Innovation of quality improvement to reduce weld defect through six sigma methods in the fabrication process of power plant component

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Abstract. This study aims to improve the quality of boiler through six sigma methods. Quality of boiler in the thermal power plant should be maintained with a good performance in order to assure that power plant can operate normally. DMAIC principle, defining, measuring, analyzing, improving, and controlling processes is implemented in this research. The research finding that the average rejection rate that exceeds the target rejection rate are Radiography Test (RT) of welding tube- tube, header-header, and header-end caps. Porosity is a type of weld defect that often occurs, around 36%. Project team concluded three critical that influence the output variables the most. These four variables are welder skill, welding fluxes gas, and welding condition. By implemented improvement of six sigma methods, sigma value increased from 4.1 become 5.

1. Introduction

In this era of changing customer needs and demand of highly reliable products, the company need to improve their quality and operational performance continuously to survive and grow in the highly competitive business world. This study aims to improve the quality of boiler as one of important component in the power plant industry. Quality of boiler in the thermal power plant should be maintained with a good performance in order to assure that power plant can operate normally. The main component of thermal power plant consists of four components, such as boiler, turbine, condenser, and generator. Thermal power plant is widely used due to high efficiency, economic cost, and operational flexibility. Based on regulation of Indonesian government through Ministry of Energy and Mineral Resources No.1567 K/21/MEM/2018, the government plans to increase the capacity target of energy and electricity sector in Indonesia by 106 GW to fulfill the electricity demands [1]. The main process of boiler fabrication is welding the materials. As one of power plant component, poor quality of welding process influence the operational of power plants. An innovation of quality improvement to reduce the weld defect of boiler fabrication through hybrid methode of six sigma will be discussed in this research. Six Sigma has become one of the widely popular methodologies for problem-solving and performance improvement in the industry and service sector. Many large organizations like Motorola, General Electric, Honeywell, Texas Instruments, 3M and Caterpillar have reported a lot of success stories and financial savings due to the application of Six Sigma methodology [2]. Six Sigma is one of comprehensive framework to provide solutions to the industrial problems using a set of quantitative tools [3]. It is designed to reduce process variation by DMAIC principle, defining, measuring, analyzing, improving, and controlling processes [4]. It is a well-established approach to identify and eliminate mistakes, defects, or failures in business processes or systems [5].

2. Method and materials

2.1. Data Collection
Research on quality improvement of welding process of boiler fabrication using all of welding product which conducted an inspection by Inspector of Quality Control Department from October 2017 – September 2019 during the boiler fabrication process. Inspection report consist of quantity and type of rejection material, dimension, PMI (Positive Material Identification), and NDT (Non-Destructive Test) such as Magnetic Test, Penetrant Test, Radiography Test, and Ultrasonic Test. In addition, parameter or condition during the welding process also collected by direct observation and discussion.

2.2. Method
Six sigma methods implemented to reduce weld defect in the boiler fabrication process. The DMAIC denotes the five critical phases or stages in six sigma methodology, namely definition, measure, analysis, improvement, and control [6]. The major activities of DMAIC approach in the case study mentioned in Figure 1 with explanation bellow:

- **Define**
  In definition phase, selection of project team, preparation of project charter, identification the project scope and goal, problem statement, development of business case and preparation of project schedule are carried out [7-8]. Moreover, SIPOC and Voice of Costumer tools are used in this phase.

- **Measure**
  This phase presents the detailed data collection chart, evaluation of the existing system, assessment of the current level of process performance, and quality cost calculation.

- **Analyze**
  In the analysis phase, the potential root cause of the problem was identified through cause and effects matrix. The deliverable of the analyze phase of six sigma methodology is to list down the root causes of the problem [9-10].

- **Improve**
  The goals of this phase are selected the problem solution, carried out experimentations to validate solutions and relations between the effects and causes [11]. This step using creative ways to find new ways to do things better, cheaper or faster through Root Cause Analysis (RCA) tools, brainstorming, and discussion.

- **Control**
  The last phase of DMAIC methodology is control, this phase was taken to ensure that the improvements will be sustained in the process [12].

![Figure 1. Research Methodology](image-url)
3. Results and discussion

The primary objective of six sigma project is customer satisfaction. Six Sigma is proven to provide solutions to eliminate the defect of products in the industrial sector [13-14]. Every stage of DMAIC on the Six Sigma method will be carried out continuously. Herewith results of DMAIC method for this case of study.

3.1 Define

At this stage, the first step is to determine the project to be carried out based on a predetermined priority scale, problem definition, and determine the CTQ. Here is the project charter for this study.

| Table 1. Project Charter |
|---------------------------|
| Project Title | Quality improvement to reduce weld defect through hybrid method of six sigma |
| Project Location | Boiler manufacturing industry in Banten Province, Indonesia |
| Case Study | Welding is one of the most critical processes on fabrication process of boiler. Higher repair rate effects to production cost, decrease the productivity, and low profit. By decreasing the welding repair rate overall project quality and productivity would be improved, cost will be saved, and customer satisfaction level will be increased. This research using DMAIC sequence to improve quality, reduce weld defect, and increase sigma level. |
| Project Scope | Departemen of Production, Quality Control, Material Control & Warehouse, Engineering, and Procurement. |
| Project Phase | Define, Measure, Analyze, Improve, Control |

The next step is determined the SIPOC diagram for more understanding the problem and fabrication process of boiler. Figure 2 shows SIPOC diagram of boiler fabrication process as one of power plant component.

**Figure 2. SIPOC Diagram of Boiler Fabrication Process**

The first process of boiler fabrication is preparation the welding map and procedure, WPS/PQR, and detail weld joint drawing. After all of preparation already complete, the membrane and widening process of tube boiler will be start. At the widening stage, the sub panels generated by the membrane machine will be welded between the sub panels. The joint panel fabrication process is a process of combining two boiler panels by conducting a welding process.
between tubes on the panel. This process is one of the critical points in boiler fabrication. On the boiler panel, there are different types of attachments that have different functions.

Voice of Customer is identified by brainstorming and discussion between departments both internal and external who are directly involved in the boiler fabrication process. The results obtained Voice of Customer are testing laboratory certificate, qualification of welding procedures, complete welding equipment, implementation of codes and standards, the quality of the welding electrode. Based on data collection, Figure 3, it is found that the average rejection rate that exceeds the target rejection rate are RR Material and RR RT. Material checking is carried out before the boiler fabrication process. Because this process is carried out before the fabrication process and does not involve the welding process, this study does not further discuss RR Material. Therefore, this study focuses on RR RT.

![Figure 3. Rejection Rate of Boiler Fabrication Process](image3)

The next stage of define phase is to establish CTQ (Critical to Quality) which focuses on the problems that occur in order to meet customer desires. Based on data processing and Figure 4, there are 10 types of defects that become CTQ studies, i.e. porosity, internal concavity, debris, slag inclusion, incomplete fusion, incomplete penetration, crack, root undercut, tungsten inclusion, and excess.

![Figure 4. Rejection Rate of Radiography Test](image4)
The type of defect with the highest percentage is porosity around 36%. Porosity is the presence of cavities in the weld metal caused by the freezing in of gas released from the weld pool as it solidifies.

3.2 Measure
The second step in the DMAIC stage is measure. Table 2 shows the number of defects and current sigma level from welding results of joints headers to headers, headers to end caps, and tubes to tubes by NDT radiography. The average sigma level is 4.1 which could explain the productivity and financial condition of the company. Besides, based on internal discussion poor quality of the product effected to the profit. In the four level of sigma, 50% cost for expenses, 20% cost for rework/waste, and only 30% for profit [15]. Research [16] confirmed that the implementation of FMEA method, industri get an overview of the steps to be taken for the future so that the reliability of a steam generator boiler system can be improved.

| Month | Total Inspection | Total Defect | % Defect | DPU | DPMO | Yield | Sigma Level |
|-------|------------------|--------------|----------|-----|------|-------|-------------|
| Oct-17 | 4240            | 298         | 7.03%    | 0.007 | 7028.3 | 99.30% | 4.0 |
| Nov-17 | 4082            | 107         | 2.62%    | 0.002 | 2621.2 | 99.74% | 4.3 |
| Dec-17 | 132             | 1           | 0.76%    | 0.000 | 757.58 | 99.92% | 4.7 |
| Jan-18 | 10261           | 532         | 5.18%    | 0.005 | 5184.6 | 99.48% | 4.1 |
| Feb-18 | 4966            | 232         | 4.67%    | 0.004 | 4671.7 | 99.53% | 4.1 |
| Mar-18 | 3726            | 161         | 4.32%    | 0.004 | 4320.9 | 99.57% | 4.1 |
| Apr-18 | 9329            | 315         | 3.38%    | 0.003 | 3376.5 | 99.66% | 4.2 |
| May-18 | 1146            | 19          | 1.66%    | 0.001 | 1657.9 | 99.83% | 4.4 |
| Jun-18 | 3030            | 100         | 3.30%    | 0.003 | 3300.3 | 99.67% | 4.2 |
| Jul-18 | 6148            | 196         | 3.19%    | 0.003 | 3188.0 | 99.68% | 4.2 |
| Aug-18 | 4888            | 276         | 5.65%    | 0.005 | 5646.4 | 99.44% | 4.0 |
| Sep-18 | 574             | 37          | 6.45%    | 0.006 | 6445.9 | 99.36% | 4.0 |
| Total | 52522           | 2274        | 4.33%    | 0.004 | 4329.6 | 99.57% | 4.1 |

3.3 Analysis
Cause and effect diagrams show the relationship between problems that are faced with possible causes as well as factors that are influence it. The factors that influence and become causes of damage to welds in general can be classified as follows man/personals, material, measurement, methods, machines and environment as mentioned in Figure 5.
Cause and Effect diagram should be validated by using san-gen shugi methods as company principle in Table 3. San-gen shugi means principle of three realities, i.e. genba (real place), genbutsu (real part), genjitsu (real facts). On the basis of the Cause and Effect matrix, Project team concluded three critical that influence the output variables the most. These three variables are welder skill, welding fluxes gas, and welding condition.

| No | Causes                | Validation Methods | Valid/Not Valid |
|----|-----------------------|--------------------|-----------------|
| 1  | Welder Skill          | Genba              | Valid           |
| 2  | Welder Qualification  | Genba              | Valid           |
| 3  | Welding Tools         | Genbutsu           | Not Valid       |
| 4  | Welding Machine       | Genbutsu           | Valid           |
| 5  | Welding Electrode     | Genbutsu           | Valid           |
| 6  | Welding Wire          | Genbutsu           | Not Valid       |
| 7  | Welding Fluxes Gas    | Genbutsu           | Valid           |
| 8  | WPS/PQR               | Genba              | Not Valid       |
| 9  | Welding Map           | Genba              | Not Valid       |
| 10 | Welding Process       | Genba              | Valid           |
| 11 | Capability Inspector  | Genba              | Not Valid       |
| 12 | Visual & NDT          | Genjitsu           | Valid           |
| 13 | Welding Condition     | Genba              | Valid           |
| 14 | Electrode Storage     | Genba              | Valid           |

3.4 Improve

Based on previous section, the highest percentage of weld defect type with the highest percentage is porosity around 36%. Moreover, there are three critical that influence it, such as welder skill, welding fluxes gas, and welding condition. This item will be the main improvement priority in welding process of boiler fabrication. Welder skill is a strong factor phase to bring quality improvement in the welding process. Proper testing of the welders before execution for every new welding project was necessary to be done. In most of the welding companies in the world, this testing of welders should be done and called as welding operator performance qualification test.
(WPQ). Preparation of material surfaces before fabrication process can prove to be as critical a point for clean weld as welding itself. The after effects of fabrication can lead to surface contamination and porosity if proper care is not taken to clean. This in turn can lead to unsound welds with poor mechanical properties, which require rework or replacement at the expense of time and money. Porosity can eventuate in case of inappropriate gas shield inducing air entrapment. The welding worker is required to check the attachment of the gas hose with the equipment, and get rid of any hose contamination. Moreover, if the flow rate of gas shield is too high, and then air can be pulled into the weld metal, which may lead to turbulence. Welder should optimize the gas flow, offer welds of quality without gas loss. In general, the amount of electric current used during the process welding takes place will affect the mechanical properties in the weld area. Moreover, welding condition also effected the welding products. Welder should monitor workplace for strong air flows or currents that could affect the weld puddle or gas shield. In addition, welder should check the arc length. The further away the gun is from the weld site, the more likely air and gas will seep into the weld puddle causing bubbles to form which will in turn make a weak weld.

3.5 Control
The last phase of DMAIC is control, which ensure the processes continue to work well, produce desired output results, and maintain quality levels. The tools used in this phase is control plan, check sheet and monitoring. After implemented the quality improvement, sigma level increased from 4.1 become 5 sigma.

4 Conclusion
Quality of boiler in the thermal power plant should be maintained with a good performance in order to assure that power plant can operate normally. In this research, six sigma with DMAIC methods are used to to reduce the weld defect of boiler. The first phase of six sigma is define phase. Based on data collection, the average rejection rate that exceeds the target rejection rate are RR Material and RR RT. Material checking is carried out before the boiler fabrication process. Therefore, this study focuses on RR RT. Critical to Quality on this study are porosity, internal concavity, debris, slag inclusion, incomplete fusion, incomplete penetration, crack, root undercut, tungsten inclusion, and excess. The type of weld defect with the highest percentage is porosity around 36%. The current condition of sigma level through measurement phase is 4.1 sigma. In the four level of sigma, 50% cost for expenses, 20% cost for rework/waste, and only 30% for gross profit. By using cause-effect diagram and cause validation, Project team concluded three critical that influence the output variables the most. These three variables are welder skill, welding fluxes gas, and welding condition. All of critical item that influence welding results should be improve. After implemented the quality improvement, sigma level increased from 4.1 become 5.

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