Experimental testing of centrifugal pump: small and medium sized enterprise product

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Abstract. This paper reports the experimental testing for centrifugal pump for fisherman ship, manufactured by small and medium sized enterprises in Central Java Province, Indonesia. The research covers material analysis, component observation, endurance and vibration test. Six centrifugal pumps are tested and three main pump components are discussed: shaft, bearings and seals. The results show that the material of the shaft is predicted to support and transmit the load from the engine to impeller. The problem found in the tolerance and geometry accuracy of the shaft which causes difficulties during assembling process, excessive wear and leakage during testing. From the endurance and vibration test, the ball bearings fail and lock the shaft due to the fatigue on the rolling elements and raceways. The oil seal and water seal also fail in maintaining the oil and water in the chamber and induce the unlubricated system for the ball bearings. Some suggestions are delivered to improve the product quality of the centrifugal pump. A good quality of the centrifugal pump for fishermen ship and long life span is expected to be produced by local SMEs to win the free trade competition in the Indonesian market.

1. Introduction
In the last two decades, Small and Medium Sized Enterprises (SMEs) in Indonesia have been considered as pillar of Indonesian economy. In 2011, Minister of Cooperatives and SME, Republic of Indonesia stated in his annual report that 98% of all Indonesian enterprises (around 55 million companies) are categorized as SME and employ more than 90 million employees which equal to more than 95% of Indonesian employees [1]. SMEs also have historically proven as the significant players in the Indonesian economy and survived in several global and regional economic crises. Nowadays, big challenge comes to SMEs in Indonesia due to regional free trade agreement among South East Asia countries and China, as a consequence of global market. Indonesian trade policy is changed from a protected to an open economy due to the implementation of the regional free trade agreement. This situation could be a threat for the impressing and positive growth of SMEs during a last decades. The impact of this policy could be received by SMEs in Central Java Province Indonesia, especially metal manufacturer SMEs. They will found that the competition in selling the metal product in the market is not easy anymore due to global competition.

In the future, there are pessimistic opinions that Indonesian SMEs will not survive in the era of trade liberalization, although some reports assured that until 2011, no significant impact of free trade agreement on SMEs sustainability [2]. However, based on the field observation in Central Java
Province, metal manufacturer SMEs are facing various constraints, including lack of technology application, product development, qualified human resource and product quality assurance [3]. These constraints are negative factors for SMEs in confronting the regional free trade agreement. This leads researchers conduct evaluation and testing on the metal product of SMEs and propose some improvements. One of the projects is supporting and evaluating SMEs which manufacture metal product for marine application. These projects are proposed to evaluate the technology application, design, material and component selection, manufacturing process, product performance and quality assurance.

One of the products which should be evaluated is centrifugal pump for marine application, manufactured by several SMEs in Central Java Province, Indonesia. Figure 1 depicts the installation of the centrifugal pump in the fisherman marine boat, connected to the marine engine using a belt to transmit the power. Figure 2 shows the bearings and shaft in the centrifugal pump.

![Figure 1](image1.png) **Figure 1.** The centrifugal pump, manufactured by SME: the installation of the pump on the fisherman boat.

![Figure 2](image2.png) **Figure 2.** Bearings and shaft of the pump.

The research on centrifugal pump of SME focuses on two steps: product evaluation and product improvement. The product evaluation step investigates material and components selection and defines problems of centrifugal pump during the tests. Experimental evaluation and condition monitoring are frequently used by researchers to diagnose and investigate the condition of existing pump components [4-7]. The improvement step focuses on the suggestions to improve the quality, endurance and life time of the centrifugal pump. The present work focuses on the first step of the research (product evaluation) and discusses several suggestions for SMEs in Central Java Province which produce centrifugal pump. This paper reports the experimental tests for the centrifugal pump, manufactured by SMEs in Central Java Province which covers: material and component assessment, endurance test and vibration test and suggests improvements to increase the quality and life time of the pump.

2. Research Methodology

Product evaluation is initiated from components and material selection, manufacturing and assembling process observation, quality control assessment and endurance performance measurement. Six centrifugal pumps are tested in Laboratory for Engineering Design and Tribology, Diponegoro University. One of the pumps is disassembled and the components are tested to observe its properties and functions whereas five pumps are tested in test rig. A disassembled pump is observed for the three important components: shaft, bearings and seals. Based on the field observations and the interviews with the fishermen, it was reported that the failure of the SME pumps is related with these components. The chemical composition test, microstructure observation, hardness test and tensile test are conducted to the pump shaft material. A series of geometry test is carried out to observe the
tolerance and geometry accuracy of the shaft. For the bearing, a SEM observation is conducted to study the new and used bearings. The new and used component observation is also conducted to the pump seals.

Five centrifugal pumps, manufactured by SMEs in Central Java, are prepared to be evaluated in the test rig, depicted in Figure 3. Two imported products from foreign competitor are involved in this research to compare the components selection and the product performance. These pumps are tested in a rig to evaluate the endurance of the pumps. Figure 3 depicts a testing equipment where each pump are connected to a 1 HP electric motors (three phases) to recirculate the sea water. The pumps recirculate the sea water for 12 hour non-stop for a day with 2200 rpm and it is repeated until 40 days. A vibration test, showed in Figure 4, is carried out for the new pumps and for the pumps with the high noise due to initial failure of the bearings or shaft. The pump is moved to the vibration test when high noise is found in the endurance test rig.

![Figure 3. A test rig to evaluate the performance of centrifugal pumps.](image1)

![Figure 4. Vibration testing of centrifugal pump and the two sensors on the bearing.](image2)

3. Results

3.1. Shaft
The result from the spectrometer test for determining the chemical composition of the shafts is listed in Table 1. Only the main elements are reported in this table whilst the other is neglected due to the small contributions. Based on the laboratory test, hardness number of the shaft is 30 HRC whereas the
tensile strength is 808 MPa. The material of the pump shaft, made from stainless steel with high tensile strength and hardness, is predicted to support and transmit the load from the engine to the impeller. Some comparisons of the SME shaft with the imported pump shaft product were discussed in the previous paper [8]. The microstructure of the shaft below microscope observation is shown in Figure 5 (a) with 100 x magnifications and Fig. 4 (b) 500 x magnifications.

**Table 1.** Chemical composition of the stainless steel shaft.

| Chemical Composition | Fe  | C    | Si   | Mn   | Cr   | Ni   | Cu  |
|----------------------|-----|------|------|------|------|------|-----|
| %                    | 71.2| 0.124| 0.340| 10.8 | 14.6 | 1.23 | 1.35|

![Figure 5](image.png)

**Figure 5.** The microstructure of the centrifugal pump shaft: (a) 100 x magnifications and (b) 500 x magnifications

However the problem is found for the shaft when a series of geometry test is carried out to 20 pump shafts for investigating the tolerance and geometry accuracy. Two critical positions on the shaft where the bearings are located are highly varied between (-) 0.3 mm until (+) 0.3 mm for 20 mm of the shaft diameter. The turning operator pays less attention on the accuracy of the shaft diameter and causes the undesirable tolerance and fits between the shaft and bearings and leads the excessive wear on the shaft (for the large clearance fit) and the damage of the bearing during assembly process (for the shrink fit). The normal clearance should be 0.05 – 0.1 mm.

### 3.2. Bearings

There are 4 ball bearings in a centrifugal pump shaft to support the radial load, see Figure 2. The bearings are observed in two conditions: the new bearing and the failure bearing after the endurance test. From the endurance test it is found that 1 pump failures on the 21st day of the test. The shaft is locked due to the failure of the bearings. The other 4 pumps reach the last day (40th day) in the endurance test with relatively high noises and vibrations, indicating an initial failure of the bearings. In a centrifugal pump, defective bearing can cause more number of serious problems such as abnormal noise, leakage, high vibration, etc. [5]. The results of the vibration test for the new pump and the nearly failure pump are depicted in Figure 6 (a-b) and Fig. 7 (a-b), respectively. These figures were obtained from the vertical vibration sensor. The amplitude versus time and the FFT graphics are presented as the common vibration analysis [6].

The vibration monitoring records the range of amplitude of the failure pump on the 21st day (Figure 7a) is 50 times higher than the range of amplitude of the new pump (Figure 6 a). It indicates that the failure of bearing produce higher vibration and noise. After the pump fails and the bearings are locked then the pump is disassembled and the bearings are checked and cut to observe the condition of the inner raceway, outer raceway and the spherical balls. SEM analyses for the failure bearings are depicted in Figure 8-10 (a-b). Figure 8 shows the fatigue failure on the rolling element bearing where
spalls are found on the spherical ball surface. Figure 9 and 10 depict the wear on the inner and outer raceway of the ball bearing. The failure mode limiting bearing life is mostly rolling-element fatigue of either a bearing race or rolling elements. Rolling-element fatigue is extremely variable but is statistically predictable depending on the steel type, steel processing, heat treatment, bearing manufacturing and type, lubricant used and operating conditions [7]. In the case of the centrifugal pumps product there are some causes of the bearing failure: (i) SME uses a low quality bearings, (ii) the leakage of the lubricant in lubricant chamber leads the unlubricated system and (iii) the tight fits due to excessive geometry tolerance of the diameter shaft cause the ball bearing received higher force during assembling process.

![Figure 6](image6.png)

**Figure 6.** The vibration monitoring on vertical direction of the bearing for the new pump: (a) amplitude vs time graphic and (b) FFT graphic.

![Figure 7](image7.png)

**Figure 7.** The vibration monitoring on vertical direction of the bearing in the nearly failure pump: (a) amplitude vs time graphic and (b) FFT graphic.

### 3.3. Seals

There are two types of seal in the centrifugal pumps: oil seal to avoid the lubricant leakage and gasket to avoid the water leakage, see Figure 11. SME uses a low quality of oil seal and manufacture the gasket by them self from the non-standard rubber. The result can be predicted easily, the leakages are found. During the endurance test, all of the pumps indicate the initial water leakage after 3-5th day of running and the oil leakage is identified after 8-10th day of running.

Figure 12 depicts the oil leakage on the pump holder in the test rig which causes dry contact situation on the ball bearings. It can be caused by: (i) a low quality of the oil seal where the springs easy to break and induce the leakage of the lubricant, see Figure 13, (ii) the failure of the seal because of
assembling process, (iii) a large clearance between the shaft and oil seal and (iv) the sharp shape of the shaft break the oil seal when it is pressed into the shaft.

![Figure 8. SEM on the ball bearing: (a) failure on the ball and (b) zoom view of the failure ball.](image)

![Figure 9. SEM on the inner raceway of the failure bearing. Pitting wear is found at (a) the centre of the inner raceway surface and (b) several distances from the centre.](image)

![Figure 10. SEM on the outer raceway of the failure bearing. Fatigue wear is found at several points at the outer raceway surface (a-b).](image)
Figure 1. Oil seal and water seal (gasket) in centrifugal pump.

Figure 2. The leakage of the lubricant during the endurance test.

Figure 3. The failure of springs of the oil seal after the pump is disassembled.

4. Suggestion for Improvement
In this section some suggestions are given to SMEs for improving the quality, endurance and life time of the centrifugal pump. The suggestions are listed in Table 2 which covers the shaft, bearing, seal and
quality control. The improvement of the shaft is related to the dimension accuracy, chamfer on the seal entrance and the quality control. The chamfer around 2-3 mm is suggested to avoid the seal crack during assembly process. The quality control, such as the use of go-no-go gauge, should be applied to increase the dimension accuracy of the shaft.

**Table 2. Suggestions for SMEs to improve the centrifugal pump quality.**

| Target        | Improvements                                                                 |
|---------------|------------------------------------------------------------------------------|
| Shaft         | • Increase the accuracy of the dimension to obtain the best fit between the shaft and bearings  
• Create chamfer on the entrance of the oil seal  
• Quality control for the shaft dimension |
| Bearing       | • Use good quality bearings  
• Assembly the bearings properly using the new press equipment  
• Ensuring the lubricated system on the bearings |
| Seal          | • Use good quality oil seal and sea water seal  
• Assembly the seals properly to avoid seal cracking  
• Ensuring the lubricated system on the bearings |
| Quality control | • Quality control should be conducted for every pump components: shaft, impeller, housing, pulley, etc.  
• SMEs should provide an endurance test rig to check some sampling of the centrifugal pumps  
• A running-in stage of centrifugal pump is recommended after the assembly process and before the pump is wrapped |

The suggestion for the bearing covers the selection of good quality bearings, the new press equipment to assembly the bearings and ensuring the lubrication system on the bearings. The new press equipment, see Figure 14, is suggested to avoid the bearing failure during assembly process. The suggestion for the seal focuses on the selection of good quality seals and the assembly process of the seal.

A last suggestion is related to the quality control and assurance. Previously, SMEs did not provide controller for checking the components dimension and quality. The quality control officer checks all components, manufactured locally by SMEs and manufactured by third parties, to obtain a proper dimensional and tolerance accuracy. An endurance test rig and running-in test rig are also suggested to the SMEs to assure the quality of the centrifugal pumps. The running-in stage of the pumps is required for ensuring the conforming contact and the fully lubrication system before the pump is installed to the ship and receive the high load. Every contacting component, such as bearing, gears, camshaft, piston, etc. is suggested to experience the running-in phase with lower load before a real maximum load is applied to the components. The running-in stage of the pump is expected to be finish in few hours and suggested to be conducted by SMEs before the pump is wrapped and delivered to the customer.

The proposed improvements are still adapted and applied by SMEs in their manufacturing process. Some centrifugal pumps are manufactured with researcher supervisions. These improvements increase the centrifugal pumps around 10-20% but the productive time of the pump is predicted to increase 3-4
times. The results of the improvement are still tested in the endurance test rig with the good preliminary results of the noise and vibration.

Figure 14. A new design for pressing tool to assembly the bearings into the shaft and the pump housing based on the literature is proposed to SMEs.

5. Conclusion
The paper reported the evaluations and assessments of the centrifugal pumps, manufactured by SME in Central Java Province Indonesia. The evaluation and assessment are required to improve the quality of the centrifugal pumps due to a higher competition on the marine product after the implementation of regional free trade agreement in South East Asia region. The evaluation step covers the shaft, bearing and seal components as well as the quality control and product assurance during the manufacturing and assembly process in SMEs. The results show that the pump shaft, made from stainless steel with high tensile strength and hardness, is able to support and transmit the load from the engine to the impeller. However the problems of the shaft are the tolerance and geometry accuracy which lead the excessive wear on the shaft (for the large clearance fit) and the damage of the bearing during assembly process (for the shrink fit). The bearings of a pump are failure on the 21\textsuperscript{st} day of the endurance test and lock the shaft. SEM analyses for the failure bearings are observed to determine the fatigue failure on the rolling element and raceway. During the endurance test, all of the pumps indicate the sea water leakage after 5\textsuperscript{th} day of running and the oil leakage is identified after 10\textsuperscript{th} day of running which indicates the problem of the quality of seal and assembling processes. Some suggestions have been delivered to improve the product quality and assurance of the centrifugal pump. The good quality centrifugal pump with a product assurance and long life span is expected to be produced by local SMEs to win the free trade competition in the Indonesian market.

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