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The Influence of Puncture Valve Wear on Bosch Pump Pressure and Main Engine Performance: A Quantitative Analysis of KM. Tanto Bersinar

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Abstract

The Main Mover Diesel Engine or Main Engine on a ship is the main device responsible for moving the ship forward and backward. The diesel engine fuel system, which includes the Bosch Pump, is a critical component in maintaining the engine's performance by providing the fuel necessary for combustion and propulsion of the vessel. The injector, which is used to spray fuel into the engine cylinder, is an important part of the system that supports the efficient combustion process in the main engine. The method used is a quantitative method which includes the collection and analysis of numerical data. By conducting surveys, experiments, or secondary data analysis, researchers can find patterns or generalizations in a larger population. By using quantitative methods, it will be possible to determine the cause of the decrease in Bosch pump pressure on the ship MV.Tanto Bersinar. The analysis of running hoaurs of puncture valve on the fuel injection pump for cylinder 1-8 demonstrates that the wear of puncture valve especially in cylinder 2 with 4.970 hours approaching the planned maintenance system (PMS)limit of 5.000 hours significantly affects injection pressure stability ,combustion,quality ,and main engine officiency ,which can be restored throngh critical component replacement,inspections close to PMS and injection pump recalibration.

Keywords*: Master Machine, Bosch Pump, Quantitative, Puncture Valve*

1. Introduction

Seafaring is a profession that is full of challenges, the need for the profession of seafarers in the world is increasing in direct proportion to the rate of increase in the world economy (Zainuddin, 2021). The global maritime industry serves as the backbone of international trade, accounting for the transportation of over 80% of global merchandise by volume. In the context of Indonesia, the world's largest archipelagic state, sea transportation is not merely a commercial sector but a vital artery for national integration, economic distribution, and logistical connectivity. The reliability of this transportation network is inextricably linked to the operational readiness of the merchant fleet, which is predominantly powered by large, slow-speed, two-stroke diesel engines. These engines are engineering marvels designed for durability and thermal efficiency, yet they rely on intricate subsystems to function. Among these, the fuel injection system is arguably the most critical, acting as the heart of the engine by pressurizing and metering fuel for combustion.

The maritime domain employs communications for a variety of critical applications, including safety, routine operational activities, and commercial applications such as trade and general correspondence (Yudianto et al., 2024). The fuel injection pump, often referred to as the Bosch pump due to the prevalence of the jerk-pump design pioneered by Robert Bosch, is responsible for generating the immense hydraulic pressures—often exceeding 800 bar in modern engines requisite for atomizing Heavy Fuel Oil (HFO) into the combustion chamber. The precise control of this injection process determines the engine's power output, fuel efficiency, and emissions profile. However, the performance of the Bosch pump is contingent upon the integrity of its internal components, including the plunger, barrel, suction valve, and the puncture valve.

The puncture valve is a safety and control device integrated into the top cover of the fuel injection pump on MAN B&W MC series engines. Its primary function is to interrupt the fuel injection process during engine stop sequences, reversing maneuvers, or emergency shutdowns (Ashadrul et al., 2016). It operates by utilizing compressed air to actuate a piston that "punctures" the hydraulic seal, venting high-pressure fuel back to the circulation line, thereby preventing injection regardless of the fuel rack's position. Despite its auxiliary role as a safety device, the puncture valve is subjected to the same cyclic hydraulic stresses as the pumping elements. Consequently, it is prone to tribological degradation, including abrasive wear on the piston and adhesive wear on the sealing surfaces.

Operational data from the KM. Tanto Bersinar, a container carrier operating on the Surabaya-Medan route, indicates a correlation between the extended running hours of these valves and a decline in Bosch pump injection pressure. When a puncture valve wears, it loses its ability to seal effectively during the injection stroke. This creates a parasitic leak path where fuel intended for the injector nozzle bypasses the delivery valve and returns to the suction side. The result is a drop in injection pressure, leading to poor atomization, incomplete combustion, and a noticeable loss of engine power (Yaqin et al., 2020).

This phenomenon is critical because a decrease in Bosch pump pressure does not merely reduce vessel speed; it fundamentally alters the thermodynamic balance of the engine. Incomplete combustion results in the formation of soot and carbon deposits, which can foul the turbocharger, exhaust valves, and economizer, leading to a cascading deterioration of the vessel's machinery. Furthermore, if the pressure drop is localized to a single cylinder—as observed in this case study—it creates a power imbalance across the crankshaft, inducing torsional vibrations that can threaten the structural integrity of the engine .

While the general principles of diesel engine maintenance are well-documented in marine engineering literature, there is a paucity of specific, quantitative case studies that isolate the puncture valve as a primary failure mode in the MITSUI MAN B&W 8S50MC engine series. Previous research, such as the work by (Firdaus, 2022), has analyzed Bosch pump damage broadly, focusing on rack jamming or plunger seizure caused by fuel contamination. Similarly, studies by (Sarean, 2024) have focused on the injector nozzle's spray pattern and atomization efficiency.

However, the specific correlation between the *running hours* of the puncture valve—specifically as it approaches the Planned Maintenance System (PMS) limit—and the catastrophic loss of injection pressure remains under-analyzed in applied engineering journals. Most literature treats the puncture valve as a binary component (working/not working) rather than a component that undergoes progressive degradation affecting thermodynamic parameters. This research seeks to fill that gap by providing a granular analysis of how puncture valve wear directly influences exhaust gas temperatures and rack positions, serving as a diagnostic indicator for marine engineers).

2. Research Methodology

2.1 Research Design

This study employs a quantitative descriptive research design (Waruwu et al., 2025). It relies on the systematic collection and statistical analysis of numerical data to identify patterns, causal relationships, and trends associated with engine component failure. The research moves beyond qualitative troubleshooting to quantify the relationship between running hours (wear) and performance deviation.

2.2 Time and Location of Research

The research was conducted onboard the merchant vessel KM. Tanto Bersinar during a period of sea service (Pranala) spanning 12 months and 2 days, from 10 July 2024 to 12 July 2025. The vessel is owned and operated by PT. Tanto Intim Line, serving the domestic shipping route between Terminal Teluk Lamong (Surabaya) and Port of Gabion (Medan).

Ship Particulars :

- Name: KM. Tanto Bersinar
- Type: Container Carrier (1005 TEUs)
- Length Overall (LOA): 161.85 Meters
- Gross Tonnage (GRT): 13,235 RT
- Main Engine: MITSUI MAN B&W 8S50MC
- Power (MCR): 15,520 PS x 127 RPM

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Fig. 1. KM Tanto Bersinar

2.3 Variables

Independent Variable: The condition of the puncture valve, measured by Running Hours (R/H) relative to the PMS limit (5,000 hours). Dependent Variable: The performance of the Bosch Pump and Main Engine, measured by Fuel Rack Position (load command) and Exhaust Gas Temperature (combustion result).

2.4 Data Collection Technique

To Data was acquired through three primary methods, ensuring the reliability and validity of the findings (Jaya, 2024).

1. Direct Observation: The researcher performed daily monitoring of the Main Engine parameters in the Engine Control Room (ECR). Observations focused on the deviation of exhaust temperatures and the physical behavior of the fuel rack (hunting vs. stable) (Sahir , 2022)..
2. Documentation (PMS and Logbooks):
   - Engine Log Book: Provided the snapshot data of temperatures and pressures at the exact moment of failure (30 November 2024).
   - Planned Maintenance System (PMS): Provided the historical maintenance data, specifically the running hours of the fuel injection pumps for all 8 cylinders. This allowed for a comparative analysis between the failed cylinder (No. 2) and the healthy cylinders.
   - Manual Books: Used to establish the baseline specifications for rejection limits and normal operating parameters (e.g., fuel viscosity/temperature ranges).
3. Interviews: Discussions were held with the Chief Engineer and Second Engineer to understand the historical context of the engine's maintenance and to validate the troubleshooting steps taken during the incident (Gudiato et al., 2024). .

2.5 Data Analysis Method

The data was analyzed using a comparative statistical approach (Gusti et al., 2024).

- Baseline Comparison: The abnormal parameters (Incident on 30 Nov 2024) were compared against the "Normal" parameters (post-repair) to quantify the magnitude of the failure.
- Wear Analysis: The running hours of Cylinder 2 were compared against the manufacturer's recommended interval (5,000 hours) to determine if the failure was premature or due to end-of-life wear.
- Root Cause Verification: The analysis integrated the physical findings from the dismantled valve (wear on piston M3, housing M1) to confirm the hydraulic theory of failure.

3. Results and Discussion

3.1 Results: Operational Anomaly Data

On 30 November 2024, while the vessel was underway, the engine watch team observed a critical alarm. The monitoring system indicated a deviation in Cylinder No. 2. The data recorded in the logbook at the time of the incident is presented in Table 1:

Table 1. Main Engine Operational Parameters During Failure Incident (30 Nov 2024)

Component Parameter	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6	Cyl 7	Cyl 8	Unit
Fuel Rack Position	33	34	34	33	32	33	34	33	mm
Exhaust Gas Temp	300	100	305	300	300	305	300	300	∘C
Jacket Cooling Temp	77	54	77	76	76	78	77	77	∘C

Data Interpretation:

- Fuel Rack Uniformity: The fuel rack position for Cylinder 2 was 34 mm, which is slightly *higher* than the average of the other cylinders (33 mm). This indicates that the engine governor was attempting to maintain load. The governor detected a drop in RPM (due to Cylinder 2 failing) and increased the fuel rack command to all cylinders, including Cylinder 2, to compensate. The rack was *mechanically* moving the plunger to the "inject" position.
- Exhaust Temperature Collapse: Despite the rack being at 34 mm, the exhaust temperature for Cylinder 2 plummeted to 100°C. In contrast, the other cylinders maintained a healthy range of 300-305°C. A reading of 100°C is essentially the temperature of the scavenging air after compression without any combustion heat release. This confirms a Total Misfire condition.
- Cooling Water Drop: The jacket cooling water outlet temperature for Cylinder 2 dropped to 54°C (normal: 77°C). This thermal drop confirms that no heat was being generated inside the cylinder liner, corroborating the misfire diagnosis.

Fig. 2. Monitor Fuel Temperature

Table 2. Main Engine Parameters After Repair (Normal Condition)

Component Parameter	Cyl 1	Cyl 2	Cyl 3	Cyl 4	Cyl 5	Cyl 6	Cyl 7	Cyl 8	Unit
Fuel Rack Position	33	32	33	32	33	33	33	33	mm
Exhaust Gas Temp	300	300	300	295	300	305	300	300	∘C
Jacket Cooling Temp	77	75	77	76	76	78	77	77	∘C

Table 2 demonstrates that after the repair intervention (puncture valve replacement), the parameters for Cylinder 2 normalized (300°C Exhaust, 75°C Jacket), proving the fault was isolated to the injection component.

3.2 Analysis of Component Running Hours (Wear Life)

To determine the root cause, the "Running Hours" (R/H) of the puncture valves were extracted from the PMS. This analysis is crucial for understanding the "Mean Time To Failure" (MTTF) in the vessel's specific operating environment.

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Table 3. Analysis of Puncture Valve Running Hours vs. PMS Limit

Cylinder	Actual Running Hours	PMS Limit	Condition Status
1	4	5	Operational / Safe
2	4.97	5	CRITICAL (Failed)
3	4.5	5	Warning / Approaching
4	4	5	Operational / Safe
5	4.5	5	Warning / Approaching
6	3.5	5	Operational / Safe
7	3.5	5	Operational / Safe
8	3.5	5	Operational / Safe

Running Hour Analysis: The data reveals a stark correlation. Cylinder 2 had accumulated 4,970 hours, which is 99.4% of the manufacturer's recommended 5,000-hour service interval. The failure occurred almost exactly at the predicted end-of-life. This suggests that the wear rate is consistent with the manufacturer's predictions, but it also highlights the danger of pushing components to the absolute limit in real-world conditions where variables like fuel quality can accelerate wear. Cylinders 3 and 5, at 4,500 hours, are identified as the next highest risk candidates.

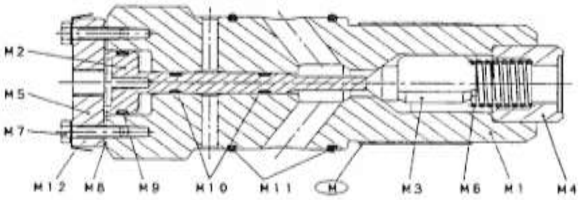

Fig. 3. Punctur Valve

3.3 Discussion: The Mechanism of Pressure Loss

The "Influencing" factor in this research is the physical wear of the puncture valve. The mechanism by which this wear translates to the observed pressure loss (results in Table 1) is hydraulic bypass.

3.3.1 Physical Wear Findings

Upon disassembly of the Cylinder 2 puncture valve, the following conditions were noted:

- Piston Wear (Component M3): The pneumatic piston exhibited significant abrasive wear. This increases the clearance between the piston and the housing.
- Housing Oversize (Component M1): The housing bore was oversized.
- O-Ring Failure: The sealing O-rings were hardened and flattened, losing their elasticity.

Fig. 4. Exhaust Number 2

Fig. 5. the process of replacing a problematic puncture valve

Fig. 6. Broken Puncture Vakce Number 2

3.3.2 Hydraulic Bypass Dynamics

In a healthy Bosch pump, the high-pressure chamber (above the plunger) is sealed. When the plunger rises, pressure builds rapidly to 300+ bar to open the fuel injector. In the failed unit (Cyl 2), the wear in the puncture valve created a continuous path between the high-pressure chamber and the fuel return line.

- The Physics of the Failure: As the plunger rose to compress the fuel, the fuel did not build pressure. Instead, it flowed through the path of least resistance—the leaking puncture valve—back to the circulation line.
- Result: The peak pressure never reached the nozzle opening pressure (320 bar). Consequently, the injector needle remained seated. No fuel was sprayed. The cylinder experienced a complete misfire, explaining the 100°C exhaust temperature.

3.4 The Role of Fuel Temperature and Viscosity

An operational finding adds nuance to this failure. On the day of the incident, the Fuel Oil Inlet Temperature was recorded at 111°C.

- Standard: The manual for the MAN B&W 8S50MC specifies a fuel inlet temperature of 120°C-150°C to ensure the heavy fuel oil reaches the correct viscosity (10-15 cSt) for injection.
- Impact of 111°C: At this lower temperature, the HFO is significantly more viscous (thicker). While intuitively one might think thicker oil seals better, in dynamic hydraulic systems, high viscosity can cause sluggish movement of valve components (sticking) and increase the pressure drop across narrow passages. The high viscosity likely exacerbated the stress on the already worn O-rings and piston of the puncture valve, acting

as the final trigger for the seal failure. The increased hydraulic resistance in the return lines due to high viscosity might have also affected the pressure balance across the valve.

3.5 Maintenance Strategy Evaluation

The reliance on a fixed 5,000-hour PMS interval (Time-Based Maintenance) proved insufficient in this case, as the component failed at 4,970 hours—technically before it was "due" for replacement. This failure resulted in unscheduled downtime and operational risk (navigating with 7 cylinders).

- Condition-Based Monitoring: The research suggests that relying solely on running hours is risky. Condition indicators, such as slight deviations in exhaust temperature or rack variance (hunting) in the preceding days, should be used to trigger early maintenance.

Buffer Implementation: A safety buffer of 10% (500 hours) should be applied. Puncture valves should be scheduled for overhaul at 4,500 hours rather than 5,000 hours to account for variations in fuel quality and operational stress.

Fig. 7. exhaust number 2 experienced a decrease in temperature

4. Conclusion

This research provides a quantitative validation of the impact of puncture valve degradation on the performance of the MITSUI MAN B&W 8S50MC main engine. Direct Correlation: There is a definitive causal link between the running hours of the puncture valve and the loss of Bosch pump pressure. The failure of Cylinder 2 at 4,970 hours confirms that wear approaching the 5,000-hour PMS limit creates a high probability of functional failure. Quantitative Impact: The wear of the puncture valve (piston and housing) leads to internal fuel leakage. This results in a catastrophic drop in performance, quantified by 200°C decrease in exhaust gas temperature (from 300°C to 100°C and a 23°C decrease in jacket cooling water temperature, indicating a total cessation of combustion in the affected cylinder. Aggravating Factors: Operational deviations, specifically the low fuel oil temperature (111°C vs. the required 120°C+), likely accelerated the failure of the marginal components by increasing fluid viscosity and hydraulic stress. Based on the analysis, the following technical recommendations are proposed for the maintenance of KM. Tanto Bersinar and similar vessels: Revised PMS Schedule: The maintenance interval for puncture valves should be reduced from 5,000 hours to 4,500 - 4,800 hours. This preemptive replacement strategy prevents in-service failures. Immediate Action for High-Hour Units: Cylinders 3 and 5 (currently at 4,500 hours) should be prioritized for immediate overhaul during the next port stay or anchorage to prevent sequential failures. Viscosity Management: Engine crew must strictly adhere to the fuel temperature guidelines (120-150°C) to ensure optimal viscosity. This reduces mechanical stress on fuel system seals. Complete Overhaul Protocol: When servicing the Bosch pump, it is insufficient to merely replace O-rings. The dimensions of the puncture valve housing (M1) and piston (M3) must be measured against rejection limits. If wear is detected, the entire valve assembly must be renewed, followed by a pump calibration to ensure balanced injection timing and volume across all cylinders. By implementing these measures, the vessel can maintain optimal injection pressure, ensuring fuel efficiency, reliable propulsion, and adherence to environmental emission standards.

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