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(Research Article)

Application of artificial neural networks in predicting early failures in industrial pumps

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Abstract

Maintenance optimization is a critical aspect of industrial operations, ensuring reliability, efficiency and cost effectiveness. Traditional maintenance strategies, such as corrective maintenance, often lead to excessive downtime or avoidable resource consumption. This research work focused on the maintenance optimization of centrifugal pumps used in Nigerian refineries. In this study, The Griswold pump (101-PM-2A) was used as a case study and its operational data as well as field performance readings were obtained from Warri Refining and Petrochemical Company (WRPC).The maintenance optimization model employed in this research is Artificial Neural Networks (ANN) to predict failures and suggest maintenance routine for the pump while in operation. The result shows that the vibration values exceeding *29Hz* may damage the pump system. It is highly recommended that the operation of the pump has to be halted should a vibration reading close to *29Hz* be registered on the vibrometer. The findings demonstrate that ANN-based maintenance strategy outperforms traditional approaches by drastically minimizing failures, optimizing resource allocation and extending equipment lifespan.

Keywords: Centrifugal pump; Vibration; Optimization; Artificial Neural Networks

1. Introduction

In today's fast-paced industrial landscape, effective maintenance strategies are critical to ensuring operational efficiency, minimizing downtime, and reducing costs. Traditional maintenance approaches, such as reactive or time-based maintenance, often lead to unnecessary expenses and unexpected failures. This is where maintenance optimization comes into play—a strategic approach that leverages data, predictive analytics, and advanced technologies to enhance asset reliability and performance (Mobley, 2021). By optimizing maintenance processes, industries can shift from a reactive mind-set to a proactive and predictive approach, improving equipment lifespan and overall productivity (Banjevic etal, 2006). The dominant reason for this ineffective management is the lack of factual data that qualify the actual need for repair or maintenance of plant machinery and systems. However, the development of microprocessor and other computer-based instrumentation used to monitor the operating condition of plant equipment, machinery and systems have provided the means to manage maintenance operations. This positive development has enabled us reduce or eliminate unnecessary repairs and prevent catastrophic machine failures. Regular *monitoring* of actual machine conditions and operating efficiency of process systems ensure maintenance optimization thereby minimizing the number and costs of unscheduled outages created by machine-train failures and improve the overall availability of operating plants (Philip, 2013).

Augusto, et al (2022) employed the use of CFD-code Fluent for the vibration analysis of two test pumps of end-suction volute type, one of low specific speed and one of medium specific speed. For both, head as function of flow rate for constant rotational speed is known from the experiment. First, the impeller is generated. One impeller channel is

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meshed and is then rotationally copied the necessary number of times. The Steady calculation methods such as the Frozen Rotor method and the Mixing Plane method were used to analyze the performance of volute centrifugal pumps.

Carsten et al (2022) investigated the complex internal flow in a centrifugal pump impeller with six multiple blades by simulation using a three-dimensional Nervier-Stokes code with a standard *k*-e two-dimensional equation turbulence model. It was observed that the shaft frequently wobbled due to misalignment; hence the excessive vibration was constantly experienced at every 1000 cycle's performance of the pump.

Waleed, A. et al., (2022) investigated centrifugal pump impeller crack detection using vibration analysis in which the vibration index increases as the impeller crack size increases.

Abid et al. (2014) created an alternative reliability centered model technique that has incorporated life data analysis.

Jagathy and Deepak (2013) used reliability centered model to identify limitations of traditional RCM by calling for a new RCM framework in refineries, which comprise comparable oil and gas process plants as well as other process plants.

Gandhare and Akarte (2012) have found Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to be very effective in determining effective maintenance strategies.

Selvik and Aven (2011) carried out an investigation and established a framework for reliable and risk-based maintenance that proposed extending reliability centered model (RCM) to include risk that is not properly addressed in standard RCM.

Momeni et al., (2011) have found application in decision making in various industries such as oil and gas process plants. An evaluation of the multi-criteria decision-making methodologies utilized in the adoption of maintenance strategies reveals that they assist in improving decision making.

Cheng et al. (2008) incorporated artificial intelligence into RCM analysis, which entails doing RCM evaluation on new machinery using a guide derived from past comparable equipment RCM analysis data.

Wang et al., (2007) a hierarchical decision-making method had been found to be useful for maintenance decision making.

Zare, et al., (2018) used TOPSIS multi-criteria decision method to modify and utilize various maintenance strategy selections.

Golbabaei et al (2020) have studied various parameters which affect the pump performance and energy consumption like the impeller outlet diameter, the blade angle and the blade number and evaluated the performance of impellers with the same outlet diameter having different outlet blade angles. The influence of the outlet blade angle on the performance is verified with the Computational Fluid Dynamic simulation. The numerical simulations reasonably predict the total performance and the global characteristics of the pump.

Khan et al (2019) discovered the results of measurements of parameters of a high speed impeller pump with open-flow impeller having radial blades. It was found that at high rotational speed pump has obtained a large delivery head, because the blade angle at outlet from the impeller is wide, liquid flowing out the impeller has large absolute velocity and dynamic delivery head of the impeller is large.

Pang et al (2019) evaluated the performance of impellers with the same outlet diameter having multiple blade numbers for centrifugal pumps. The impeller performance was simulated and predicted by using Ansys Fluent software. The simulation result depicts that the failure increases as the working substances are becoming heavier.

Abdulkareem (2014) carried out analysis on the detection of the centrifugal pump impeller blades cracks using vibration analysis technique which was investigated using both time and frequency domain methods. In time domain, a time index parameter is applied as fault indicator and the power spectrum analysis is used as a frequency domain analysis. Initially, the vibration of centrifugal pump is measured at healthy condition and compared with nine different artificial cracks sizes which were introduced in the impeller blades. The results show the effectiveness of using both time index parameter and frequency spectrum for fault diagnosis. The amplitude of the impeller passing frequency and the vibration time index increased as the blade crack size is developed, which can be used as indicator for fault severity.

Abdel-Rahman and El-Shaikh (2014) have investigated the effects of pump unbalance and misalignment on the overall pump vibration level. Overall vibration levels indicate severity of vibration and compared with ISO 10816-1. Also, the vibration spectra, which indicate the relation of vibration amplitude with frequency, are measured to determine the excitation frequencies and the source of high vibration. The unbalance condition for the motor fan showed a high vibration spectrum in the axial and radial directions of maximum amplitude at the motor speed.

Bianchini, A. et tal (2019) developed and applied a condition based maintenance (CBM) procedure to assist decision making in schedule maintenance industrial centrifugal pump.

Shigemitsu et al.,(2013) carried out numerical and experimental investigation of mini semi-open impeller; addition of splitter blades at high outlet angle of impeller blades Back-flow region suppressed, vortex loss at volute casing decreased.

Abid, M. et al., (2011) carried out simulation and optimization of centrifugal pump impeller by modifying main blade and splitter profile using Bezier curves to improve pump performance by reducing secondary flow.

Balakrishnan, K. et al., (2016) modified of number of blades, outlet blade angle and splitter length of a centrifugal pump to give high pump performance while pumping water.

Namazizadeh et al.,(2020) tested a centrifugal pump for pumping water by modifying splitter length and position from main blade as well as varied them to improve pump head with negligible efficiency change.

Cheng, Z. et al., (2008) carried out experimental testing of centrifugal pump impeller by optimizing splitter blade lengths which achieved optimized locations of splitter blades.

Siddique et al.,(2021) carried out experimental analysis of centrifugal pump for pumping water by modifying number of blades, splitter length, wrap angle through optimizing shape and length of splitter blade which improved pump performance.

Khanis, B., (2007) carried out an investigative study for centrifugal pump for water application by modifying number of blades and splitter length to improve pump performance for a small number of blades.

Nordmann, et al.(2015) devised a predictive maintenance model for centrifugal pumps under improper maintenance conditions by lengthening the pump useful life using RCM approach.

Moubray, J., (2000) carried out an assessment of mechanical problems for centrifugal pumps in which the percentage of frequency occurrence of various problems faced varies between 31.1% and 44.2%.

Liang, F. et al., (2012) diagnosed centrifugal pump faults using comparative vibration source with respect to passage of current, voltage and flow rate.

Abid et al. (2014) created an alternative reliability centered model technique that has incorporated life data analysis.

Panchal and Kumar (2017) used reliability centered model to identify limitations of traditional RCM by calling for a new RCM framework in refineries, which comprise comparable oil and gas process plants as well as other process plants.

Gandhare and Akarte, (2012) have found Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to be very effective in determining effective maintenance strategies.

Bevilacqua and Braglia, (2000) carried out an investigation and established a framework for reliable and risk-based maintenance that proposed extending reliability centered model (RCM) to include risk that is not properly addressed in standard RCM.

2. Materials and methods

The method employed in this research is the application of Artificial Neural Network model with field readings recorded from a particular pump in operation in order to predict failures and suggest maintenance routine for the pump while in operation. The following set of data was obtained from Warri Refining and Petrochemical Company-Nigeria for a period of forty two (42) days in a daily interval of twelve (12) hours.

2.1. Research Instruments

The main instruments used in this research work to collect data are discussed hereunder:

- Electronic Tachometer
- Electronic Vibrometer

2.1.1. Tachometer

A tachometer also known as revolution-counter or RPM gauge is primarily used to measure the rotational speed of a shaft or disk in machinery. It displays revolutions per minute (rev/min).

Figure 1 Electronic Tachometer (WRPC, 2022)

2.1.2. Vibrometer

A vibrometer possesses a two beam laser interferometer that detects the frequency (in Hertz) difference between an internal reference beam and a test beam. It is a precise instrument whose natural frequency is lower than that of the vibration to be measured. It equally measures the displacement of a vibrating machine.

Figure 2 Vibrometer (WRPC, 2022)

2.2. Operational Data

The first step of this research is the field data acquisition from Warri Refining and Petrochemical Company-Nigeria on their pumps in operation. These data were then filtered to extract information needed to successfully run simulations.

The information obtained is divided into operational information and field vibration information which were obtained using vibrometer on the pump while on operation. Electronic tachometer was used to measure the pump's rotational speed in revolutions per minute.

Table 1 Sludge pump rating

liquid	Speed (RPM)	Power rating (Hp)	Voltage (Volts)	Frequency (Hz)	Discharge capacity (m^3/h)	Head (m)	Temperature (Celsius)
Sludge	2950	50	380	40	25	150	32-50

The table below contains vibration data taken from pump as follows:

I= Pump inlet, O= Pump outlet and V= Pump volute

In table 2 the vibration was taken at three (3) different points on the pump *inlet, outlet and volute*.

Table 2 Operational Vibration Data

Serial No	Date	Inlet vibration (Hz)	Outlet vibration (Hz)	Volute vibration (Hz)
1	27/3/2022	30.95	32.95	30.2
2	28/3/2022	28.61	34.6	38.15
3	30/3/2022	39.7	30.7	29.5
4	31/3/2022	34.8	30.15	33.95
5	03/3/2022	46.1	34.75	38.45
6	05/4/2022	33.6	34.4	26.35
7	7/4/2022	32.05	34.45	33
8	10/4/2022	30.4	34.75	34.4
9	12/4/2022	45.1	39.65	34.25
10	13/4/2022	39.05	35.15	34.3
11	14/4/2022	39.5	37.35	30.3
12	15/4/2022	29.35	32.15	33.8
13	17/4/2022	34.41	32.94	32.52
14	18/4/2022	29.3	28.15	29.45
15	20/4/2022	39.9	30.8	34.35
16	24/4/2022	30.7	32.2	30.65
17	26/4/2022	30.8	31.35	33.2
18	27/4/2022	34.6	33.2	32.3
19	1/5/2022	46.1	45.40	44.95
20	3/5/2022	37.7	31.25	32.95
21	5/5/2022	39.8	30.15	29.25
22	7/5/2022	30.6	31.25	28.3
23	15/5/2022	39.7	30.95	29.7

24	16/5/2022	31.45	34.9	32.1
25	19/5/2022	34.1	33.15	29.75
26	22/5/2022	34.7	34.2	33.9
27	24/5/2022	32.8	34.9	33.8
28	26/5/2022	34.6	32.5	33.9
29	29/5/2022	33.4	33.15	24.75
30	2/6/2022	34.35	33.5	45.15
31	5/6/2022	31.65	34.25	33.15
32	7/6/2022	30.95	31.45	39.85
33	9/6/2022	32.05	34.1	33.1
34	12/6/2022	30.35	23.6	32.65
35	14/6/2022	31.25	29.35	38.05
36	19/6/2022	31.85	30.05	31.45
37	21/6/2022	38.05	38.05	39.08
38	23/6/2022	33.75	33.25	32.6
39	26/6/2022	31.05	34.5	32.95
40	28/6/2022	45.2	45.35	44.99
41	30/6/2022	34.15	33.3	28.35
42	3/7/2022	38.8	39.25	31.5
43	5/7/2022	32.95	33.3	33.12
44	7/7/2022	30.2	33.75	32.95
45	10/7/2022	34.3	33.55	33.95

Table 3 Sludge pump working data

Suction head m	**Discharge head m**	**Total head m**	**Speed (RPM)**	**Flow (m^3/h)**	**Voltage (Volts)**	**Motor efficiency %**	**Pump efficiency %**
0	171.5	171.5	2980	-	380	87	-
0	171.5	171.5	2980	6	380	88	13.38
0	167.5	167.5	2975	14	380	88	26.21
0	160.5	160.5	2970	21	380	88	33.27
0	153	153	2970	26	380	88	37
0	139	139	2970	31	380	88	37.7

3. Results and discussion

From the ANN architecture below, Pump head, Pump rotational speed and Discharge capacity are the inputs while frequency is the predicted output.

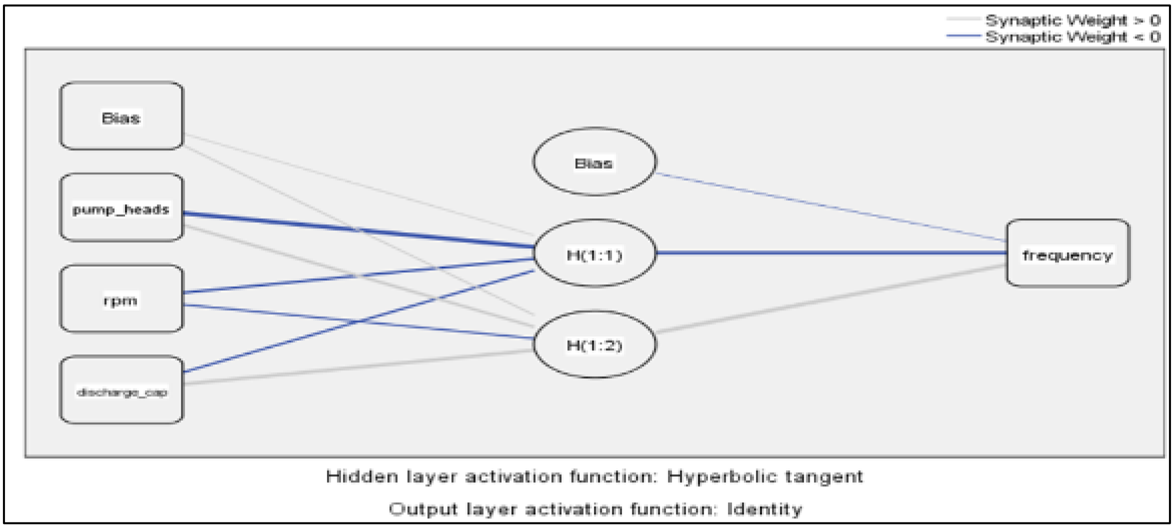

Figure 3 ANN Architecture of the Griswold pump vibration data

3.1. Model Summary

The statistical summary of the ANN simulation is presented hereunder:

Table 4 Model Summary

Training	**Sum of Squares Error**		**51.767**
	Average Overall Relative Error		1.046
	Relative Error for Scale Dependents	i. Pump head	0.980
		ii. Speed	1.070
		iii. Discharge capacity	1.087
	Stopping Rule Used		1 consecutive step(s) with no decrease in error
	Training Time		0:00:00.01
Testing	Sum of Squares Error		123.692
	Average Overall Relative Error		1.307

3.2. Model Charts

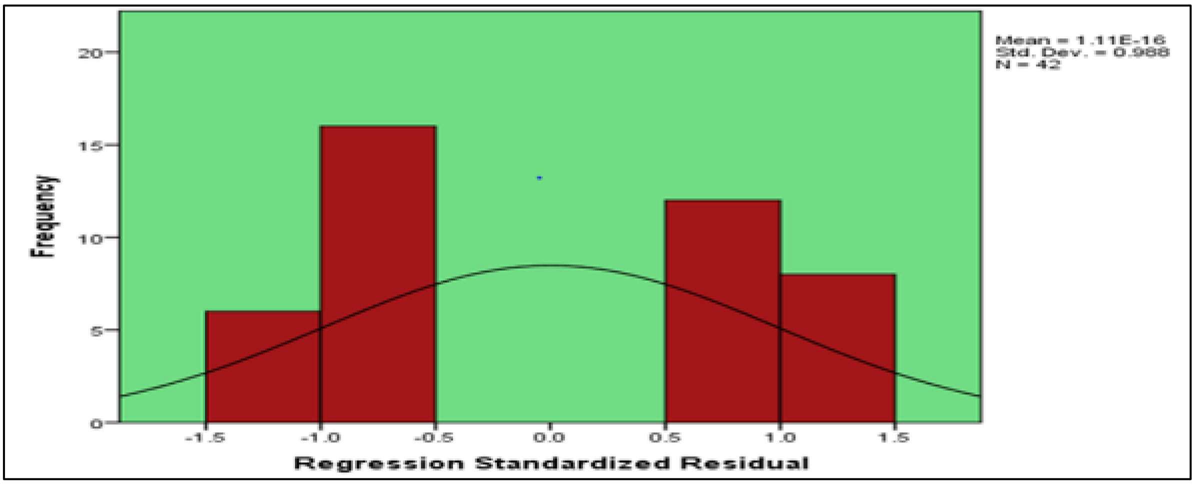

Figure 4 Graph of Frequency vs. Regression standardized residual

From the graph above, the standard deviation (errors) was found to be 0.988 which shows that the highest level of accuracy and reliability of the vibration data are attained.

3.3. Residuals Statistics

Table 5 Maximum and minimum Predicted vibration values

	Minimum (Hz)	Maximum (Hz)	Mean	Std. Deviation	No. of runs
Predicted Value	28.4507	28.9421	15.0764	1.34992	3
Residual	10.38219	10.32878	0.00000	7.16737	3
Std. Predicted Value	-1.671	1.671	0.000	1.000	3
Std. Residual	-1.431	1.423	0.000	0.988	3

4. Discussion

The Artificial Neural Networks (ANN) provides the most robust solution as it suggests that the vibration level should not exceed 28.94Hz in the pump while in operation. Based on the above analysis, it can be deduced that the frequency of vibration of 29Hz is the optimal vibration level which the vibration monitoring unit of the refinery should use as a benchmark for the centrifugal pump. Warri Refining and Petrochemical Company; Vibration Monitoring Unit subjects pumps to fault identifications when 40Hz is detected on the vibrometer. The attention of the maintenance unit (MTCE) is drawn to identify faults and correct them where applicable. Based on these research findings, it is advisable to halt the Griswold pump operation and identify faults when a vibration level of 29Hz is registered on the vibrometer.

5. Conclusion

Operation of the pump should be halted should a vibration reading close to 29Hz be registered on the vibrometer. An immediate maintenance routine to rectify the effect of the excessive vibration should be carried out to avoid damage to the pump and downtime. Even while operating under safe conditions, due to the tendency of fatigue, the pump components should be examined after reasonable working cycles. Integrating ANN-based maintenance strategies in maintenance management systems will enhance reliability, reduces costs, supports data-driven decision-making as well as making it a valuable asset for industries towards improving their maintenance practices.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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