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FAILURE ANALYSIS OF CENTRIFUGAL PUMPS BASED ON SURVEY

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ABSTRACT

The problems commonly encountered in a centrifugal pump are leakage, excessive noise, excessive heat, suction clog no-pumping, and damage of its components. Major reasons for the failure of a pump are excessive stress, reduction in strength of its component, variation in applied load, and poor design. Continuous working of the centrifugal pumps is essential in process industries such as paper mills, textile mills and refineries, for non-stop operation of the plants. In such cases reliable functioning of the pump is an absolute necessity. The major objective of this paper is the analysis of component life and frequency of occurrence of problems in a centrifugal pump. A survey was conducted among pump users to collect data on component life and occurrence of problems in pumps. Data collected through the survey were subsequently analyzed.

Keywords: Centrifugal pump, component failure, reliability.

1. INTRODUCATION

Centrifugal pumps are the most widely used type of pumps in domestic, agricultural and industrial applications. Over 80 percentage of all the pumps used are single-stage, end-suction type centrifugal pumps. A mechanical component fails due to either a decrease in its strength or an increase in load acting on it [1]. Failure of a component affects the performance of a pump, causing either a reduction in its efficiency or its complete break-down. In industrial applications, the probability of occurrence of critical problems such as component damage and pump failure is high due to heavy loads and the demand for continuous operation of the pump.

In such cases, the entire plant will have to be shut down until the pump is either brought back to service or replaced. In order to prevent huge economic losses incurred due to such a shut-down, a pump must function reliably under specified operating conditions [2]. Main objective of this research work is to analyze the life of components and frequency of occurrence of problems in a centrifugal pump. Data pertaining to these two survey items were collected by conducting a survey among pump users through questionnaire. The vulnerable components and frequently occurring problems in a pump are identified by analyzing the survey data.

Major reasons for failure of pump components are over-load, cyclic loading, decrease in material strength, corrosive and erosive working conditions, insufficient tolerances, poor surface finish and improper heat treatment [3]. In this research work, failure data were collected from the users and analyzed in order to identify the weaker components and frequently occurring problems. In order to strengthen the components and improve the reliability of a centrifugal pump, suitable design modifications will be subsequently made through simulation and experimentation methods.

2. LITERATURE REVIEW

Failure analyses of various components of a centrifugal pump have been carried out in manufacturing, processing and service industries, to identify causes of component failure. Om Prakash and Pandey have suggested that proper heat treatment and a fine surface finish can improve fatigue strength of the impeller [4]. Das et al., have identified that improper heat treatment of drive shaft and improper fitting of drive pulley on drive shaft cause breakage of shaft in a centrifugal pump assembly [5].

Sakthivel *et al.*, have diagnosed faults occurring in a centrifugal pump by considering six conditions namely normal running, bearing fault, impeller fault, seal fault, combined impeller and bearing fault and cavitation [6]. Mona Golbabaei Asl *et al*., have optimized design parameters of pump casing in order to improve the reliability of centrifugal pump [7]. Bloch has reported in his paper that premature failure of bearing in a centrifugal pump occurs as a result of faulty assembly procedures, fabrication errors and operational errors. Packing failure occurs mainly due to incorrect operating conditions, liquid contamination and misalignment of pump components [8].

This study is a maiden attempt to conduct failure analysis of a centrifugal pump from the perspective of life of its components and frequency of occurrence of problems in it. A survey was conducted among the three categories of pump users namely domestic, agricultural and industrial users based on questionnaire. Data collected through the survey were subsequently analyzed. This research paper provides direction for future research by identifying the vulnerable components and frequently occurring problems in the pump.

3. RESEARCH OBJECTIVE AND METHODOLOGY

Main objective of this paper is to analyze life of components and frequency of occurrence of problems in a centrifugal pump. Survey questionnaire is the survey instrument employed for data collection, which has been developed after discussions with academicians and industrial experts. It covers the following key points:

- Demographic data of pump users
- Useful life of pump components prior to failure

- Frequency of occurrence of problems in the pump

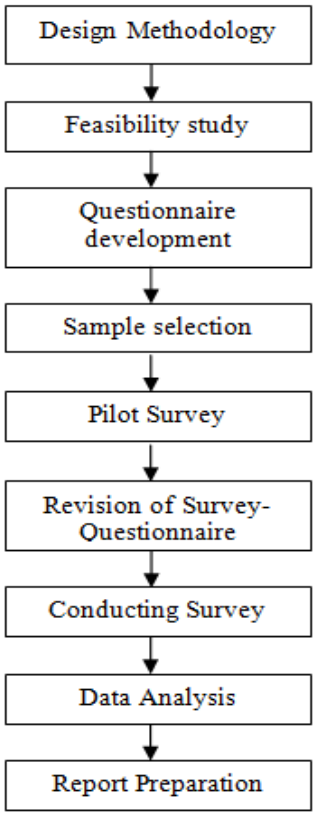

Figure-1. Survey Methodology.

A five-point interval scale and a five-point category scale were employed to obtain responses on life of components frequency of occurrence of problems in a pump, with a minimum rating of 1 and a maximum rating of 5, with an equal interval of 1[9] . Survey methodology adopted for this research work is illustrated in Figure-1 [10].

A. Sampling Plan

Pump users can be categorized into three major groups namely domestic, agricultural and industrial users. Population for this survey is the complete enumeration of these three groups of users. Sample chosen for this survey is obtained by stratified sampling from the population of pump users and survey was conducted through personal interview. Respondents to the survey questionnaire were domestic users, agricultural farmers, and industrial workers who operate and maintain centrifugal pump.

B. Survey Criteria

Content validity of the questionnaire was checked by professionals in the academia and pump industry. Further refinements were made in the questionnaire after conducting a pilot survey. Reliability of the survey instrument was tested by calculating Cronbach's alpha coefficient, using SPSS (Statistical Package for Social Sciences) software. Sensitivity of measurement scale was enhanced by employing a five-point category scale and interval scale to obtain responses [11].

C. Hypothesis formulation

Significance of responses given by pump users to survey questions is tested by formulating the following set of hypotheses.

Null Hypothesis (H0): Responses given by pump users to survey items are not significant.

Alternative Hypothesis (Ha): Responses given by pump users to survey items are significant.

4. RESULTS AND DISCUSSIONS

Data collected through survey are the foundation for subsequent analysis, and therefore they must be reliable. Cronbach's alpha coefficient reflects internal consistency of collected data. Its value should be not less than 0.7, for the data to be considered as reliable. The survey questionnaire was tested for its reliability by calculating the coefficient value for two groups of survey questions indicated in Table-1.

Cronbach's alpha coefficient values calculated for the two groups of questions are 0.826, 0.808 for domestic users, 0.793, 0.815 for agricultural users and 0.844, 0.902 for industrial users respectively, as shown in Table-1. Since all the calculated values are greater than 0.7, the survey data are considered to be reliable and hence they can be used for further analysis.

Table-1. Cronbach's Alpha Values for the Test Related Questions.

Pair of Related Questions	Cronbach's alpha value		
	Domestic users	Agricultural users	Industrial users
9 , 13	0.826	0.793	0.844
10, 14	0.808	0.815	0.902

A. Pump user demographics

Overall distribution of the category of survey respondents is illustrated in Figure-2. Totally 168 responses were collected, 92 from domestic users, 50 from agricultural users and 26 from industrial users. Responses obtained in terms of percentage are 55, 30 and 15 respectively from domestic, agricultural and industrial users, as depicted in Figure-2. Useful life of the components and frequency of occurrence of problems in the pump were analyzed by calculating mean and standard deviation values for the useful life of pump components for each category of pump users. Analysis and results of the survey are discussed in the following sections.

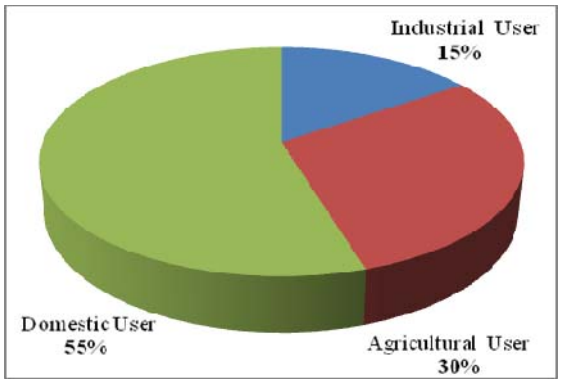

Figure-2. Overall distribution of the Survey respondents.

B. Hypothesis testing

Statistical analysis of survey data was performed using SPSS software. Hypothesis framed in Section-3.3, was tested by conducting non-parametric Friedman test on collected data with a 0.05 level of significance. Results of the test comparing calculated test statistic with critical value from statistics table are shown in Table-2.

Critical values from statistical table are compared with test statistics calculated using SPSS software. In all the three categories of pump usage, calculated values of test statistic exceed critical values for two sets of questions, as shown in Table-2. Hence, alternative hypothesis Ha is accepted and null hypothesis H0 is rejected. Results indicate that there is a significant degree of difference among survey responses.

C. Life of Centrifugal Pump Components

Mean values of time to failure of centrifugal pump components namely bearing, packing, impeller, shaft and casing for domestic, agricultural and industrial usage are calculated and presented in Table-3. Survey data indicate that centrifugal pumps used in domestic applications operate for an average daily duration of one hour. In agricultural use, its average daily usage ranges from six to twelve hours. Due to shorter operating hours pump components in domestic usage tend to have longer life when compared to agricultural use. In industrial usage, the presence of corrosive environment due to pumping of effluent or slurry and demand for continuous operation of pump are the two key factors responsible for early failure of pump components.

The packing or seal in a centrifugal pump has lowest life among the five major components, as indicated in Table-3. Mean values for life of packing are 3.25, 3.18 and 3.20 years for industrial, agricultural and domestic usages respectively.

Main function of a packing or seal in a centrifugal pump is to prevent leakage of pumped liquid from the volute casing. In domestic and agricultural applications, load on pump ranges from light to medium, in terms of operating hours. On the other hand, demand for continuous operation of pump, and presence of corrosive working environment prevailing in industries

Table-2. Results of Non-parametric Friedman's test.

S. No.	Sub-title of Questionnaire	D.O.F. (n-1)	Critical Value (χ^2_α)	Calculated test statistic			Result
				Domestic user	*Agricultural User*	*Industrial user*	
1	Life of pump components	4	9.488	95.62	80.51	64.18	H_0 is rejected
2	Frequency of occurrence of problems in pump	4	9.488	60.25	58.83	23.74	H_0 is rejected

Table-3. Life of Centrifugal Pump Components.

Life → / Component ↓	Domestic user		Agricultural user		Industrial user	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Bearing	3.61	0.628	3.56	0.635	3.28	0.717
Packing	3.25	0.514	3.18	0.622	3.22	0.675
Impeller	3.84	0.477	3.61	0.515	3.40	0.603
Shaft	4.35	0.536	4.20	0.608	4.11	0.684
Casing	4.75	0.462	4.64	0.573	4.56	0.519

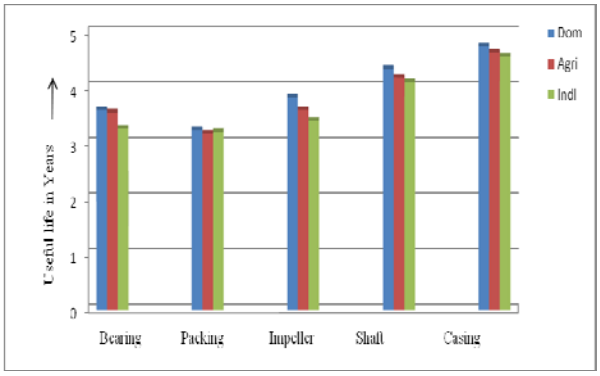

Figure-3. Life of Centrifugal pump components.

The bearing is the second component with a shorter life. Mean values for life of bearing are 3.61, 3.56 and 3.28 years for industrial, agricultural and domestic applications respectively. A bearing fails as a result of incorrect lubrication, misalignment or improper maintenance. Other factors responsible for failure of a bearing are presence of reactive environment and high temperature of the pumped liquid. Remedial measures to be adopted are correct lubrication, proper alignment of rotating parts of the pump and periodic maintenance activities.

Impeller failure ranks third in terms of component life, in all the three categories of pump usage. The values for impeller life are 3.84, 3.61 and 3.40 for domestic, agricultural and industrial usage respectively. An impeller fails due to fatigue failure caused by cyclic loading and pressure pulsations in the pump. Selection of suitable type material with higher fatigue strength and better surface finish are some of the ways to improve the strength of an impeller.

Failure of shaft or casing is not a common occurrence in a centrifugal pump. Mean values of life of these components exceed four years for all the three categories of usage as shown in Table-3. Impeller failure occurs due to improper heat treatment, poor surface finish or insufficient radial clearance between impeller and volute casing. Corrective measures to be adopted are proper heat treatment, improving surface finish of impeller and provision of sufficient clearance between impeller and casing.

Pump shaft which drives impeller is subjected to combined effects of tension, compression, bending and torsion. In addition to these stresses, prevalence of corrosive environment causes formation of cracks and subsequent fracture of shaft [12]. Selection of proper grade shaft material and correct heat-treatment procedure are two main ways are strengthening a shaft. A casing may fail in extreme conditions wherein magnitude of stress exceeds its material strength. Main factors influencing strength of a casing are material properties, geometrical parameters, load acting on it and temperature of pumped liquid. Periodic maintenance of filters and strainers and water treatment can mitigate erosion wear of pump casing. The useful life of these five components of centrifugal pump is depicted in the form of bar chart in Figure-3.

D. Problems occurring in Centrifugal Pumps

Common problems occurring in a centrifugal pump, which are considered for this study are excessive noise, overheat, leakage, suction line clog and no-delivery. A five-point category scale was used to obtain responses for frequency of occurrence of these problems.

In the category scale chosen, value 1 refers to always occurs; 2, most frequently occurs; 3, occasionally occurs; 4, rarely occurs and 5, never occurs. Mean values for frequency of occurrence of five problems are shown in Table-4. In domestic and agricultural applications, leakage and excessive noise are the two problems which occur most frequently. Mean values for frequency of their occurrence are 3.21, 3.17 for leakage and 3.07, 3.11 for excessive noise for domestic and agricultural usages, as depicted in the bar chart shown in Figure-4.

Packing or seal is provided in the pump assembly to control leakage. Packing has to be inspected once in three months to ensure adequacy of its performance. Leakage rate of 60 drops per minute is permitted in a pump, in order to cool the packing and shaft, provided the liquid being pumped is clear water. Excessive leakage occurs in a pump as a result of improper selection of packing material, abrasive wear, and misalignment. Suspended solids such as sand and dirt in pumped liquid cause abrasive wear of packing, impeller and shaft. A clear liquid free from such abrasive particles must be injected into packing to prevent abrasive wear. Correct alignment of shaft, impeller and bearing; selection of correct grade packing material and proper fitting of packing help to overcome leakage problem in a centrifugal pump.

Table-4. Frequency of Occurrence of Problems in Centrifugal Pumps.

Frequency → / Problem ↓	Domestic user		Agricultural user		Industrial user	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Excessive noise	3.07	0.682	3.11	0.618	2.90	0.632
Overheat	3.87	0.530	3.75	0.669	2.50	0.540
Leakage	3.21	0.566	3.17	0.452	4.02	0.556
Suction clog	4.08	0.638	4.15	0.628	3.54	0.615
No pumping	4.14	0.722	4.42	0.515	3.62	0.682

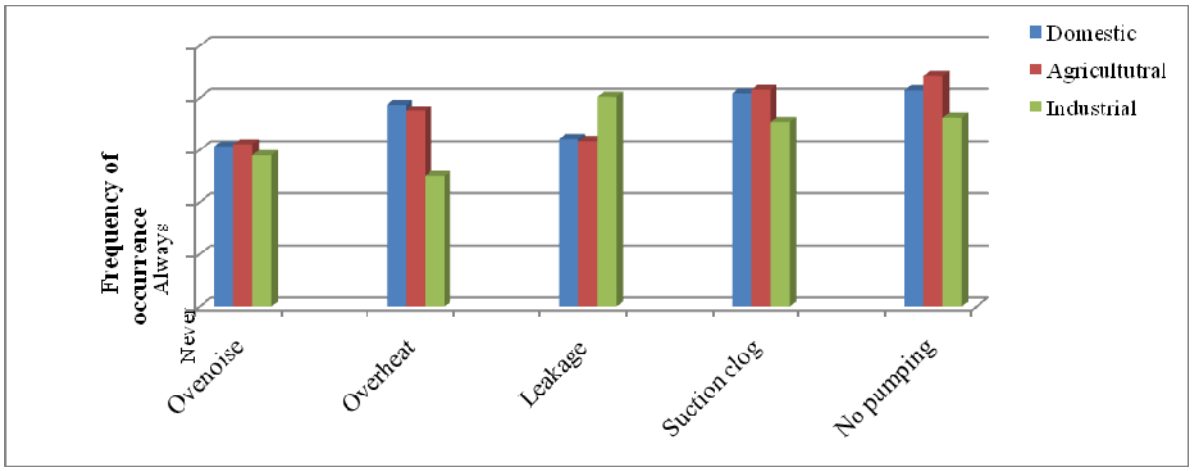

Figure-4. Frequency of Occurrence of Problems in Centrifugal Pumps.

Noise levels in excess of 100 decibels indicate potential mechanical failures or vibration problems in a centrifugal pump. Main reasons for excessive noise are impeller damage, misalignment, worn-out bearing, bent shaft or lack of prime. Corrective measures for reducing excessive noise include replacement of worn out or damaged parts such as impeller, bearing and shaft, alignment of rotating parts and provision of appropriate priming methods.

Most frequent problems occurring in industrial pumps as indicated by the survey are overheat and excessive noise. Mean values for frequency of their occurrence are 2.50 for overheat, and 2.90 for excessive noise. A centrifugal pump gets overheated due to faulty packing or bearing, misalignment and obstruction in delivery line. Periodic maintenance activities such as proper tightening of packing, cleaning dirt in bearings and packing them with correct grade lubricant in correct quantity and prudent plumbing layout are the corrective steps to overcome overheat problem.

Problems which are found to occur less frequently in a pump are suction line clog and no-delivery, in all the three categories of pump usage. Clogging occurs in suction line, impeller or delivery line due to presence of debris such as mud, sand and grit in the pumped liquid. Strainer, screen and filter in plumbing system must be serviced periodically to prevent clogging problem. A pump does not deliver liquid due to lack of prime, clogging, reduced discharge pressure or damaged impeller. Use of self-primping pump, periodical cleaning of filters, selection of correct size delivery pipe and replacement of impeller are the corrective steps to be taken.

5. CONCLUSIONS

This survey paper presented a methodology to analyze the component failure and problems occurring in a centrifugal pump. A survey questionnaire was designed and developed to quantify the survey items. Questionnaire was tested for its validity and reliability. Data collected from the three categories of pump users namely domestic, agricultural and industrial users were analyzed. Most vulnerable components in a centrifugal pump are packing and bearing, as revealed by analysis of survey data. Impeller ranks third in terms of useful life, in all the three categories of pump usage. Excessive leakage, misalignment corrosive environment and cyclic loads are the responsible factors for the failure of these components, which can be counteracted by the selection of proper grade packing material and impeller material and correct alignment of rotating parts of the pump. Problems which are found to occur most frequently in centrifugal pumps are leakage and excessive noise in domestic and agricultural applications, and overheat and excessive noise in industrial usage. The corrective measures to be adopted to control these problems are the selection of appropriate packing material, correct alignment of rotating parts, proper lubrication, prudent plumbing layout, and replacement of worn-out or damaged components.

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