by-step, the bolt elongation should be verified using a measuring gauge. The manual states the following in this regard:

"The bolt elongation is to be measured for comparison with a reference value in the case of bolted connections of primary significance. This is to ensure that the required pre-tension is actually present in the form of the elongation of the bolt and compressing of the parts to be tensioned. This is not guaranteed if the tensioning tool is blocked or the tension pressure is partly or fully dissipated by friction."

The permissible reference values for the bolt elongation are listed in the same spreadsheet as the required torque value (see Spreadsheet 5 on page 35).

Although the BSU's investigators did not receive any information regarding the exact procedure for inspecting the connecting rod bearing on the THETIS D, the bolted connections examined do permit conclusions as to the type and quality of the inspection by the then chief engineer officer. When examining the upper connecting rod nuts, it was noticed that one of the nuts still had a broken tommy bar in the bore (see Figure 23).

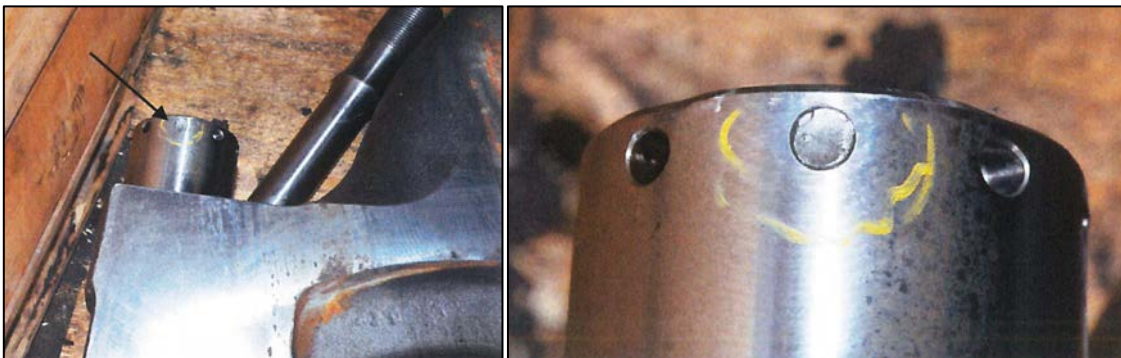


Figure 23: Broken tommy bar in one of the upper connecting rod nuts

Tommy bars are used to tighten the tensioner nuts by hand. The tommy bar's diameter was 12 mm, meaning it could not have snapped due to manual tightening alone. The fragment found is thus an indication of the application of greater force, e.g. by lateral blows with a hammer.

Different scenarios as to why deviations from the specified clamping pressure may have occurred are conceivable. For lack of a comprehensible statement from the engineers involved, it was not possible to establish conclusively during the investigation whether and, if so, why there were problems with tightening the bolted connection. In the absence of documentation of the work steps, the finding remains therefore that the works could not have satisfied the technical requirements because a piston seizure occurred.

As part of the safe engineering watch, routine maintenance of the machinery must be carried out with the knowledge of the officer in charge of the engineering watch and the chief engineer officer (part A, chapter VIII, section A-VIII/2 part 3-2 No 79

STCW¹² Code). As regards the maintenance of marine engineering systems, the STCW Code lays down the general criteria for assessing the ability of officers in charge of an engineering watch as follows:

"Function: Maintenance and repair at the operational level
[...]

Isolation, dismantling and re-assembly of plant and equipment is in accordance with accepted practices and procedures. Action taken leads to the restoration of plant by the method most suitable and appropriate to the prevailing circumstances and conditions."¹³

In the absence of any conflicting evidence, the BSU's investigators assume that the required equipment (tensioning tools, hydraulic high-pressure pump, hose connections) was serviceable. For the work steps to be carried out on the THETIS D, the manufacturer provided summary tables with the required values and detailed work cards. Moreover, the inspection was carried out by engine room personnel with the requisite qualifications. Under these circumstances, the manufacturer's instructions for clamping pressure should have been adhered to in order to preserve the safety of the bolted connection and thus of the machinery. It was not possible to determine how much the clamping pressure deviated from the required 1000 bar at the time of the accident in retrospect because the bolted connection had to be cut open for the examination. However, the deviation must have been beyond the tolerances specified by the manufacturer, otherwise the given damage pattern would not have been possible.

The owner claimed that the bearing was opened for inspection purposes. A specific reason for the inspection was not given. The THETIS D started her second class period in March 2014. The then classification society, DNV GL, advised that the bearing inspections required for the class period had reportedly already been credited in October 2013 in preparation for the class renewal planned at the time. Accordingly, the next inspection of the bearings would not have to be carried out until March 2019. The annual machinery survey had been credited on time in April 2015.

The BSU's investigators assume that the connecting rod bearing was inspected on the recommendation of the manufacturer of the machinery. In the operating manual's maintenance chapter for key engine components, a thorough inspection is recommended after 30,000 to 36,000 service hours. At 30,400 service hours, the connecting rod bearing inspected on the THETIS D was within this recommended inspection window in March 2015. It is not uncommon for such maintenance inspections to be carried out by qualified engine room personnel rather than by service companies or the classification society.

¹² Seafarer's Training, Certification and Watchkeeping Code.

¹³ Part A, chapter III, section A-III/1, table A-III/1 STCW Code.

On its website, the owner claims that it makes use of the advantages of computer-assisted, planned maintenance and servicing.¹⁴ A maintenance and servicing plan basically improves planning, recording and implementing maintenance works and inspections on board. Under ideal conditions, maximum availability of the systems can be guaranteed, as failures do not occur in the first place. The THETIS D's owner operated its planned maintenance and servicing system alone without the support of the classification society. This is common practice and does not represent a problem from the perspective of investigations, provided that the personnel involved adhere to the manufacturer's instructions, *inter alia*. In the case of the THETIS D, the inspection of the connecting rod bearing proved counterproductive to the extent that the failure to properly seal the bearing halves caused the piston seizure and thus also the subsequent accident. The good practice of maintaining the serviceability of key elements of the main engine in good time was undermined by deviations from the clear instructions of the manufacturer with regard to the tightening of connecting rod bearing bolts.

4.4 Qualification of the engine room's crew

The German chief engineer officer who removed and reinstalled the connecting rod bearing shell has been employed by the owner since 2007. He served on the THETIS D as second engineer officer in 2009 and then as chief engineer officer from 2010 until 2015. He therefore had enough experience to carry out an inspection of the connecting rod bearing.

It was not possible to establish in the course of the investigation why and with what work steps the crew carried out the connecting rod bearing inspection itself. A written query to the owner with regard to any requirements for works on the bearings or documentation of the works went unanswered.

The chief engineer officer on the day of the accident has served on the THETIS D since 2013 as second engineer officer and then took up his current position in mid-May 2015. This means that he was qualified to recognise faults in the main engine by monitoring the alarm and safety system and the recorded performance data, as well as to initiate the necessary steps to remedy them.

The mandatory international provisions of the STCW Code on minimum requirements for chief and second engineer officers state that the second engineer officer shall be in a position to assume the responsibilities of the chief engineer officer at any time. Accordingly, he must be able "to assimilate all available information that affects the safe operation of the ship's machinery [...]."¹⁵ According to the binding specifications of the STCW Code, the minimum standard of competence includes:

¹⁴ <http://www.reederei-drevin.de/Schiffsmanagement>, retrieved on 11 January 2018.

¹⁵ See section A-III/2.3 of the STCW Code.

- the ability to monitor and ensure the safety of the main propulsion machinery¹⁶,
- knowledge of safety equipment for the main engine in conjunction with the operation of the system in accordance with the operating manuals¹⁷,
- troubleshooting of monitoring systems¹⁸,
- the detection of machinery malfunction, location of faults and action to prevent damage¹⁹.

The BSU's investigators were not able to ascertain subsequently the extent to which the chief engineer officers in March 2015 and at the time of the accident were familiar with the manufacturer's recommendations for maintenance of the connecting rod bearings and the associated work cards. The owner has not provided the BSU with information regarding training given to the engine room personnel (scope, frequency). The owner did not submit to the BSU a statement as to how the accident could have been possible, either.

Between the failure of the splash-oil sensor in cylinder 7 and the damage occurring, the engine room's crew did not have enough time to track the alarm signal and to shut down the main engine manually if necessary to avert further damage. Given the damage pattern, the BSU's expert concluded that the first occurrence of damage to the connecting rod bearing would inevitably have led to an increased supply of fuel. The reason for this is reportedly the temperature rise of the splash-oil mass flow in the pistons due to the friction. It was not possible to ascertain whether this was tracked and associated with the connecting rod bearing inspection. However, the BSU's investigators assume that such an increase in fuel would have been marginal and therefore difficult to detect.

4.5 Safety management

According to the International Safety Management (ISM) Code²⁰, the THETIS D's owner is required to provide for safe practices in ship operation and a safe working environment, among other things. The ISM Code also seeks to continuously improve safety management skills of personnel ashore and aboard ships. The vessel operator itself determines the scope of the safety management system (SMS).

¹⁶ See table A-III/2 of the STCW Code, Function: Marine engineering at the management level, Practical knowledge.

¹⁷ See table A-III/2 of the STCW Code, Function: Electrical, electronic and control engineering at the management level, Theoretical knowledge.

¹⁸ See table A-III/2 of the STCW Code, Function: Electrical, electronic and control engineering at the management level, Practical knowledge.

¹⁹ See table A-III/2 of the STCW Code, Function: Electrical, electronic and control engineering at the management level, Practical knowledge.

²⁰ The ISM Code is part of the International Convention for the Safety of Life at Sea (SOLAS Convention, chapter IX). Moreover, Regulation (EC) No 336/2006 requires its implementation throughout Europe.

The owner of the THETIS D has such a system in place. This was certified by the former classification society, DNV GL, at the time of the accident. Classification has been carried out by Bureau Veritas since 18 August 2016.

An assessment of the SMS practiced on board and the owner's guidelines for this could be made only to a very limited extent during the investigation because the owner failed to cooperate in this regard. Requested documents were not submitted. Accordingly, it was not possible to determine whether the owner had issued guidelines for preparing for, performing safely and recording maintenance works on key components of the main engine in March 2015. Given its legislative nature, the ISM Code does not impose on the vessel operator specific requirements for the actual content of a SMS. In this respect, the Code is confined to general guidelines, which the vessel operator then has to develop.²¹ Various guidelines from the ISM Code are relevant to the accident involving the THETIS D, starting with:

Part A – Implementation

[...]

10. Maintenance of the ship and equipment

10.1 The Company should establish procedures to ensure that the ship is maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may be established by the Company.

[...]

The more general guidelines of the ISM Code are supplemented by recommendations of the International Association of Classification Societies (IACS)²². Both DNV GL and Bureau Veritas have undertaken to comply with the IACS Standards. With regard to the above guidelines of the ISM Code, the IACS states the following in its recommendation for ISM audits:

Re 10.1 of the ISM Code

The maintenance of the ship and equipment should be in accordance with the procedures established by the Company. These procedures should take into account international conventions, Flag and Port State regulations, classification rules, requirements from manufacturers, feedback information from failures, damages, defects and malfunctions.

There are a number of acceptable systems associated with maintenance of equipment. The choice depends on ship design and Company philosophy. The auditor should expect to find maintenance process documentation and records indicating compliance with maintenance program requirements.

²¹ Since the THETIS D sails under the flag of Liberia, the Ship Safety Division (BG Verkehr) has never been responsible for monitoring compliance with the guidelines of the ISM Code.

²² Recommendation 41 – Guidance for IACS Auditors to the ISM Code, Rev. 4.

Objective evidence is necessary to confirm conformance with established maintenance requirements.

Examples of objective evidence found at the Office and onboard the ship may include:

- documented procedures and instructions for the onboard work routine;
- verification of their implementation in the day-to-day operation of the ship by the appropriate personnel.

The BSU's investigators believe that the owner has never issued any written procedures pointing to the need to comply with the manufacturer's instructions for maintenance works on major parts of the THETIS D's main engine. However, it is precisely this accident that clearly shows that a failure to comply with specified torque values for bolted connections can have severe implications for ship safety and thus constitute a serious risk to members of the crew. In this case, the investigators believe that the safety management manual for operations on board should provide guidelines on how to prepare, carry out and record works on major parts of the main engine. Moreover, a maintenance manual for planned, time-dependent maintenance should contain appropriate work cards and safety instructions. The aim should be to raise the safety awareness of crew members and to minimise the emergence of risks to safety and health through good preparation for important work steps. The BSU's investigators are conscious of the fact that – in today's world, especially – routine ship operation often leaves little scope for additional discussions on the subject of safety due to the multitude of tasks and scarce resources. In particular, it is the flood of information (manufacturer's manuals, safety manuals, maintenance manuals, etc.) in combination with routine tasks that can result in guidelines being ignored and works being carried out "in the same way as they always have been." However, the high-performing main engines of today are more sensitive to tolerance value deviations than earlier models, meaning the manufacturer's checklists and work cards should not only be carried on board but also observed.

It is the duty of the vessel operator to raise the crew's awareness of the issue of safety and to monitor compliance with guidelines through regular training and clear policies tailored to ship operation. The quality of maintenance and servicing instructions affects that of the works required. The IACS recommendations indicate that the manufacturer's instructions and recommendations should always form the starting point for the preparation of the vessel operator's guidelines.

Discussions held during the investigation with the owner and the engine room personnel gave rise to doubt on the part of the investigators as to whether ship safety was accorded the necessary importance in terms of safe ship operation on the THETIS D and possibly other ships of the same fleet, in respect of the machinery's safety systems, in particular.

For example, it was evident that the ship's command of the THETIS D regularly enables override mode in estuary trading. Override is an emergency mode that can be enabled by pushbutton on the bridge and in the ECR. When override is enabled, the main engine is not stopped automatically if limits previously defined in the system are exceeded or not reached. The main engine's numerous safety systems are virtually cancelled out, i.e. the main engine continues to run unimpeded. The purpose of override is to keep the ship manoeuvrable in exceptional situations when greater risks would otherwise prevail.

The pushbutton on the bridge and in the ECR for enabling override mode is positioned next to the main engine's emergency shutdown and has a safety cover to prevent unintentional operation (see Figures 24 and 25).

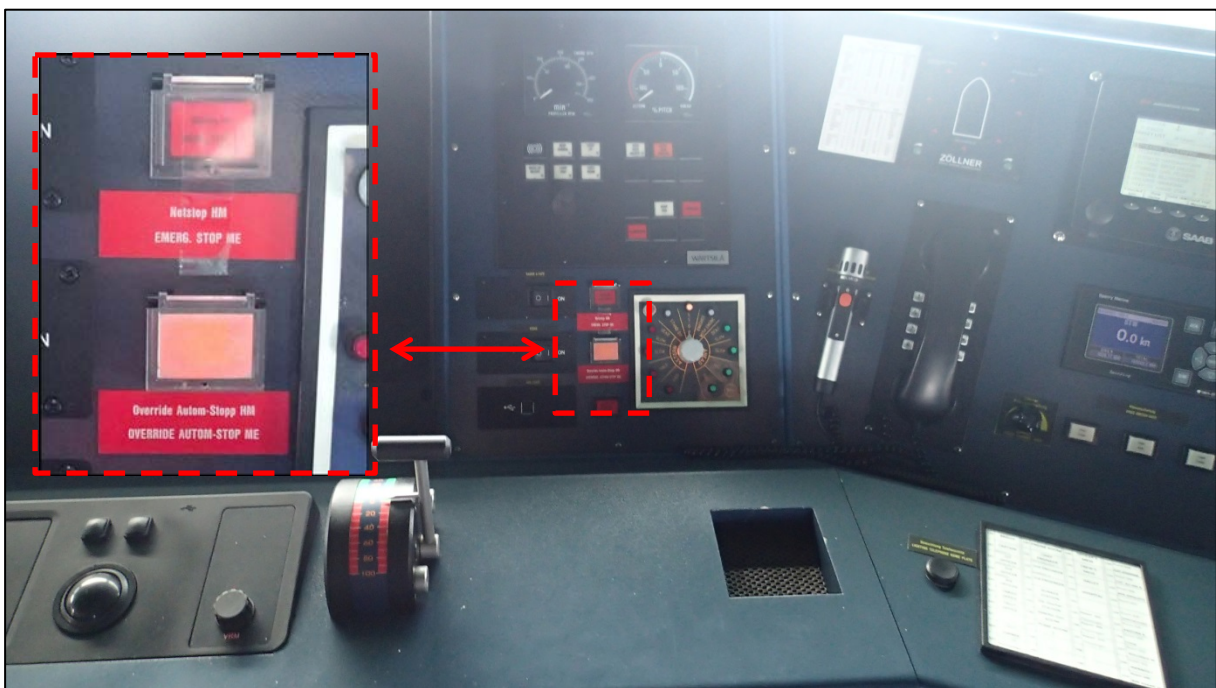


Figure 24: Override pushbutton in the control console on the bridge

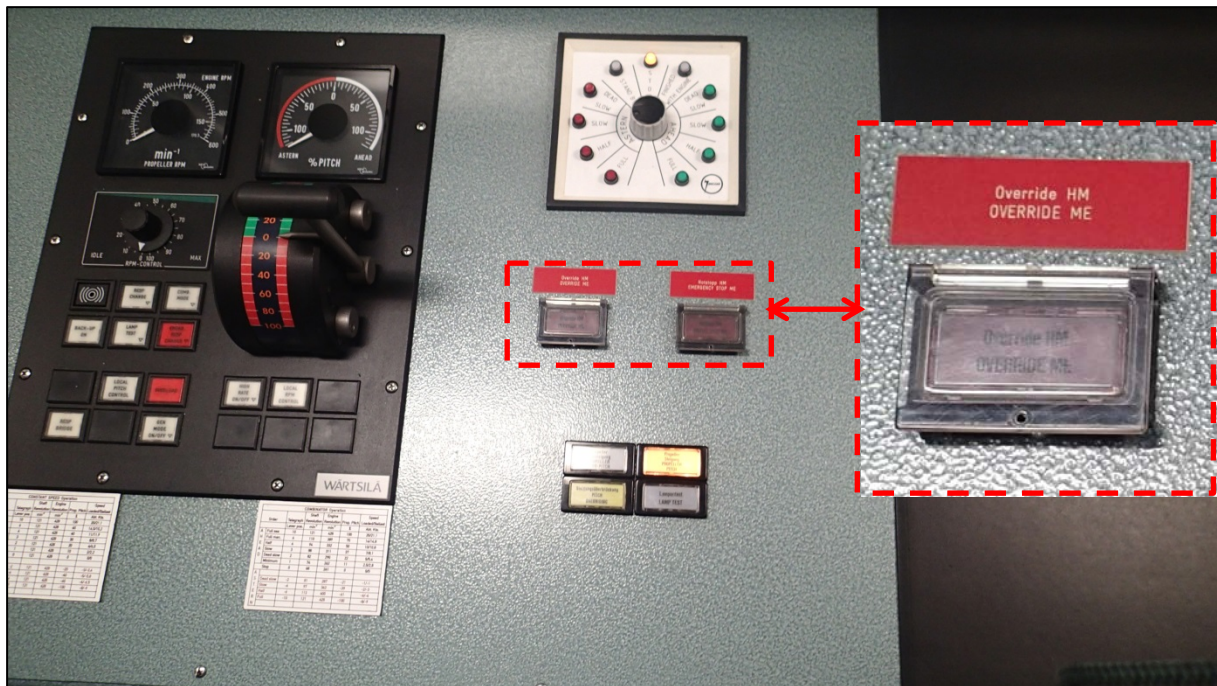


Figure 25: Override pushbutton on the control panel in the ECR

We are all aware that other cargo ships with a four-stroke engine are also operated regularly in override mode when in estuary trade due to concerns that false alarms might impair manoeuvrability by stopping the main engine automatically. Regularly disabling the main engine's automatic emergency shutdown in estuary trading by pressing the override carries its own risks, however. Engine safety systems, such as drive chamber monitoring by oil mist detectors or the splash-oil monitoring system are rendered ineffective in dangerous situations. When asked about this misuse of the emergency system, the shipowner told the investigators that as a master he grounded because the ship's main engine stopped automatically. He explicitly approved of the practice of the masters engaged on the THETIS D of sailing with override. The THETIS D was initially sailed with override enabled after casting off in Gdynia on the day before the accident, too. This was disabled again during the sea passage, however. The decision to enable override mode always rests with the ship's command. Regardless of that, the BSU's investigators consider it necessary to draw attention to the above risks.

The THETIS D's owner answered questions of the BSU concerning safety extremely tersely or not at all. The BSU's investigators believe it would be useful if the classification society were to examine the issue of safety management on the THETIS D both on board and ashore, as occasion demands. ISM audits are generally carried out on a ship-by-ship basis. Accordingly, the annual inspections provide a good opportunity to review in greater detail certain areas of safety management in addition to the general audit.

It should be ensured that the owner deals with the issue of safe operation of the ship in a comprehensible and timely manner. Specific guidance should be provided for standard maintenance procedures on key components of the main engine. The risk of an unplanned failure of the main engine should be minimised by a planned maintenance and servicing system, which the owner has according to its website. This would also render the decision to sail regularly in override mode unnecessary.

4.6 Communication

When the ship's command became aware of the accident at 0830 following the fire alarms and simultaneous failure of the propulsion plant, fighting the fire was unquestionably the main priority. The fire was extinguished after 20 minutes. The ship's command then contacted the VTS on VHF radio and reported engine damage. Whether the actual extent of the damage was known at this point is of secondary importance, as apart from announcing the towing operation at 1100, the ship's command of the THETIS D gave no additional information to the VTS as the day progressed. VTS Travemünde reported the accident to the WSP and the BSU (among others) as a machinery failure. The message did not attract much attention to begin with because machinery failures occur quite frequently and are of no particular interest to the BSU or WSP if there is no further damage. Moreover, in the usual sense of the term the VTS would interpret the message *engine damage* as *machinery failure*. The VTS had no reason to assume the course of the accident would be more severe.

Due to the cursory information, which gave rise to incorrect conclusions, the true extent of the damage and thus the existence of a serious marine casualty only became apparent in the evening. The ship's command failed to comply with its obligations to report the accident and to back up the VDR data pursuant to Articles 7 and 7a of the Ordinance on the Safety of Shipping respectively. Data storage was not initiated until late in the evening, by which time the system had already overwritten the data from the period relevant to the accident, thus complicating the investigation of this marine casualty significantly.

4.7 Port State controls on the THETIS D

The THETIS D was inspected in the course of port State controls six times in the past five years. Two of these six port State controls were carried out after the THETIS D was involved in an accident (see section 4.8).

With the exception of a survey on 12 March 2015 in Helsinki, in which the lack of rescue facilities was challenged, the relevant authorities did not notice anything else on the THETIS D.

4.8 Other accidents involving the THETIS D

The THETIS D has been involved in four other accidents in German waters in the past five years.

On 16 May 2013, the THETIS D's wake and wash caused damage to another ship and a loading bridge in the port of Brunsbüttel due to excessive speed. The accident did not cause injury to any individual.

On 29 January 2016, the THETIS D sustained minor damage from the wake and wash of another ship when she was moored at the pier in the port of Hamburg.

On 27 December 2016, six containers on the THETIS D went overboard in the German Bight. No faults were found during a subsequent port State control in Rotterdam.

On 22 April 2017, the THETIS D's forward starboard side came into contact with the quayside at a pier in the port of Hamburg. At the time of the accident, a tug was operating at the stern but unable to keep the ship clear of the quayside due to the weather. Material damage was sustained in the form of indentations over a length of about 5 m.

The BSU did not investigate these four accidents due to their minor impact. Other accidents involving the THETIS D outside German waters are beyond the knowledge of the BSU. The BSU investigators' multiple attempts to make contact with the flag State representatives appointed by the flag State of Liberia for accident investigation were unsuccessful.

5 ACTIONS TAKEN

The ISM Code states that vessel operators shall maintain a system whereby lessons for safe ship operation can be learned from accidents, among other things:

Part A – Implementation

[...]

9. Reports and analysis of non-conformities, accidents and hazardous occurrences

9.1 The SMS should include procedures ensuring that non-conformities, accidents and hazardous situations are reported to the Company, investigated and analysed with the objective of improving safety and pollution prevention.

9.2 The Company should establish procedures for the implementation of corrective action, including measures intended to prevent recurrence.

The associated IACS recommendation is²³:

Re 9.1 of the ISM Code:

Records of non-conformities, accidents, hazardous situations and relevant investigations produced by shipboard personnel and/or by the Company from operations or internal audits, should be provided to the auditor during audits to demonstrate effective functioning of the SMS.

Non-conformity means an observed situation where objective evidence indicates the nonfulfillment of a specified requirement. Non-conformities may be identified as result of such activities as internal and external audits, class surveys, flag or port state inspections. The NCs may include non-fulfillment of technical as well as operational requirements.

Accidents are events that lead to unintended harm or damage such as deaths or injuries, pollution or property damage. Hazardous situations include near misses/near accidents and are often defined events that under slightly different circumstances may lead to an accident.

The auditor should be aware that terminology in reporting such events vary from company to company.

The auditor would also expect to see the effective implementation of a documented procedure dealing with the review and analysis of the events stated above. Analyses should aim to determine basic causes, not only symptoms. This should include the objective for improvement. Corrective action should include both the “repair” to deal with the immediate situation as well as measures taken to prevent or reduce likelihood of recurrence.

Re 9.2 of the ISM Code:

The Company should have procedures for carrying out the corrective actions suggested by analysis relevant to non-conformities, accidents and hazardous situations identified from internal audits and during operations.

Auditors should focus on the effectiveness of the procedure(s) for implementing corrective actions. Failure to comply with these issues in a timely manner should qualify for a non-conformity. Consistent, grave inability to comply in time should result in the issue of a major non-conformity.

Examples of objective evidence found at the Office and onboard the ship may include:

- *Personnel aware of procedure procedures ensuring that non-conformities, accidents and hazardous situations are reported, investigated, analyzed and followed up*
- *Records of non-conformities, accidents and hazardous situations reported (check against documents such as class, flag and port state reports, medical logs and interviews)*
- *Records of accident investigation and analysis*
- *Evidence of corrective action including actions to prevent recurrence*
- *Evidence of effective and timely implementation of corrective action.*

The BSU's investigators strongly doubt that the THETIS D's owner complied with the above requirements for it to follow-up the accident internally to an appropriate extent. Contrary to an undertaking made by the owner, an internal investigation report was not submitted. As regards information requested on action already taken, the owner claimed that after the accident it:

"Coordinated its planned maintenance programme in respect of the damage and has pointed explicitly to the damaged components, stipulating more controls accordingly."

This message completely disregards the fact that the accident was caused by an inspection. With that in mind, it cannot be assumed that even more inspections will prevent accidents of this nature in the future. What actually would have been expected after the internal analysis of the events leading up to and during the accident was the preparation of a circular to the relevant ship's command and/or the fleet, which drew attention to the dangers involved in not carrying out inspections of the main engine's major parts properly. Further training courses would be equally as appropriate in this case as raising the crew's awareness of the fact that even minor deviations from the recommended pre-load pressure in bolted connections can facilitate the development of piston seizure. Accordingly, the investigators consider it necessary for the classification society to verify the owner's corrective actions on a case-by-case basis by way of the annual ISM audit.

6 CONCLUSIONS

6.1 Installation error

The serious engine damage followed by fire on the THETIS D is essentially due to an installation error during a routine inspection of the connecting rod bearing seven months prior to the accident. The connecting rod bearing bolts were tightened neither using the manufacturer's recommended method nor with the necessary pressure. This led to increased connecting rod bearing clearance, which ultimately caused piston seizure and the ensuing destruction of cylinder 7's drive unit. That nobody was in the vicinity of the main engine when the drive unit burst open is thanks only to fortuitous circumstances.

When the first alarms pointing to a problem with the drive unit were issued on the day of the accident, it was too late for the engine room's crew to take corrective action. The extent to which the emergence of the piston seizure could and should have been noticed by engine room personnel qualified to form part of the watch in the months following the improper inspection could not be fully established. The BSU's expert is convinced that there must have been indications of this. The engineers responsible on board the THETIS D denied any irregularities pointing to a drive unit problem, however. In the latter case, even greater emphasis should therefore be given to complying with the manufacturer's instructions for bolt torque values, so as to prevent the undetected development of a piston seizure that leads to the sudden destruction of the drive unit.

As regards preparing for, recording and carrying out maintenance and servicing works on key components of the main engine, it can be concluded from the investigation that the engine room personnel responsible should attend additional training on the consequences of not complying with the manufacturer's instructions and recommendations.

6.2 Reporting obligations and preservation of evidence

The ship's command reported the accident to the VTS only very briefly as engine damage. More detailed reports on the serious marine casualty were not made. Contrary to legal requirements, the ship's command failed to arrange for the data on the VDR to be backed up. When the actual extent of the damage became known, the accident data had already been overwritten by the VDR automatically.

6.3 Safety management

It can be concluded from the investigation that the safety management of the THETIS D's owner should be reviewed by the classification society in the course of routine audits. In particular, this concerns the instructions needed to assist the engine room's crew during maintenance and servicing works on key components of the main engine and their implementation on board, as well as the owner's accident follow-up with concrete implementation of appropriate improvements.

7 SAFETY RECOMMENDATIONS

The following safety recommendations do not constitute a presumption of blame or liability in respect of type, number or sequence.

7.1 Owner of the THETIS D

The Federal Bureau of Maritime Casualty Investigation recommends that the owner of the THETIS D take such steps as safety briefings, circulars and any other measures that are necessary and appropriate (e.g. training sessions) to ensure that qualified engine room personnel prepare for, carry out and record maintenance and servicing works on key components of the main engine properly.

7.2 Owner of the THETIS D

The Federal Bureau of Maritime Casualty Investigation recommends that the owner of the THETIS D advise its ship's commands on the obligation to back up VDR data after a marine casualty and possibly to incorporate this in procedural instructions.

7.3 Classification society of the THETIS D

7.3.1 ISM: Maintenance and servicing

The Federal Bureau of Maritime Casualty Investigation recommends that the classification society of the THETIS D check during the next routine ISM audit whether a procedural instruction for maintaining and servicing key components of the main engine, which meets the requirements of the ISM Code, exists and is implemented.

7.3.2 ISM: Accident follow-up

The Federal Bureau of Maritime Casualty Investigation recommends that the classification society of the THETIS D check during the next routine ISM audit whether the owner's internal accident follow-up procedure satisfies the requirements of the ISM Code and is implemented effectively on board.

8 SOURCES

- Witness interviews
- Crew list
- Extracts from the THETIS D's engine room log
- Recordings of the THETIS D's safety and alarm system
- Technical opinion of Professor Diederichs
- Opinion of the MAN materials testing laboratory
- AIS data on the course of the voyage and VHF recordings from the VTS
- MAN manual and main engine's technical documentation
- Investigation reports of WSP Kiel
- Port State control reports
- Recordings of the VDR
- Marine casualty database entries