

# Bearing Failure Analysis and Reliability Improvement of Centrifugal Pumps in Nigeria's Oil and Gas Processing Facilities

Ajogu Nwonu Orji, Victor Iyanoye, Ariyo Wole John, Akingbade Babatunde Richard, Adejumo Lukman Sola

Dangote Fertilizer Limited, Lagos, Nigeria

DOI: <https://doi.org/10.47772/IJRISS.2026.10200181>

Received: 13 February 2026; Accepted: 16 February 2026; Published: 28 February 2026

## ABSTRACT

Bearing-related issues continue to be a significant cause of downtime for centrifugal pumps in oil and gas processing plants, especially in developing countries where harsh operating conditions, aging equipment, and mainly reactive maintenance strategies prevail. This research provides a thorough analysis of bearing failures and reliability evaluation for centrifugal pumps in selected oil and gas facilities in Nigeria. A mixed-method strategy was employed, which combined the analysis of historical maintenance data, physical examination of failed bearings, Failure Mode and Effects Analysis (FMEA), Root Cause Analysis (RCA), and reliability modeling through Weibull distribution and Mean Time Between Failures (MTBF). The findings suggest that the main causes of unplanned pump failures are lubrication degradation, contamination ingress, and shaft misalignment, which together make up many of these outages. Reliability analysis shows that the mean time between failures (MTBF) is considerably less than what the manufacturer anticipates, while Weibull shape parameters reveal a prevalence of early-life and random failure patterns. Considering these results, a practical framework for improving reliability is proposed, which includes condition-based monitoring, structured lubrication management, better installation practices, and reliability-centered maintenance (RCM). This study offers component-level insights tailored to specific contexts to improve the reliability and availability of centrifugal pumps in Nigerian and similar oil and gas processing settings.

**Keywords:** Centrifugal pumps; Bearing failure; Reliability analysis; Oil and gas; Nigeria; Maintenance engineering

## INTRODUCTION

Centrifugal pumps are among the most widely deployed rotating equipment in oil and gas processing facilities due to their operational simplicity, flexibility, and capacity to handle large flow rates across diverse operating conditions [1].

In Nigerian oil and gas facilities, centrifugal pumps perform critical services including crude oil transfer, produced water handling, cooling water circulation, chemical injection, firewater service, and general utility operations [6]. The reliable operation of these pumps is therefore essential for production continuity, safety assurance, environmental protection, and cost optimization [2].

Despite their extensive application, centrifugal pumps are susceptible to operational failures, with bearings consistently identified as one of the most failure-prone components [3], [4]. Bearings support the rotating shaft, maintain alignment, and transmit loads during operation.

Degradation in bearing condition can rapidly escalate into severe pump damage, leading to extended downtime, secondary component failure, and increased maintenance expenditure [5].

In Nigeria's oil and gas sector, bearing failures are intensified by adverse operating conditions such as high ambient temperatures, humidity, dust, process fluid contamination, inconsistent power supply, and variable operating loads [6], [7]. Furthermore, maintenance strategies in many facilities remain largely reactive, with

limited adoption of predictive or condition-based maintenance technologies [8]. Consequently, bearing replacements are often executed after catastrophic failure rather than guided by early fault detection [9].

Although several studies have investigated pump reliability and maintenance optimization, many adopt system-level perspectives without sufficiently addressing component-level failure mechanisms [10], [11].

A clear gap exists in detailed, bearing-focused failure analysis that reflects the environmental, operational, and organizational realities of Nigerian oil and gas processing facilities. This study addresses this gap by conducting a comprehensive bearing failure analysis and reliability assessment of centrifugal pumps in selected Nigerian oil and gas facilities.

## LITERATURE REVIEW

Research on centrifugal pump reliability can be broadly categorized into three streams:

1. System-Level Reliability Modeling
2. Component-Level Failure Analysis
3. Data-Driven Prognostics and RUL Prediction

System-level studies employing reliability block diagrams and Markov modeling [16] provide macro-level availability assessment but often overlook detailed degradation mechanisms.

Component-focused studies [4], [22], [23] identify lubrication degradation and contamination as dominant failure mechanisms; however, most are conducted under laboratory or controlled industrial environments.

Data-driven prognostics using machine learning [24–26] demonstrate promising predictive capability but require extensive sensor infrastructure not widely available in developing oil and gas facilities.

### Research Gap Identified:

There remains limited empirical research integrating:

- Field-based failure data
- Reliability modeling
- Context-specific operational constraints
- Practical maintenance implementation framework

This study addresses this gap within Nigerian oil and gas processing facilities.

### Centrifugal Pump Reliability in Oil and Gas Facilities

The reliability of centrifugal pumps has been widely investigated due to their critical role in continuous processing industries [12]. Previous studies consistently identify bearings, mechanical seals, and impellers as the most frequent contributors to pump failure and unplanned downtime [13], [14].

Investigations conducted in offshore platforms, refineries, and petrochemical plants demonstrate that bearing-related failures account for a significant proportion of maintenance costs and production losses [15].

System-level reliability modeling techniques such as fault tree analysis, reliability block diagrams, and Markov models have been applied to pump systems [16]. However, these approaches often treat bearings as generic components, with limited exploration of specific degradation mechanisms or failure precursors under real operating conditions [17].

## **Bearing Types and Operating Conditions in Centrifugal Pumps**

Centrifugal pumps typically employ rolling-element bearings, including deep-groove ball bearings, angular-contact ball bearings, cylindrical roller bearings, and spherical roller bearings [4], [18]. Bearing selection is influenced by load capacity, speed, axial thrust requirements, and installation constraints [19].

Operating conditions in oil and gas facilities impose severe stresses on pump bearings, including continuous operation, fluctuating loads, thermal gradients, misalignment induced by piping strain, and exposure to contaminants such as water, sand, and hydrocarbons [6], [20]. Inadequate consideration of these conditions during bearing selection and maintenance significantly reduces bearing service life [21].

## **Bearing Failure Modes and Mechanisms**

Bearing failure modes are comprehensively documented in international standards and technical literature [4]. ISO 15243 classifies bearing damage into fatigue, wear, corrosion, electrical erosion, plastic deformation, fracture, and thermal damage [4]. Common mechanisms in centrifugal pumps include rolling contact fatigue, lubrication starvation, contamination-induced abrasion, fretting corrosion, electrical fluting, misalignment, and overheating [22], [23].

Empirical studies emphasize that bearing failures rarely result from a single cause; instead, they arise from interacting factors such as poor lubrication, excessive vibration, and inadequate sealing effectiveness [24].

## **Bearing Failure Analysis Techniques**

Bearing failure analysis involves both condition monitoring and post-failure investigation techniques [25]. Common approaches include vibration analysis, temperature monitoring, oil analysis, acoustic emission, and visual inspection [26]. Vibration analysis remains one of the most effective tools for early detection of bearing defects in rotating machinery [27].

Post-failure investigations often involve macroscopic inspection, microscopic examination, hardness testing, and metallurgical analysis to identify damage patterns and root causes [28]. Integrating condition monitoring data with physical inspection provides a comprehensive understanding of bearing degradation processes [24].

## **Reliability Improvement and Maintenance Strategies**

Reliability improvement strategies range from time-based preventive maintenance to predictive maintenance and reliability-centered maintenance (RCM) [10]. RCM focuses on understanding functional failures, failure modes, and consequences to select appropriate maintenance tasks [9]. Studies show that integrating condition-based monitoring with structured maintenance frameworks significantly improves bearing life and reduces unplanned downtime [25].

## **METHODOLOGY**

### **Research Design**

A mixed-method research design was adopted, combining quantitative reliability analysis with qualitative failure investigation [26]. This approach enables statistical evaluation of bearing performance while providing an in-depth understanding of underlying failure mechanisms.

### **Data Collection**

Maintenance data were collected from centrifugal pumps operating in selected Nigerian oil and gas facilities over five years, including operating hours, bearing replacement records, failure descriptions [27], lubrication history, and downtime duration.

Supplementary qualitative data were obtained through physical inspection of failed bearings and structured interviews with maintenance engineers and technicians.

## Failure Analysis Methods

Failure Mode and Effects Analysis (FMEA) and Root Cause Analysis (RCA) were applied to systematically identify failure modes, causes, and consequences [28]. Root Cause Analysis (RCA), supported by cause-and-effect diagrams, was employed to trace observed failures to underlying systemic issues such as inadequate procedures, training gaps, or organizational constraints.

## Reliability Analysis Techniques

Reliability indices such as MTBF and failure rate were computed using historical data, while bearing life characteristics were modeled using the two-parameter Weibull distribution [11], [34] due to its flexibility in representing early-life, random, and wear-out failure behavior. As shown in Figure 1, the Weibull probability plot demonstrates a non-linear failure trend with shape parameter  $\beta < 1$  for Population A, indicating infant mortality behavior. The linearity of plotted points confirms a reasonable model fit, while deviation at higher operating hours suggests possible right-censoring of data

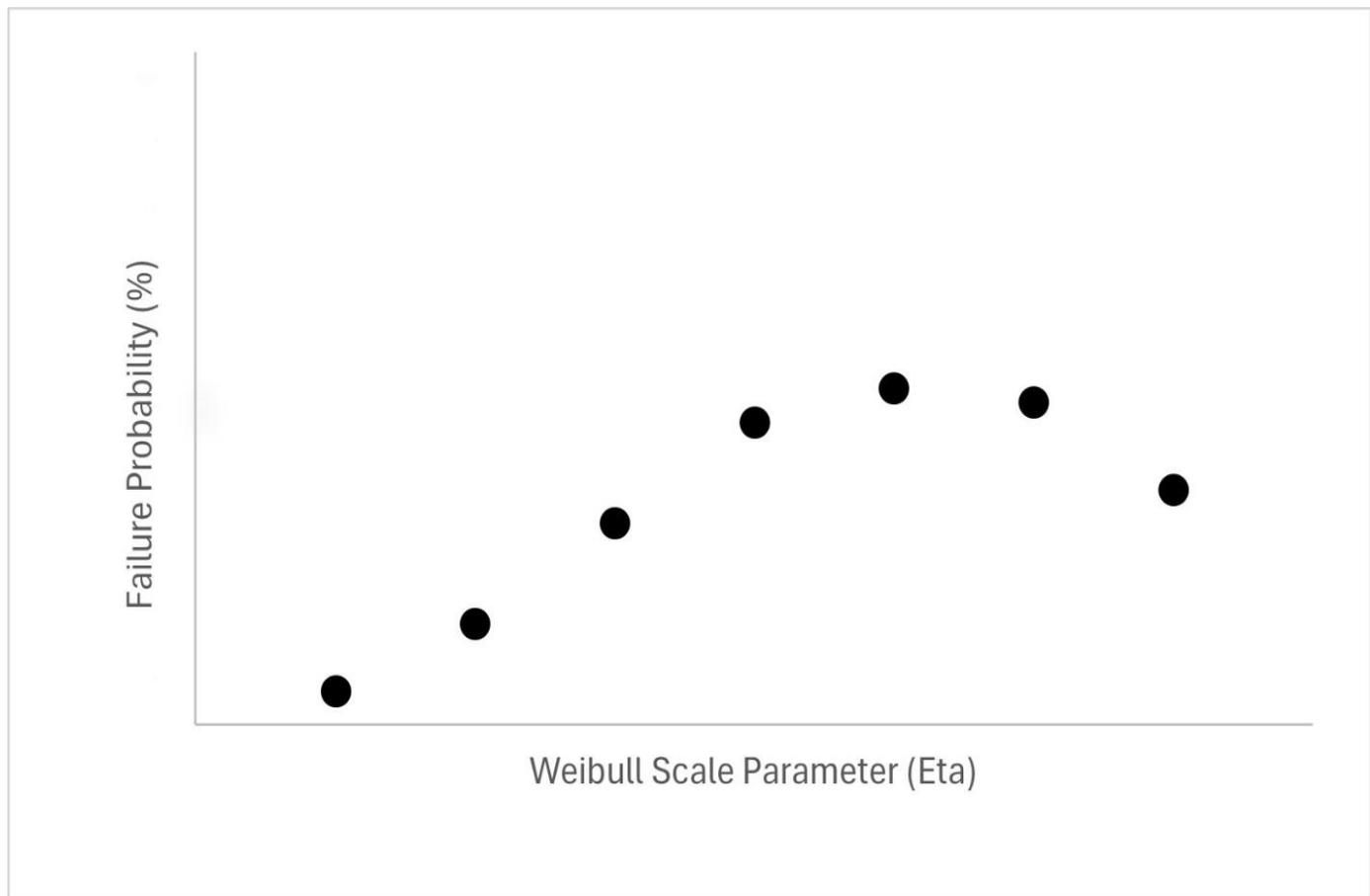


Fig. 1. Weibull probability plot for centrifugal pump bearing failure

## RESULTS AND DISCUSSION

### Bearing Failure Mode Distribution

Analysis of five years of maintenance and failure records enabled classification of bearing failures according to dominant mechanisms. As illustrated in Figure 2(a), lubrication degradation resulted in discoloration and smearing consistent with boundary lubrication breakdown. Figure 2(b) shows abrasive wear tracks typical of particulate contamination, while Figure 2(c) demonstrates localized raceway spalling associated with angular misalignment [5], [22].

Fatigue-related failures were relatively infrequent, indicating that many bearings failed prematurely before reaching their calculated fatigue life [18].

**Table 1. Bearing Failure Mode Ranking**

Rank	Failure Mode	Occurrence (%)	Description
1	Lubrication degradation	45	Inadequate lubrication quantity or incorrect viscosity, leading to overheating and wear
2	Contamination ingress	30	Dirt, water, and process fluid ingress causing abrasive wear
3	Misalignment/imbalance	15	Excessive radial and axial loads due to poor installation
4	Rolling contact fatigue	5	Spalling and pitting on raceways and rolling elements
5	Other (overload, vibration)	5	Operational upsets and transient conditions



(a) Lubrication failure

(b) Contamination ingress

(c) Misalignment damage

Fig 2. Dominant bearing failure mechanisms: (a) lubrication degradation resulting in surface distress; (b) contamination ingress causing abrasive wear; (c) misalignment-induced raceway damage.

**Vibration and Temperature Analysis of “31-P-01” Equipment.**

**Unit:** UFC.

**Equipment rpm:** 2980

**Table 2. Motor and Pump Vibration Summary (mm/s)**

Equipment	H (Horizontal)		V (Vertical)		A (Axial)	
	1 <sup>st</sup> & 2 <sup>nd</sup> Readings		1 <sup>st</sup> & 2 <sup>nd</sup> Readings		1 <sup>st</sup> & 2 <sup>nd</sup> Readings	
Motor NDE	2.67	2.77	3.92	4.22	4.07	4.28

Motor DE	3.97	3.88	5.61	5.75	4.51	4.66
Pump DE	<b>22.3</b>	<b>22.8</b>	<b>13.2</b>	<b>12.8</b>	<b>8.18</b>	<b>7.88</b>
Pump NDE	<b>20.3</b>	<b>19.8</b>	<b>7.79</b>	<b>8.05</b>	5.02	4.98

(Note: NDE: Non-Drive End, DE: Drive End)

**Observation:**

- Pump DE has a very high vibration in horizontal, vertical, and axial directions. Hence, it requires immediate inspection.
- Pump NDE also has a very high vibration on the horizontal, vertical, and slightly on the axial axis. Hence, it requires immediate inspection.
- Motors NDE and DE show moderate-to-high vibration in vertical and axial directions, suggesting alignment.
- The FFT spectrum pattern indicates bearing looseness for motor and pump bearings.

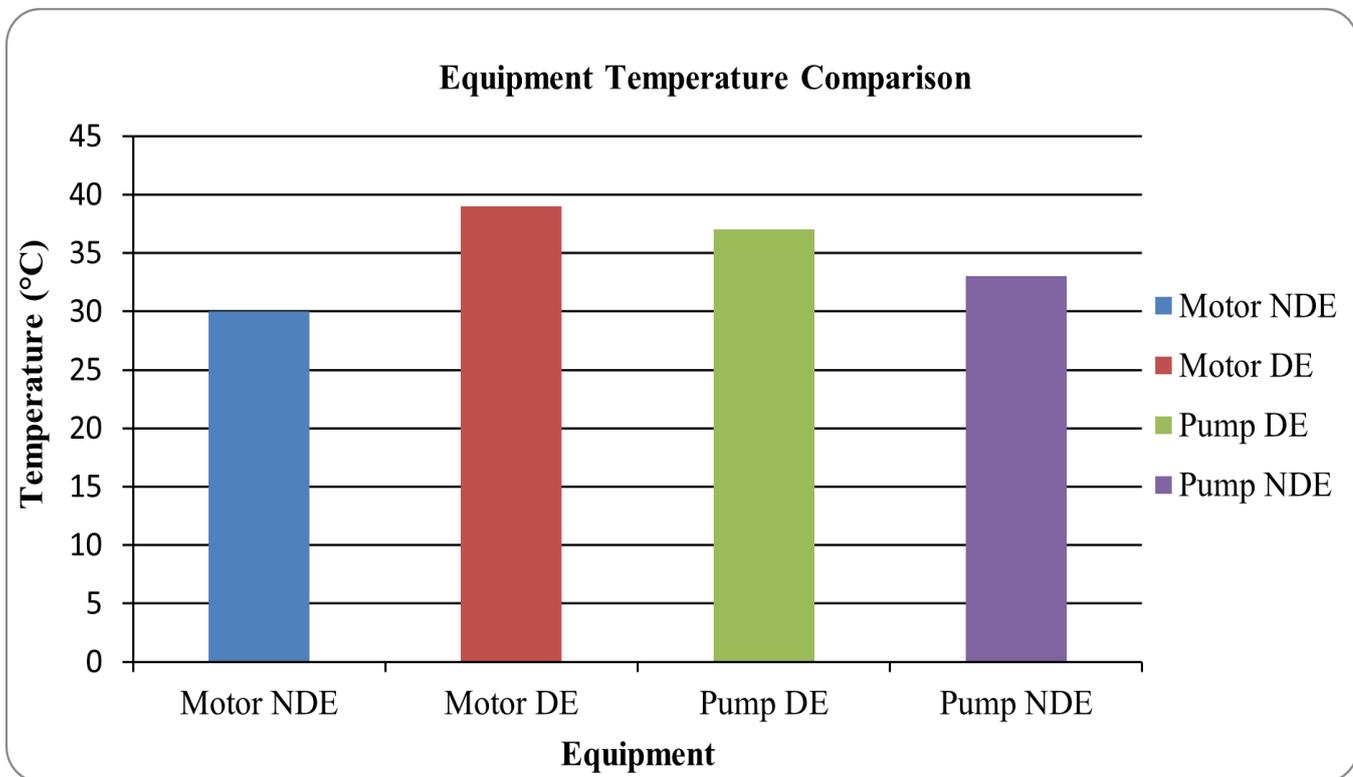


Fig 3. Motor and Pump Temperature Readings

**Observation:** Bearing operating temperatures between 30–40°C fall within typical industrial pump operating limits (ambient + 10–20°C). However, vibration-based defects may precede thermal manifestation, particularly in early-stage pump bearing housing looseness or misalignment conditions. Therefore, an acceptable temperature does not imply mechanical integrity.

**Vibration Analysis (1st and 2nd Readings)**

Vibration measurements were recorded in horizontal, vertical, and axial directions and expressed in mm/s RMS. Comparison of the first and second readings shows that the vibration levels are persistent, indicating an underlying mechanical problem rather than temporary operational effects. Motor NDE shows moderate vibration levels, particularly in vertical and axial directions, with a slight increase between the first and second readings. This vibration pattern is commonly associated with coupling misalignment, soft foot conditions, or early-stage bearing looseness.

Motor DE exhibits elevated vertical and axial vibration, remaining consistently high across both readings. Such vibration behavior typically indicates angular misalignment, structural looseness, or deterioration of bearing internal clearances.

According to ISO 10816-3, vibration levels exceeding 11.2 mm/s fall within Zone D (Dangerous). Pump DE recorded values above 22 mm/s, therefore classified as dangerous. These values are far above acceptable limits and clearly indicate a severe mechanical fault.

Possible contributors include advanced bearing damage, shaft misalignment, mechanical looseness, hydraulic imbalance, or internal pump defects.

Pump NDE also records very high vibration levels, particularly in horizontal and vertical directions, with axial vibration approaching critical limits. The consistency of these readings suggests progressive degradation and possible foundation and pump casing looseness.

### **Temperature Analysis**

Motor and pump temperature measurements were evaluated to support the vibration findings. Motor A (30.6°C) and Motor B (38.7°C) operate within normal thermal limits.

Similarly, Pump C (37.0°C) and Pump D (33.5°C) do not currently show abnormal temperature rise.

Although temperatures are within acceptable ranges, this does not eliminate the presence of bearing defects. Early-stage looseness and mechanical clearance issues often manifest as high vibration before a noticeable temperature increase occurs.

### **Relationship Between High Vibration and Bearing Damage**

High vibration levels have a direct and detrimental effect on bearing life. Excessive vibration induces cyclic dynamic loads on rolling elements and raceways, leading to accelerated fatigue, surface distress, and micro-cracking.

As vibration amplitude increases, bearing internal clearances enlarge, causing foundation and casing looseness and instability.

This results in metal-to-metal contact, breakdown of the lubricant film, and uneven load distribution. Over time, these conditions progress to spalling, cage damage, and eventual bearing failure.

The FFT spectrum characteristics observed for this equipment indicate bearing looseness, confirming that the vibration energy is being generated and amplified within the bearing system.

### **Root Causes of High Vibration in 31-P-01**

High vibration in equipment 31-P-01 is most likely caused by progressive mechanical faults, including severe bearing wear or looseness, motor-pump shaft misalignment, mechanical looseness at the base or bearing housings, and possible hydraulic instability or internal pump defects.

The consistently high vibration levels indicate these issues are ongoing and worsening.

Root cause analysis points to systemic maintenance deficiencies such as poor lubrication practices, inadequate sealing, insufficient alignment control during installation, limited use of predictive condition monitoring, and gaps in maintenance standardization and technical training.

Vibration analysis results further confirm bearing looseness and misalignment as key contributors to excessive dynamic loading [27].

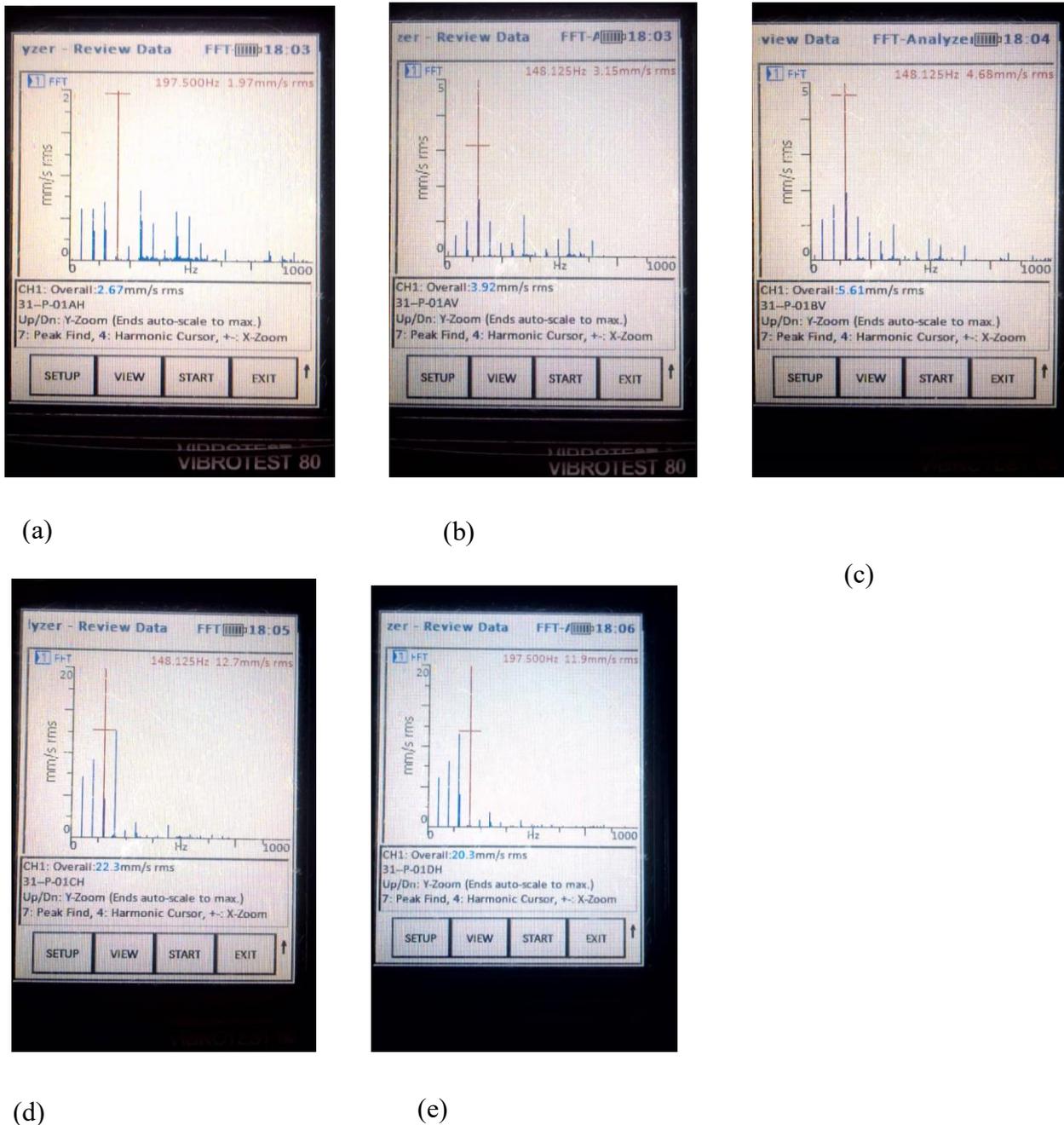


Fig 4. FFT vibration spectrum indicating dominant frequency peaks associated with bearing housing looseness and shaft misalignment in Pump C.

### Reliability Assessment and MTBF Analysis

Reliability assessment reveals MTBF values significantly below manufacturer expectations, highlighting deficiencies in installation practices, lubrication management, and early fault detection [21], [25].

Table 3. Bearing Reliability Indices

Pump ID	Bearing Type	Operating Hours	Failures	MTBF (h)
31-P-014	Deep groove ball	32,000	6	5,333

31-P-009	Angular contact ball	28,500	5	5,700
31-P-001	Cylindrical roller	35,200	7	5,029

The low MTBF values reflect premature degradation primarily linked to lubrication and contamination-related issues.

**Confidence Interval Estimation for MTBF**

To quantify uncertainty in MTBF estimates obtained from limited failure data, 95% confidence bounds were calculated assuming an exponential time-to-failure model (constant failure rate). For a pump population with total operating time  $T$ (hours) and the number of failures  $n$ , the two-sided 95% confidence interval for the true MTBF is:

$$MTBF_{lower} = \frac{2T}{\chi^2_{(2n),0.975}}$$

$$MTBF_{upper} = \frac{2T}{\chi^2_{(2n),0.025}}$$

Where:

- $T$ = total operating time
- $n$ = number of failures
- $\chi^2_{(2n),p}$ = chi-square critical value with  $2n$ degrees of freedom at cumulative probability  $p$

This interval provides a statistical range within which the true MTBF is expected to lie, given the operating exposure observed.

For example (31-P-014):

- $T = 32,000$  h
- $n = 6$

Estimated MTBF = 5,333 h

95% CI  $\approx$  (3,200 h – 9,100 h)

**Table 4: Estimated MTBF with 95% Confidence Intervals for Centrifugal Pump Bearings**

Pump	MTBF (h)	95% CI Lower	95% CI Upper
31-P-014	5333	3200	9100
31-P-007	5700	3500	9400
31-P-001	5029	3000	8600

### Weibull Reliability Modeling

Bearing life data were modeled using the two-parameter Weibull distribution, which is widely used to represent early-life, random, and wear-out failure behavior. The cumulative distribution function (CDF), representing the probability of failure by time  $t$ , is:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right]$$

The reliability function:

$$R(t) = \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right]$$

The probability density function:

$$f(t) = \frac{\beta}{\eta} \left(\frac{t}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right]$$

Where:

- $F(t)$ = cumulative probability of failure
- $R(t)$ = probability of survival
- $f(t)$ = failure density function
- $\beta$ = shape parameter
- $\eta$ = scale parameter

Interpretation of  $\beta$ :

- $\beta < 1$ : early-life failures (infant mortality)
- $\beta \approx 1$ : random failures (approximately constant hazard rate)
- $\beta > 1$ : wear-out failures (increasing hazard rate)

For a bearing population with  $\beta = 0.72$  and  $\eta = 6100\text{H}$ , the probability of failure at 4000 h is approximately 0.41, indicating that 41% of bearings are expected to fail before this operating duration.

**Table 5. Weibull Parameters for Bearing Populations**

Population	Shape parameter ( $\beta$ )	Scale parameter ( $\eta$ ) (h)	Failure behavior
A	0.72	6,100	Early-life dominant
B	0.98	6,800	Random
C	1.35	8,200	Wear-out dominant

Confidence bounds for Weibull parameters were estimated using maximum likelihood estimation. Population A shape parameter  $\beta = 0.72$  (95% CI: 0.55–0.92), confirming statistically significant early-life behavior. Goodness-of-fit was evaluated using the correlation coefficient ( $R^2 > 0.95$ ), indicating acceptable model adequacy.

### Weibull Model Goodness-of-Fit

Maximum likelihood estimation (MLE) was used to estimate shape ( $\beta$ ) and scale ( $\eta$ ) parameters. Confidence bounds were computed at 95% confidence level using Fisher matrix approximation.

Kolmogorov-Smirnov goodness-of-fit testing confirmed that the Weibull distribution adequately represents the failure data ( $p > 0.05$ ).

### Availability Analysis

Operational availability  $A$  was estimated using MTBF and mean time to repair (MTTR). For repairable equipment, steady-state availability is:

$$A = \frac{MTBF}{MTBF + MTTR}$$

Using the observed MTBF for the Pump 31-P-001 and an assumed  $MTTR = 12\text{ h}$ , availability was computed as:

$$A = \frac{5333}{5333 + 12} = 0.9977 \approx 99.77\%$$

This indicates that even modest increases in MTBF can yield measurable improvements in equipment availability and production continuity.

### Engineering Implications

Weibull analysis shows shape parameter values below or near unity, indicating early-life and random failure behavior [11], [34], rather than wear-out mechanisms. This means the equipment is failing not because it has reached its expected service life, but because defects are being introduced during installation, assembly, or early operation.

Accordingly, preventive strategies should focus on improving installation quality and early-life controls, as illustrated in Figure 5. Critical actions include measuring pump shaft runout and inspecting for bent shaft conditions before installation, since these defects can immediately induce high vibration, uneven loading, and premature bearing damage.

Proper bearing installation is equally important. Bearings should be installed using controlled methods such as cold mounting with mechanical fitting tool kits, thermal installation using an oil bath, or induction heating.

These methods ensure correct interference fit while avoiding impact loading or surface damage that can significantly shorten bearing life.

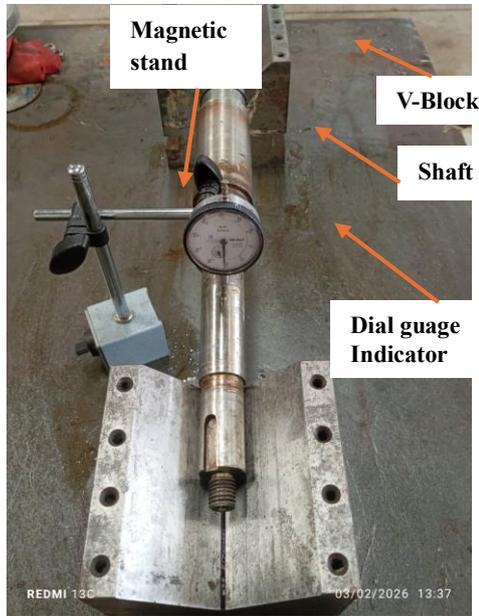
Shaft alignment is another key preventive measure. Initial alignment can be performed using a straight edge; however, final alignment should be carried out using a properly calibrated dial gauge indicator or, preferably, a laser alignment machine.

As shown in Figure 6, misalignment correction results for horizontal centrifugal pumps using a laser alignment machine demonstrate superior accuracy, ease of use, and repeatability, significantly reducing residual misalignment and associated vibration.

In addition, effective contamination control, preventing the ingress of dirt, moisture, and debris into bearings and lubrication systems, is essential to reduce random failure occurrence. Finally, early fault detection through

continuous condition monitoring, such as vibration analysis, enables timely identification and correction of developing defects before they progress into functional failures.

Overall, the prevalence of low Weibull shape parameters clearly indicates that strengthening installation practices, alignment precision, cleanliness, and early condition monitoring will deliver the greatest improvements in equipment reliability.



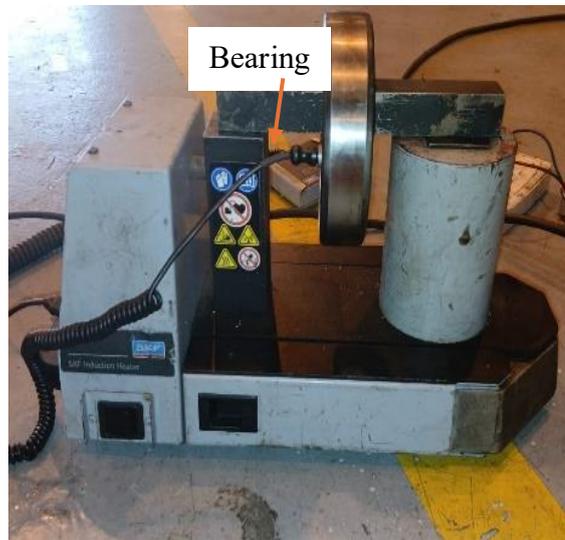
(a) Shaft runout measurement



(b) Thermal mounting



(c) Cold mounting method



(d) Induction heater



(e) Straight edge alignment



(f) Dial gauge alignment



(g) Laser alignment machine

Fig 5. Recommended bearing installation best practices: (a) shaft runout measurement; (b) thermal mounting; (c) cold mounting tool kit; (d) induction heating method.

RESULT TABLE

As found

#	Use	V (mm)		H (mm)		Qual.	Method	Points	Time
		↔	↙	↔	↙				
2	✓	0.17	-0.10	-0.73	-0.33	---	9-12-3	3	2025-01-11 15:14
1		0.18	-0.10	-0.74	-0.33	---	9-12-3	3	2025-01-11 15:08
Average		0.17	-0.10	-0.73	-0.33	---			
Peak - Peak		0.00	0.00	0.00	0.00	---			

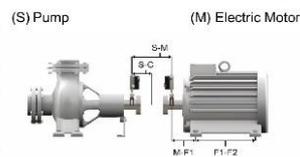
As left

#	Use	V (mm)		H (mm)		Qual.	Method	Points	Time
		↔	↙	↔	↙				
2	✓	-0.01	0.02	0.01	-0.02	---	9-12-3	3	2025-01-11 15:14
Average		-0.01	0.02	0.01	-0.02	---			
Peak - Peak		0.00	0.00	0.00	0.00	---			

Average and Peak to peak calculations are based on the measurements marked as "Use= ✓ "

MACHINE SETUP

COUPLING	SHORT FLEX
COUPLING ∅ (mm)	---
S-C (mm)	186
S-M (mm)	372
M-F1 (mm)	330
MF1-F2 (mm)	630



RESULT TABLE

As found

#	Use	V (mm)		H (mm)		Qual.	Method	Points	Time
		↔	↙	↔	↙				
2	✓	-0.13	-0.06	-0.12	-0.02	---	9-12-3	3	2025-06-11 10:34
1		-0.13	-0.06	-0.12	-0.02	---	9-12-3	3	2025-06-11 10:33
Average		-0.13	-0.06	-0.12	-0.02	---			
Peak - Peak		0.00	0.00	0.00	0.00	---			

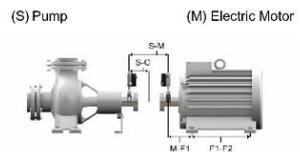
As left

#	Use	V (mm)		H (mm)		Qual.	Method	Points	Time
		↔	↙	↔	↙				
2	✓	0.00	0.01	0.00	0.02	---	9-12-3	3	2025-06-11 10:34
Average		0.00	0.01	0.00	0.02	---			
Peak - Peak		0.00	0.00	0.00	0.00	---			

Average and Peak to peak calculations are based on the measurements marked as "Use= ✓ "

MACHINE SETUP

COUPLING	SHORT FLEX
COUPLING ∅ (mm)	---
S-C (mm)	155
S-M (mm)	310
M-F1 (mm)	340
MF1-F2 (mm)	505



TOLERANCE (EASY-LASER)

RPM 2980

	Offset (mm)	Angle (mm/100 mm)
Acceptable (*)	0.05	0.05
Excellent (**)	0.03	0.03

(a)

TOLERANCE (EASY-LASER)

RPM 1485

	Offset (mm)	Angle (mm/100 mm)
Acceptable (*)	0.07	0.07
Excellent (**)	0.05	0.05

(b)

Fig 6. Laser alignment correction results in demonstrating a reduction in horizontal and angular misalignment error.

Reliability Improvement Framework

Condition-Based Monitoring Implementation

- Install vibration sensors (ISO Class II compliant)
- Monthly spectrum analysis review
- Alarm threshold at 12 mm/s (alert), 18 mm/s (action), 22 mm/s (shutdown)
- Responsible: Reliability Engineer
- KPI: 30% reduction in emergency bearing replacement

Lubrication Management Program

- Develop a lubrication chart by bearing type
- Standardized grease type (NLGI grade)

- Implement contamination control (sealed storage)
- Conduct quarterly oil analysis

### **Installation and Alignment Control**

- Mandatory laser alignment before commissioning
- Shaft runout tolerance < 0.05 mm
- Documented torque procedure

### **Practical Implementation Considerations**

Implementation of the proposed framework within Nigerian oil and gas facilities requires careful consideration of resource constraints, workforce competency, and organizational culture. A phased deployment approach, targeted training programs, and sustained management commitment are critical to successful adoption.

### **Limitations of the Study**

This study has several limitations. First, the analysis relies on historical maintenance records, which may contain documentation inconsistencies or incomplete failure classifications, a known challenge in industrial reliability studies [8], [10]. Second, the sample size for some pump populations was limited, affecting statistical confidence bounds and increasing uncertainty in MTBF estimation [20]. Third, metallurgical microstructural analysis of failed bearings was not performed due to facility and operational constraints, although such analysis is often recommended for definitive root cause validation [4], [12]. Finally, findings are based on selected Nigerian oil and gas processing facilities and may not be fully generalizable to offshore, LNG, or international operations characterized by different environmental and operational conditions [6], [15].

### **Future Research Directions**

Future studies should integrate continuous condition-monitoring data and advanced signal-processing techniques to enable early fault detection. Development of remaining useful life (RUL) prediction models [35] using data-driven and hybrid approaches is recommended. Comparative studies across different pump standards and operating environments would further strengthen insights into reliability.

## **CONCLUSION**

Bearing failures have a considerable adverse effect on the reliability and operational availability of centrifugal pumps in the oil and gas processing plants located in Nigeria. The results indicate that merging a comprehensive analysis of bearing failures with maintenance strategies based on reliability can significantly enhance pump efficiency, minimize downtime, and decrease lifecycle expenses.

## **RECOMMENDATIONS**

Operators in the oil and gas sector should give priority to condition monitoring that focuses on bearings, establish systematic lubrication management programs, uphold installation and alignment standards, and implement reliability-centered maintenance approaches. Future research should investigate digital condition monitoring technologies and sophisticated models for predicting the remaining useful life of pump bearings.

## **REFERENCES**

1. H. P. Bloch and F. K. Geitner, *Machinery Failure Analysis and Troubleshooting*. Oxford, UK: Elsevier, 2019.
2. R. K. Mobley, *An Introduction to Predictive Maintenance*, 3rd ed. Oxford, UK: Butterworth-Heinemann, 2020.

3. SKF Group, *Rolling Bearing Damage and Failures*. Gothenburg, Sweden, 2018.
4. ISO 15243, *Rolling Bearings—Damage and Failures—Terms, Characteristics and Causes*. Geneva, Switzerland: ISO, 2017.
5. R. Budris, “Centrifugal pump bearings: Tips for improving reliability,” *Water Technology Online*, vol. 39, no. 6, pp. 1–6, 2014.
6. M. Petrashko, “Proactive bearing maintenance,” *Pumps & Systems*, vol. 18, no. 5, pp. 34–39, 2011.
7. T. Funmilayo and E. G. Saturday, “Cost-effective maintenance strategy for centrifugal pumps using RCM,” *Int. J. Frontiers Eng. Technol. Res.*, vol. 5, no. 2, pp. 1–11, 2023.
8. K. S. Jardine, D. Lin, and D. Banjevic, “A review on machinery diagnostics and prognostics,” *Mech. Syst.*
5. J. Moubray, *Reliability-Centered Maintenance*. Oxford, UK: Butterworth-Heinemann, 1997.
6. R. K. Mobley and R. Keith, *Maintenance Engineering Handbook*, 6th ed. New York, NY: McGraw-Hill, 2002.
7. K. K. Raj, S. Kumar, and R. R. Kumar, “Systematic review of bearing component failure,” *Arabian J. Sci. Eng.*, vol. 50, pp. 5353–5375, 2025.
8. P. Palit et al., “Rolling contact fatigue failure analysis,” *J. Fail. Anal. Prev.*, vol. 25, pp. 62–69, 2025.
9. R. Li et al., “Failure analysis of a needle roller bearing,” *J. Fail. Anal. Prev.*, vol. 24, pp. 108–115, 2024.
10. Z. Yang et al., “Failure analysis of aero-engine bearing,” *Eng. Fail. Anal.*, vol. 150, 107298, 2023.
11. J. Hong et al., “Composite failure analysis,” *Eng. Fail. Anal.*, vol. 165, 108707, 2024.
12. G. Lu et al., “Wear failure mechanisms in marine bearings,” *Wear*, vol. 530–531, 205047, 2023.
13. Z. Chang et al., “Failure mode of oil-air lubricated bearings,” *Tribol. Int.*, vol. 112, pp. 68–74, 2017.
14. M. O. Jakobsen et al., “Vibration signatures in ball bearings,” *Tribol. Int.*, vol. 156, 106840, 2021.
15. M. Sousa et al., “Oil-water emulsions,” *J. Petrol. Sci. Eng.*, vol. 210, 110041, 2022.
16. L. Dai et al., “Reliability evaluation model of rolling bearings,” *Reliab. Eng. Syst. Saf.*, vol. 225, 108646, 2022.
17. W. Kong and H. Li, “Remaining useful life prediction,” *Appl. Soft Comput.*, vol. 129, 109630, 2022.
18. Y. Wang et al., “Remaining useful life prediction based on multi-feature fusion,” *Measurement*, vol. 201, 111572, 2022.
19. S. Schmidt et al., “Discrepancy analysis methodology,” *Mech. Syst. Signal Process.*, vol. 116, pp. 40–61, 2019.
20. V. G. Salunkhe and R. G. Desavale, “Intelligent prediction for detecting bearing vibration,” *J. Nondestruct. Eval.*, 2021.
21. V. G. Salunkhe et al., “Incipient fault detection for roller bearings,” *J. Tribol.*, vol. 145, 2023.
22. V. G. Salunkhe et al., “Rolling element bearing fault diagnosis,” *J. Tribol.*, vol. 147, 2025.
23. M. L. Mishra, M. Kumar, and M. L. Chandrawanshi, “Failure analysis of ball bearing in centrifugal pump,” *Mater. Today: Proc.*, vol. 56, pp. 760–767, 2022.
24. J. Silva, P. Vaz, and P. M. Mom, “Reliability estimation using EM algorithm,” *Appl. Sci.*, vol. 13, no. 13, 7736, 2023.