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## Implementation of Failure Mode and Effect Analysis (FMEA) for centrifugal pump maintenance in water supply distribution system

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### Abstract

A centrifugal pump is an essential mechanical device in the Regional Drinking Water Company (PDAM) to distribute sterile water from the reservoir to local community houses by flowing the fluid through the pipeline. However, improper and inadequate maintenance of centrifugal pumps can result in component damage, including bearings that are broken, ripped, or damaged mechanical seals. Therefore, for the water supply to continue smoothly, proper maintenance needs to be carried out so that the engine's performance will be maintained and last longer. This study aims to conduct a maintenance analysis on centrifugal pumps utilized by the PDAM of Madiun City. The Failure Modes and Effects Analysis (FMEA) method was employed to assess the potential failure of a system, design, process, or service by implementing a systematic approach to analyze damage and devise maintenance strategies. The FMEA analysis revealed that the shaft of the centrifugal pump component had the highest Risk Priority Number (RPN) value, which amounts to 294. The wearing ring had the lowest RPN value among the centrifugal pump components, with a value of 54. The Pareto diagram results classified six components: shaft, clutch, stuffing box, motor, impeller, and mechanical seal to recommend preventative maintenance action. Additionally, three other components suggested for corrective maintenance were the bearing, packing, and wearing rings.

### Keywords:

Centrifugal pump, FMEA, maintenance, PDAM, RPN.

### 1 Introduction

The centrifugal pump is extensively employed in various industrial applications, including boiler feed water and water-cooling pumps in nuclear power plants. It is also commonly used for boosting drinking water in residential complexes [1], [2]. This pump is utilized by the Regional Drinking Water Company (PDAM) of Madiun City to supply sterile water from the reservoir to local community houses by flowing the fluid through the pipeline. Generally, a centrifugal pump comprises an impeller connecting to the motor via the shaft. By rotating the motor, it can suck in water from the inlet to the outlet with, generating water pressure [3], [4].

Data shows that PDAM in Madiun (East Java) often faces problems related to the centrifugal pump's component damage. Typical issues include damage to parts such as pump casings that experience corrosion, cracks in bearings, and mechanical seals that are damaged or torn. Factors such as age, environmental conditions, and high pressure can affect the performance of a centrifugal pump and cause failure [5]. Therefore, it is necessary to have good maintenance to ensure centrifugal pumps function correctly and efficiently. Failure analysis is a preventive action.

There are several maintenance analysis methods, such as Root Cause Analysis (RCA), Reliability Centered Maintenance (RCM), and Failure Mode and Effect Analysis (FMEA) [6], [7]. Each method has its own characteristics. The selection of FMEA in this study was based on its proactive approach to identifying failures, as contrasted with incident and root cause analysis, which are conducted retrospectively [8]. The other advantage of FMEA is that it also offers maintenance action suggestions based on the component with the highest risk of failure [9].

The FMEA methodology initially discovers prospective failure modes through regular consultations with key decision-makers, subsequently determines significant failure modes using the Risk Priority Number (RPN), and formulates practical corrective action plans for these crucial failure modes. The risk priority of traditional failure modes, as described by RPN, involves calculating RPN by multiplying the values of three factors: severity (S), occurrence (O), and detection rate (D) of the defect (SOD). RPN is obtained through the application of probabilistic estimation. The RPN value's magnitude determines the risk level associated with the order. Usually, identifying and ranking risks is done by considering the RPN score [10].

The primary purpose of the present study is to investigate the potential failure of centrifugal pump components at PDAM Madiun City using the FMEA method. This study could help develop maintenance plans and regular schedules as well.

### 2 Research Methods/Materials and Methods

The study comprised five main steps, as ordinally illustrated in Fig. 1 [11]. The Centrifugal Pump (CP) machine was first analyzed, summarizing the component's high failure rate. Then, the FMEA questionnaire is filled out by several engineers. After that, the SOD data was collected to be assessed. Next, before determining the suitable maintenance recommendation, the RPN value was calculated from the SOD database.

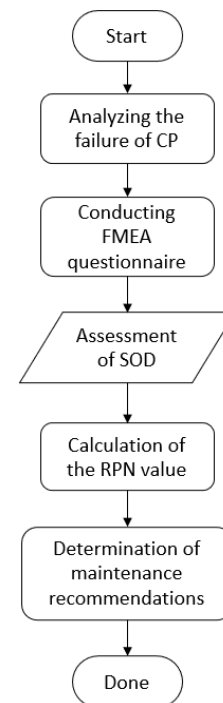


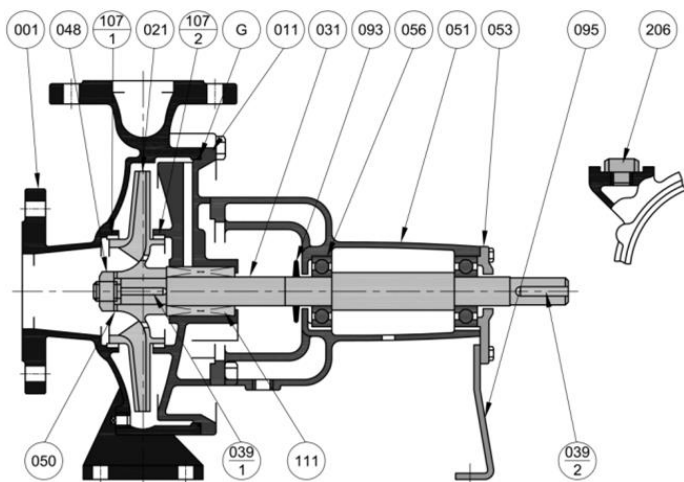
Fig. 1. Flowchart diagram.

## 2.1 Centrifugal Pump (CP)

A centrifugal pump is a device that transforms the mechanical energy from a driving mechanism into the kinetic energy of a fluid. Subsequently, the fluid is propelled towards the exhaust channel with pressure. The kinetic energy produced is transformed into hydrodynamic pressure using a rotating impeller inside the pump casing [12]. Due to its rapid rotation and high pressure, this equipment necessitates consistent and thorough maintenance in order to sustain its performance and ensure optimal functionality [13]. The type of centrifugal pump used by PDAM is a filter pump with the specifications in Table 1. Fig. 2 displays the cross-sectional view of the Ebara 200×150 FS4JA centrifugal pump [14].

Table 1. Centrifugal pump specification

Description	Specification
Model	Filter pump
Type	Ebara 200×150 FS4JA
Drive	4 poles
Max. working pressure	16 bar
Synchronous speed	1500 rpm
Casing	Ductile cast iron
Impeller	Bronze
Shaft	403 stainless steel
Hydro test	24.5 kg/cm <sup>2</sup>
Power	15 kW
Frequency	50 Hz
Shaft Dia.	42 mm



No.	Part Name	Material	Qty	
G	O-Ring	Rubber	1	
206	Plug	Steel		
111	Mechanical Seal	-		
107-2	Casing Ring	Bronze		
107-1	Casing Ring			
095	Bearing Support	Steel		
093	Deflector	Rubber		
056	Ball Bearing	-		2
053	Bearing Cover	Cast Iron		
051	Bearing Housing			
050	Impeller Nut Washer	Brass	1	
048	Impeller Nut			
039-2	Coupling Key	Stainless Steel		
039-1	Impeller Key			
031	Shaft			
021	Impeller	Bronze		
011	Casing Cover	Cast Iron		
001	Casing			

Fig 2. Sectional view of centrifugal pump Ebara 200×150 FS4JA.

## 2.2 Maintenance Analysis using FMEA

FMEA is an evaluation method used to evaluate the possibility of failure in a system, design, process, or service to formulate handling steps. The FMEA identifies three primary factors:

severity (S), occurrence (O), and detection (D), often called SOD, which are assessed on a scale ranging from 1 to 10 with their criteria on each scale [15].

The respondents who filled out the SOD questionnaire in this study were three engineers of PDAM employees with over three years of experience and expertise in maintaining centrifugal pump machines. Every respondent provided SOD scores for each component, which were then multiplied together to calculate RPN [16] (Eq. 1).

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

The RPN result can be used to assess the likelihood of failure for different components, ranking them from high risk to low risk. The RPN value can also be used to identify the priority of maintenance on the centrifugal pump component by calculating the critical score. Components with a value exceeding the critical RPN score are crucial and require increased attention or prioritization in maintenance endeavors. The critical RPN can be achieved by dividing the cumulative total RPN by the number of risk components (Eq. 2).

$$\text{Critical RPN} = RPN \text{ total} / \text{the number of risks} \quad (2)$$

Following this, a Pareto analysis can be utilized to minimize maintenance efforts by focusing on the basic principles, where 80% of the effects result from 20% of the causes [17]. The last step was to make maintenance suggestions for each component of the centrifugal pump. Based on the maintenance criteria, each component is assigned a distinct maintenance approach to reduce the probability of failure, as determined by the RPN score. The classification of maintenance can be found in Table 2 [18].

Table 2. Maintenance classification

Rank	Maintenance type	Range value
1	Predictive maintenance	RPN > 300
2	Preventive maintenance	200 < RPN < 300
3	Corrective maintenance	RPN < 200

Multiple treatment options are available for each maintenance technique. Predictive maintenance entails the examination of the performance patterns of components and subsequently recommending appropriate maintenance actions. Preventive maintenance involves activities such as cleaning, tightening, and inspection. Corrective maintenance entails the replacement of equipment that has been damaged or has reached the point where it is no longer functional [19], [20].

## 3 Results and Discussion

Based on the results of data collection on the frequency of damage to centrifugal pump components, it was found that several components had high damage data. The two years data was collected from January 2021 until December 2022. The recapitulation of component damage can be seen in Table 3.

Table 3. Recapitulation of component damage

Components	Damage frequency
Bearing	15
Gland packing	10
Mechanical seal	13
Clutch	8
Stuffing box	6
Wearing ring	11
Impeller	2
Shaft	4
Motor	2

The FMEA questionnaires administered to participants were summarized to get the average severity (S), average occurrence (O), and average detection (D) findings. Subsequently, the

collected findings comprised each centrifugal pump component's Risk Priority Number (RPN) value, as shown in Fig. 3.

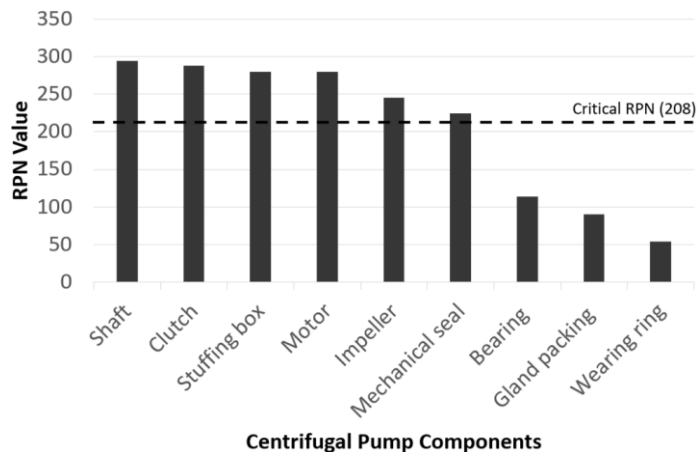


Fig. 3. RPN diagram of centrifugal pump components.

The components presented in Fig. 3 have been arranged in descending order based on their RPN values. The shaft had the highest RPN value of 294, indicating a failure mode of failed engagement. On the other hand, the wearing ring had the lowest RPN value of 54, indicating a failure mode of leakage. The total cumulative RPN value was 1869. Thus, the critical RPN score was 207.6 (208). Six components scored higher than the critical RPN: shaft, clutch, stuffing box, motor, impeller, and mechanical seal.

The shaft possessed the highest Risk Priority Number (RPN) value compared to the other components due to its crucial role in facilitating power transfer from the drive to the impeller. According to the data, the type of failure observed was bending and a broken clutch connector. Bending can lead to significant vibration, while a fractured clutch connector can result in loose nut nuts on the clutch connection, causing the shaft to wobble and eventually shatter.

The clutch had the second-highest priority number value in terms of risk. A clutch is a mechanical device that connects and disconnects shafts. Damaged and loose bolts and nuts caused this type of failure in terms of potency. The probable repercussions of failure in both cases included poor shaft straightness due to severe vibration, which might lead to interrupted operation.

Conversely, the least risky priority number was wearing a ring. This component served to minimize the occurrence of leaks between the casing and impeller. The only sort of failure it experienced was damage. The potential ramifications of failure included the occurrence of leaks. The potential factors contributing to failure were high pressure and excessive vibration within large casing spaces.

The Pareto analysis showed that five out of nine components had a cumulative percentage position above 80% on the Pareto chart, as shown in Fig. 4. These components included the shaft, clutch, stuffing box, motor, and impeller, which should be given priority in maintenance.

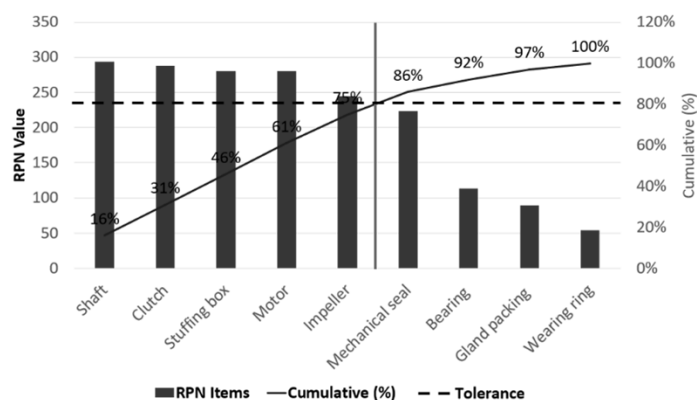


Fig. 4. Pareto chart of centrifugal pump components.

Hence, components with an RPN value surpassing a critical RPN score and beyond the tolerance of 80% Pareto chart should be given priority for maintenance. In contrast, components with an RPN below the threshold should still be considered for maintenance treatment. The maintenance type recommendation can be derived based on the information provided in Table 2 based on the interval RPN value for each component. Table 4 shows the maintenance type recommendation for the centrifugal pump components.

Table 4. Maintenance recommendation

Components	RPN	Maintenance recommendation
Shaft	294	Preventive maintenance
Clutch	288	Preventive maintenance
Stuffing box	280	Preventive maintenance
Motor	280	Preventive maintenance
Impeller	245	Preventive maintenance
Mechanical seal	224	Preventive maintenance
Bearing	144	Corrective maintenance
Gland packing	90	Corrective maintenance
Wearing ring	54	Corrective maintenance

These recommendations guide engineers in taking the necessary actions to minimize component failures. The maintenance actions according to the RPN value classification, namely preventive maintenance in the form of weekly maintenance and three-monthly maintenance, as well as corrective maintenance in the form of component replacement, which can be explained in Table 5.

Table 5. Maintenance actions

Maintenance	Actions
Weekly maintenance	1. Centrifugal pump inspection 2. Check pump lubrication 3. Check the pump for leaks 4. Check the condition of the impeller 5. Check the condition of the motor
3 monthly treatment	1. Check vibration and noise on the pump 2. Check the condition of components (impeller, bearing, clutch, shaft, gland packing, mechanical seal, stuffing bottle, wearing ring, motor)
Corrective treatment	1. Bearing replacement 2. Replacement of gland packing 3. Change of wearing ring 4. Clutch replacement 5. Replacement of mechanical seal

#### 4 Conclusion

The Ebara 200×150 FS4JA centrifugal pump in the Regional Drinking Water Company (PDAM) of Madiun (East Java) was selected as the subject of maintenance analysis in this study. The FMEA method was applied to analyze and assess potential failures. Based on observations conducted with engineers, it was determined that nine machine components frequently suffer damage due to imbalance, misalignment, and vibration. The nine components consisted of bearings, mechanical seals, wearing rings, gland packing, clutch, stuffing box, shaft, impeller, and motor. The FMEA and Pareto analyses revealed that the shaft component had the highest RPN value, precisely 294. The wearing ring of the centrifugal pump had the lowest RPN value, exactly 54.

The six components shaft, clutch, stuffing box, motor, impeller, and mechanical seals, possessed a susceptible RPN ranging from 200 to 300, necessitating preventive maintenance. Furthermore, the bearing, gland packing, and wearing ring components had values that were less than 200, indicating the need for corrective maintenance. Preventive maintenance encompasses regular inspections, lubrication, and condition

monitoring. Corrective maintenance is substituting worn components that have been damaged or have reached the end of their lifespan. Implementing these maintenance guidelines can mitigate unforeseen malfunctions and significantly prolong the machine's lifespan.

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