Proposed Preventive Maintenance of The Kaeser Bsd-75 Compressor Through The Integration of Reliability-Centered Maintenance (Rcm) and Root Cause Analysis (RCA)

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Abstract.
The Kaeser BSD-75 air compressor serves as vital support equipment on a knock-down furniture production line, providing pressurized air for pneumatic tools. However, the current maintenance strategy is purely corrective, lacking a preventive schedule. This study aims to identify failure modes and their root causes, subsequently formulating a proposed preventive maintenance policy by integrating Reliability Centered Maintenance (RCM) and Root Cause Analysis (RCA). The research data encompasses nine breakdown incidents (January 15, 2022 – February 7, 2026) resulting in a total of 37 hours of downtime, supplemented by field observations and interviews with four maintenance personnel. The RCM analysis includes defining functions and functional failures, conducting a Failure Mode and Effects Analysis (FMEA) based on the Risk Priority Number (RPN), and selecting maintenance policies; system reliability is evaluated using Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), and availability. The RCA utilizes Pareto charts, the "5 Whys" technique, and fishbone diagrams. The results indicate that the coupling elastomer holds the highest priority (RPN 378; 31.7%), with the top three components accounting for 68.0% of the total RPN. The calculated metrics are an MTBF of 4,452 hours, an MTTR of 4.11 hours, and an availability of 99.91%. The root causes are systemic, stemming from the absence of procedures for alignment, vibration monitoring, lubrication and oil specification control, periodic hose inspections, and systematic breakdown documentation. The proposed interventions include scheduled maintenance for three components, condition-based maintenance for three components, and five corrective actions. As the RCA process involves analytical deduction beyond the documented causes, these findings require field verification.

Keywords: *Preventive Maintenance, Reliability Centered Maintenance, Root Cause Analysis, FMEA, screw compressor and MTBF.*

I. INTRODUCTION

The continuity of production processes in the manufacturing industry is determined not only by primary production machinery but also by the reliability of supporting equipment that provides essential utilities air compressors being a prime example. Machinery that operates continuously is susceptible to performance degradation or even failure if not supported by an effective maintenance system; in the case of rotary screw air compressors, performing maintenance only after a component has failed inevitably leads to significant downtime (Susilo & Widjajati, 2024). In a knock-down furniture production line, compressed air powers various pneumatic tools; consequently, any disruption to the air compressor can bring all dependent workstations to a complete standstill.

The Kaeser BSD-75 air compressor serves as the source of compressed air for equipment such as boring machines, pneumatic nail guns or staplers, strapping tools, and spray guns used during the finishing stage. This unit is an oil-injected rotary screw compressor with a maximum working pressure of 8.50 bar, designed for continuous, 24-hour-a-day operation. Historical data from a manufacturer of knock-down panel furniture reveals that between January 15, 2022, and February 7, 2026, there were nine unplanned breakdowns, resulting in a total of 37 hours of downtime. Observations and interviews with the mechanics responsible for compressor maintenance and repair indicate that all interventions were purely correctivecarried out only after a component had already failed. Furthermore, there were no records of scheduled preventive maintenance, such as periodic inspections or component replacements based on specific time intervals.

Preventive maintenance refers to planned maintenance performed before a failure occurs, aimed at reducing breakdowns and maintaining equipment performance (Firmansyah & Rizqi, 2022). To avoid over-maintenance, the specific types of actions and their corresponding intervals must be determined based on the nature of potential failures. A framework commonly used for this purpose is Reliability-Centered Maintenance (RCM), a systematic process for determining the most effective maintenance actions for an asset (Cahyani & Iftadi, 2021; Yudistia et al., 2026). In the case of air screw compressors, the application of

FMEA and modular design for preventive maintenance has been reported to yield a 41.55% improvement in maintenance cost efficiency (Susilo & Widjajati, 2024), while RCM based on reliability parameters has been applied to gas compressors (Omozuhiomwen et al., 2025).

However, RCM based on Failure Mode and Effects Analysis (FMEA) fundamentally addresses what should be maintained and when; yet, the causes identified in FMEA typically stop at the immediate or direct cause (e.g., shaft misalignment or inadequate lubrication). The question of why these direct causes occur and repeatedly recur remains unanswered. Company data illustrates this issue: an elastomer coupling failed three times, each time attributed to the same cause, while a thermostatic valve jammed twice (in 2023 and 2026) due to the same underlying issue despite repairs having been performed after each incident. Such recurring failures indicate that the repairs addressed only the symptoms rather than the root causes. Consequently, Root Cause Analysis (RCA) is necessary to complement RCM (Yanuarsah et al., 2023). The integration of FMEA, the fishbone diagram, and RCM for compressors has been shown to yield a maintenance strategy that combines scheduled and condition-based actions, while the combination of the fishbone diagram and the "5 Whys" technique has been used to trace the root causes of production issues in industrial case studies (Almuhari & Jazuli, 2025).

This study aims to: (1) identify failure modes, risk priorities, and the reliability level of a Kaeser BSD-75 compressor using RCM and FMEA based on the Risk Priority Number (RPN) along with indicators such as MTBF, MTTR, and availability; (2) trace the root causes of failures using RCA, employing Pareto charts, the "5 Whys" technique, and fishbone diagrams; and (3) formulate an integrated preventive maintenance policy that combines RCM-derived maintenance strategies with corrective actions addressing the root causes identified through RCA. The contribution of this research lies in an integrated RCM–RCA analytical framework, developed using four years of failure data from a screw compressor in the knock-down furniture industry, which can serve as a reference for similar manufacturing companies.

II. METHODS

Research Design and Object

This research is a case study employing a descriptive quantitative-qualitative approach. The quantitative aspect encompasses risk assessment (using the Risk Priority Number, or RPN) and the calculation of reliability indicators, while the qualitative aspect involves functional analysis, failure analysis, and root cause investigation. The subject of this study is a Kaeser BSD-75 air compressor an oil-injected rotary screw compressor with a maximum working pressure of 8.50 bar which is controlled by a SIGMA CONTROL 2 system and operates continuously, 24 hours a day.

Data Collection Techniques

Primary data were obtained through (a) field observations of the compressor's condition and operation, including documentation of its nameplate and control panel, and (b) interviews with four maintenance personnel: one Head of Maintenance (All Units), one Compressor Maintenance Supervisor, and two Compressor Maintenance Technicians. The interviews covered frequently failing components, types and causes of failures, the impact of such failures, existing maintenance systems, and corrective actions taken. Secondary data consisted of the company's internal failure history for the period from January 15, 2022, to February 7, 2026 detailing dates, components, failure types, causes, actions taken, and repair durations as well as relevant literature and manufacturer brochures.

Reliability Centered Maintenance (RCM)

RCM is a systematic approach that focuses on asset functions, failure modes and their effects, and the selection of the most effective maintenance actions based on associated risk levels (Cahyani & Iftadi, 2021; Simanungkalit et al., 2023). The process involves identifying functions and functional failures, analyzing failure modes and their effects typically through Failure Mode and Effects Analysis (FMEA) and subsequently determining maintenance policies. This approach has been applied to various types of machinery, such as lathes (Wibowo et al., 2021), hoist cranes (Najah et al., 2023), and screw presses (Yudistia et al., 2026). The output of RCM consists of maintenance policies, including scheduled maintenance, condition-based maintenance, failure-finding (to detect hidden failures), and "run-to-failure"

(allowing equipment to operate until it fails). The selection of a specific policy is determined by the system's functions, failure modes, and risk levels (Siagian et al., 2024), and can be further refined by establishing maintenance intervals based on Mean Time Between Failures (MTBF) (Puspita Sari et al., 2025).

Failure Mode and Effects Analysis (FMEA)

FMEA identifies failure modes, their causes, and their effects, subsequently assessing the associated risks through three parameters severity (S), occurrence (O), and detection (D) each rated on a scale of 1–10 (Simanungkalit et al., 2023). These parameters are multiplied to calculate the Risk Priority Number (RPN) (Equation 1), with failure modes yielding the highest RPN being prioritized (Puspita Sari et al., 2025). FMEA is widely applied across various industries (Zuniawan, 2020; Dahlia & Profita, 2024).

$$RPN = S \times O \times D \quad (1)$$

The conventional RPN method has been criticized for several shortcomings (Zuniawan, 2020). Due to the multiplicative nature of the calculation, different combinations of S, O, and D can result in the same RPN value; furthermore, the method assumes that all three parameters carry equal weight. Consequently, RPN results should be interpreted in conjunction with actual failure data.

Table 1. Rating scale for Severity, Occurrence, and Detection

Rating	Severity (S)	Occurrence (O)	Detection (D)
1–2	Very low: does not affect operation	Very rare: almost never occurs	Very easy: failure is very easy to detect
3–4	Low: minor disturbance to operation	Rare: occurs occasionally	Easy: failure is fairly easy to notice
5–6	Moderate: production slightly disturbed	Moderate: occurs several times	Moderate: failure is sometimes difficult to notice
7–8	High: production significantly disturbed	Frequent: occurs often	Difficult: failure is hard to detect
9–10	Very high: machine stops completely or is hazardous	Very frequent: occurs very often	Very difficult: failure cannot be detected

Reliability Indicators

Reliability is the probability that a component or system will perform its function adequately over a specified period and under specified operating conditions (Simanungkalit et al., 2023). Three commonly used indicators are mean time between failures (MTBF), mean time to repair (MTTR), and availability. MTBF represents the average operating time between failures (Equation 2), where Ti is the operating-time interval between the i-th failure and the next failure, and n is the number of intervals. This indicator is commonly used to measure the failure rate (Mujiarto et al., 2022). MTTR represents the average repair time and reflects maintainability (Equation 3; Rifai et al., 2025), where ti is the repair duration for the i-th failure and N is the number of failures. Inherent availability represents the probability that equipment is ready for operation (Equation 4; Paoprasert et al., 2022; Puspita Sari et al., 2025).

$$MTBF = (\Sigma\, T_i) / n, \quad i = 1, \ldots, n$$

$$MTTR = (\Sigma\, t_i) / N, \quad i = 1, \ldots, N$$

$$A = [MTBF / (MTBF + MTTR)] \times 100\%$$

If the failure rate is assumed to be constant, reliability at operating time t is expressed by the exponential distribution (Equation 5).

$$R(t) = \exp(-t / MTBF)$$

Root Cause Analysis (RCA)

RCA is a structured process for identifying the fundamental causes of a problem so that corrective actions address the causes rather than the symptoms (Yanuarsah et al., 2023). This study uses three tools: (a) the Pareto diagram, which ranks contributors to a problem from highest to lowest and presents cumulative percentages to identify dominant contributors (Puspita Sari et al., 2025; Yanuarsah et al., 2023); (b) the 5 Whys technique, which repeatedly asks “why” until a controllable cause is identified (Yanuarsah et al., 2023; Almuhari & Jazuli, 2025); and (c) the cause-and-effect or fishbone diagram, which groups causes into the 6M categories: man, machine, method, material, measurement, and environment. In gas compressors,

fishbone analysis has shown that failure causes originate from material wear, lubrication quality, and incorrect maintenance procedures (Ari et al., 2025). Condition-based maintenance reduces downtime and costs by avoiding unnecessary maintenance and detecting failures at an earlier stage (Ali & Abdelhadi, 2022).

III. RESULT AND DISCUSSION

Failure History and Existing Maintenance Conditions

Table 2 presents nine compressor failure events recorded between January 15, 2022 and February 7, 2026.

Table 2. Failure history of the Kaeser BSD-75 compressor

No.	Date	Component	Failure mode	Recorded cause	Downtime (hours)
1	15/01/2022	Elastomer coupling	Cracked (cracking)	Motor–airend misalignment; excessive vibration	4
2	23/02/2022	Screw bearing	Broken (fracture)	Poor lubrication or oil quality	6
3	06/04/2022	Elastomer coupling	Cracked (cracking)	Motor–airend misalignment; excessive vibration	4
4	18/12/2022	Elastomer coupling	Broken (fracture)	Motor–airend misalignment; excessive vibration	5
5	21/02/2023	Thermostatic valve	Stuck	Dirt or deposits in the oil and thermostat element	3
6	17/05/2023	Cooler	Clogged	Oil thickening due to a change in oil brand	2
7	20/07/2024	Hose assembly	Leaking (leakage)	Material aging; poor hose quality	2
8	09/03/2025	Motor bearing	Worn (wear)	Wear; inadequate lubrication	8
9	07/02/2026	Thermostatic valve	Stuck	Dirt or deposits in the oil and thermostat element	3
				Total	**37**

Over approximately 4.1 years, the compressor experienced nine failures involving six components, with total downtime of 37 hours. A summary of failure frequency and downtime by component is presented in Table 3.

Table 3. Summary of failure frequency and downtime by component

Component	Frequency (times)	Events (%)	Downtime (hours)	Downtime (%)	Average (hours/event)	Action taken
Elastomer coupling	3	33,3	13	35,1	4,33	Replacement
Thermostatic valve	2	22,2	6	16,2	3,00	Disassembly and cleaning
Motor bearing	1	11,1	8	21,6	8,00	Replacement
Screw bearing	1	11,1	6	16,2	6,00	Replacement
Cooler	1	11,1	2	5,4	2,00	Cleaning
Hose assembly	1	11,1	2	5,4	2,00	Replacement
Total	**9**	**100,0**	**37**	**100,0**	**4,11**	–

The elastomer coupling was both the most frequently damaged component and the largest contributor to downtime, accounting for one-third of all events and 35.1% of downtime. In contrast, the motor bearing failed only once but required the longest repair (8 hours), followed by the screw bearing (6 hours). By year, failures occurred four times in 2022 (19 hours of downtime), twice in 2023 (5 hours), once in 2024 (2 hours), once in 2025 (8 hours), and once in 2026 through February 7 (3 hours). The year 2022 accounted for 44.4% of events and 51.4% of downtime. All three elastomer coupling failures occurred in 2022, and no similar failure had been recorded since December 18, 2022. The reason for this change cannot be established from the available data and should be confirmed with technicians, for example, whether

realignment was performed after the third event. Until the underlying causes—misalignment and excessive vibrationare proven to have been eliminated, the risk of elastomer coupling failure is still considered to exist.

Regarding the handling of failures, six of the nine events (66.7%) were resolved by replacing components, accounting for 29 hours (78.4%) of downtime, while three events (33.3%) were resolved through disassembly or cleaning, taking 8 hours (21.6%). All actions were performed after failures occurred. Interviews confirmed that the existing maintenance system is corrective maintenance, and no records of periodic inspections or interval-based replacements were found. Consequently, each failure caused unplanned downtime that reduced air pressure to all pneumatic equipment. Based on the recorded causes, failures can be grouped into three categories: lubrication and oil-condition factors (screw bearing, thermostatic valve, motor bearing, and cooler), accounting for five events (55.6%) and 22 hours (59.5%); mechanical factors involving misalignment and vibration in the elastomer coupling, accounting for three events (33.3%) and 13 hours (35.1%); and material aging in the hose assembly, accounting for one event (11.1%) and 2 hours (5.4%).

Functions and Functional Failures

The compressor's main function is to generate and supply compressed air stably to pneumatic tools. Air enters through the filter and inlet valve into the airend, where it is compressed by a pair of screw rotors with oil injection that serves as a lubricant, sealant, and coolant. The air-oil mixture is separated in the separator tank; clean air passes through the minimum pressure valve and aftercooler into the distribution network, while the oil is cooled in the cooler under the control of the thermostatic valve, filtered, and injected back into the airend. The entire process is monitored by SIGMA CONTROL 2. Because all pneumatic workstations depend on this compressor, any disruption directly affects production, making the compressor a critical supporting asset. The functions, functional failures, and impacts of the six components that have failed are presented in Table 4.

Table 4. Functions and functional failures of Kaeser BSD-75 compressor components

Component	Function	Functional failure	Failure impact
Elastomer coupling	Transmits motor rotation to the airend and dampens vibration and shaft misalignment within certain limits	Unable to transmit rotation due to cracking or fracture	Rotation is not transmitted; compressor stops completely
Screw bearing	Supports the screw rotors in the airend so they rotate normally during air compression	Unable to support the rotor due to fracture	Compressor cannot operate; major repair and prolonged downtime
Thermostatic valve	Regulates oil flow to the cooler according to operating temperature	Unable to regulate oil flow because it is stuck	Operating temperature is unstable; the unit may shut down automatically
Motor bearing	Supports the motor rotor shaft to ensure stable and aligned rotation	Unable to support the shaft stably due to wear	Vibration and noise increase; motor stops
Cooler	Dissipates heat from the oil and compressed air	Unable to provide cooling because it is clogged	Cooling performance decreases; unit shuts down automatically
Hose assembly	Delivers lubricating oil in the compressor system	Unable to retain oil due to leakage	Oil level decreases; lubrication is insufficient; airend is at risk of damage

FMEA Results

The S, O, and D assessments and RPN calculations are presented in Table 5, where the sequence number indicates the RPN ranking.

Table 5. FMEA results for the Kaeser BSD-75 compressor

No.	**Komponen dan mode kegagalan**	Failure effect	Cause	**S**	**O**	**D**	RPN
1	*Coupling* elastomer: retak atau pecah	Rotation is not transmitted; compressor stops completely	Motor–airend misalignment; excessive vibration	9	6	7	378

No.	Komponen dan mode kegagalan	Failure effect	Cause	S	O	D	RPN
2	*Bearing screw*: pecah	*Airend* tidak berputar normal; kompresor tidak dapat beroperasi	Poor lubrication or oil quality	10	3	8	240
3	*Thermostatic valve*: macet	Suhu kerja tidak stabil; unit berhenti otomatis	Dirt or deposits in the oil and thermostat element	8	4	6	192
4	*Bearing* motor: aus	Getaran dan kebisingan naik; motor berhenti	Wear; inadequate lubrication	10	3	6	180
5	*Cooler*: tersumbat	Cooling performance decreases; unit shuts down automatically	Oil thickening due to a change in oil brand	7	3	5	105
6	*Hose assembly*: bocor	Oli berkurang; risiko *airend* rusak	Material aging; poor hose quality	8	3	4	96
	Total RPN						**1.191**

The elastomer coupling ranked first (RPN 378; 31.7% of the total) because it had the highest combination of scores: severity 9 (the compressor stops completely), occurrence 6 (the most frequent, three times during the data period), and detection 7 (initial cracks are difficult to identify during normal operation without direct inspection). The screw bearing ranked second, mainly because of its severity score of 10 and detection score of 8, since its failure occurs inside the airend and is difficult to identify before the bearing breaks, although it occurred only once (occurrence 3). The thermostatic valve ranked third with an occurrence score of 4 because it became stuck twice. The screw bearing and motor bearing both had a severity score of 10 but ranked second and fourth, respectively, because their occurrence was low. This illustrates the multiplicative nature of RPN: the highest severity does not automatically result in the highest ranking (Zuniawan, 2020). Because bearing failures caused the longest downtime (6 and 8 hours), both components still require special attention through condition monitoring. The FMEA results are consistent with historical data because the component with the highest RPN was also the component that failed most frequently and contributed the most downtime.

Pareto Analysis

The Pareto diagram of RPN values is presented in Figure 2. The three highest-ranked failure modes elastomer coupling, screw bearing, and thermostatic valve collectively account for 68.0% of the total RPN and are designated Priority I. When the motor bearing is added, the cumulative contribution reaches 83.1%, indicating that four failure modes dominate compressor risk.

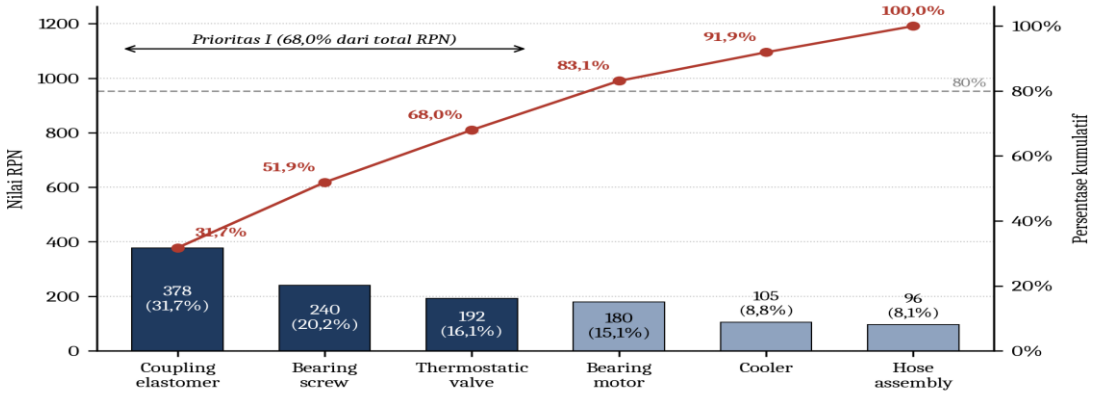


Fig 1. Pareto diagram of RPN values for Kaeser BSD-75 compressor failure modes

When the Pareto analysis is based on downtime, the elastomer coupling remains in first place (35.1%), followed by the motor bearing (21.6%, cumulative 56.8%), and the thermostatic valve and screw bearing, each at 16.2% (cumulative 73.0% and 89.2%). Both perspectives agree that the elastomer coupling is the dominant failure mode, while the motor bearing rises from fourth place in RPN ranking to second place in downtime because its repair took 8 hours. Accordingly, the 5 Whys analysis was applied to all six failure modes, with detailed tracing for Priority I and a concise analysis for Priority II.

Reliability: MTBF, MTTR, and Availability

Because the compressor operates 24 hours per day, the intervals between failures were converted into operating hours by multiplying the number of days by 24 (Table 6). The nine failure events produced eight intervals.

Table 6. Intervals between failures of the Kaeser BSD-75 compressor

No.	From	To	Interval (days)	Interval (operating hours)
1	15/01/2022	23/02/2022	39	936
2	23/02/2022	06/04/2022	42	1.008
3	06/04/2022	18/12/2022	256	6.144
4	18/12/2022	21/02/2023	65	1.560
5	21/02/2023	17/05/2023	85	2.040
6	17/05/2023	20/07/2024	430	10.320
7	20/07/2024	09/03/2025	232	5.568
8	09/03/2025	07/02/2026	335	8.040
	Total		**1.484**	**35.616**

The calculated reliability indicators are presented in Table 7. MTBF was 35,616 hours ÷ 8 = 4,452.0 hours, equivalent to 185.5 days or approximately 6.1 months; MTTR was 37 hours ÷ 9 = 4.11 hours; and availability was 99.91%.

Table 7. Reliability indicators of the Kaeser BSD-75 compressor

Indicator	Calculation	Result	Interpretation
MTBF	35,616 hours ÷ 8 intervals	4,452.0 hours (±6.1 months)	Adequate; failures about twice per year
MTTR	37 hours ÷ 9 failures	4.11 hours	Good; less than one *shift* (8 hours)
Availability	4,452.0 ÷ (4,452.0 + 4.11)	99.91%	Good numerically
MTBF : MTTR ratio	4,452.0 ÷ 4.11	±1,083 : 1	The main problem lies in frequency, not repair duration

An MTBF of 4,452.0 hours means that the compressor experiences approximately two failures per year (8,760 hours ÷ 4,452.0 ≈ 1.97), consistent with the historical record of nine failures over 4.1 years. The intervals vary widely, from 39 days (936 hours) to 430 days (10,320 hours), with four failures clustered in 2022. At the component level, the elastomer coupling has the shortest MTBF among components that failed more than once, namely 4,044 hours (two intervals of 81 and 256 days), with an MTTR of 4.33 hours. An MTTR of 4.11 hours indicates relatively quick repairs; however, because the compressor operates continuously and no downtime outside production is available, every repair immediately interrupts the compressed-air supply. The 99.91% figure is inherent availability, which does not include spare-part waiting time or planned maintenance. This high value does not reflect the impact of each failure on all pneumatic workstations and therefore cannot justify delaying improvements to the maintenance system. A combination of FMEA–RPN with MTBF and MTTR has also been used for other production machines (Paoprasert et al., 2022).

As an additional analysis, assuming a constant failure rate (Equation 5), the probability that the compressor will operate without failure is 84.9% over one month (730 hours), 61.1% over three months (2,190 hours), 37.4% over six months (4,380 hours), and only 14.0% over one year (8,760 hours). The probability of remaining failure-free for six months is only about one-third, confirming that waiting for a failure to occur is not a safe strategy. The constant-rate assumption is a simplification because failures were clustered in 2022 and involved different mechanisms (wear in the coupling and bearings, and contamination in the thermostatic valve). Therefore, distribution testing, such as Weibull analysis, is needed in future research.

Maintenance Policies Based on RCM

Maintenance policies were determined based on the deterioration characteristics of each component (Table 8). Scheduled maintenance was selected for components whose failures are associated with service life or dirt accumulation, allowing preventive actions to be scheduled before failure. Condition-based

maintenance was selected for components whose deterioration symptoms—such as oil seepage, vibration, noise, and rising temperature—can be monitored, so action can be taken when conditions begin to deviate from normal limits. This reduces unnecessary maintenance and enables earlier failure detection (Ali & Abdelhadi, 2022).

Table 8. RCM-based maintenance policies for Kaeser BSD-75 compressor components

Komponen (RPN; peringkat)	Deterioration characteristics	Maintenance policy	Historical downtime (hours)
Coupling elastomer (378; 1)	Cracking due to cyclic loads from misalignment and vibration; initial cracks are difficult to see without direct inspection	*Scheduled maintenance*	13
Bearing screw (240; 2)	Failure occurs inside the airend; symptoms can be monitored through airend and oil temperatures, noise, vibration, and oil condition	*Condition-based maintenance*	6
Thermostatic valve (192; 3)	Accumulation of dirt or deposits on the thermostat element; can be restored by cleaning	*Scheduled maintenance*	6
Bearing motor (180; 4)	Progressive wear indicated by vibration, noise, and rising temperature	*Condition-based maintenance*	8
Cooler (105; 5)	Blockage due to thickened oil; cleaned together with the thermostatic valve	*Scheduled maintenance*	2
Hose assembly (96; 6)	Material aging indicated by seepage and cracks that can be visually inspected	*Condition-based maintenance*	2

The components proposed for scheduled maintenance (elastomer coupling, thermostatic valve, and cooler) account for 21 hours (56.8%) of historical downtime, while those proposed for condition-based maintenance (screw bearing, motor bearing, and hose assembly) account for 16 hours (43.2%). Together, they cover all 37 hours of unplanned downtime. These figures indicate the share of downtime targeted for prevention, not a prediction of the reduction, because outcomes after implementation have not yet been measured. Failure finding was not selected because no hidden functions were identified in the six failure modes; their functional failures are clearly visible to operators when they occur. Run-to-failure was not selected because every failure interrupts the air supply to all pneumatic workstations.

Root Cause Analysis (RCA)

Whys Analysis

The 5 Whys results for Priority I are presented in Table 9 and those for Priority II in Table 10. Answers marked “recorded” are based on failure history or interviews, while answers marked † represent analytical tracing that requires field verification.

Table 9. 5 Whys analysis of Priority I failure modes

Level	***Coupling* elastomer retak atau pecah**	***Bearing screw* pecah**	***Thermostatic valve* macet**
Problem	Cracked or fractured three times (2022); 13 hours of downtime	Fractured once (February 23, 2022); 6 hours of downtime	Stuck twice (2023 and 2026); 6 hours of downtime
Why 1	Motor–airend shaft misalignment and excessive vibration place stress on the elastomer (recorded)	Poor lubrication or oil quality (recorded)	Dirt or deposits in the oil and thermostat element (recorded)
Why 2	Cyclic loading continues throughout 24-hour operation because shaft position is not corrected	The circulating oil has deteriorated in quality or become contaminated	Contaminants are not removed because the oil and filter are not replaced on time
Why 3	Alignment is not measured periodically or verified after coupling or bearing replacement	Oil and filter replacement is not controlled according to the manufacturer's intervals or the SIGMA CONTROL 2 counter	The valve is only disassembled and cleaned after it becomes stuck, without a cleaning schedule

Level	***Coupling* elastomer retak atau pecah**	***Bearing screw* pecah**	***Thermostatic valve* macet**
Why 4	There are no standard alignment procedures, measuring tools, or tolerance limits	There is no standard oil specification or control over oil-brand changes or mixing (the oil brand was changed in 2023)	The 2023 failure was not followed by preventive action, resulting in recurrence in 2026
Why 5 (root cause)	There is no preventive program or vibration monitoring; maintenance is entirely corrective	There is no lubrication control or airend condition monitoring (temperature, noise, vibration, oil)	There is no oil-condition control or recording and analysis of recurring failures

Table 10. Summary of 5 Whys analysis of Priority II failure modes

Component	Causal chain (Why 1 to Why 4)	Root cause
Bearing motor aus	Worn due to inadequate lubrication (recorded) → bearing lubrication is not scheduled → bearing condition (vibration, temperature, noise) is not monitored	No lubrication control or condition monitoring
Cooler tersumbat	Oil thickening due to an oil-brand change (recorded) → brand changed without compatibility assessment → no standard oil specification or replacement control	No oil specification or replacement control
Hose assembly bocor	Material aging and poor hose quality (recorded) → hose age and condition are not inspected → no hose replacement criteria	No periodic hose inspection

Fishbone Diagram

The causes identified through all 5 Whys analyses were synthesized into a 6M-category fishbone diagram in Figure 3. The method category contains the largest number of causes and is present in all six failure modes: the absence of a preventive maintenance schedule, alignment procedures, lubrication control and oil specifications, and periodic hose inspections. The material category includes changes in oil brand, oil thickening, dirt and deposits in the oil, and hose aging. Together with the method category, oil- and hose-related factors are associated with six of the nine events. The machine category includes motor–airend misalignment, excessive vibration, and bearing wear. The measurement category includes the absence of vibration, temperature, and noise monitoring, as well as unsystematic failure records, consistent with the high detection scores (7–8) for coupling and screw bearing failures. The man category describes a reactive work pattern and maintenance decisions that depend on technicians' experience. The environment category only includes the 24-hour operating pattern without a planned shutdown window; the available data contain no evidence that physical environmental factors such as dust or room temperature caused the failures.

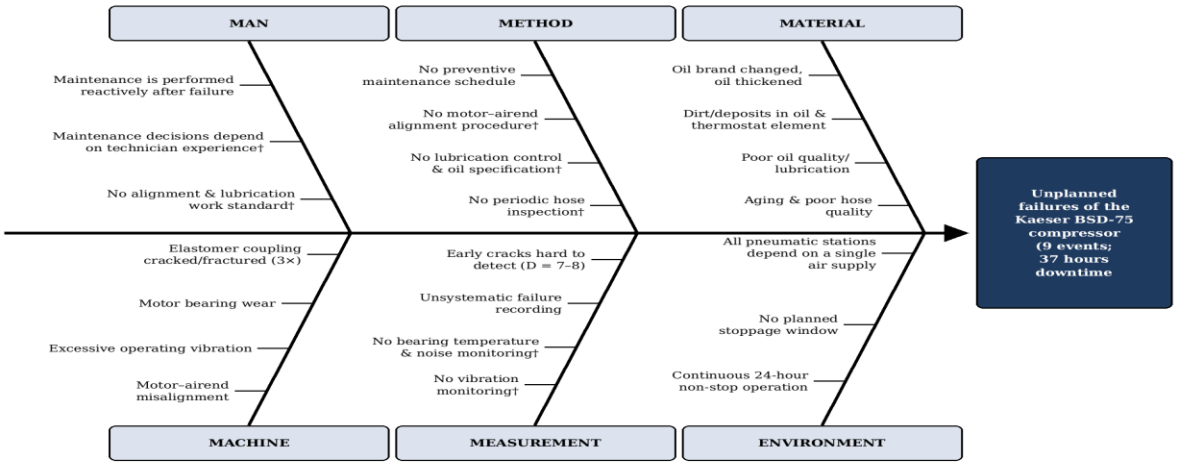


Fig 2. Fishbone diagram of unplanned failures of the Kaeser BSD-75 compressor

Systemic Root Causes and Corrective Actions

The synthesis of the 5 Whys and fishbone analyses produced five systemic root causes and their corrective actions (Table 11). Lubrication control and oil specifications have the greatest leverage because they are associated with five of the nine events and 22 of the 37 downtime hours (59.5%), while alignment procedures and vibration monitoring address the causes of recurring elastomer coupling failures.

Table 11. Systemic root causes and corrective actions

No.	Systemic root cause	Related failure modes	Corrective action
TK-1	No motor–airend alignment procedure or verification†	*Coupling* elastomer (3 kejadian; 13 jam)	Develop an alignment SOP (measuring tools and tolerance limits in accordance with the manufacturer's manual) and require verification during every inspection and after coupling or bearing replacement
TK-2	No vibration and condition monitoring†	*Coupling* elastomer, *bearing screw*, *bearing* motor	Establish periodic vibration, temperature, and noise measurements using checklists and warning limits as the basis for condition-based maintenance
CA-3	No lubrication control or oil specification†	*Bearing screw*, *thermostatic valve* (2 kali), *bearing* motor, *cooler* (5 kejadian; 22 jam)	Establish oil specifications in accordance with the manufacturer, prohibit brand changes or mixing without approval, and schedule oil and filter replacement according to the SIGMA CONTROL 2 interval counter
TK-4	No periodic hose inspection†	*Hose assembly* (1 kejadian; 2 jam)	Include visual inspection for seepage, cracks, and hose aging in the checklist, with replacement criteria
TK-5	Failure and operating-hour records are not systematic	Seluruh mode kegagalan, terutama kerusakan berulang	Establish a failure and maintenance log (date, operating hours, component, cause, action, duration) and periodically review MTBF, MTTR, and recurring failures

These findings explain why RCM alone is insufficient. Scheduled replacement of the elastomer coupling without controlling alignment and vibration merely replaces a consumable component while leaving the cause of its damage unresolved. Similarly, cleaning the thermostatic valve without controlling oil condition does not prevent recurrence of sticking, as shown by the 2023 and 2026 events. These findings are consistent with Ari et al. (2025), who identified lubrication quality and incorrect maintenance procedures as sources of gas compressor failures. Yanuarsah et al. (2023) also traced problems to systemic conditions; through Pareto, fishbone, and 5 Whys analyses, they found that blower nozzle blockage originated from initial installation settings and the absence of a cleaning schedule. In rotating machinery, coupling misalignment is a source of vibration that can damage couplings and bearings, making vibration monitoring useful for preventive maintenance (Kumar et al., 2021).

Integrated RCM–RCA Preventive Maintenance Proposal

The combination of RCM policies and RCA corrective actions is presented in Table 12. Unlike the existing condition, which is entirely corrective, this proposal is proactive: actions are performed before failure, either according to a schedule or based on condition, and are accompanied by controls on root causes to prevent recurrence. This combination of scheduled and condition-based actions is consistent with proposals for air screw compressors (Susilo & Widjajati, 2024) and gas compressors (Omozuhiomwen et al., 2025; Ari et al., 2025).

Table 12. Integrated RCM–RCA preventive maintenance proposal

Component	Maintenance activity (RCM policy)	Supporting corrective action (RCA)
Elastomer coupling	Scheduled maintenance: periodic inspection, vibration and alignment checks, and scheduled elastomer replacement	CA-1 (alignment SOP); CA-2 (vibration monitoring)
Screw bearing	Condition-based maintenance: monitor airend and oil temperatures, noise, vibration, and oil quality; replace when symptoms exceed limits	CA-2; CA-3 (oil control)
Thermostatic valve	Scheduled maintenance: disassembly, cleaning, and inspection of the thermostat element	CA-3; CA-5 (recordkeeping)
Motor bearing	Condition-based maintenance: measure bearing vibration, noise, and temperature; lubricate according to specifications	CA-2; CA-3
Cooler	Scheduled maintenance: clean together with the thermostatic valve; use oil that meets specifications	CA-3
Hose assembly	Condition-based maintenance: visually inspect for seepage and cracks; replace when condition deteriorates	CA-4 (hose inspection)
Sistem perawatan	Combination of scheduled maintenance (3 components) and condition-based maintenance (3 components)	CA-5 and planned shutdown windows

Implementation intervals should refer to the manufacturer's manual and the SIGMA CONTROL 2 interval counter, and then be agreed upon with technicians. As an initial upper limit, the inspection interval for the elastomer coupling should be shorter than its component MTBF of 4,044 hours, or approximately 168 days. Because the compressor operates 24 hours per day and there is no downtime outside production, implementation should be scheduled during planned shutdown windows coordinated with PPIC and the production department, for example on holidays or when compressed-air demand is low, by grouping several actions into one shutdown. Minimum stocks of critical spare parts (elastomer couplings, bearings, thermostatic valves, and hoses) should be provided to prevent repair delays, and the capacity of the air receiver tank or a backup unit should be evaluated. The proposal's effectiveness should be evaluated by comparing the baseline MTBF of 4,452.0 hours and MTTR of 4.11 hours, as well as the frequency of recurring elastomer coupling and thermostatic valve failures. Intervals should be reviewed periodically to avoid over-maintenance, since the proposal adds planned activities that require downtime and technician labor.

IV. CONCLUSION

This study draws five conclusions. First, maintenance of the Kaeser BSD-75 compressor remains corrective, with no preventive schedule. Between January 15, 2022 and February 7, 2026, nine unplanned failures occurred in six components, resulting in 37 hours of downtime. Second, FMEA ranked the elastomer coupling highest (RPN 378; 31.7%), followed by the screw bearing (240) and thermostatic valve (192), which together account for 68.0% of the total RPN of 1,191 and were designated Priority I through the Pareto diagram. Third, the reliability indicators were MTBF 4,452.0 hours, MTTR 4.11 hours, and availability 99.91%; repairs are relatively quick, but failures still occur approximately twice per year. Fourth, RCA using 5 Whys and fishbone analysis showed that the root causes are systemic: the absence of alignment procedures, vibration monitoring, lubrication control and oil specifications, periodic hose inspections, and systematic failure records. Tracing beyond recorded causes is analytical and requires field verification. Fifth, the integrated preventive maintenance proposal includes scheduled maintenance for the elastomer coupling, thermostatic valve, and cooler; condition-based maintenance for the screw bearing, motor bearing, and hose assembly; and five corrective actions addressing the root causes. The proposal has not yet been tested, so the extent of downtime reduction cannot be stated.

The company is advised to begin implementation with the elastomer coupling, screw bearing, and thermostatic valve, establish planned shutdown windows in coordination with PPIC, and maintain stocks of

critical spare parts. Future research should use a longer dataset with actual operating hours and test failure distributions (for example, Weibull), add cost analysis to determine optimal intervals, verify analytically traced causes in the field, and compare MTBF, MTTR, and downtime before and after implementation of the proposal.

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