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QUALITY IMPROVEMENT OF REMANUFACTURING LIFT ARM USING SIX SIGMA METHODS IN THE HEAVY-DUTY INDUSTRY IN INDONESIA: A CASE STUDY

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Abstract: *The high remanufacturing forecast reaching 160 billion dollars/year in the world of the equipment industry (heavy duty) is a promising business opportunity. However, the remanufacturing industry has a higher risk of product failure compared to original Equipment products. The remanufacturing of the heavy-duty industry in Indonesia in carrying out its production has a product failure rate of 834586,47 DPMO and is at 1.91 sigma with COPQ IDR 650,800,000.00 Six Sigma method is used in this research and is successful in reducing remanufacturing defective product for lift arm to 140762,5 DPMO, is at the level of 2.43 Sigma and COPQ IDR. 135,000,000.00 or decreased 78.71% from the previous condition.*

Key words: *Quality Improvement, Remanufacturing, Six Sigma, Product Failure*

1. Introduction

1.1. General

The Remanufacturing industry has been around for at least 28 year and provide significant economic, social and environment benefit. Strategy 3R (Reduce, Reuse and Recycle) ,system was founded in the USA and remanufacturing operation have grown substantially and become common practice in many Industries. In development countries, the remanufacturing engineering also developed rapidly and has been applied to industry. The United States Environment Protection Agency (EPA) implemented a Comprehensive Procurement Guidelines (CPG) program to enact waste reduction and resource conservation through the Reuse of used materials and ensuring recycling programs for certain materials can be made into materials to create new products. Reman world Magazine, March/April edition, 2018 states the remanufacturing industry is spreading in various countries with a total forecast of $ 160 billion/year with spread: the USA $ 100 billion, Europe $ 32, Asia $

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27 billion and Brazil $ 1.4 billion. The Asian region (including Indonesia) ranks third in the distribution of the remanufacturing industry.

The high remanufacturing forecast reaching 160 billion dollars/year in the remanufacturing industry is a promising business opportunity. However, the remanufacturing industry has a higher risk of product failure compared to original equipment products. In Indonesia, the remanufacturing industry, which is engaged in the Heavy-duty equipment industry, supports the repair of mining equipment and vehicles both in open pit and underground in running its production, experiencing a product failure rate of 834586.47 DPMO if the capability of the process is measured at the level of 1.91 sigma and the Cost of Poor Quality must be borne by USD. 43386.57 for January ~ May 2019. Valles et al., 2009 state that Six Sigma is a strategy of continuous organizational improvement to find and eliminate the causes of errors, damage, and delays in business organization processes. Gijo et al., 2014 with the application of the Six Sigma method resulted in a reduction intolerance related to problems and increased yield values from 85% to more than 99%. Get a total savings of US $70,000 per year. Hassan, 2013 shows that, for the calculation of the yield value of 95.75%, from this result, the sigma level was calculated and found an initial sigma value of 3.22 and a DPMO of 42,500. Using a target of a 2% defect rate, the target sigma value is calculated to be 3.55 and the DPMO value is 20.000. The results achieved 98.24%, according to the sigma level of 3.6 and the DPMO value of 17.600. Referring to various studies on problem-solving with the help of Six Sigma methods showing positive results that are marked by decreasing product failure rates and increasing sigma levels, then in this study, Six Sigma methods are expected to be used in the failure of remanufacturing lift arm products in the Heavy-duty industry in Indonesia to be reduced so that the process capability is getting better, COPQ can be suppressed and will certainly increase company profits.

1.2. Motivating of research

The companies engaged in manufacturing tools in Indonesia that support the repair of mining equipment and vehicles both in the open pit or underground. Companies are required to make innovation efforts so as not to lose their market share. Consumers always want innovative products, because their tastes and needs tend to change with the changing times. Products that consumers want are products that are not only able to meet their needs but are also able to provide satisfaction for their users. The activity carried out is to suppress as little as possible the name of the product defect to zero defect. In line with the principle of zero defects, Remanufacturing Companies engaged in heavy equipment, have full attention to this matter. Evidenced by improvement activities carried out by all company employees to reduce product defects. Lower-level employees (operators) to the top level of management, improvement activities carried out continuously. This research was conducted to examine the level of disability in the Machine Rebuild section with the Machining and Welding process in the company. The section is the final section of the process in the production process, where the level of disability is still high based on the 2018 Machining and Welding quality reports. Based on internal data of the 2018 Machining and Welding product defects, 1.99% with types of defective products as follows: Lift Arm (73.5%), Bucket (7.9%), Front Frame (3.3%), Rear Frame (3.3%), Tilt Lever (3.3%), Tilt Link (2.6%), Cabin (2.0%) and others (4.0%). Based on the 2018 defect product data, this study is motivated to reduce the Lift Arm product failure of the Machining and Welding process which has the highest accumulation of defective products by 73.5%, with the hope that Lift Arm quality can be improved to meet customer satisfaction and provide a more optimal company advantage.

2. Literature review

2.1. Quality Improvement

The purpose of quality control is to make the final product produced according to product specifications and standard sets (James, 2012). Speaking of quality, of course, there is no definite understanding of quality and quality has a broad scope and has a different understanding (Suwendra, 2014. Quality in terms of producers is the fulfillment of quality standards that have been owned (Purba, 2017). In addition there are several objectives for quality control, namely: (1) To improve the uncontrolled process, (2) To control the finished product, in this case it is done by taking the sample of the receipt, (3) To produce quality products, (4) Work for inspection or inspection cost to minimize, (5) strives to reduce the cost of product design and processes using certain production quality, and (6) Make sure the cost of production is minimized as low as possible (Cullison et al., 2013). For some of the widely used quality features, among others : (a) Quality is compliance with requirements or claims, (b) Quality is a match with use, (c) Quality is continuous improvement and improvement, (d) Quality is an effort to meet the needs of consumers from the beginning and at all times, (e) Quality is something that can satisfy the user (Chunxioa et al., 2013). Quality can generally be interpreted as a measure of quantity that indicates the stage of the good of a product, or can be interpreted as the best condition within certain limits in accordance with the will of the consumer. In general, the conditions required by consumers as the most important are product prices and product benefits. The two things are related: a. Specification of operating characteristics, b. Product age and reliability, c. Manufacture of product, d. The condition in which the product is made, e. Installation and maintenance of products and facilities in the field (Milln et al., 2013). So briefly the quality can be defined as satisfaction in the use of products that include aspects of: Product quality: The quality of the product or service Cost quality: Quality of cost, Delivery quality: Quality delivery products, Safety quality: Safety quality, utility of spirit: Quality in serving customers (Pylväs et al., 2015). Referring to the definition of quality, the improvement of product quality to increase customer satisfaction is an important attribute in a business organization (Nugroho, 2015).

2.2. Remanufacturing industry

In 2005 the remanufacturing industry began when the United States Environmental Protection Agency (EPA) implemented a comprehensive procurement Guidance program (CPG) to enact waste reduction and resource conservation guidelines through the Reuse of waste materials and ensuring recycling programs for certain materials can be made into materials to create new products. In 2004, the EPA established several remanufactured vehicle parts. Remanufacturing is to use a portion of its original form and replace or rebuild damaged parts. The testing process follows the same specification process as the new product manufacturing process (https://www.epa.gov/).

The remanufacturing industry is an industry that uses a portion of its original form/original equipment to rebuild damaged parts and replace it with new equipment through the testing process following the same specifications as the new product manufacturing process. The quality of Re-manufacturing products has the same standard as the manufacturing of new products (Ijomah, 2008; Ijomah and Childe, 2010). One of the complicating characteristics in remanufacturing is the stochastic and sporadic nature in the condition and quantity of the returned cores which impacts on many levels in the planning and control (Junior et al., 2012). Returned products can range from minor scratches to extensive damage and thus inspection and sorting procedures are required to filter the valuable cores. High quality returns are preferred as the quality of the returns determines the level of the remanufacturing effort required, the processing time, the rate of remanufacturing success, the process sequence used, the amount of cost savings, and the amount of cores being scrapped (Ortegon et al., 2013). The extent to which remanufacturing is done and the definition of sufficient quality depend on the type of remanufacturers and the business model; independent remanufactures try to repair as many parts as possible, whereas OEM remanufacturers can be more selective on the cores to accept. Reliable engineering expertise and capabilities is the backbone to a successful remanufacturing facility. Remanufacturing depends extensively on the skills of the technicians and the knowledge base related to the cores and their restoration (Ijomah. 2009).

2.3. Six sigma

Quality Six Sigma is a business strategic management which originally developed by Motorola in 1986 in order to enhance the quality of products through decreasing of product variations on manufacturing operations as they face compete in semiconductor industries. Through the application of the Six Sigma method, Motorolla has acknowledged an award of Malcolm Baldrige in 1988 as the first American's company which won its prestigious quality's award (Parsana et al. 2014). Quality in terms of producers is the fulfillment of quality standards that have been owned (Purba, 2017. According to these facts, by considering an obtained quality level for only 99 percent or 1 percent of defect levels on such cases in manufacturing industries or services can potentially lead to fatalities. Hence, for gaining the target of quality level of 99.9996 percent or free-defects, an organization requires both flexibility and discipline in solving problems using statistical approach rather than using simple intuition or by trial and error; wider usage of statistical treatments is one of the benefits of Six Sigma method (Pacheco, 2014). Application of Six Sigma's method is more valuable due to its contribution to the science and practice for particularly reduces waste and provides added values. Six Sigma allows users to identify waste and hidden costs, eliminates defects, increases profit margin, satisfies customers, encourages employee commitment and satisfaction as well as expands businesses (Patil et al, 2015). Six Sigma as a management system is applied to ensure that efforts and critical opportunities for improvement are well developed through metric methodology and an applied level is inline with its business strategy. Six Sigma enables an organization to improve quality process by identifying and eliminating the causes of defects and error terms through minimizing variability in manufacturing and business processes (Mittal, 2014). The stages for improve process ability (process capability) regarding Six Sigma method are specifically allowing the standard steps such as define, measure, analyze, improve, and control for interlinked statistical tests. For a particular project within organization of applied of Six Sigma the stage is typically consists of a step-by-step requires for obtain measurable target values i.e. reduces cycle time, decreases air pollution, reduces costs, improves customer satisfaction, and increases profits (Mittal, 2014). It is inevitable, in order to gain benefits, as a results of Six Sigma's application in an organization or company, would require relatively high of initial investment, but might be offer benefits in long terms including cost savings, generated profits, improved consistency of quality processes, better employee performance, and better service quality and products. Those elements particularly would lead an organization or company to provide a higher customer satisfaction as well as to gain the ultimate goal of organization (Mittal, 2014). By applying DMAIC using a statistical approach, the root causes of the problem can be found and can improve the production process. The results of the six sigma improvement show the process capability increased from 2.2 to 3.1 sigma, saving $18,394.2 per month (Syafwiratama et al., 2017). Six sigma is a systematic, flexible, measurable and effective method in solving various problems in the industrial world (Trimarjoko et al., 2019). Seeing the results of the studies mentioned above, the Six Sigma method is used in improving the quality of Remanufacturing Lift Arm in the Heavy-duty equipment industry in Indonesia to be better to meet customer satisfaction and provide better company benefits.

3. Research methodology

The research methodology is a systematic description of the steps taken by the author from the beginning to the end of the study so that the implementation of the research becomes clear and focused following the research objectives. Through the following principal steps: (1) Describe the issue that is happening (2) Measure baseline performance or sigma level as an initial standard Re-manufacturing the Lift Arm process. (3) Analyzing the cause of product failure factors in the Lift Arm Remanufacturing process. (4) Determine the improvement efforts that can be done to improve the quality of the Re-manufacturing Lift Arm process, (5) Evaluate and control the results of repairs. The 5 stages are following the rules of problem-solving using the Six Sigma method namely the DMAIC phases (Define, Measure, Analyze, Improvement and Control). The research methodology used in this study is shown in Figure 1.

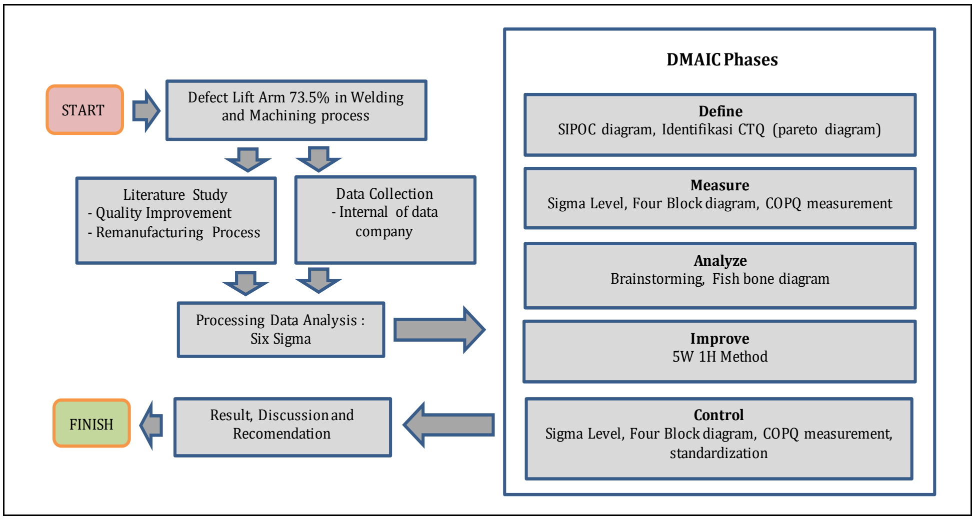

Figure 1. Research Methodology of Problem Solving Lift Arm in Welding and Machining Process

4. Processing and analysis

Processing and Analysis in this study using the Six Sigma (DMAIC) method based on previous research studies Six Sigma is a systemic, flexible, measurable and effective method, with a combination of methods and other tools proven to be able to reduce defective products, reduce errors, reduce customer complaints and improve process capability in maintaining company sustainability and can improve company competitiveness. Six Sigma has structured steps known as DMAIC phases (define, measure, analyze, improve, control).

4.1. Define phase

At the stage of defining activities carried out to identify problems that occur based on consumer needs and determination of goals (reduction of product failure). The initial step of the define stage is to identify the sequence of activities that occur in the welding and machining process that aims to find out at which stage the problem is. As for the sequence of activities intended in the SIPOC Diagram as in Table 1.

Table 1 SIPOC Diagram of Remanufacturing Lift Arm.

Supplier	Input	Process	Output	Customer
Disassembly Area	Damage part	Welding Process	Part finish process	Assembly Area
Scope Of Work Schedule	Consumable Welding	Machining Process	Remanufacturing	
Material	Consumable Machining		OK tag from Quality Control	

The Welding and Machining process is critical in this research. The next step is to find out the Critical to Quality in the Lift Arm welding dam machining process is carried out the production data collection and Welding and Machining Lift Arm product failure in January ~ May 2019 with the percentage and types of product failure as in Pareto diagram Figure 2.

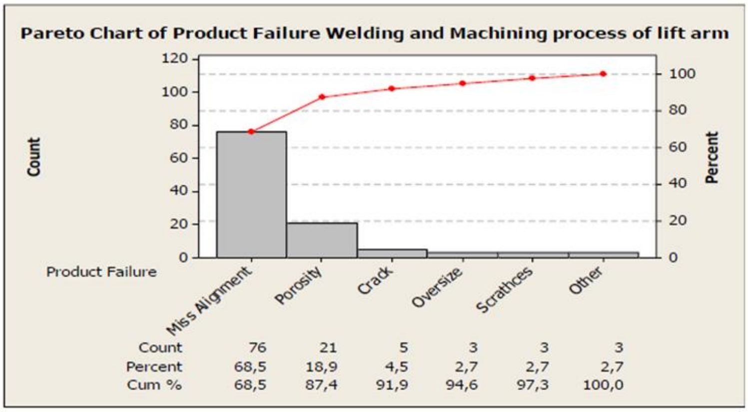

Figure 2 Pareto Chart of product failure Welding and Machining process Lift Arm

Refer to the Pareto diagram as in Figure 3. Can be interpreted that 6 types of defective products occur in the welding process and Machining Lift Arm, namely: Miss Alignment (68.5%), Porosity (18.9%), Crack (4.5%), Oversize (2.7%) Scratches (2.7%) and Others (2.7%). Based on the concept of Pareto product failure that has an accumulation of 80% into the improvement priority in problem-solving, then CTQ in this study there are 2 types are Miss Alignment and Porosity product failure with cumulative 68.5% + 18.9% = 87.4%. Research focuses on solutions to eliminate these two defects

4.2. Measure phase

The measuring stage is the second stage in the quality improvement program with the Six Sigma method in this stage, the capability process/sigma level measurement is used to determine the ability of the process before improvement, plotting the ability of the process into 4 block diagrams to determine the improvement direction from the control side of technology and also carried out measurements cost of poor quality (COPQ) to determine the financial losses caused by defective products.

4.2.1. Capability process/Sigma level measurement

Based on the collection of production data and product failure (defects) in the Remanufacturing Lift Arm process from January to May 2019 obtained from the report of the production department and Quality control total production 266 part, and total defect 111 part, the calculation of the process capability/sigma level is shown in Table 2.

Table 2. Measurement of Level Sigma Current Condition that Representative of Before Improvement

Item	Value
Total Production	266
Total Product Failure (defect)	111
CTQ (Control to Quality)	2
DPMO (Defect per Million Opportunity)	834586,47
Level of Sigma	1,91

4.2.2. Four block diagram

Four block diagram is a description of a process and states improvement direction that leads to two sides of improvement, namely technology and control which is a description of the ability of the process (Z) of an ongoing process. Based on Sigma Level 1.91, it can be calculated Zshif value as a reflection of control ability and Zst value which reflects the ability of technology and then plots it in Four block diagrams that show the capability of the ongoing process (Z). The Zshif and Zbench.lt calculations in the four-block diagram are as follows:

$$
\begin{aligned}
Zst &= Zbench.lt + 1.5 \\
1.91 &= Zbench.lt + 1.5 \\
Z\ bench.lt &= 1.91 - 1.5 \\
&= 0.41 \\
Zshift &= Zbench.st - Zbench.lt \\
&= 1.91 - 0.41 \\
&= 1.50
\end{aligned}
$$

The next step is after knowing the value of Z shif (control ability) and Zst (sigma level) then it can be done by making four block diagrams to illustrate the current process condition (current condition), as for the Four block diagrams referred as in Figure 3.

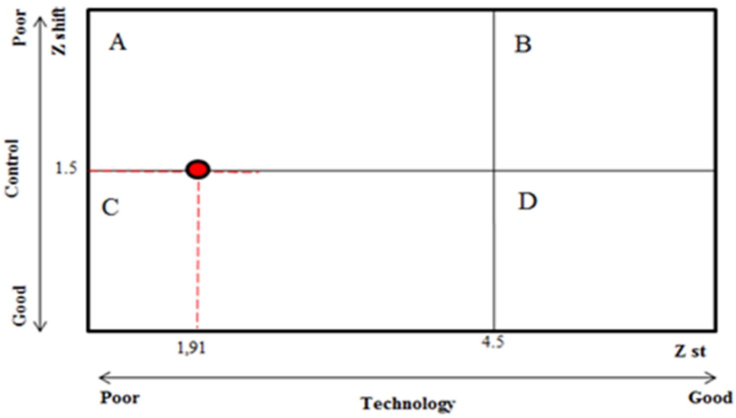

Figure 3. Four Block Diagram Product Failure (Defect) Welding and Machining process Lift Arm

Looking at the Four block diagram above(figure 4), it is known that from the control side it is good and still lacking in technology, meaning that improvements are needed so that both sides are expected in the category of proper control and technology.

4.2.3. Cost of poor quality (COPQ) mesurement

In addition to measuring the baseline performance of the Remanufacturing Lift Arm process, a cost analysis is also carried out due to poor quality, in this case, the cost of losses caused by product failure. The company's internal source costs must be borne due to product failure resulting in rework. Cost of Poor Quality US$ 390,87 per pcs. As a result, the costs of losses due to product failure in January - May 2019 are as follows:

Table 3. Calculation of Cost of Poor Quality January - May 2019

No	Month	Product Failure (Pcs)	COPQ (USD)
1	January 2019	22	8599.14
2	February 2019	18	7035.66
3	March 2019	22	8599.14
4	April. 2019	23	8990.01
5	May 2019	26	10162.62
	Total	111	43386.57

Table 3. shows the cost of losses resulting from product failure from January to May 2019 Cost of Poor Quality of USD 43386.57.

4.3. Analyze phase

Analyze Phase is the third stage of the DMAIC method. In this stage, what needs to be done is to analyze why deviations or product failures occur by looking for the causes that cause these product failures. In this case, a defect analysis arises in the Remanufacturing Lift Arm process which consists of 2 types of product failure eg alignment and porosity Fishbone diagram (Cause and Effect diagram) as in Figures 4 and 5.

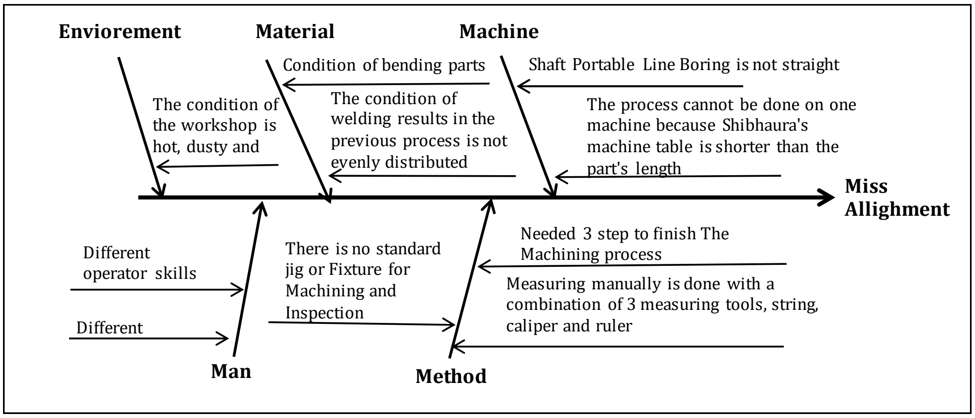

Figure 4. Cause and Effect diagram of product failure Miss Alignment

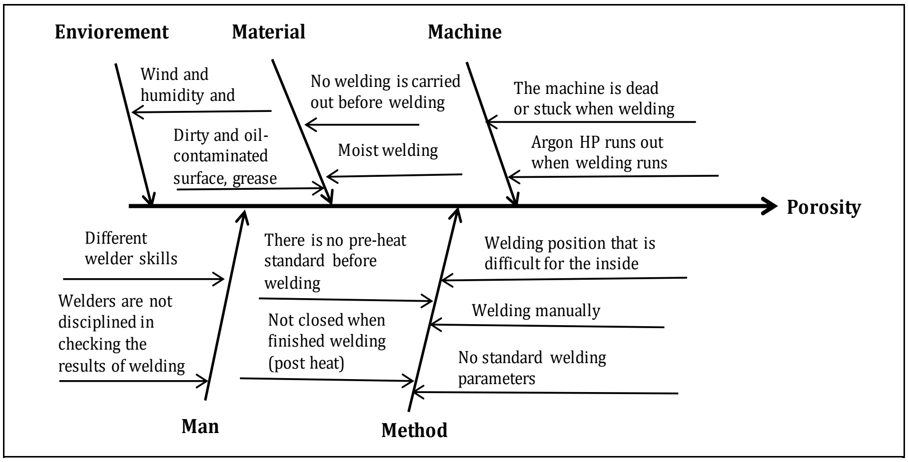

Figure 5. Cause and Effect diagram of product failure Porosity

From the cause and effect diagram, in Figure 4 the root cause of Miss Alignment in the Remanufacturing Lift Arm process is: (1) The process cannot be done in a CNC machine because parts are longer than the machine table. (2) If done with a Portable Line boring machine, the machining and inspection process is done manually so that it depends on the operator's skill. (3) Different parts condition when received such as bending, crack, and welding results from the previous process are uneven. (4) There is no standard process using jigs and fixtures. (5) The absence of standard parameters, methods for the machining process. From the cause and effect diagram, in Figure 5. the root cause of Porosity in the Remanufacturing Lift Arm process is (1) Dirty, oil-contaminated, grease and inconsistent surface cleaning by grinding before welding. (2) The welding process is carried out without Jigs, fixtures, parameters, and procedures as well as the inconsistency of checking after welding. (3) Humid winds and conditions in the welding area. (4) Difficult welding for inner diameter. (5) Uneven Welder Skill.

4.4. Improve phase

Improve stage is determining the proposed improvement of the root causes that have been done at the Analyze stage. The improvement plan is carried out using the 5W + 1H method that contains plans and corrective actions for each of the factors causing product failure Miss Alignment and porosity that have accumulated 80% of the largest product failures from the overall product failures that occur in the welding and machining process.

4.4.1. Improve plan product failure of Miss Alignment

Miss Alignment product failure that occurs in the machining process is a major problem in the Machining process based on joint discussion with the 5w + 1H method. Miss alignment problem is reconditioned: The Machining process changes from a manual process with 3 settings to 1 time setting with "Jig". This changes from the previous process of series per 1-2 holes into 10 holes directly in 5 different places. The inspection or checking process can also be reduced by eliminating the alignment checking/alignment from using the meter, caliper, ruler, thread and pendulum become unnecessary because the Jig hole size has been adjusted to the part specifications. Quality Control focuses on checking dimensions with bore gauge and caliper and visual smoothing of machining results. The process is faster than the previous 4 days to 2 days so that it can increase the capacity of workshops that were previously 13-14 units to 24-25 units per month. The engine parameters with a speed of 200 rpm, feeding rate. 1,2 and feeding 0.5 - 1 mm per step. From the operator side, this process will change from grade 4 or multi-skill CNC operator to grade 2 semi-automatics. The Jig referred to above is as in Figure 6.

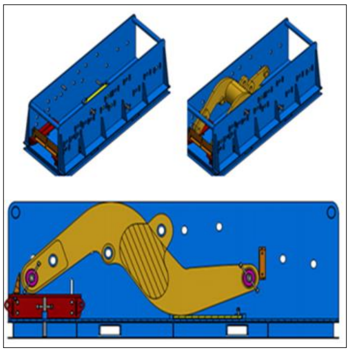

Figure 6. Jig Machining process design

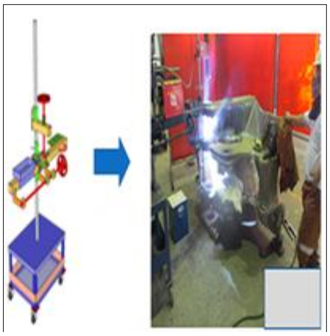

Figure 7. Jig Semi Automatic Welding process design

4.4.2. Improve plan product failure of Porosity

Product Porosity failure that occurs in the Welding process is a major problem in the Machining process based on joint discussion with the 5w + 1H method. Miss alignment problem is reconditioned: The welding process for Inside diameter or the inner hole is replaced from before the manual process becomes semi-automatic by modifying the machine and making Jigs and fixtures. With this process, a change occurred before Welder did welding to just run the machine correlated with Jigs and fixtures so that the welding results will be standard, even and the operator can prepare other parts in the queue. The making of Welding Procedure Standard starts from the cleaning process with chemical and grinding, preheat up to a temperature of 120º Celsius, welding and PWHT with glass wool after finishing. In the surrounding area of welding made a cover or screen to keep the wind and humidity. The improvements to the welding process in question are shown in Figure 7.

4.4. Control phase

This stage is the final phase of the DMAIC phase. What is done at this stage is monitoring and controlling the results after improvement. Process capability/sigma level, mapping sigma level into four blocks are salted and the calculation of the cost of poor quality (COPQ) is again carried out to determine the effectiveness of the results of improvements, in addition to the process of standardization of new processes that are also carried out to avoid similar failure products occurring in the future.

4.5.1. Capability process/sigma level measurement (after improvement)

Based on data taken from the production and quality control department with a duration from the first week of July 2019 to the fourth week of November 2019, the total production for Lift Arm is 341 units with a total of 24 units of product failure, with a percentage of 7.03%. The calculation of process capability/sigma level is presented in Table 4.

Table 4. Calculation of process capability/sigma level after improvement

Item	Value
Total Production	341
Total Product failure (defect)	24
CTQ (Control to Quality)	2
DPMO (Defect per Million Opportunity)	140762,5
Sigma level	2,43

Table 4. Shows that the capability of the welding and machining process after Improvement is at 2.4 sigma with DPMO 140762.50 better than the conditions before Improvement 1.91 sigma with DPMO 834586.47.

4.5.2. Four block diagram (after improvement)

Referring to Table 3 above and the same calculation as in the measure phase, the sigma level after improvement (2.43) can be mapped in the four-block diagram as in Figure 8.

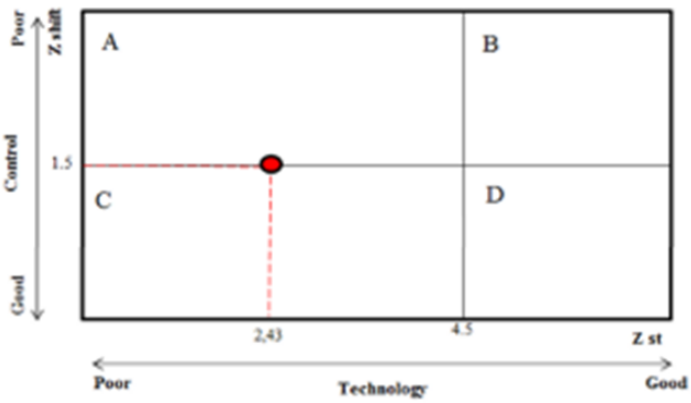

Figure 8. Four Block Diagram Product Failure (Defect) Welding and Machining process Lift Arm (after improvement)

4.5.3. Calculation of cost of poor quality (COPQ) after improvement

Just as in the measuring stage, the calculation of the cost of poor quality (COPQ) is a calculation of the company's losses that must be borne by the product failure that occurs. Cost of Poor Quality US$ 390,87 per pcs. The COPQ calculations after improvement can be seen in Table 5.

Table 5. Calculation of Cost of Poor Quality After Improvement

No	Month	Product Failure (Pcs)	COPQ (USD)
1	July 2019	5	1954.35
2	August 2019	5	1954.35
3	September 2019	5	1954.35
4	October 2019	5	1954.35
5	November 2019	4	1563.48
	Total	24	9380.88

Table 5. Above can be interpreted that the loss that must be borne by the company due to product failure after improvement as much as USD 9380.88 decreased from before improvement USD 43386.57 equivalent to 78.37%.

4.5.4. Standardization

To avoid similar failure products, namely Miss Alignment and Porosity Lift Arm in the process of welding and machining in the Indonesian remanufacturing industry, socialization of the results of improvement to all relevant levels and the creation of new standards in the form of Operational Procedure Standards (SOP) related to welding and Machining processes.

5. Conclusion

Referring to the entire stages of this research, it can be concluded that improving quality by using the Six Sigma method in this study can reduce Lift Arm failure products in the welding and machining process and can increase company profits due to decreased product failure. This study generally strengthens previous studies that the Six Sigma method is effective in identifying and analyzing product failures, and can improve the capability/level of sigma to get better quality products. Seeing the positive results contained in this study, it is recommended for further studies the use of the Six Sigma method in combination with other tools of quality can be used in improving quality in the other remanufacturing industries. To increase the repertoire of research using the Six Sigma method becomes more varied.

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