Minimizing Metal Casting Defects: Insights from Six Sigma Implementation

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Abstract. The aim of this study is to reduce the number of defects in the metal casting finishing process through the implementation of the Six Sigma method. The study identifies various defects such as pouring metal, mold material, porosity, and shrinkage defects, and provides recommendations to minimize them. The Six Sigma method involves five stages - define, measure, analyze, improve, and control, and the process capability level was found to be 96.47%. However, the sigma and DPMO values obtained were 3,943 and 9,333.36, respectively, indicating that the target of 6 sigma and 3.4 DPMO has not been achieved. The most dominant defect was found to be in the mold material, and this was caused by human factors, machines, methods, and materials. Suggestions for improvement include providing regular training for workers and carrying out intensive maintenance and inspections for each machine used during the production process. The implication of this study is that by implementing the Six Sigma method and adopting the recommendations provided, manufacturers can minimize defects in the metal casting finishing process, leading to better quality products and increased customer satisfaction.

Keywords: Defect · Six Sigma · DMAIC · DPMO · Industrial Management

1 Introduction

In the current era of globalization, the development of the manufacturing industry is growing rapidly [1]. This happens in line with the development of science and technology [2]. Therefore, technological advances in manufacturing are very important for competitive advantage in global competition [3]. Indonesia is currently focusing on achieving one of the expected targets, namely the National Industrial Development Vision as stated in Presidential Regulation Number 28 of 2008 concerning National Industrial Policy which will make Indonesia a Resilient Industrial Country in 2025.

A company tries to maintain the quality of its production and distribution system well. It's just that there are some neglected production systems [4] For this reason, efforts need to be made to ensure product quality against possible failures or defects, whether caused by machines, production processes, materials, and humans [5] air, and shift [6].

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Efforts that can be made are to minimize failures or defects, both products and product production processes to minimize the number of defective products using the six sigma method [7].

The six sigma method aims to reduce defects in a product that is not in accordance with specifications and minimize variations in the occurrence of defects [8]. In this study, the six sigma method is used which will focus on reducing variations in the occurrence of defects in the product. Therefore, it is necessary to analyze and evaluate product quality in the process of finishing operations using the six sigma method [9].

2 Methodology

The data used comes from company data in PT. Mitra Rekatama Mandiri, Klaten, Central Java and the results of field observations. In this study, the DMAIC concept of six sigma is used. The steps taken are [10]:

1. Define

   This stage will define and define important issues in the process.

2. Measure

   This stage will calculate the process capability.

3. Analyze

   At this stage, we will analyze and determine the root cause of a defect or failure.

4. Improve

   At this stage, an improvement plan will be made based on the results of calculations and analyses that have been done previously.

5. Control

   This stage makes a control plan for the improvement plan that has been made.

3 Results and Discussion

According to the method described previously in this study, the data used are data obtained from companies and observations. Furthermore, analysis and discussion is carried out according to the Six Sigma method to determine the results of the study.

1. Define

In this stage, the research object has been determined, namely the main Pulley product. Next, identify the value of quality characteristics or CTQ (Critical To Quality) on the Main Pulley. Determination of the value of quality characteristics (CTQ) can be determined based on the number of types of defects in the product. There are four types of defects in the Main Pulley, namely Pouring metal defect, Mold material defect, Porosity, and Shrinkage defect, so the CTQ value can be determined, which is four. Types of defects in Main Pulley are as follows:

a. Pouring metal defect

This defect occurs because the molten metal does not fill the mold cavity enough. Generally, blockages occur due to the molten metal rushing to solidify before filling the print cavity as a whole.

b. Mold material defect

Mold material casting defects occurs on sands and can always be prevented by modifying the mold.

iii. Porosity

Gas porosity takes place on casted metal when it traps gasses like nitrogen, oxygen, or hydrogen during casting. The casting defect appears on metals as small holes, rounded, or circular cavities. The holes are formed when the casting cools and solidifies because the solid form of metal cannot store a lot of gas as of the liquid form. Gas porosity casting defects are caused by an escape route on mold and cores at which gases can pass and when mold and cores do not allow dry before use.

iv. Shrinkage defect

These types of casting defects occur during the solidification of the casting. Its porosity appears with angular edges when compared with round surfaces of gas porosity. Shrinkage casting defects happen because metals are less dense as a liquid than a solid. These branches of casting defect might also be paired with cracks. Shrinkage with large cavities can cause the casting to eventually break under stress.

2. Measure

In this second stage, the data is calculated so that the next stage of analysis can be carried out. The data used is total production data and the number of defective products (Table 1).

Table 1. Data on types of defects in Main Pulley

o	**Types of defects**				Total
	Pouring metal defect	Mold material defect	Porosity	Shrinkage defect	
1	3	2	2	0	7
2	0	0	1	0	1
3	0	2	1	0	3
4	3	1	1	0	5
5	1	3	0	2	6
6	2	8	0	0	10
7	1	0	1	0	2
8	0	3	0	0	3
9	0	5	2	0	7
10	2	2	0	0	4
11	2	0	0	0	2
12	0	1	0	0	1
13	1	1	1	0	3
14	5	1	0	0	6
15	20	29	9	2	60

3. Analyze

In this step, what is done is to examine why defects occur in Main Pulley products, then look for the reasons behind them. P diagram is used to analyze process capability, while to identify the factors causing dominant defects by using a causal diagram.

Based on Table 2, to identify the most dominant type and as follows for the development of steps to be taken in process improvement, a Pareto diagram can be made as follows. After knowing that the most dominant type of defect is Mold material defect. Then it can be searched for the cause of the emergence of defective products and the reasons for the shot blasting process by using a causal diagram. Based on observations while at the research site, the causes of defects are caused by several factors, namely humans, machines, methods, and materials. In the following figure is a causal diagram that causes the Mold material defect.

Based on Table 2, it can be seen that the most dominant defect in the shot blasting machine is mold material defect with a total of 29 defective products and a percentage of 48.33%, followed by Pouring metal defect 33.34%, Porosity 15%, and Shrinkage defect 3.33%.

To identify the factors that cause the failure rate on Main Pulley products using a causal diagram. A cause-and-effect diagram is performed for defects due to mold material defect which is the most dominant type of defect.

Table 2. Result on types of defects in Main Pulley

No	Types of Defects	Total of Reject	Total of Defect	Frequency (%)	Cumulative (%)
1.	Pouring metal defect	20	20	33.34	33.34
2.	Mold material defect	29	49	48.33	81.67
3.	Porosity	9	58	15	96.67
4.	Shrinkage defect	2	60	3.33	100

Table 3. Proposed Improvement Plan

Factors Causing of Defect	Reasons Factors of Defect	Improvement Plan
Human	Lack of skills	Conducted training within a certain time
	Lack of careful	Implementation of SOP and sanctions for workers
Machine	Old machine	Regular check up for machine
Method	SOP are not appropriate	Re-creating SOP
Material	Material quality is not good	Make a selective selection of the producer or distributor of the material to be used

4. Improve

At this stage, make an improvement plan on the Main Pulley product. This stage is carried out after knowing the factors that cause defects. The following are some proposed improvement plans to minimize the factors that cause defects (Table 3).

5. Control

The control plan of the improvement plan that has been put forward in the previous improve stage can be seen in the following (Table 4).

Table 4. Control Plan

Maintenance Plan	Control Plan
Training in a certain time	The training that will be carried out is prepared as well as possible so that the process is efficient and optimal
Implementation of SOP and sanctions for workers	The policies and sanctions for workers are reviewed once a month until the appropriate policies and sanctions are found
Regular check up for machine	It is necessary to set-up the machine on a regular basis in addition to regular checks carefully
Re-creating SOP	Re-manufacture of work procedures is carried out periodically because it adjusts the material used
Make a selective selection of the producer or distributor of the material to be used	In addition to selecting producers or distributors selectively, it is necessary to periodically check the quality of the materials used.

4 Conclusion

The study concludes that the level of capability for the finishing process on the shot-blasting machine for a month is 96.47%, but the sigma and DPMO values are still far from the Six Sigma targets of 6 sigma and 3.4 DPMO. The most dominant defect is mold fallout, caused by human, machine, method, and material factors, as revealed by the Pareto and causal diagrams. To minimize these factors, the study recommends operational training, regular equipment maintenance and inspection, improvement of health and safety facilities, scheduled cleaning and inspection of machines, re-manufacture of work procedures, regular adjustment of process standards, selective selection of producers/distributors, and periodic material quality checks. Implementation of these solutions can help minimize defects and improve the quality of metal casting finishing, increasing customer satisfaction.

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