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Root Cause Analysis of a Diesel Generator Blackout Due to Fuel Rack Malfunction on the MV Sinar Sorong

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ABSTRACT

The electrical supply of a ship depends on its diesel generators, whose reliability in turn depends on a fuel system that delivers the correct quantity of fuel to each cylinder at the correct time. This study analyses a blackout on the container ship MV Sinar Sorong, which occurred while the ship was working cargo in the port of Singapore during the authors' sea practice from October 2022 to October 2023, in order to identify its root cause, explain the mechanism of failure, and propose preventive measures. A qualitative descriptive case study design was used, with data collected through observation, semi-structured interviews with the engineers and generator operators involved, documentation of damage reports, photographs, and engine and alarm logs, and a literature review; the causes were classified with a fishbone (Ishikawa) diagram. The incident began with a high exhaust gas temperature alarm on cylinder No. 3 of diesel generator No. 2, whose exhaust temperature rose from a normal value of about 370 °C to about 420 °C. This was followed by an overspeed alarm, as the engine speed rose from the nominal 900 rpm to about 960 rpm within 10 seconds, exceeding the overspeed trip setting of 105% of nominal speed (945 rpm), and the generator was shut down automatically, causing the blackout. Inspection showed that the fuel rack of the cylinder No. 3 Bosch-type injection pump was mechanically stuck in the high-fuel position and that the pump had a severely worn plunger and barrel and a clogged delivery valve. The worn and fouled pump caused poor injection and late combustion in cylinder No. 3, raising its exhaust temperature, while the seized rack prevented the governor from reducing the fuel supply when the load changed, leading to the overspeed trip. Planned maintenance of the fuel injection pumps on a running-hour basis, regular checking of the free movement of the fuel racks and governor linkage, close monitoring of individual cylinder exhaust temperatures, and thorough recording of component wear are recommended.

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1. INTRODUCTION

In most ships, the primary source of electricity is a set of diesel engines driving synchronous generators that supply the entire ship's electrical network (Tarnapowicz et al., 2023). Several generators are usually installed and connected to the main switchboard, and they are operated singly or in parallel to meet the power demand while providing redundancy in case one unit fails (German-Galkin et al., 2020; Michalopoulos et al., 2022). SOLAS requires the

main source of electrical power to consist of at least two generating sets with sufficient capacity that the services necessary for normal operation and habitable conditions can be maintained with any one set out of action (IMO, 2020). The reliability of these generators depends on the correct functioning of their supporting systems, particularly the fuel, cooling, and lubrication systems (Nahim et al., 2015; Stanivuk et al., 2021; Stoliaryk, 2022).

Among these, the fuel system plays a critical role in delivering clean fuel at the correct pressure, quantity, and timing to each cylinder, while the governor adjusts the fuel supply through the fuel racks to keep the engine speed constant under varying electrical loads (Woodyard, 2009). Settling and service tanks, purifiers, and filters prepare and clean the fuel, and pumps and heaters deliver it at the correct pressure, temperature, and viscosity (Anantharaman et al., 2015; Islam et al., 2019; Yang & Sun, 2022). Reliability studies of marine fuel oil systems show that the injection equipment is among the components most prone to failure (Anantharaman et al., 2015; Islam et al., 2019). Any imbalance or mechanical failure in the fuel delivery mechanism can lead to poor combustion, severe loss of efficiency, and, ultimately, the shutdown of a generator and a blackout of the ship's electrical network.



Figure 1. Diesel generators of the MV Sinar Sorong

In jerk-type (Bosch-type) injection pumps, which are widely used on medium-speed generator engines, each cylinder has its own pump consisting of a plunger and barrel, a delivery valve, and a control sleeve rotated by a fuel rack, as shown in Figure 2. The racks of all pumps are connected to a common regulating shaft driven by the governor, so that the quantity of fuel injected into each cylinder is changed by rotating the plunger relative to the spill port (Woodyard, 2009; Heywood, 2018).

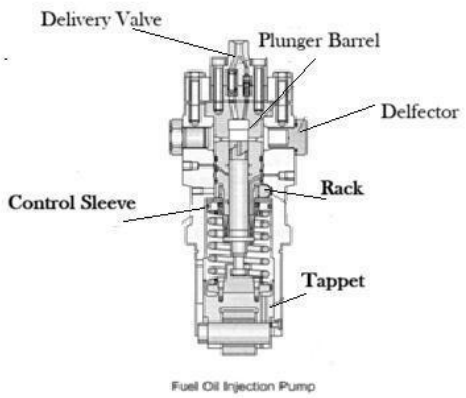


Figure 2. Main components of a Bosch-type fuel injection pump

Although the literature on diesel generator maintenance is extensive, there are few field-based case studies that trace how the failure of a single cylinder's fuel pump can lead to a ship-wide blackout. This gap is evident in the blackout that occurred on the MV Sinar Sorong, where a high exhaust gas temperature deviation in one cylinder was followed by an overspeed trip of the generator. This study therefore aims to (1) identify the root causes of the fuel rack failure on cylinder No. 3 of diesel generator No. 2; (2) analyse the effect of this localised mechanical failure on the performance of the engine, particularly the exhaust gas temperature deviation and the overspeed condition; and (3) propose preventive measures and maintenance practices to prevent recurrence. The contribution of the study is a component-level analysis of a real shipboard blackout that links a specific fuel rack malfunction to a system-wide failure, which can serve as a technical reference for maritime education and ship operators.

2. LITERATURE REVIEW

The fuel system of a marine diesel engine must deliver fuel of suitable quality in the correct quantity and at the correct time. Fuel treatment by settling, filtration, and centrifugal purification removes water and solid contaminants that would otherwise cause wear and deposits in the injection equipment (Anantharaman et al., 2015; Onishchenko et al., 2023). In the injection pump, wear of the plunger and barrel increases internal leakage, reducing the injection pressure and quantity and delaying the start of injection, while a leaking or fouled delivery valve affects the residual pressure in the injection line and the sharpness of injection; both lead to poor atomisation, late and incomplete combustion, and higher exhaust temperatures (Woodyard, 2009; Heywood, 2018). Deposits, corrosion, or wear can also cause the fuel rack or control sleeve to stick, so that the quantity of fuel no longer follows the governor.

Cooling and lubrication systems are equally important for engine reliability. The cooling system prevents overheating, and models of the cooling and lubrication systems help to diagnose faults (Nahim et al., 2015; Moussa Nahim et al., 2016; Stanivuk et al., 2021). Lubricants reduce friction, wear, and corrosion of engine components, and regular oil purification preserves their quality (Stoliaryk, 2022; Onishchenko et al., 2023).

Condition monitoring of individual cylinder exhaust temperatures is one of the most effective means of detecting combustion faults early, because a deviation of one cylinder from the others indicates a problem with its injection, valves, or compression (Ji et al., 2023). Data-driven and machine learning methods can identify such faults from engine data (Chin & Nazli, 2021; Koçak et al., 2023), and fault tree and root cause methods help to identify the critical components of engine subsystems (Knežević et al., 2020). Maintenance strategies for ship machinery are shifting from corrective and time-based maintenance towards preventive and condition-based maintenance (Jimenez et al., 2020; Song et al., 2022; Karatuğ et al., 2023). Studies of generator failures on Indonesian ships similarly show that inadequate maintenance of the fuel and combustion systems leads to loss of power and engine damage (Ridwan et al., 2020; Zega et al., 2024).

3. METHODS

This study used a qualitative descriptive case study design (Moleong, 2011) to describe in detail the technical phenomenon of a fuel system failure on a ship's diesel generator, based on the authors' experience during sea practice. The study was carried out on board the MV Sinar Sorong, a container ship operating on domestic and international routes, from 16 October 2022 to 17 October 2023. The incident analysed was a blackout caused by the failure of the fuel rack of one cylinder of a diesel generator while the ship was working cargo in the port of Singapore.

Primary data were collected through semi-structured interviews with the engineers and generator operators who experienced the incident and through participatory observation of the condition of the fuel system, the damaged components, and the generator control system. Secondary data were obtained from technical documentation, including damage reports, photographs of the components, and the engine and alarm logs. The data were analysed with a fishbone (Ishikawa) diagram, a cause-and-effect tool widely used in quality and engineering analysis (Ishikawa, 1986), in which the causes were classified into the categories of man, machine, method, material, and environment.

4. RESULTS AND DISCUSSION

4.1. Sequence of the Incident

The data from observation, interviews, photographs, and the alarm logs of the diesel generators made it possible to reconstruct the sequence of events leading to the blackout, as summarised in Table 1.

Table 1. Sequence of events leading to the blackout

Stage	Observation	Source
1	Exhaust gas temperature of cylinder No. 3 of DG No. 2 rose from the normal value of about 370 °C to about 420 °C; high exhaust gas temperature alarm in the engine control room	Alarm log, local thermometer (Figure 3)
2	Overspeed alarm: engine speed rose from the nominal 900 rpm to about 960 rpm within 10 seconds, exceeding the overspeed trip setting of 105% (945 rpm)	Engine monitoring system, operational log
3	Automatic overspeed shutdown of DG No. 2 and loss of power on the main switchboard (blackout)	Alarm log, interviews
4	Inspection: fuel rack of the cylinder No. 3 injection pump mechanically stuck in the high-fuel position; generator could not be restarted until the pump was repaired	Physical inspection, damage report
5	Dismantling of the Bosch-type pump: severely worn plunger and barrel and clogged delivery valve (Figure 4)	Physical inspection, photographs



Figure 3. Exhaust gas thermometer of the diesel generator

The first sign of the fault was the rise of the exhaust gas temperature of cylinder No. 3 above its normal range, which triggered the high exhaust gas temperature alarm. Shortly afterwards, the overspeed alarm sounded, and the engine monitoring system showed that the speed of diesel generator No. 2 rose from 900 rpm to about 960 rpm in less than 10 seconds. Because this exceeded the overspeed trip setting of 105% of nominal speed, the safety system shut the generator down, and the loss of the generator resulted in a blackout. Physical inspection

after the shutdown showed that the fuel rack of the cylinder No. 3 pump was stuck in the high-fuel position and did not respond to the governor or to the shutdown command.



Figure 4. Dismantled fuel injection pump of cylinder No. 3

To find the cause of the stuck rack, the Bosch-type pump of cylinder No. 3 was dismantled. The inspection revealed severe wear of the plunger and barrel and a heavily clogged delivery valve. These defects restricted the free movement of the control sleeve and rack and impaired the injection process, which explains both the localised rise of the exhaust gas temperature in cylinder No. 3 and the loss of fuel control.

4.2. Root Cause Analysis

The causes of the blackout identified from the field data are shown in the fishbone diagram in Figure 5. Only the machine factors were confirmed by physical inspection; the factors in the other categories are possible contributing factors identified from the interviews and the literature.

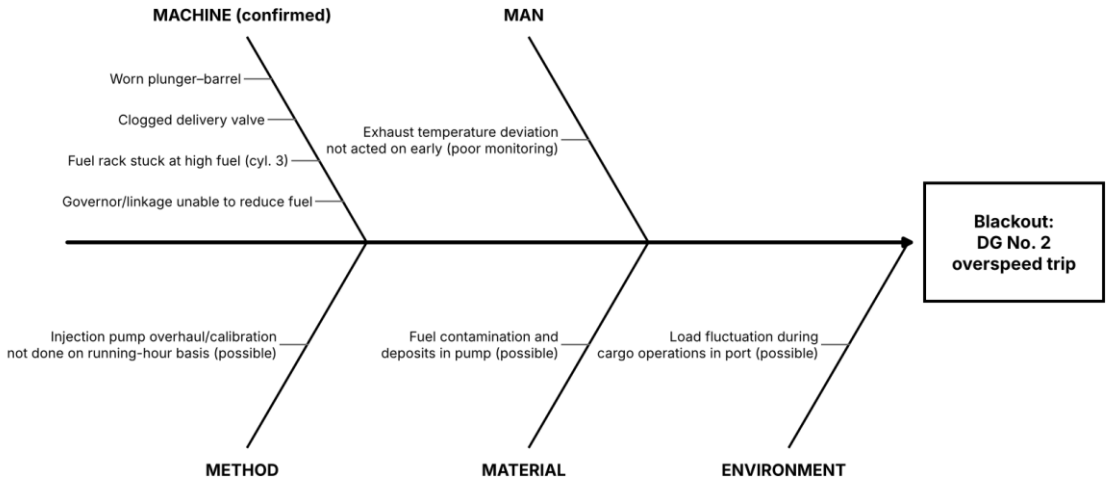


Figure 5. Fishbone diagram of the blackout on the MV Sinar Sorong

a. Relationship between the injection pump condition and the exhaust gas temperature. The rise of the exhaust gas temperature in cylinder No. 3 is explained by the condition of its injection pump. Wear of the plunger and barrel increases internal leakage, so that the injection pressure builds up more slowly and the start of injection is delayed, while the clogged delivery valve disturbs the delivery of fuel to the injector. The result is poor atomisation and late combustion, which continues into the expansion stroke. Late combustion lowers the peak cylinder pressure and the work done on the piston but raises the temperature of the gases leaving the cylinder, so that more of the fuel energy is lost as exhaust heat (Heywood, 2018). The high exhaust temperature also accelerates the wear of the exhaust valves and the turbocharger (Knežević et al., 2020). Monitoring the deviation of individual cylinder exhaust temperatures from the mean is therefore an effective early warning of injection faults (Ji et al., 2023).

b. Overspeed as a consequence of the stuck fuel rack. The fuel racks of all cylinders are linked to the governor through a common regulating shaft. When the rack of cylinder No. 3 seized in the high-fuel position, the governor could no longer reduce the fuel supply effectively, either because the seized rack restricted the movement of the common linkage or because the cylinder continued to receive excess fuel regardless of the governor. When the electrical load on the generator decreased, which is common during cargo operations when cranes and other consumers are switched on and off, the fuel supply could not be reduced quickly enough, and the engine accelerated beyond its safe speed. The overspeed trip then shut down the generator to prevent mechanical damage, and because the remaining

power supply could not take over the load in time, the result was a blackout (Woodyard, 2009).

c. **Contributing factors.** The wear and fouling found in the pump indicate that the injection equipment had not been overhauled or tested before reaching the end of its service life, and that the early warning given by the rising exhaust temperature was not acted on in time. Contaminated fuel and deposits are a common cause of clogged delivery valves and sticking racks (Anantharaman et al., 2015; Islam et al., 2019). These findings are consistent with studies showing that combustion and fuel system faults are among the main causes of generator failures on ships and that planned and condition-based maintenance reduces such failures (Jimenez et al., 2020; Karatuğ et al., 2023; Zega et al., 2024).

4.3. Preventive Measures

Based on the root cause analysis, the following preventive measures are recommended: (1) overhaul and calibration of the fuel injection pumps and injectors at the intervals specified by the manufacturer, based on running hours; (2) regular checking of the free movement of each fuel rack and of the governor linkage, for example by moving the regulating shaft through its full range with the engine stopped; (3) monitoring of individual cylinder exhaust temperatures and their deviation from the mean, with immediate investigation of any abnormal deviation; (4) regular testing of the overspeed trip and the governor response; (5) maintenance of fuel treatment equipment, including purifiers and filters, to prevent contamination of the injection equipment; and (6) thorough recording of component wear and maintenance in the planned maintenance system (Song et al., 2022; Karatuğ et al., 2023). This study is limited to one incident and to qualitative data; the running hours of the injection pump, measurements of plunger clearance, and fuel analysis results were not available, so the relative contribution of each cause could not be quantified.

5. CONCLUSION

The blackout on the MV Sinar Sorong was caused by mechanical failure of the fuel injection pump of cylinder No. 3 of diesel generator No. 2, consisting of a fuel rack stuck in the high-fuel position, severe wear of the plunger and barrel, and a clogged delivery valve. The worn and fouled pump caused poor injection and late combustion in cylinder No. 3, raising its exhaust gas temperature from about 370 °C to about 420 °C, while the stuck rack prevented the governor from controlling the fuel supply, so that the engine speed rose from 900 rpm to about 960 rpm, exceeding the overspeed trip setting and causing the generator to shut down and the ship to black out.

To prevent recurrence, marine engineers should overhaul and calibrate the injection equipment on a running-hour basis, check the free movement of the fuel racks and governor linkage regularly, monitor individual cylinder exhaust temperatures closely, test the overspeed protection, maintain the fuel treatment equipment, and record component wear thoroughly.

6. DECLARATIONS

Author contributions: D.D.S.: Conceptualization, Methodology, Supervision, Writing – review & editing; R.U.: Formal analysis, Validation, Writing – review & editing; M.R.S.A.: Investigation, Data curation, Writing – original draft; A.D.M.: Visualization, Writing – review & editing. All authors have read and approved the final manuscript.

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Data availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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