Jurnal Venus
Volume 13 Number 1, 2025, pages 68-79
p-ISSN: 2338-4611, e-ISSN: 2798-0995

Analysis of Broken Piston Rings in the Auxiliary Engine of the MV Fatime

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ABSTRACT

The auxiliary engines that drive a ship's generators must operate reliably, and their piston rings are critical for maintaining compression and preventing the leakage of combustion gases. This study identifies the causes of the piston ring damage in an auxiliary engine of the MV Fatime and the measures taken to repair it and prevent recurrence. A descriptive qualitative design was used, with data collected through observation, interviews with engineers and crew, and technical documentation, including engine operating records, during the authors' sea practice. On 14 January 2024, during a voyage from China to Brunei, the auxiliary engine stopped, and the Third Engineer found the piston of cylinder No. 3 sticking. Dismantling revealed a broken compression ring and a worn and corroded oil ring. The operating records showed that, compared with the normal condition, the exhaust gas temperature of cylinder No. 3 fell progressively from 325 °C to 265 °C over 24 hours and the engine speed fell from 714 to 660 rpm, while the other cylinders remained at about 328–332 °C; after repair, cylinder No. 3 returned to 328–331 °C and the speed to 719–720 rpm. The damage was attributed mainly to exceeded running hours and inadequate lubrication, with cooling problems and contaminated intake air as possible contributing factors. The broken rings were replaced and the cylinder head and piston were cleaned. Lubricating oil changes according to the maker's schedule, monitoring of running hours and of individual cylinder exhaust temperatures, and regular measurement of ring clearances are recommended.

Keywords: Piston Ring, Auxiliary Engine, Engine Failure, Ship Maintenance, Exhaust Gas Temperature

ABSTRAK

Mesin bantu yang menggerakkan generator kapal harus beroperasi secara andal, dan ring piston merupakan komponen penting untuk menjaga kompresi serta mencegah kebocoran gas pembakaran. Penelitian ini bertujuan untuk mengidentifikasi penyebab kerusakan ring piston pada mesin bantu kapal MV Fatime serta langkah perbaikan dan pencegahan yang dilakukan. Penelitian menggunakan metode deskriptif kualitatif dengan pengumpulan data melalui observasi, wawancara dengan masinis dan awak kapal, serta dokumentasi teknis, termasuk catatan operasional mesin, selama praktik laut penulis. Pada 14 Januari 2024, dalam perjalanan dari China menuju Brunei, mesin bantu mati, dan Masinis III menemukan piston silinder nomor 3 macet. Pembongkaran menunjukkan ring kompresi patah serta ring oli aus dan berkarat. Catatan operasional menunjukkan bahwa, dibandingkan kondisi normal, temperatur gas buang silinder nomor 3 turun secara bertahap dari 325 °C menjadi 265 °C dalam 24 jam dan putaran mesin turun dari 714 menjadi 660 rpm, sedangkan silinder lainnya tetap sekitar 328–332 °C; setelah perbaikan, silinder nomor 3 kembali ke 328–331 °C dan putaran kembali ke 719–720 rpm. Kerusakan terutama disebabkan oleh jam kerja yang terlampaui dan pelumasan yang tidak memadai, dengan masalah sistem pendingin dan udara masuk yang kotor sebagai faktor pendukung yang mungkin. Ring yang patah diganti, serta cylinder head dan piston dibersihkan. Disarankan penggantian

minyak lumas sesuai jadwal pabrikan, pemantauan jam kerja dan temperatur gas buang setiap silinder, serta pengukuran celah ring secara berkala.

Kata Kunci: Ring Piston, Mesin Bantu, Kerusakan Mesin, Perawatan Kapal, Temperatur Gas Buang

Article Info
Received January 10, 2025
Revised February 27, 2025
Accepted March 31, 2025

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Citation: Suyuti, Musriady, Danduru, A., & Darwis. (2025). Analysis of broken piston rings in the auxiliary engine of the MV Fatime. *Jurnal Venus*, *13*(1), 68–79. https://doi.org/10.48192/vns.v13i1.744

1. INTRODUCTION

Technological progress has intensified business competition, and many sectors depend on reliable transport to support their operations. In an archipelagic country such as Indonesia, sea transport plays a vital role in the distribution of goods and services between islands because it is efficient, safe, and able to reach wide areas. Shipping companies are therefore required to provide timely, secure, and safe services, which in turn requires ships, and especially their machinery, to be kept in prime condition.

One of the vital components of a ship's machinery is the auxiliary engine, which drives the generators that supply the ship's electrical system. The performance of an auxiliary engine depends on the condition of its components, including the pistons and piston rings. Piston rings maintain gas pressure during the compression and combustion strokes, prevent the leakage of combustion gases from the combustion chamber, control the lubricating oil film on the cylinder liner, and transfer heat from the piston to the liner (Rao et al., 2021). Damage to the piston rings, such as a broken ring, can reduce engine efficiency, cause further damage to other components, and even stop the ship's operation (Caldera et al., 2017; Ruban & Bulgakov, 2020). The condition of individual cylinders can be monitored through operating parameters such as exhaust gas temperature (Prasetyo, 2022; Ji et al.,

2023), and engine performance can be evaluated through systematic testing (Wahyu, 2019).

In practice, many shipping companies still apply conventional maintenance based only on written records, without in-depth analysis of potential failures, so problems that could be prevented are difficult to detect early (Karatuğ et al., 2023). National studies have analysed piston ring failure in a main engine (Ngatmin et al., 2023), cylinder liner cracking in a diesel generator (Tona & Rohman, 2023), and the causes of generator diesel engine damage (Zega et al., 2024), but few have linked piston ring damage in an auxiliary engine to the trend of its operating data. This study therefore analyses the case of broken piston rings in an auxiliary engine of the MV Fatime, with the aim of identifying the causes of the damage and its effects and recommending appropriate maintenance measures to prevent similar damage in the future.

1.1. Auxiliary Engines and Their Working Principle

An auxiliary engine, or diesel generator, combines a diesel engine and an electric generator to produce electricity for the ship's needs, including lighting. Diesel engines may operate on the two-stroke or four-stroke cycle, and the arrangement of the cylinders and the firing order are designed to keep the engine running smoothly and to prevent excessive vibration. In a four-stroke engine, when the piston moves from top dead centre (TDC) to bottom dead centre (BDC), the intake valve opens and air enters the cylinder. When the piston moves from BDC to TDC with the intake and exhaust valves closed, the air is compressed, raising its pressure and temperature. Shortly before TDC, fuel is injected into the cylinder and ignites in the hot air, and the thermal energy of combustion is converted into mechanical energy through the crankshaft.

1.2. Piston Rings and Their Failure

Piston rings are split rings fitted in grooves on the piston. They seal the gap between the piston and the cylinder wall, prevent the piston from rubbing directly against the liner, and thereby reduce friction and wear. Compression rings seal the combustion chamber, while the oil ring regulates the amount of lubricating oil reaching the cylinder wall and prevents excess oil from entering the combustion chamber (Rao et al., 2021; Soejima et al., 2017). Piston rings can break because of inadequate lubrication, degraded or contaminated lubricating oil, overheating,

excessive running hours, incorrect clearances, or deposits and wear (Caldera et al., 2017; Motamen Salehi et al., 2017). When a ring breaks, combustion gases leak past the piston (blow-by), so that the compression pressure and temperature fall and combustion in that cylinder becomes incomplete (Rao et al., 2021). Condition monitoring of the liner and ring set is therefore an important part of diesel engine maintenance (Rao et al., 2021; Asimakopoulos et al., 2024).

2. METHOD

This study used a descriptive qualitative approach with inductive analysis, in which events observed in the field were used as the objects of the study (Moleong, 2004). Data were collected during the authors' sea practice on the MV Fatime through direct observation and documentation of the damaged piston rings of the auxiliary engine, interviews with the engineers and crew involved, and technical documents, including the engine operating records and the maker's maintenance schedule. The persons involved are identified only by their rank. The data were processed and analysed by collecting, grouping, and interpreting the observations, comparing the operating data under normal, abnormal, and post-repair conditions, and mapping the repair method and maintenance steps on the basis of the analysis.

3. RESULTS AND DISCUSSION

3.1. Piston Ring Failure Incident

On 16 December 2023, the MV Fatime left the Philippines for Muara Port, Brunei, for repairs, including the dismantling and replacement of auxiliary engine components. On 14 January 2024, during a voyage from China to Brunei, the auxiliary engine stopped. The Third Engineer found that the piston of cylinder No. 3 was sticking and reported this to the Chief Engineer. The engine was then dismantled, and damage to the piston rings was found: the compression ring was broken, causing a loss of compression and reduced combustion efficiency, and the oil ring was worn and corroded, resulting in poor lubrication and accelerated wear of other components. The Chief Engineer ordered the replacement of the damaged rings and a thorough cleaning of the cylinder head and piston to restore the engine's performance. The used piston rings are shown in Figure 1.

Figure 1. Used Piston Rings Removed from the Auxiliary Engine

3.2. Operating Data of the Auxiliary Engine

The operating data of the auxiliary engine under normal conditions, during the abnormal condition before the failure, and after repair are presented in Tables 1–3.

Table 1. Operating Data of the Auxiliary Engine under Normal Conditions

Time (h)	T1	T2	T3	T4	T5	T6	CW in (°C)	LO p (bar)	Speed (rpm)	FO p (bar)
00:00–04:00	330	328	332	331	329	330	77	4.0	719	6.5
04:00–08:00	331	329	330	330	332	331	78	4.0	718	6.5
08:00–12:00	332	330	331	329	330	331	77	4.0	718	6.5
12:00–16:00	329	331	330	332	328	330	79	4.0	718	6.5
16:00–20:00	330	332	329	331	330	331	78	4.0	720	6.5
20:00–24:00	331	330	330	332	329	331	78	4.0	719	6.5

T1–T6: exhaust gas temperature of cylinders 1–6 (°C); CW in: cooling water inlet temperature; LO p: lubricating oil pressure; FO p: fuel oil pressure.

Table 2. Operating Data of the Auxiliary Engine under Abnormal Conditions

Time (h)	T1	T2	T3	T4	T5	T6	CW in (°C)	LO p (bar)	Speed (rpm)	FO p (bar)
00:00–04:00	331	329	325	329	330	331	78	4.0	714	6.5
04:00–08:00	330	331	305	329	331	330	77	4.0	710	6.5
08:00–12:00	332	330	285	330	332	330	77	4.0	700	6.5
12:00–16:00	328	329	280	330	329	331	78	4.0	690	6.5
16:00–20:00	329	330	275	332	331	330	79	4.0	675	6.5
20:00–24:00	330	331	265	331	332	332	79	4.0	660	6.5

T1–T6: exhaust gas temperature of cylinders 1–6 (°C); CW in: cooling water inlet temperature; LO p: lubricating oil pressure; FO p: fuel oil pressure.

Table 3. Operating Data of the Auxiliary Engine after Repair

Time (h)	T1	T2	T3	T4	T5	T6	CW in (°C)	LO p (bar)	Speed (rpm)	FO p (bar)
00:00–04:00	332	331	329	330	331	330	77	4.0	719	6.5
04:00–08:00	331	332	328	331	332	330	78	4.0	719	6.5
08:00–12:00	331	331	329	332	331	331	79	4.0	720	6.5
12:00–16:00	330	328	330	331	328	332	77	4.0	720	6.5
16:00–20:00	330	331	330	331	330	329	77	4.0	719	6.5

Time (h)	T1	T2	T3	T4	T5	T6	CW in (°C)	LO p (bar)	Speed (rpm)	FO p (bar)
20:00–24:00	329	330	331	330	329	330	78	4.0	720	6.5

T1–T6: exhaust gas temperature of cylinders 1–6 (°C); CW in: cooling water inlet temperature; LO p: lubricating oil pressure; FO p: fuel oil pressure.

Under normal conditions (Table 1), the exhaust gas temperatures of all six cylinders were uniform at 328–332 °C, and the engine speed was stable at 718–720 rpm. In the abnormal condition (Table 2), the exhaust gas temperature of cylinder No. 3 fell progressively from 325 °C to 265 °C over 24 hours, while the other cylinders remained at 328–332 °C, and the engine speed fell from 714 rpm to 660 rpm. The cooling water inlet temperature (77–79 °C), lubricating oil pressure (4.0 bar), and fuel oil pressure (6.5 bar) did not change. After repair (Table 3), the exhaust gas temperature of cylinder No. 3 returned to 328–331 °C, in line with the other cylinders, and the engine speed returned to 719–720 rpm.

The progressive fall in the exhaust gas temperature of a single cylinder indicates that less fuel was being burned effectively in that cylinder, which is consistent with a loss of compression caused by the broken compression ring and the resulting blow-by. The fall in engine speed reflects the loss of power from this cylinder. Because the lubricating oil and fuel oil pressures remained constant, the problem was local to cylinder No. 3 rather than a failure of the lubricating or fuel supply systems. Individual cylinder exhaust temperatures are therefore a useful early-warning indicator of developing faults (Ji et al., 2023; Liu et al., 2023; Koçak et al., 2023), and continuous monitoring of the trend in Table 2 could have allowed the problem to be detected several hours before the engine stopped.

3.3. Periodic Maintenance and Inspection

The maker's periodic maintenance schedule for the diesel generator, as applied on board during the sea practice, is summarised in Table 4. Each item is assigned a checking period class.

Table 4. Periodic Maintenance Schedule of the Diesel Generator

System	Part	Service	Class	Remarks
Fuel oil system	Fuel injection pump	Check rack scale position	A	
	Fuel injection valve	Check injection pressure and atomisation	B	Replace if faulty
	Fuel injection valve	Remove carbon; disassemble, clean, and check	B	
	Fuel injection valve	Replace nozzle spring	C	Replace nozzle
Fuel oil filter and tank	Filter	Drain; disassemble and clean	A	
	Fuel tank	Check oil volume	A	

System	Part	Service	Class	Remarks
	Fuel tank	Discharge sediment and moisture; drain	C	
Fuel feed pump	Pump	Disassemble and check major parts	B	
	Oil seal	Replace	C	Every 20,000 running hours
	Oil seal	Check for oil leakage	A	
Lubricating oil system	Lubricating oil pump	Disassemble and check major parts	B	
	Oil pan	Check oil volume	A	
	Lubricating oil strainer	Drain	A	
	Lubricating oil cooler	Disassemble, clean, and check	B	Every 20,000 running hours
	Lubricating oil cooler	Replace	C	
	Intake valve rocker	Check oil feeding condition	A	
Reciprocating parts	Piston and piston pin	Draw out piston and rings; remove carbon; measure	B	
	Connecting rod	Check and replace piston pin bush	B	Every 15,000 running hours
	Cylinder liner	Measure inner diameter	D	
	Water jacket	Remove and check	C	
	Main bearing	Check bearing; check clamping bolts	A / B	
	Main bearing	Replace	C	
Cooling water system	Fresh water pump	Check leakage from mechanical seal	A	
	Sea water pump	Check water leakage	A	
	Anti-corrosion zinc	Check and replace	A	
	Thermostat	Disassemble, check, and clean	C	

Inspection and maintenance on board are organised into daily checks of basic components and periodic work every 200–250, 400–500, 1,000–1,200, 2,000–2,500, 4,000–5,000, and 8,000–10,000 running hours. Inspection of the piston rings involves (a) removing the components needed to access the piston and rings, such as the cylinder head; (b) visually inspecting the rings for wear, cracks, or deformation; (c) checking that there are no deposits of dirt or carbon on the rings and around the oil passages; (d) checking for corrosion or uneven wear; (e) testing the compression after the visual inspection, where possible; and (f) measuring the ring end gap and side clearance with a clean and flat feeler gauge, which is essential for maintaining compression pressure (Hermawati et al., 2020).

3.4. Causes of the Piston Ring Damage

Based on the observations and interviews, the following factors were identified as causes or possible contributors to the piston ring damage.

a. Lubricating oil changes not in accordance with the schedule. The on-board practice specified a lubricating oil change every 250 running hours under normal conditions, or every 100–200 hours under heavy conditions. Failure to follow this schedule leads to oil degradation, reduced lubrication, excessive friction on the

piston rings, and abrasion by contaminants in the old oil (Motamen Salehi et al., 2017; Sentanuhady et al., 2020; Santana et al., 2022).

b. Cooling system problems. Overheating caused by problems in the cooling system raises the cylinder temperature and lowers the viscosity of the lubricating oil, which can damage the liner, piston, and rings (Subekti et al., 2022).

c. Excessive running hours. Operating the engine beyond the specified running hours without proper maintenance causes the rings to wear, while prolonged use of the oil reduces lubrication and viscosity and increases friction, load, and engine temperature (Ruban & Bulgakov, 2020). The incident on the MV Fatime shows that the running hours of auxiliary engine components must be monitored carefully.

d. Insufficient lubrication of the cylinder liner, contaminated intake air, and incorrect ring clearance. If the oil film between the rings and the liner is insufficient, friction increases and wear accelerates (Soejima et al., 2017). Dirty intake air, for example because of a clogged air filter, introduces particles that can lodge in the ring grooves and impair the rings (Akal & Selvi, 2023). Rings whose end gap or side clearance is outside the specified limits cannot seal the cylinder properly, which is why the ring clearances were checked with a feeler gauge every three months (Hermawati et al., 2020).

3.5. Repair and Preventive Measures

The broken compression ring and the worn oil ring indicate serious problems in the lubrication of the cylinder and in the combustion chamber. Maintenance such as checking the lubricating oil, changing the oil according to the standard, and checking the oil pressure regularly is therefore essential to extend the service life of the pistons and rings. The rings must be installed and sized according to the specification, and heavy operating conditions should be minimised to reduce wear. The lubricating oil used on board (reported as Shell Rimula, SAE 10W-40) should be verified against the specification of the engine maker for the Yanmar 6N165 engine, and the oil filter should be replaced together with each oil change. Regular oil analysis can further help determine the actual condition of the oil (Santana et al., 2022).

Correct installation of the piston rings is essential to prevent further damage. The procedure comprises: (1) checking the engine manual for the specification, type, and position of the rings and ensuring that the rings match the piston and

cylinder; (2) preparing a feeler gauge, a ring expander, and cleaning materials; (3) cleaning the piston, ring grooves, and cylinder of carbon and dirt and ensuring that all parts are dry; (4) inspecting the rings for cracks or deformation and measuring the ring gap with a feeler gauge; (5) fitting the oil ring in the lowest groove, with the expander first and then the scraper rings, followed by the compression rings from the bottom groove upwards using a ring expander, with the marked side (such as “TOP”) facing upwards; (6) staggering the ring gaps at about 120° intervals around the piston; (7) lubricating the rings, piston, and cylinder wall with the specified oil and inserting the piston carefully using a ring compressor, pressing it gently with a wooden or rubber mallet handle; (8) rotating the crankshaft by hand to check that the piston moves freely; and (9) carrying out a compression test, recording the results, and running the engine to confirm its performance. Pinching or damaging the rings during installation must be avoided, and the maker’s procedures must be followed.

3.6. Discussion

The failure on the MV Fatime followed a typical pattern of piston ring damage in diesel engines: a broken compression ring and a worn oil ring led to loss of compression, incomplete combustion in the affected cylinder, and eventually sticking of the piston. Similar mechanisms have been reported in failure analyses of diesel engine pistons (Caldera et al., 2017), in studies of failures of medium-speed diesel engines (Ruban & Bulgakov, 2020), and in national case studies of piston ring failure and cylinder liner damage (Ngatmin et al., 2023; Tona & Rohman, 2023; Zega et al., 2024). The operating data in Table 2 show that the fault developed over at least 24 hours before the engine stopped, which supports the use of condition monitoring of the liner and ring set and of exhaust temperatures to detect such faults early (Rao et al., 2021; Asimakopoulos et al., 2024; Ji et al., 2023). Studies of the power loss of auxiliary engines on Indonesian ships likewise emphasise the importance of systematic maintenance for maintaining generator output (Ridwan et al., 2020).

From a maintenance perspective, the case shows the limits of time-based maintenance carried out only on paper. Combining the maker’s schedule with monitoring of running hours, oil condition, and cylinder exhaust temperatures supports a shift towards predictive and condition-based maintenance (Jimenez et

al., 2020; Song et al., 2022; Karatuğ et al., 2023), while fault tree and root-cause approaches help identify the most critical components (Knežević et al., 2020). This study is limited by the absence of recorded running hours of the rings, oil analysis results, and ring clearance measurements before the failure, which would have allowed the contribution of each cause to be quantified.

4. CONCLUSION

Based on the observations and analysis, the following conclusions can be drawn.

1. The auxiliary engine of the MV Fatime stopped because the compression ring of cylinder No. 3 broke and the oil ring was worn and corroded, which caused loss of compression and poor lubrication and led to sticking of the piston.
2. The damage was reflected in the operating data: the exhaust gas temperature of cylinder No. 3 fell from 325 °C to 265 °C and the engine speed from 714 to 660 rpm, while the lubricating oil and fuel oil pressures remained constant. After the rings were replaced and the cylinder head and piston were cleaned, the exhaust temperature and speed returned to normal.
3. The main causes were exceeded running hours and inadequate lubrication, with cooling problems, contaminated intake air, and incorrect ring clearances as possible contributing factors. Lubricating oil changes according to the maker's schedule, monitoring of running hours and individual cylinder exhaust temperatures, regular measurement of ring clearances, and correct ring installation are recommended.

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