Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation

Investigation Report 282/20

Serious Marine Casualty

Grounding of the RUBINA after steering gear failure on the River Weser on 27 August 2020

7. April 2022

This 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.

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1 SUMMARY

At about 2155 on 27 August 2020, the Portugal/Madeira-flagged bulk carrier RUBINA ran aground on the River Weser.

The RUBINA was sailing from Bremen outbound on the Weser on the evening of the accident. Both steering gears were running and a helmsman was steering using the hand wheel.

When the helmsman tried to return the rudder to midships from a rudder angle of about 15° starboard, nothing happened at first. Despite the hand wheel being in the correct position, the rudder remained at 15°. After a few seconds, a clearly audible alarm sounded and the steering control system switched to override[1].

At the same time, the rudder angle changed to hard starboard (45°) and then remained there, while still failing to respond to rudder orders at the hand wheel. The ship's turning speed accelerated even more rapidly.

Despite an immediately initiated full-astern manoeuvre and emergency operation of the steering gear directly in the steering gear room, the RUBINA's prow ran aground within minutes. Luckily, this happened in a relatively 'harmless' position on the river. The rudder responded again just a brief moment later.

After the salvage operations on the following day, the RUBINA was towed to a waiting pier in Brake. The ship was able to continue her voyage two days later.

The cause of the non-responsive rudder was found to be a pilot valve of steering gear pump no. 2, which had stuck in an open position for a while. It was not possible to establish conclusively what had caused the pilot valve to stick.

[1] See section 3.1.1 for more details.

2 FACTUAL INFORMATION

2.1 Photograph of the ship

Figure 1: Bulk carrier RUBINA[2]

2.2 Ship particulars

Name of ship:	RUBINA
Type of ship:	Bulk carrier
Flag:	Portugal (MAR)
Port of registry:	Madeira
IMO number:	9725512
Call sign:	CQZG
Owner:	Peter Doehle Schiffahrts-KG
Shipping company:	Julia Schiffahrtsgesellschaft, c/o Peter Doehle Schiffahrts-KG
Year built:	2018
Shipyard:	Jiangsu Hantong Ship Heavy Industry
Classification society:	Lloyd's Register
Length overall:	179.95 m
Breadth overall:	32 m
Draught (max.):	10.75 m
Gross tonnage:	25,618
Deadweight:	39,959 t
Engine rating:	6,100 kW

[2] Source: Hasenpusch Photo Productions.

Main engine:	Wärtsilä/Doosan 5-RTflex-50
(Service) Speed:	14 kts
Hull material:	Steel
Hull design:	Double hull
Minimum safe manning:	9

2.3 Voyage particulars

Port of departure:	Bremen, Germany
Port of destination:	Houston, United States
Type of voyage:	Merchant shipping, international
Cargo information:	Steel
Crew:	14
Draught at time of accident:	D_f = 9.25 m, D_a = 9.95 m
Pilot on board:	Yes
Number of passengers:	0

2.4 Marine casualty information

Type of marine casualty:	SMC / steering gear failure
Date, time:	27/08/2020, 2257[3]
Location:	River Weser, at the mouth of the 'Rechter Nebenarm' tributary (km 44)
Latitude/Longitude:	φ = 53°21.7' N λ = 008°30.2' E
Ship operation and voyage segment:	Manoeuvring mode / pilotage waters (north-bound)
Consequences:	– grounding at the eastern edge of the Weser fairway (roughly level with Sandstedt); – first attempt to tow ship free (two tugs) at about midnight unsuccessful due to falling tide; – second attempt to tow ship free (four tugs) at next high tide (morning of the following day) successful; – vessel shifted to Brake to await repairs and class approval.

[3] All times given in this report are local (Central European Summer Time CEST = UTC + 2 h).

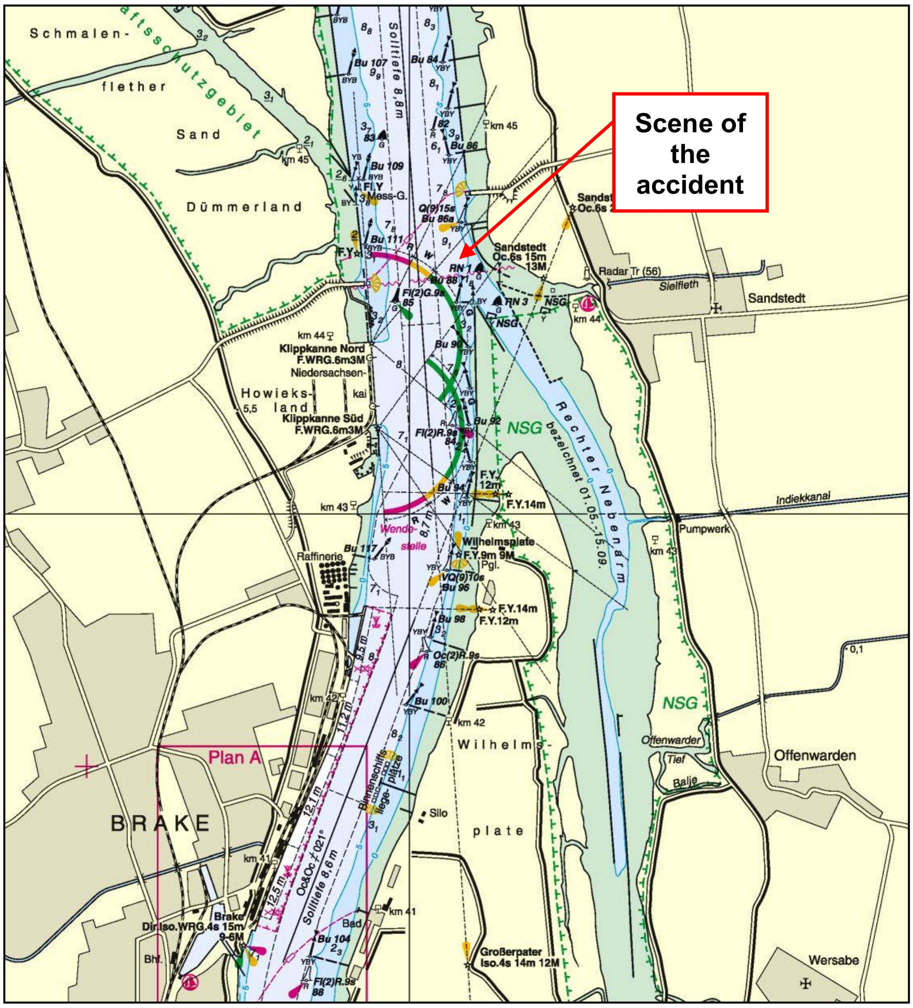

Figure 2: Scene of the accident[4]

2.5 Shore authority involvement and emergency response

Agencies involved:	- Vessel Traffic Service (VTS) Bremerhaven; - Waterways Police (WSP) Brake; - Pilot Association Weser I (shore-based radar assistance); - Maritime Safety and Security Centre (MSSC); - Waterways and Shipping Office Weser / Jade / North Sea; - German Ship Safety Division (BG Verkehr); - German Central Command for Maritime Emergencies.
Resources used:	Two tugs during first attempt to tow ship free; four tugs during second, successful attempt
Actions taken:	- traffic regulation by VTS and radar pilots; - radar assistance for ships with a max. length of 190 m and max. draught of 7.5 m; - shifting to a waiting pier in Brake after the ship had been towed free.

[4] Source: Extract from 'The River Weser from Nordenham to Farge' navigational chart, German Federal Maritime and Hydrographic Agency (BSH), Chart No 5 (INT 1458).

3 COURSE OF THE ACCIDENT AND INVESTIGATION

3.1 Course of the accident

3.1.1 Accident

On the evening of 27 August 2020, the Portugal/Madeira-flagged bulk carrier RUBINA was outbound on the River Weser in manoeuvring mode. The ship was sailing from Bremen, Germany, to Houston, United States, with a cargo of steel. A pilot was on board, both steering gears were running, and a helmsman was steering using the hand wheel.

At around 2154, the helmsman tried to return the rudder to midships from a rudder angle of about 15° starboard. Initially, nothing happened, despite a correct had steering wheel position; the rudder remained at 15°. The helmsman immediately reported the problem to the pilot and the ship's command. After about three seconds, the steering control system automatically switched into so-called “override”[5], accompanied by a clearly audible alarm.

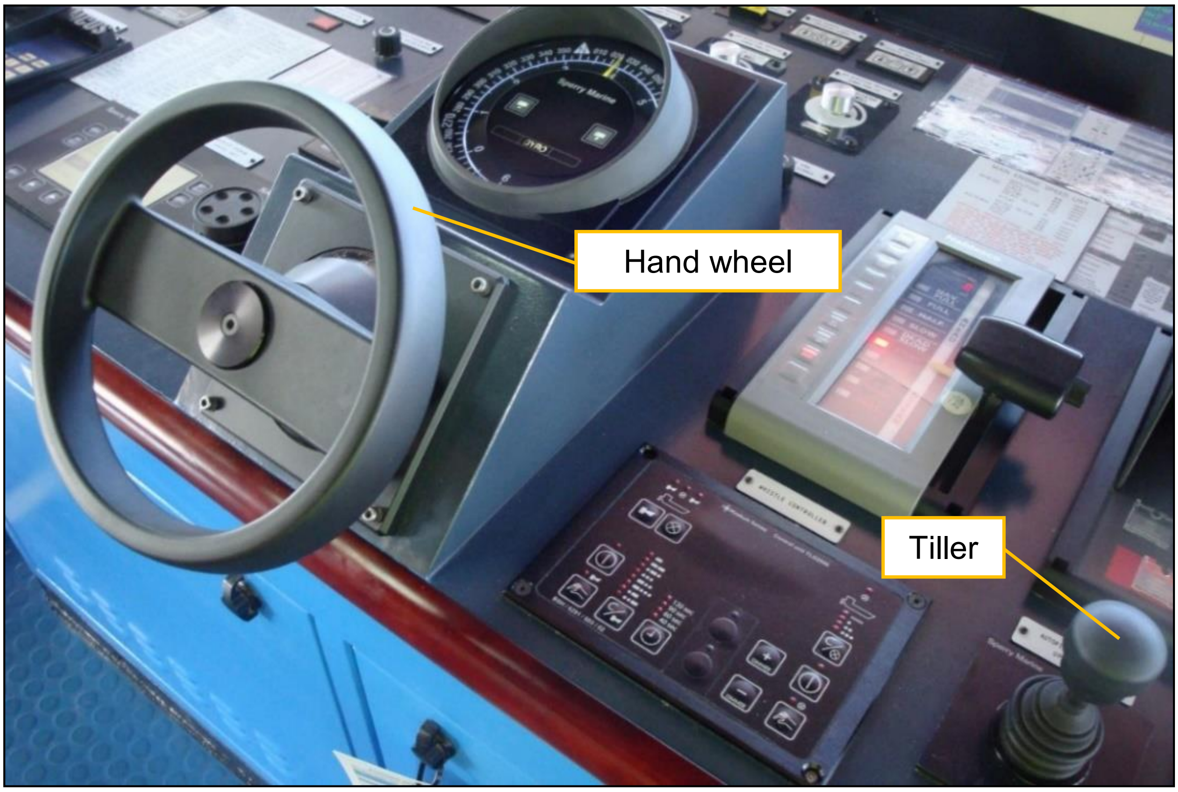

Figure 3: Hand wheel and tiller[6] on the RUBINA

[5] Override: Function that immediately activates the mode assigned to it and deactivates other modes as soon as it is activated manually or automatically. If the steering control system switches to override, then the tiller[6] is immediately active (even if it is not selected as input device).

[6] Tiller: Input device for rudder orders on a ship. Varies in design – can be a rotary wheel with scale, for example. On most ships (including the RUBINA) the tiller looks like a joystick, see Figure 3. See section 0 for a more detailed explanation.

At the same time, the rudder angle changed further to starboard to the hard-over angle of 45°, where it remained. As events unfolded, more helm orders were issued to the helmsman at the hand wheel, who continued to try and steer. However, the rudder failed to respond.

With the hard-over rudder angle, ship's rotation accelerated even more strongly, at times to a ROT[7] of almost 60 °/min. The RUBINA's speed was about 8 kts at that point.

A general steering gear alarm sounded shortly afterwards. This showed as 'Steering Gear No. 2 Hydraulic Pump overload' in the engine control room.

A member of the engine department investigated the alarm and "noted abnormal noise from the pressure relief valve of hydraulic pump no. 2." In addition, the associated pressure gauge “was found overpressed” (needle at the stop, outside of scale) and a minor, unspecified damage was reported.

After the master and chief engineer had briefly consulted over the phone at 2155, the steering gear was switched to local control directly at the unit (a form of emergency steering) and the magnetic valves on the steering pumps were operated manually. This made it possible to return the rudder to the midships position.

The pilot had immediately ordered full astern and requested a tug. At the same time, the master had issued orders to prepare to drop an anchor. However, this did not happen.

The RUBINA's prow ran aground outside the fairway before any of these immediately initiated measures could have any effect (at about 2157). Rudder control was regained almost at the same time. Luckily, the grounding occurred in a relatively ‘harmless' position on the river: at the mouth of a Weser tributary (the so-called 'Rechter Nebenarm') and outside the fairway, roughly level with Sandstedt (see Figure 2, Figure 4 and Figure 13). About two and a half minutes had passed since the rudder had jammed.

Since the RUBINA did not swerve through the fairway, there was no risk to other vessels, or of a complete standstill of transiting traffic, at any time.

[7] ROT: rate of turn – angular velocity at which a ship turns when her direction of keel (heading) changes, measured in degrees per minute (°/min).

3.1.2 Subsequent events

Steering control was returned to the bridge and tested immediately (2204). No problems were found. A jamming of the rudder did not occur again.

Figure 4: Past track of the accident (RUBINA's ECDIS)[8]

- headcount of all crew members;
- steering gear performance test;
- inspection of overall condition of propulsion equipment and engine room;
- visual inspection of hull for damage (exterior and interior), and
- repeated soundings of various spaces, such as cofferdams, machinery spaces (e.g. valve spaces running athwartships), and tanks (e.g. the forepeak and fuel tanks) in the area of and directly adjacent to the grounded section.

Neither water ingress nor other anomalies were found.

An attempt to refloat the RUBINA with the help of two stern tugs started at midnight. This salvage attempt was unsuccessful due to the ebbing tide, however. Both tugs then waited on standby.

8 Past track: Previous track of the vessel over a defined period of time. Source: Photograph of the ECDIS screen taken by the BSU during the visit on board.

In the meantime, the described soundings were repeated at regular intervals. The forepeak was drained to reduce the weight of the grounded forward section (new draught: D_f = 7.98 m and D_a = 10.70 m).

The ship was towed free and moved back into the channel with the rising water shortly before the next high tide, with the help of the tugs waiting at the scene and two other tugs, at 0854 on the following morning (28 August 2020). Assisted by two tugs, the RUBINA then sailed about 2 km further south under her own steam to a riverside berth in the port of Brake (alongside at 0954), where her original trim condition[9] was restored.

Various surveys and inspections were carried out later that same day:

- survey by the Waterways Police (WSP) Stade (police marine casualty investigators requested by WSP Brake);
- class survey;
- inspection of the steering control system by two Sperry (manufacturer) service engineers;
- inspection of the steering gear by a MacGregor/Hatlapa (manufacturer) service engineer;
- survey by representatives of the insurance company (Hull & Machinery), and
- survey by two BSU investigators.

Three representatives of the shipping company (including the responsible technical superintendent) were also present.

The ship's engineers, the superintendent, and the classification society surveyor once more inspected and/or sounded accessible tanks, cofferdams, and machinery spaces (see p. 12) in the fore section. Again, neither water ingress nor structural damage to the hull was detected. The only notable damage was the broken log[10] sensor.

The RUBINA remained at her berth in Brake for one more day and then departed for Houston at 1106 on 29 August 2020.

During this period, the manufacturer's service engineer thoroughly inspected steering gear hydraulic pump no. 2, and all functions of the entire steering gear unit (including pumps, valves etc.) were tested.

[9] Trim: Difference between a ship's forward and aft draughts.
[10] Log: Measuring device that gauges a ship's speed through the water based on the velocity of water flow along the hull.

The log's operability was inspected and its failure determined. The sensor was replaced on 18 September 2020 in the next port (Houston).

The chief engineer and the master later testified[11] that there had been no anomalies or alarms prior to the incident – neither when bridge and main engine were being prepared for departure nor before that – and that this phenomenon had apparently happened for the first time during the accident.

Divers carried out an underwater survey[12] in Veracruz, Mexico, on 1 October 2020. Apart from a few paint abrasions in the forward, flat area of the underwater hull, this did not reveal any damage.

3.2 Investigation

3.2.1 MV RUBINA

The RUBINA is a handysize[13] bulk carrier with her own cargo-handling gear and was built in 2018. She has five cargo holds and is approved for grain shipments and other cargoes. Her trade is mostly international tramp shipping.

The two-stroke five-cylinder propulsion engine with common-rail injection control acts directly on a fixed-pitch propeller. Electricity is generated by means of three auxiliary diesel engines.

At the time of the accident, the officers on board the RUBINA were from Poland, Ukraine, Russia, and Lithuania. All the ratings were from the Philippines. The language used on board was English.

3.2.2 Parties involved in the accident

The master, the helmsman, and the pilot were the people directly involved in the accident. The master came from Poland, the helmsman from the Philippines, and the pilot from Germany. They communicated in English. The VDR[14] audio recordings of the bridge microphones do not indicate a communication problem at any time.

[11] Both statements were submitted to the BSU in writing.

[12] Underwater survey: Survey of a ship's underwater hull and installations (propellers, rudders, sea chests, etc.) while she is in the water.

[13] Handysize: Smallest of the various bulk carrier size classes. Usually includes vessels with a deadweight of about 10,000 to 40,000 tdw. (Smaller units that are also capable of carrying bulk cargo are usually multi-purpose vessels.) Depending on the source, the RUBINA also falls into the ‘handymax’ subcategory (large handysize bulk carriers). There is no official definition or numerically exact distinction.

[14] VDR: Voyage data recorder.

3.2.3 Rotary vane steering gear

3.2.3.1 Basic mode of operation

The steering gear installed on the RUBINA is a so-called 'rotary vane steering gear'. The following three text excerpts summarise the mode of operation of this type of steering gear.

The *Handbuch Schiffsbetriebstechnik* [Manual of Ship Operation Technology] describes the difference between piston and rotary vane steering gears:

There are essentially two types of steering gear. In so-called piston steering gears [...], the electrically operated hydraulic pumps act on hydraulic cylinders. The latter transmit the torque via the so-called quadrant, which sits on the rudder stock like a yoke. For construction and geometric reasons, the torque that can be transmitted to the quadrant decreases at large angles. The hydraulics must compensate for this if the steering gear is to have a more or less constant torque at all angles. Due to the geometric conditions, piston steering gears are available for rudder angles up to 45 degrees. […]

Some ships require a rudder angle of greater than 45 degrees when manoeuvring in port. Since piston steering gears cannot be used in such cases, so-called rotary vane steering gears are used. There, the steering gear is positioned directly on top of the rudder stock (i.e. no quadrant), and the torque is applied via hydraulic oil that is fed into the various chambers.[15]

Klaus Bösche describes the physical operation of rotary vane steering gears as follows in his article *Ausrüstung – Seeschiffe – Ruderanlagen: Vom Handruder zur Rudermaschine* [Equipment – sea-going ships – steering systems: from hand rudder to steering gear]:

The rotor moves in a ring-shaped body that is divided into several chambers, according to its number of vanes. If an oil pressure is applied on any side of a rotary vane, it will make a rotary movement – and with it also the rudder stock . [...] The advantage of rotary vane steering gears is that there is no conversion of a linear motion [...] into a rotary motion, resulting in a significant reduction in required space.[16]

Finally, Wikipedia (German) provides information about the hydraulic principal of operation:

In hydraulic rotary vane steering gears, the pump strokes of the axial piston pump cause the rudder stock to rotate. The increasing pressure in the hydraulic spaces between the rotary vanes (which move with the rudder stock) and the partitions attached to the housing causes a force and – via the lever arm – a torque. On the suction side, the hydraulic oil flows back into the hydraulic system.[17]

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[15] Source: Meier-Peter, Hansheinrich, and Bernhardt, Frank (publ.): *Handbuch Schiffsbetriebstechnik*, p. 869.

[16] Source: Bösche, Klaus: *Ausrüstung – Seeschiffe – Ruderanlagen: Vom Handruder zur Rudermaschine*, article written for the German Maritime Museum in Bremerhaven, www.deutsches-schiffahrtsmuseum.de/DBSchiff/pdf_files/boesche_ruderanlage.pdf, last retrieved on 4 April 2022.

[17] Source: https://de.wikipedia.org/wiki/Rudermaschine_(Schiffbau), last retrieved on 4 April 2022.

3.2.3.2 Axial piston pump

The system pressure of a hydraulic system, e.g. a steering gear, is produced by a pressure-controlled hydraulic pump that delivers the required oil flow rate. Axial piston pumps are often used for this (in the so-called "swash plate" pump design, for example).

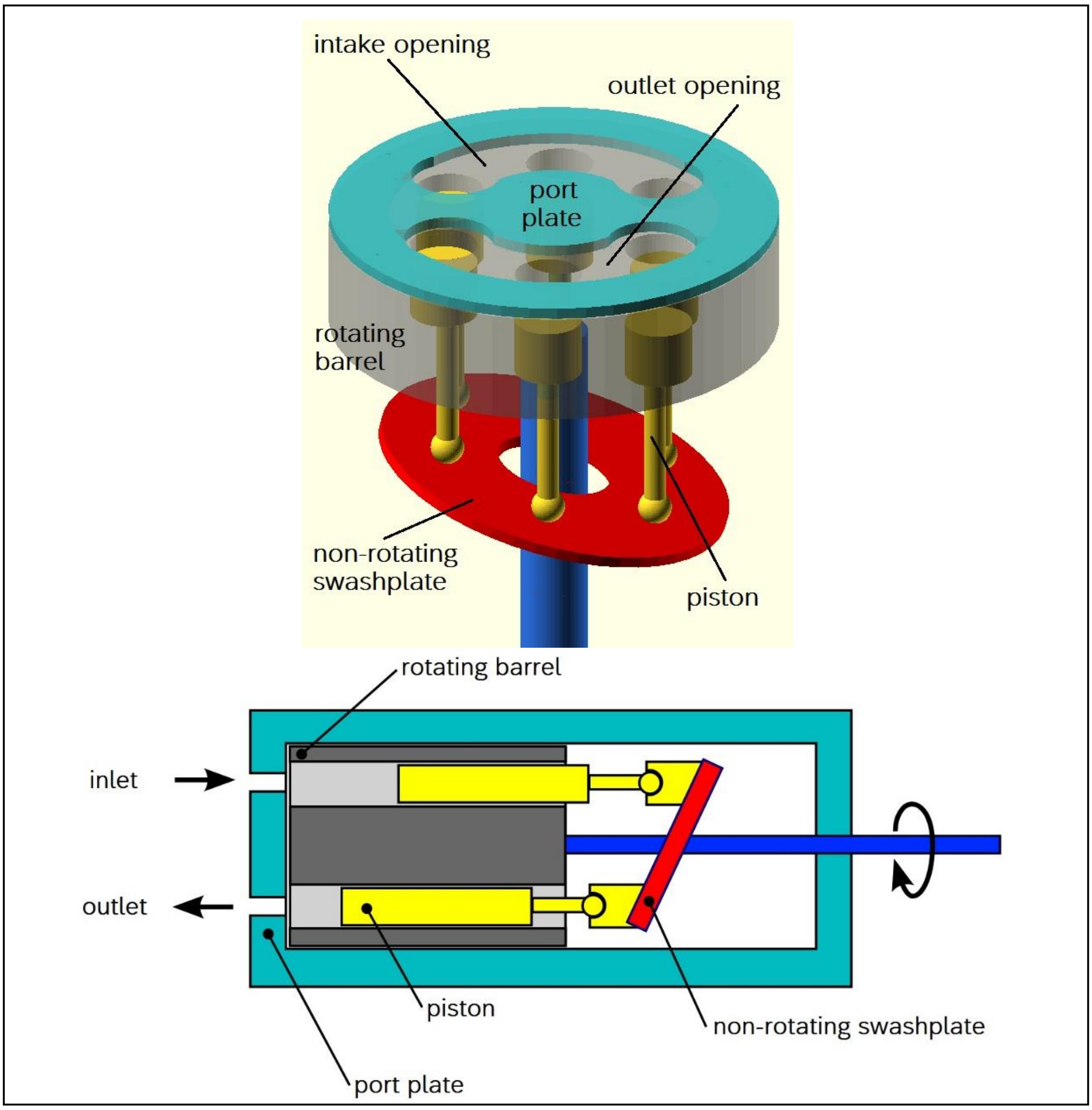

Figure 5: Axial piston pump (swash plate pump design)[18]

[18] Source: Axial piston pump, 3D render with caption and side view with caption, Michael Frey, 11 August 2017, via https://de.wikipedia.org/wiki/Axialkolbenpumpe, last retrieved on 4 April 2022.

An axial piston pump has several pistons, arranged in a circle and parallel to the drive shaft. Adjustable axial piston pumps operate according to the swash plate principle (swash plate pump) and adjust the geometric output from maximum to zero, thus varying the flow rate.

The swash plate pump has a rotating cylinder block in which the pistons are moved up and down by means of a fixed swash plate on which the piston plungers slide (sliding disc). The greater the angle of the swash plate, the greater both stroke and delivered oil volume (for a better understanding see Figure 5).

An integrated control piston (not shown here) adjusts the angle of the sliding disc and thus determines force and direction of the oil flow rate. When the direction of flow is reversed, the inlet shown in Figure 5 becomes the outlet, and vice versa. If the sliding disc is in neutral position, the pump's delivery rate is zero.[19]

3.2.3.3 MacGregor/Hatlapa TRITON 800/45

A TRITON 800/45 rotary vane steering gear is installed on the RUBINA. The number '800' in the type designation refers to the maximum available torque of 800 kNm, and '45' indicates the technically possible maximum rudder angle of 45°. For safety reasons, an electronic rudder angle limit of 35° engages at speeds of more than 5.1 kts.

Servicing and spare parts management etc. of the steering gear originally built by Hatlapa are now the responsibility of the company's legal successor, MacGregor.

The pump units of the electro-hydraulically driven TRITON series produce a working pressure of 100 bar. The necessary torque at the rudder stock is produced using variable displacement pumps (adjustable axial piston pumps), which deliver a variable hydraulic oil flow rate in the required direction.

On variable displacement pumps, a small, fixed displacement pump (servo pump) inside the pump delivers an oil flow against a pressure regulating valve. In the first step, the resulting pressure is used as 'servo pressure' for actuating the main pump's control piston with a pilot valve[20].

[19] Source: HAWE Hydraulik, https://www.hawe.com/fluid-lexicon/axial-piston-pump/, last retrieved on 4 April 2022.

[20] See colour-coded elements in the figures below. The pressure regulating valve (or the small part of it visible on the outside of the pump) is on the side facing away from the camera in all photographs, i.e. it cannot be seen. The main pump's control piston is not visible from the outside.

This is then throttled by one step to 'boost pressure' (the feed pressure in the main lines). Accordingly, the main lines are always under this pressure when the pumps are running but the steering gear is not moving. If one of the lines becomes the pressure line (with a rotation to port or starboard), then the other, i.e. the return line, remains under this boost pressure.

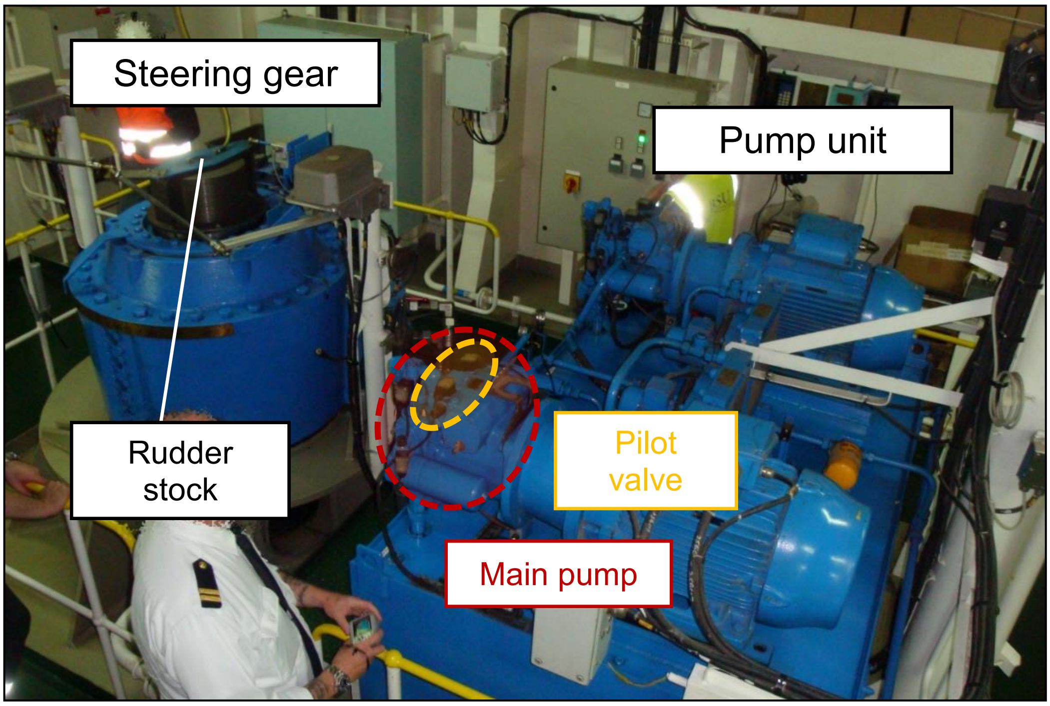

Figure 6: Steering gear on board the RUBINA (arrangement)

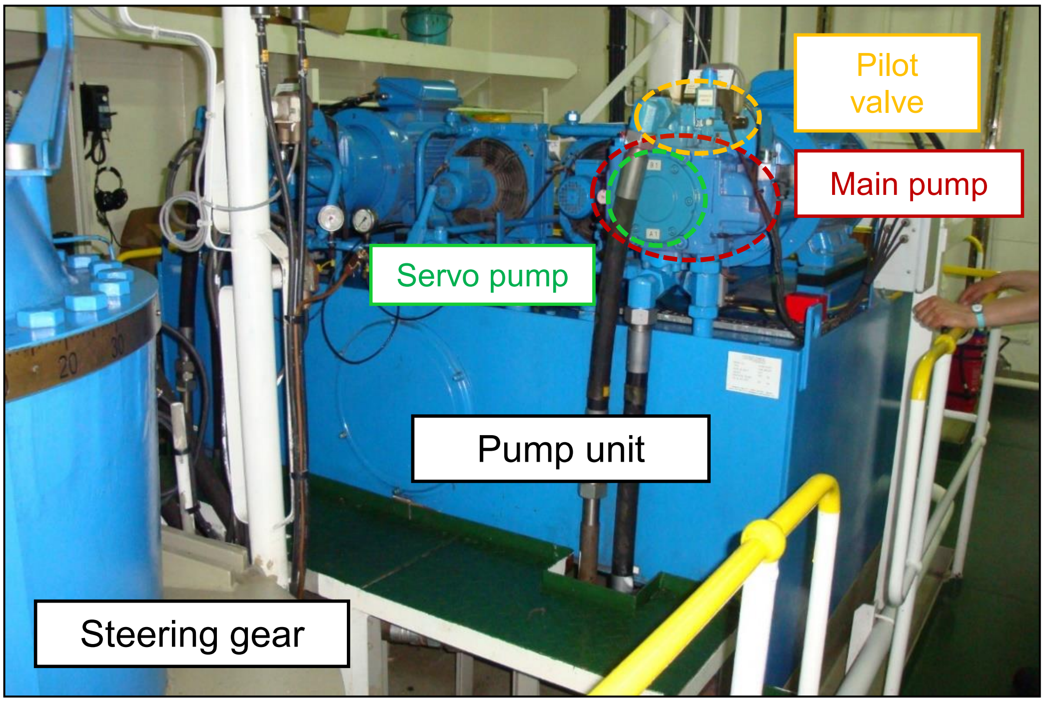

Figure 7: Steering gear on board the RUBINA (pump unit)

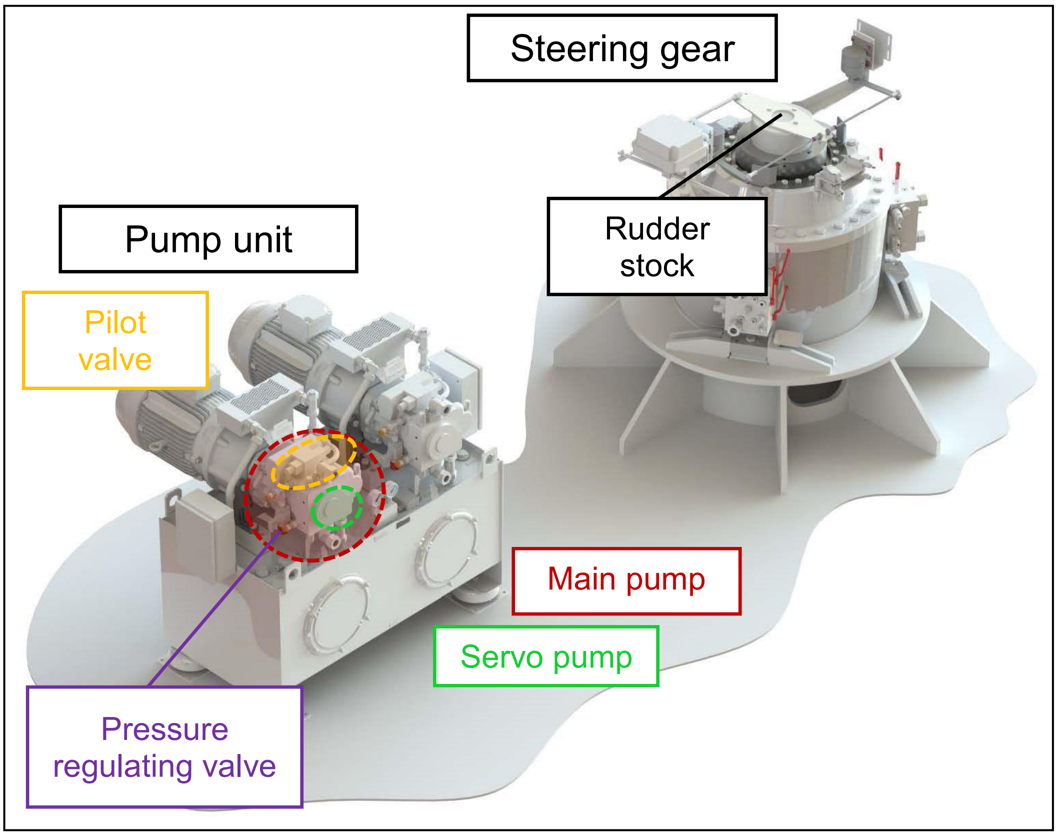

Figure 8: TRITON rotary vane steering gear[21]

[21] Figure 8 and Figure 9 source: https://www.macgregor.com/globalassets/picturepark/imported-assets/63233.pdf, last retrieved on 4 April 2022.

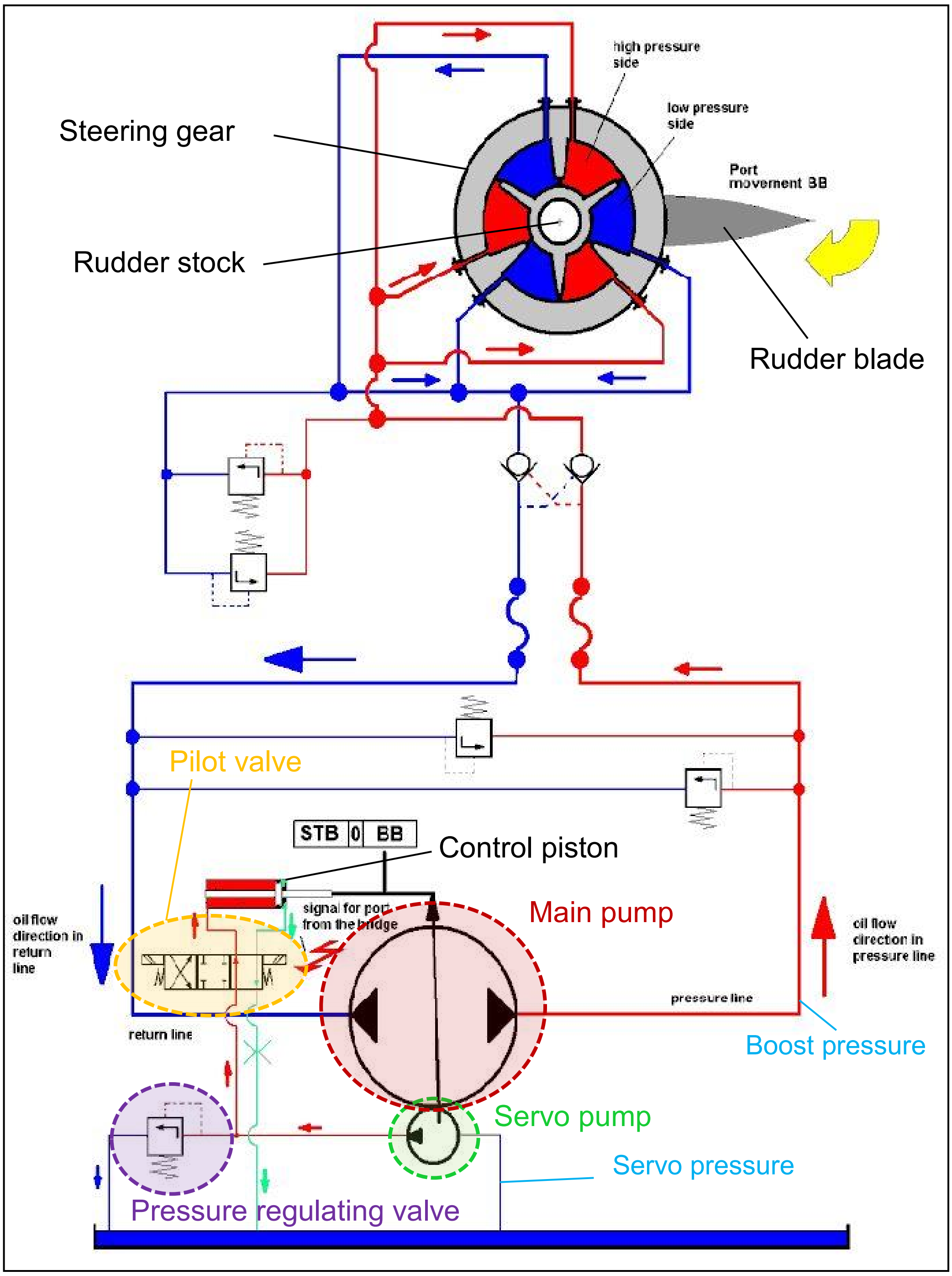

Figure 9: TRITON series: simplified hydraulic circuit diagram

The pilot valve actuates the main pump's control piston. Depending on the valve position (and thus the angle of the axial piston pump's sliding disc), the hydraulic oil is directed into the chambers at the flow rate necessary for a steering gear movement to port or starboard. It sets the required rotation of the rudder blade in motion. Therefore, manual operation of this valve is one possible emergency steering mode.

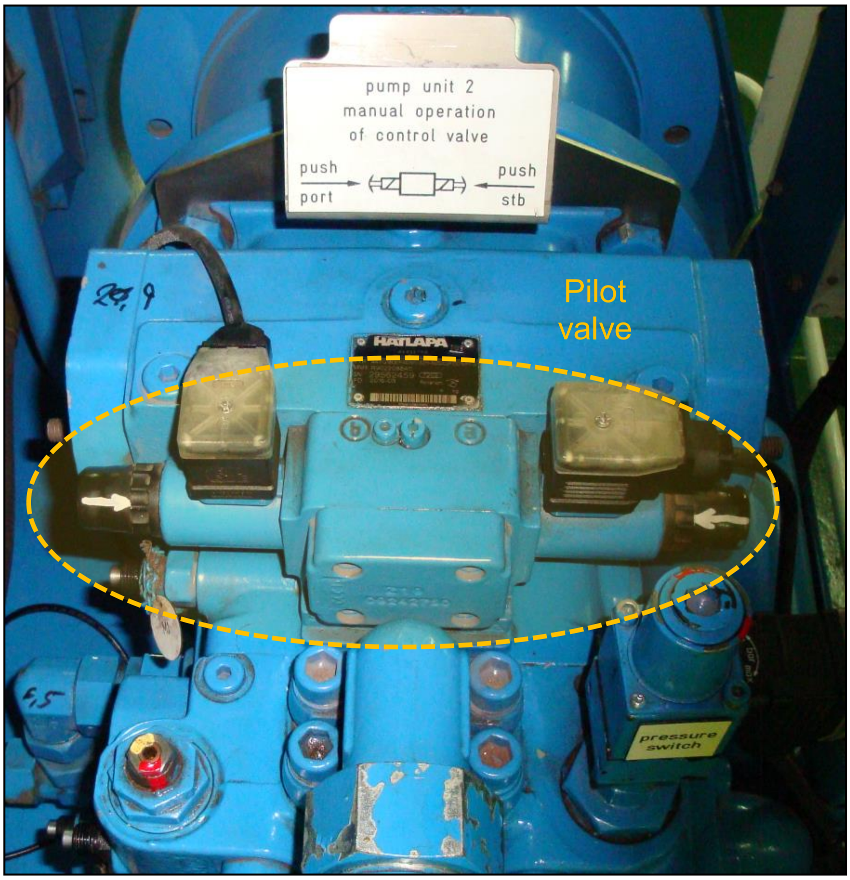

Figure 10: Steering pump 2's pilot valve, incl. brief guide for the emergency control

As stipulated and as usual, the RUBINA's steering gear has two steering pump units. Due to the hydraulic parallel connection of the pump units, the flow rates of the two pumps add up, while the maximum pressure difference (between pressure side and return line) remains the same. This means that each pump can be operated separately or they can both be operated together, with the effect that the steering gear's (and the rudder's) turning speed is doubled by adding the second pump. Maximum torque, however (a function of the pressure difference), can be achieved with one pump or both pumps.[22]

When sailing at high speeds, smaller rudder angles and thus the rudder turning speed of a single pump are sufficient to turn the ship accordingly. At low ship speeds (mostly in pilotage waters), the lower flow velocity along the rudder blade means a reduced steering effect. In these situations, both pump units are used to produce larger rudder angles more quickly and compensate for this effect.

[22] If hydraulic pumps are connected in series, their pressure heads add up; if they are connected in parallel, their flow rates add up. (Comparable to a simple electric circuit with pressure head = voltage, flow rate = current, pump = resistance.)

3.2.4 Steering modes

3.2.4.1 Basic information

To provide an overview of the steering modes, it is necessary to distinguish between the technical terms 'control' and 'closed-loop control'.

A control is used to bring about a change in a physical value via a setting device, in order to provide a specific output value.

A closed-loop control includes a control, but also has a feedback loop in which the resulting value (output variable) is compared to the target value. If the deviation (error variable) exceeds a defined value, then the closed-loop control will automatically intervene until the target value is reached. A closed-loop control comprises a certain level of automation.

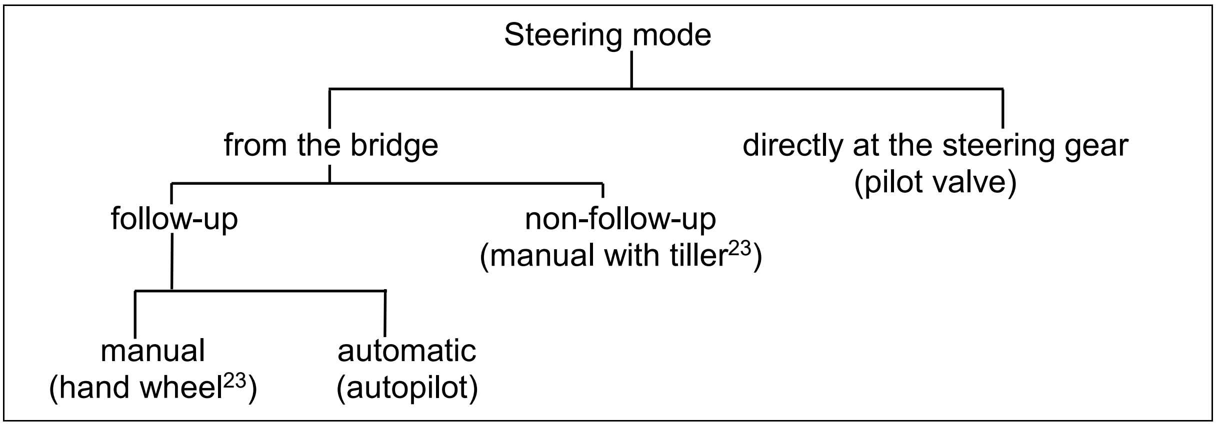

Diagram 1: Steering modes

3.2.4.2 Follow-up mode

When steering with the hand wheel, follow-up mode (FU) is engaged by default. In this mode, the required rudder angle is reached by means of a *closed-loop control* (i.e. “automatically”).

The closed-loop control turns the steering gear automatically until the target value (rudder angle) is reached. After the helmsman (also the autopilot[24], for example) has set the target rudder angle, the rudder ’follows’ this value automatically (hence ’follow-up’ mode). The closed-loop control monitors the actual rudder angle continuously, correcting it automatically as soon as necessary.

To return the rudder to the midships position, the hand wheel is put to midships. The rudder then ‘follows' automatically.

[23] In principle, it makes no technical difference which input device the manufacturer installs for steering in NFU or FU modes. The RUBINA has one of the most common layouts: hand wheel ≙ FU mode, tiller ≙ NFU mode. Other BSU accident reports also describe FU tillers, NFU buttons, etc., but we are not discussing those here. The descriptions in this report, including those of a general nature, are based on the RUBINA's technical equipment.

[24] In the case of an autopilot, the target value is not a rudder angle but rather a course. However, the rudder angle is the value that the closed-loop control adjusts in order to reach the target course.

3.2.4.3 Non-follow-up mode

When the ship is steered with the tiller, the steering gear operates in non-follow-up mode (NFU). In NFU mode there is no control loop and no automation. This is merely a *control*, with the tiller acting as the setting device.

The rudder blade is turned directly with the tiller and does not move in the direction of a target value automatically. When the tiller is released, the rudder remains exactly where it is at that moment. The steering gear drive is only actuated while the rudder is being moved. Corrections to the rudder angle must be implemented manually.

To return the rudder to the midships position, the tiller must be moved in the opposite direction until the rudder reaches the midships position. The tiller itself has no midships position, only a control signal either to port or to starboard.

Since NFU mode does not include a control loop, it represents the first stage of a series of emergency steering options in many systems (less automation = more fail-safety). If there is a defined deviation over a defined period of time that the closed-loop control cannot compensate for in FU mode, the system is immediately and automatically switched from FU to NFU (in an override). This is accompanied by an audio-visual alarm (the so-called 'Steering Failure Alarm' – SFA on the RUBINA). Thus closed-loop control and automation are bypassed and the rudder can be turned directly.

3.2.4.4 Manually versus automatically triggered override

Whenever the tiller is moved during operation (e.g. to perform a manual evasive manoeuvre while in autopilot mode), NFU mode will also engage immediately and override the closed-loop control. In other words, the tiller always has an overriding function. The reason for this is that emergency steering and/or manual intervention must be possible at all times.

This *intended and manual activation of the override* is indicated by an alarm on the so-called 'Steering Override Unit' (SOU) located next to the tiller. The 'Prev[ious] Mode' button (see Figure 11) can then be used to deactivate the override and return to FU mode.

However, after a Steering Failure Alarm (i.e. after an *unintended and automatic activation of the override* due to a problem with the rudder angle, i.e. a ‘steering failure’), a reset is not possible this way. In such cases, a reset must be carried out by switching to NFU mode and back to FU. Of course, the override can then be expected to reengage after another three seconds if the underlying problem has not been solved in the meantime.

Figure 11: Tiller and Steering Override Unit SOU

3.2.4.5 Situation on the evening of the accident

What occurred on the RUBINA was an *unintended and automatic* activation of the override. The helmsman had put the hand wheel to midships, but the rudder remained at 15° starboard (‘steering failure’).

Due to this unchanging system deviation, the override automatically engaged after three seconds, and the Steering Failure Alarm sounded. This means that NFU mode (and thus the NFU tiller) was activated, even though the hand wheel was still selected as input device (steering mode selector switch was on FU, see Figure 12 and Figure 17). The closed-loop control was therefore inoperative from the moment the alarm sounded, and none of the switching contacts for the originally selected FU mode had an effect. In other words, the rudder orders via hand wheel had no effect from this point on.

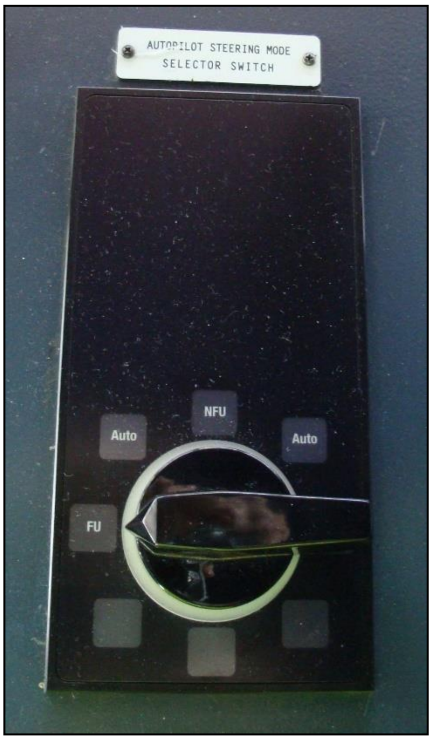

Figure 12: Steering mode selector switch
(FU: hand wheel; NFU: tiller; auto: autopilot)

3.2.5 Recordings

3.2.5.1 Track

The RUBINA's track could be retraced using various ship tracking and information platforms. However, since the data used there originate from the ship's AIS signal[25] (ultimately the GPS device[26]), it is consistent with the track found on board (see Figure 4) and has no standalone meaning.

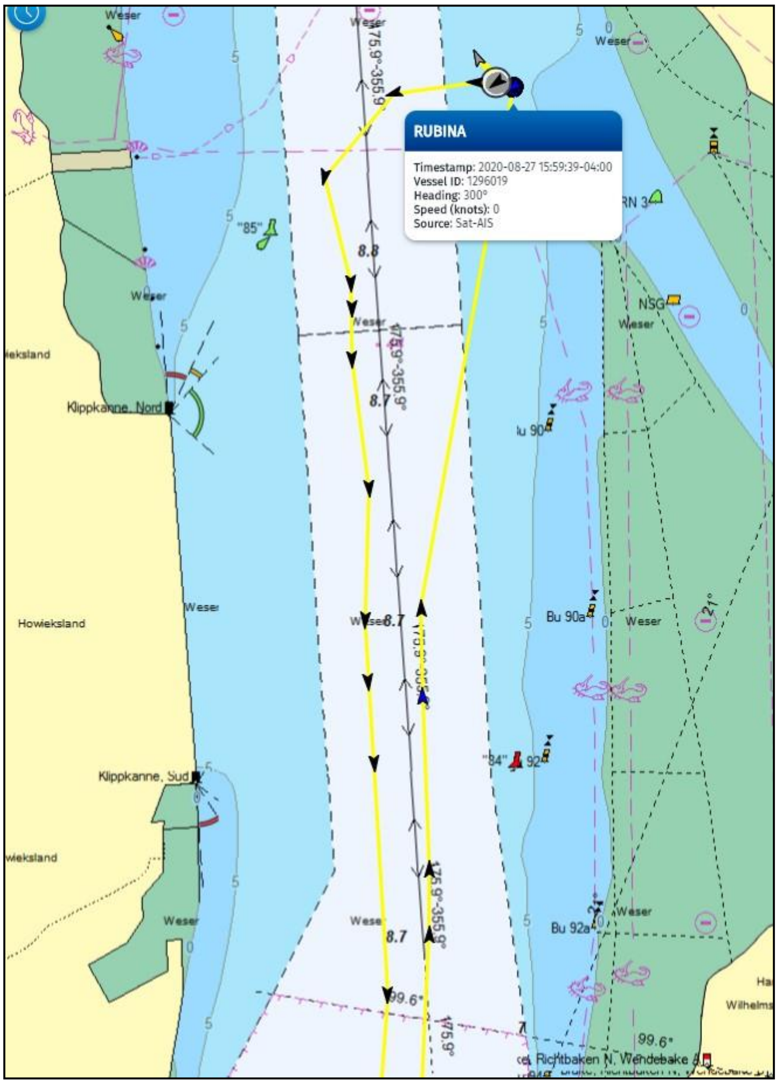

Figure 13: Past track of the accident (external recording)[27]

[25] AIS: Automatic identification service, a radio- or satellite-based system for exchanging navigational data and other ship's particulars, e.g. the position. It transmits these data to receiving stations in the vicinity, usually other ships, at short intervals of two seconds to three minutes (depending on speed, ROT, manoeuvre status, etc.).

[26] GPS: Global positioning system (global system of navigation satellites for positioning).

[27] Source: SafeSeaNet.

3.2.5.2 VDR

The statements of the parties involved and the course of the accident were confirmed during the evaluation of the VDR.

For example, the system deviation between the rudder angle of 15° starboard and the rudder order (midships) on the hand wheel at the time it first occurred is clearly visible (see Figure 14).

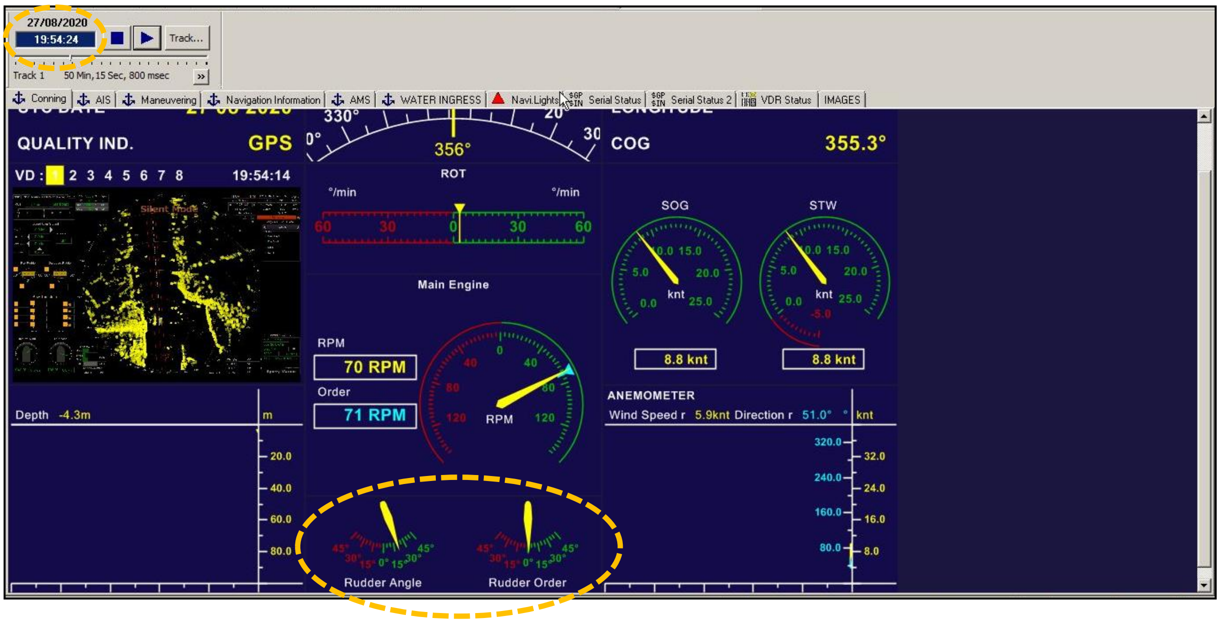

Figure 14: VDR: Non-responsive rudder (first occurrence)[28]

(215424 local time)

It should be noted that technical rudder orders can only be given with the FU hand wheel, not the NFU tiller (because target values belong to closed-loop controls, see section 3.2.4). However, not only were helm orders given to the helmsman (recorded by the VDR microphones) until the ship ran aground, but the hand wheel was also continuously used (recorded in the above figure), while the NFU tiller was not used at all.

[28] Source figures 13-20: VDR of the RUBINA.
VDR internal clock = UTC; local time at the first occurrence of the non-responsive rudder therefore CEST = UTC +2 h (215424).

About 30 seconds after failing to respond for the first time, the rudder had already deflected to the hard-over angle (despite the hand wheel position in the opposite direction – see rudder order). The ROT is already about 50 °/min. (For both see Figure 15.)

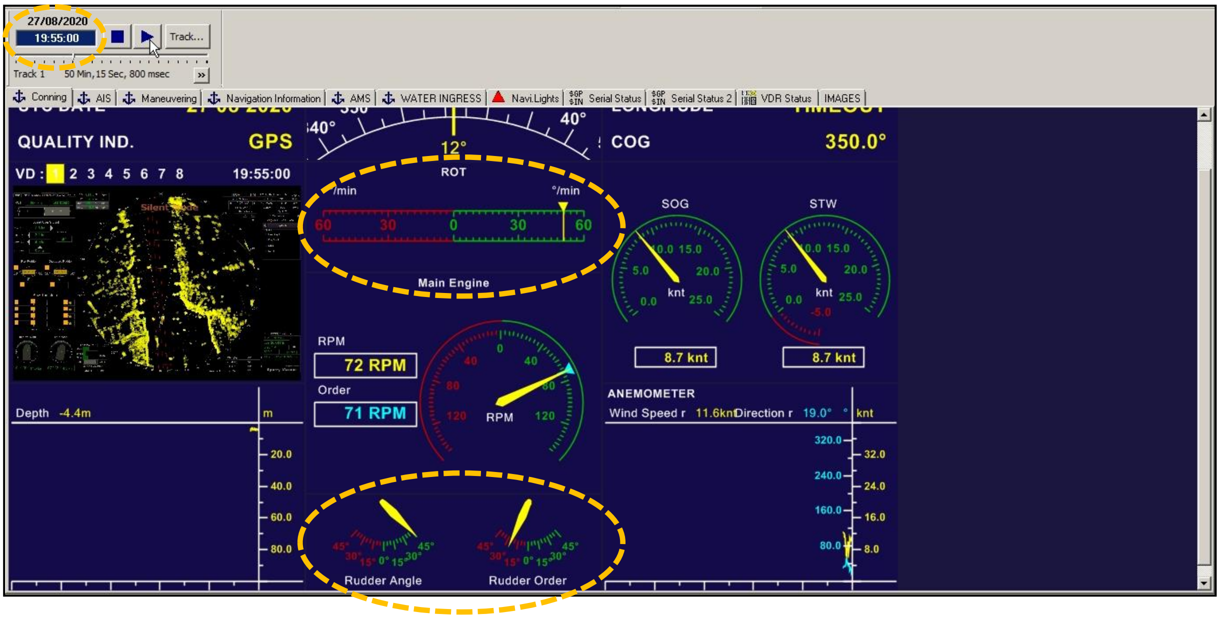

Figure 15: VDR: Hard-over rudder angle and ROT about 30 seconds later
(215500 local time)

A VDR sensor data overview shows that the steering was in FU mode (Figure 16) when the problem first occurred, and that the override activated three seconds later (Figure 17).

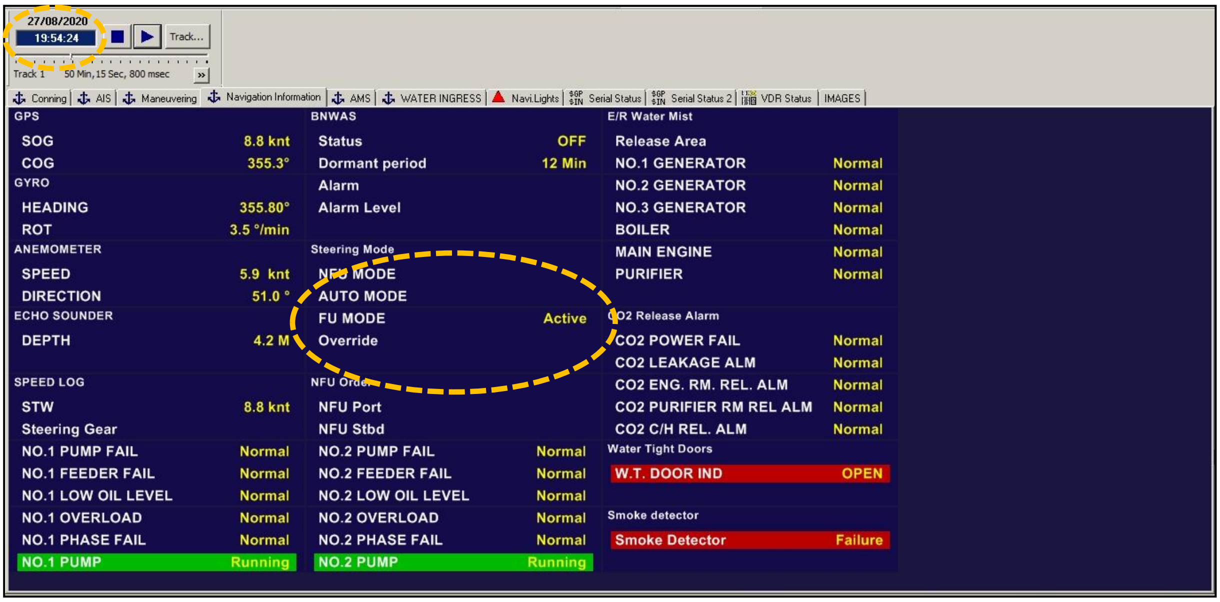

Figure 16: VDR: Non-responsive rudder (first occurrence)
(215424 local time)

(The closed-loop control is still trying to compensate for the system deviation and is not indicating any kind of failure.)

Figure 17: VDR: Override about three seconds later
(215427 local time)

(Since the closed-loop control was unable to resolve the problem, the first emergency steering stage, i.e. the override, was activated.)

A good 30 seconds after the first occurrence, the 'Pump No. 2 Overload' alarm first showed (Figure 18)[29].

Figure 18: VDR: Steering gear pump alarm
(215500 local time)

[29] On the alarm panel on the bridge, it only showed up as a general steering gear alarm.

Apparently, several unsuccessful attempts were made to regain control of the hand wheel by switching to 'Auto' steering mode and immediately back again. The VDR data clearly show this (Figure 19 and Figure 20).

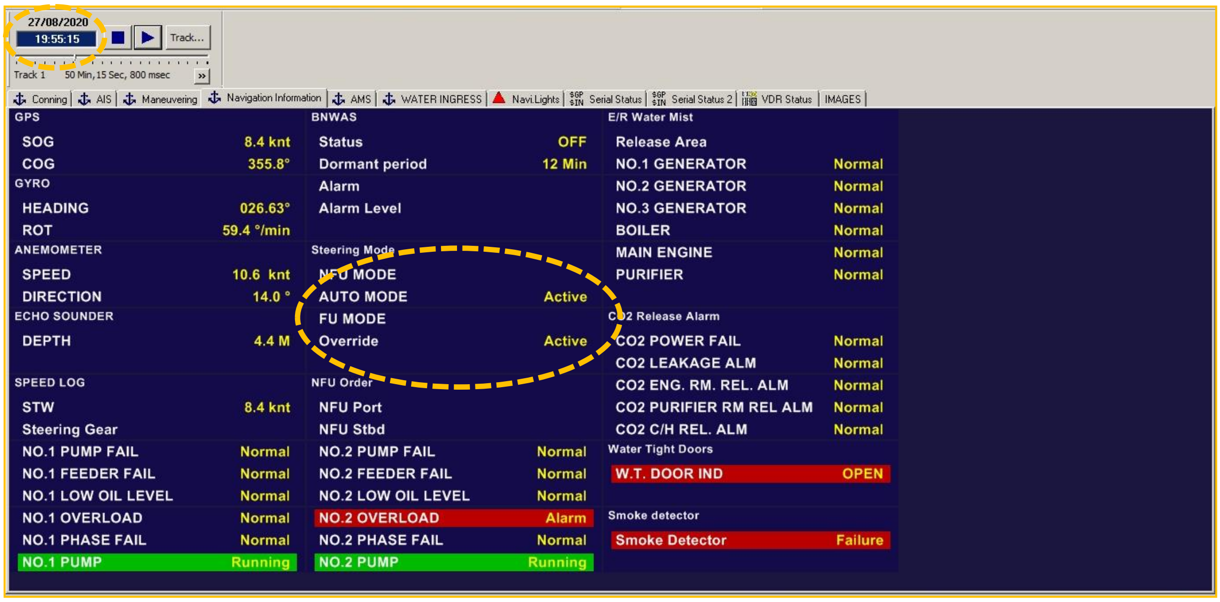

Figure 19: VDR: 'Auto' steering mode selected
(215515 local time)

Figure 20: VDR: One second later, 'Override' and 'FU' steering mode still 'Active'
(215516 local time)

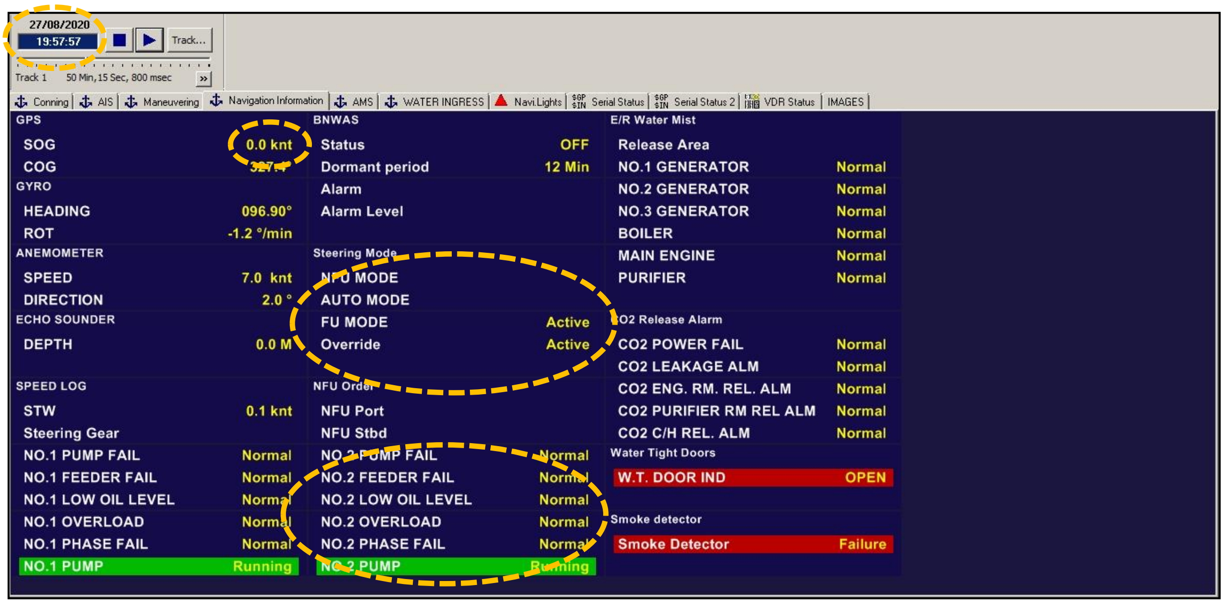

Figure 21: VDR: Time of grounding (speed: 0.0 kts[30]).

(215757 local time)
(The steering pump is already being operated manually here and no longer pumping against any resistance, i.e. a 'pump overload' no longer exists.)

The override could only have been reset by switching to NFU (see section 3.2.4.4). However, this was not tried (possibly because it did not seem logical to switch to the steering mode the system was already in). Evidently, neither ship's command nor helmsman were aware of the procedure necessary for this particular system.

However, an attempt to deactivate the override by means of a reset would have been destined to fail in any case, because it would have reengaged after three seconds due to the continuing discrepancy between rudder angle and rudder order.

In this overview, the VDR displays the steering mode that was last selected at the steering mode selector switch (see section 3.2.4 and Figure 12). The steering mode in override is nevertheless always NFU, even if it is not displayed here directly (but rather the last selected mode, FU), only indirectly through the addition of 'Override Active'. Accordingly, the tiller was active but the hand wheel was not. However, the tiller – the active input device in override mode – was not used (see also p. 27).

[30] SOG: Speed over ground.

3.2.6 Service and survey reports after the accident

3.2.6.1 Steering gear control system service report

The two service engineers from the steering control system's manufacturer began by downloading the VDR files, which were later also submitted to the BSU.

Remote control of the steering gear from the bridge was tested for proper functioning in all possible pump and steering mode combinations. This also included the electronic rudder angle limit, which normally engages at speeds of more than 5.1 kts, as well as the appropriate alarm unit response in the case of a general steering gear failure ('Steering Failure Alarm'). No problems were identified.

Following the incorrect log reading (the speed of the stationary ship at the pier was shown as -72 kts), its connections on the bridge were measured and a faulty or missing sensor was identified.

A viewing of the VDR data confirmed the statements made by the people involved in the accident. The service report points out that the direct correlation between (a) the time of the override and (b) the rudder deflection from 15° starboard to hard starboard is conspicuous.

3.2.6.2 Steering gear service report

The service engineer from the steering gear's manufacturer found what appeared to be a fully functional system. He systematically inspected its functionality in the presence of the BSU investigators.

He began by checking system parameters and functions. The times it took for one or both pumps to move the rudder from one hard-over angle to the other were unremarkable. The same was true for the functioning of the limit switches (for the electronic rudder angle limit), for alarms and pressure relief valves, as well as for system pressure, servo pressure, boost pressure, and oil temperature readings.

He then examined both pilot valves. After detaching each respective valve from the pump, its inlet ports and filters were inspected. All visible parts (e.g. O-rings) and hydraulic pipes were checked for contamination, metal abrasion, scratches, running marks, etc. The control pistons could be moved freely in the housing. There were no anomalies or indications of damage.

Both oil filters and the hydraulic oil were clean[31]. The crew took hydraulic oil samples from both steering pumps and submitted them for analysis. There were no negative findings in either case: "Oil condition is satisfactory and oil is fit for further use." It did not contain any impurities exceeding the stipulated limits (< 1 mg/kg). Additive content and chemical-physical readings were also normal.

[31] The oil filter had last been changed on 6 July 2020, and last inspected on 19 August 2020 (i.e. a good week before the accident), where it had been clean.

After reassembling the pilot valves and bleeding the pumps, all the above parameters and functions were checked once more. Following that, all steering modes were tested again, both locally and from the bridge. All readings and results were within the specifications and as such unobtrusive. No leakage was found.

Steering pump no. 2 must have been the source of the problem (the 'Overload' alarm had triggered there). Therefore, the RUBINA's chief engineer decided to replace this pump completely as a precaution, following the recommendation of the service engineer. This was carried out on 18 September 2020 in the next port (Houston). It was purely a precautionary measure deemed necessary in view of the accident (the service engineer had not been able to detect any damage to the pump).

It was suspected that the valve had stuck due to a tiny contamination, e.g. a very small piece of metal filing. This had probably jammed the sliding surface of the valve's control piston, and later come loose during the manual emergency operation (directly at the valve). It could not be found afterwards. According to the service engineer, it is known that this can happen. He was not able to establish the ultimate cause of the problem.

3.2.6.3 Survey report of the classification society

The classification society's surveyor inspected the tanks, void spaces, and machinery spaces in the fore and midships sections of the RUBINA that could possibly have been affected by the grounding. No visible damage was found there, and there was no other evidence of a warped hull (e.g. damage to the deck caused by hogging or sagging[32]).

The steering gear's full range of functionality was demonstrated to him. He also confirmed that, in addition to the log, there were other measuring devices for the ship's speed on board, in this case the two redundant GPS units. Maintenance of class was confirmed for the RUBINA, subject to the condition that the log's sensor be replaced within the following two months[33].

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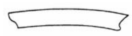
[32] 'Hogging' refers to a hull curving upwards longitudinally  and 'sagging' to a hull curving downwards . If part of a hull has grounded, buoyancy and/or weight forces (or the difference between them) can lead to considerable bending forces and even a ‘broken back’. Indications of this (e.g. warped areas and/or flaking paint) can then be observed in areas of the hull that are at risk of stretching or compressing.

[33] Since GPS measures the speed over ground, but a log measures the often deviating speed through water (which provides information about the prevailing strength and direction of the current), GPS is usually not the only approved method of measuring the ship's speed. For this reason, maintenance of class was only confirmed with restrictions, and subject to the above condition.

4 ANALYSIS

After speaking to the service engineers, reading the service reports, and reviewing the VDR data, the BSU has arrived at the following conclusion with regard to the course of the accident:

- Since no faults were found on the automation side, a mechanical problem must have caused the accident.

- The pilot valve of pump no. 2 apparently stuck in an open position for a while due to a small contamination. Briefly, it remained fully open and pumping to the starboard side.

- With the steering gear in FU mode, the closed-loop control tried to adjust the rudder angle. The jammed valve, however, 'disregarded' any signals, and its pump unit pumped to starboard at full capacity. The closed-loop control tried to compensate for this using the other pump unit, making it pump in the opposite direction. Both pump units reached an equilibrium at a rudder angle of 15° starboard ('hydraulic blockage').

- The closed-loop control was unable to compensate for the system deviation between target = 'rudder midships' and actual = 'rudder 15° starboard'. The automation system's emergency mechanism engaged after three seconds and activated the override, which was accompanied by the Steering Failure Alarm.

- The override activates the NFU mode and deactivates the closed-loop control. In NFU mode, the steering pumps are only set in motion when activated by the tiller. The BSU does not think that this happened. The fact that helm orders were still being given – even though the hand wheel has no effect as long as an override is active (even with a functioning steering gear) – proves this, as do the recordings in the VDR of continuous hand wheel rudder orders.

- The functioning pump unit stopped pumping as soon as the override became active, as is technically intended, because the closed-loop control was no longer controlling it. Meanwhile, the defective one continued to pump to starboard at full capacity (even though it, too, was of course no longer being controlled).

- The rudder therefore moved further to starboard from the moment the override was active.

- Since the stuck valve did not respond to electronic inputs, it ignored the electronic rudder angle limit of 35°. This caused the RUBINA – sailing faster than 5.1 kts at that point (about 8 kts) – to turn violently.

- The pump with the stuck valve did not stop pumping even after it had reached the mechanical limit of 45° (hard starboard). The pump kept pumping against a resistance, which led to considerable overpressure, then went into overload and triggered the associated alarm.

– Manual operation of the pilot valve evidently moved the suspected contamination, and the steering gear was fully functional again after that.

5 CONCLUSIONS

The service engineers, crew, and shipping company made every effort to find the fault and prevent a similar event from happening again in the future. By completely replacing the steering pump with the stuck valve, more was done than was indicated, based on the findings of the troubleshooting.

During the accident, all involved essentially behaved correctly. The rapid announcement of the problem by the helmsman enabled immediate action by the ship's command and pilot, for example. The pilot ordered a tug within short notice. The master's instructions to prepare the anchors quickly and the rapid changeover to emergency steering directly at the steering gear are further excellent examples of targeted action despite the stressful situation and in the midst of a multitude of alarms.

The safety checks directly after the grounding were carried out systematically and to an appropriate extent.

The handling of the steering modes is the only exception here. Despite the active override, helm orders were still issued to the helmsman at the hand wheel, even though they could not have had any effect whatsoever in the given situation.

Similarly, the exact procedure for resetting the override on this manufacturer's systems was apparently unknown, as no attempts were made to switch to NFU and back again. The fact that a reset was actually attempted, albeit to the wrong mode ('Auto'), can be seen in the VDR.

However, the BSU believes that it would have had little effect (if any) on the course of this accident if steering with the tiller had continued after the override had activated. Even then, the rudder blade would initially have deflected to hard starboard. Furthermore, steering with the active input device would not have changed anything about the mechanical cause of the stuck valve. Potentially, it might have been possible to prevent the rudder from moving all the way to the hard-over angle, and possibly a lower rudder angle could have been maintained after that. However, it is more than questionable whether the accident could have been completely prevented – especially since, at best, a rudder angle of 15° starboard could have been restored. The RUBINA may then have run aground a moment later (and only if the situation had been accurately assessed very quickly, and action taken with the appropriate presence of mind). After all, only two and a half minutes passed between the first time the rudder failed to respond and the grounding.

Ultimately, the cause of the technical failure of the steering gear remained unclear. The BSU believes that neither of the parties involved could have influenced any of the circumstances, neither beforehand (servicing and maintenance of the steering gear) nor during the accident itself.

6 ACTIONS TAKEN

After careful troubleshooting, the rudder pump with the stuck valve was completely replaced, as mentioned above. This exceeded the measures that would have been necessary following the service engineer's troubleshooting, but was consistent with his recommendation. The RUBINA's rudder has not jammed again since then.

From a technical perspective, the BSU believes that everything that could have been done in this regard was done.

7 SAFETY RECOMMENDATION

The following safety recommendation does not constitute a presumption of blame or liability in respect of type or sequence.

Peter Doehle Schiffahrts-KG
The BSU recommends the following to Peter Doehle Schiffahrts-KG:

Train crew members on the functionality of steering control systems

It should be ensured that the deck officers and master on board the ships of Peter Doehle Schiffahrts-KG know

- which changes occur in the steering control system when an override is triggered;
- how to proceed in such a case (e.g. have the helmsman switch to the tiller or other NFU input device), and
- how to properly reset the override of the system on board each respective ship.

Seafarers tasked with steering (helmsmen) on board the ships of Peter Doehle Schiffahrts-KG should know

- how the operation of the tiller (or the NFU input device installed on board) differs from the operation of the hand wheel (or the FU input device) normally used.

It should be ensured that this information is also passed on to any person with the above duties in future, as soon as they take up these duties on board. For assignments on different ships, it is important to note that some of this knowledge is specific to the equipment or its manufacturer, and that such equipment may differ from one ship to another.

8 SOURCES

In addition to those mentioned in the report, the following sources were referred to:

- written statements of the master, chief engineer, and pilot;
- VDR audio recordings from the bridge;
- VTS Bremerhaven accident report;
- email correspondence with the shipping company (technical superintendent);
- email correspondence with the steering gear control system's manufacturer (Sperry);
- head of the Department of Marine Engineering at the Hamburg University of Technology, Prof. Dr.-Ing. Christopher Friedrich Wirz, by email, as well as *Gutachten / Analysebericht zur Kollision von M/T Northsea Rational im Hamburger Hafen im November 2020* [expert/analysis report on the allision involving the MT NORTHSEA RATIONAL in the port of Hamburg in November 2020] for BSU Investigation Report 405/20, 'Allision with a quay wall by the tanker NORTHSEA RATIONAL in Hamburg on 25 November 2020';
- operation, service, and survey reports of the steering gear control system, the steering gear, the diving operations, as well as from the classification society;
- hydraulic oil analysis report;
- the RUBINA's maintenance schedule for 2020;
- talks and consultations with the engineers who carried out the services mentioned above on the day of the BSU visit on board.