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Application of Six Sigma Methodology in Welding Process of Boilers for Quality Improvement

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Abstract *- Six Sigma has been widely implemented by many different types of organizations since its inception at Motorola. The effectiveness of Six Sigma upon implementation in the industry is staggering. However, Six Sigma is still not followed in most of the small and medium scale industries. This paper focuses on the execution of six sigma in manufacturing industries. The analysis suggests that Six Sigma is appropriately defined as a brand new approach to quality management. In this work, rejection reduction in welding defects during the manufacturing of the water tube boiler is minimized by using six sigma tools. After the Six Sigma application, results have shown an impressive reduction in rejection rates of the product.*

Keywords: *boiler, DMAIC, six sigma, welding*

I. INTRODUCTION

Boilers are basically pressure vessels used for heating water or producing steam to provide process heating facilities in various industries and to generate electricity by driving steam turbines. Boilers are also useful for providing closed space heating for buildings and for producing hot water and steam consumed by users of laundries and kitchens. Six Sigma is an important development in quality management and process improvement in the last two decades. Six Sigma methodology is used in new processes as well as the existing process, which needs enhancement to increase the quality level of the product as well as reduce the rejection. Six Sigma is attained when a process does not produce more than 3.4 defects per million opportunities. Thus, whatsoever that does not satisfy the customer is called defectiveness. Figure 1 is the normal distribution curve which implies the six sigma. The normal distribution is symmetric about its mean. The area covered under the curve over the x-axis is equal to one, and the first inflection point occurs at one standard deviation away from the mean.

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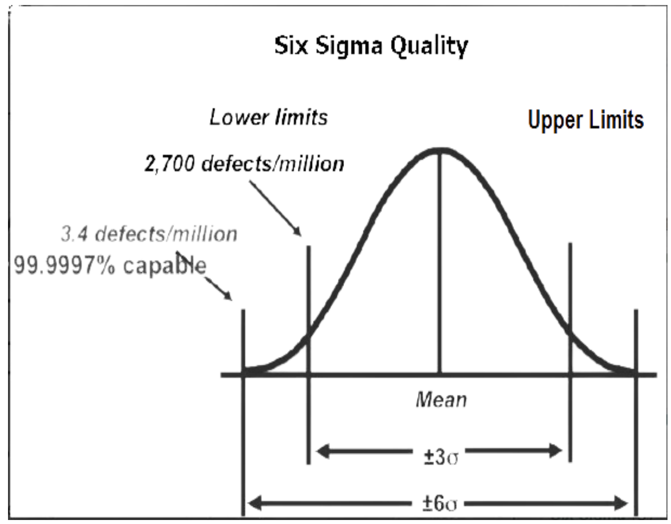

II. METHODOLOGY

DMAIC is the overriding methodology that unifies a framework for problem-solving and continuous improvements that are determined by critical business needs. These business needs are driven by fundamental voices that make a business operate, Voice of Customer, Voice of Business, and Voice of Employee. DMAIC is a data-driven quality plan used by establishments to develop processes. DMAIC is considered as a fundamental part of a Six Sigma initiative, but usually, this methodology can be used to enforce as an individual quality improvement procedure or as part of other process enhancement initiatives. DMAIC process is the significant method that lends itself to the project methodology to quality enhancement promoted by Juran.

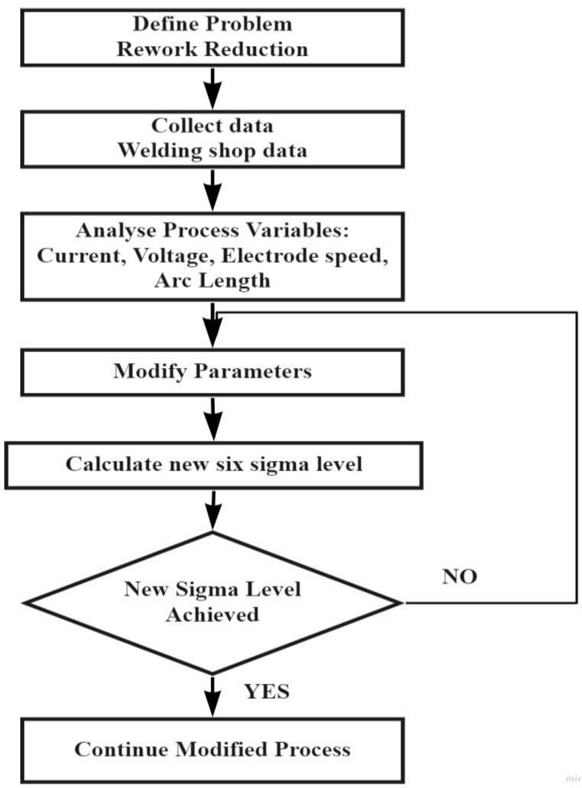

Figure 1: Methodology Flowchart

A. Define

The problem was that there was a high defect generation rate in manufacturing the boiler. The Company is responsible for the welding assembly work of the water tube boiler. However, there exist a variety of defects and a high defect rate in the welding process, from the point of view that the company's strategy and customer satisfaction, the quality level of the welds must be raised by reducing welding defects and enhancing the quality competitiveness.

B. Measure

Further analysis of the rejected parts shows the different causes of rejection of water tube boilers. A Pareto chart was drawn, which showed a clear picture. Among various causes of rejection such as spatter, weld burn, welding incomplete, blowholes, welding undercut came out to be a major contributor with 56 % of the total rejection. The average production of the water tube boiler was 10 boilers per month, and the running rejection of parts per million (PPM) was 16905. The target was set to bring down the rejection ppm and achieve the six sigma level.

Sr. No.	Defects	Quantity		
		Outer shell	Chamber	Tubes
1	Spatter	349	248	214
2	Weld burn	56	41	79
3	Weld incomplete	115	73	105
4	Welding undercut	86	53	15
5	Blow holes	59	67	46

Table No 1: check sheet data for boiler

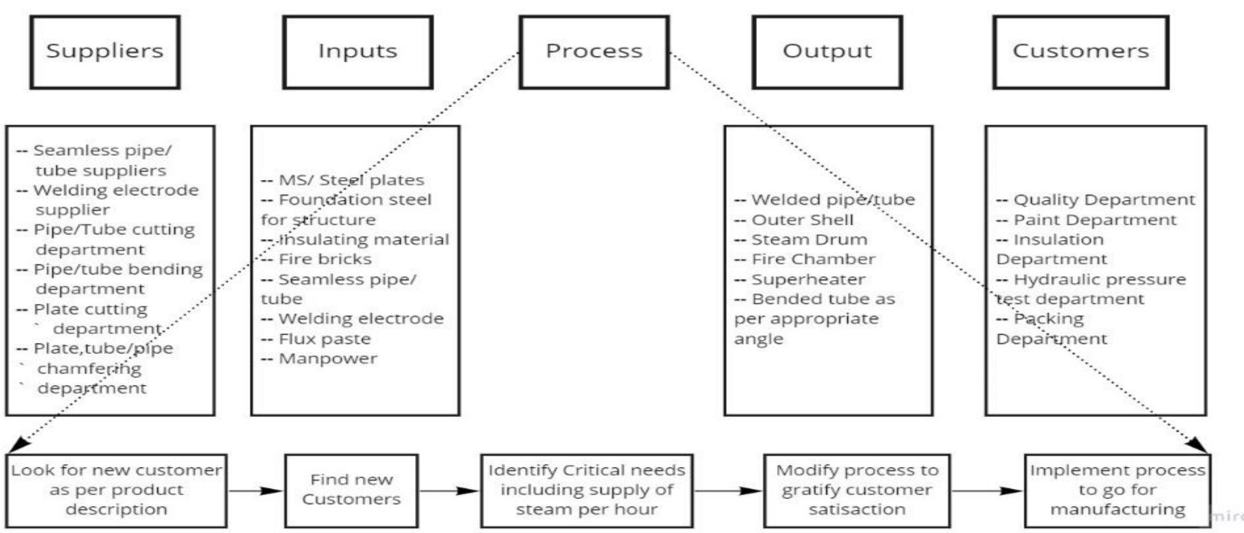

Figure 2: SIPOC Diagram

Critical to Quality is known as Critical to Quality Tree and is a Six Sigma tool used to identify the requirements of the customer and transform that data into computable product and process requirements. It permits establishments to recognize the characteristics of a product that drives more quality for customers.

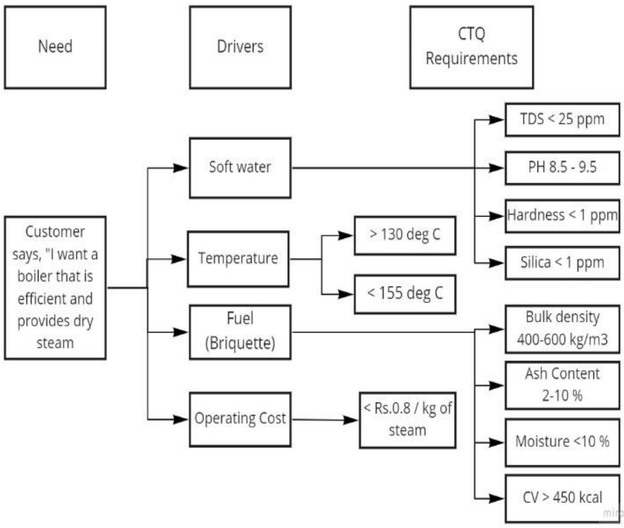

Figure 3: CTQ Tree

C. Analyze

After collecting data from check sheet data for boiler manufacturing defects, analysis has been done. It can be approached for root-cause analysis. A modest question needs to be asked: Why did the welding defect occur in the first place?

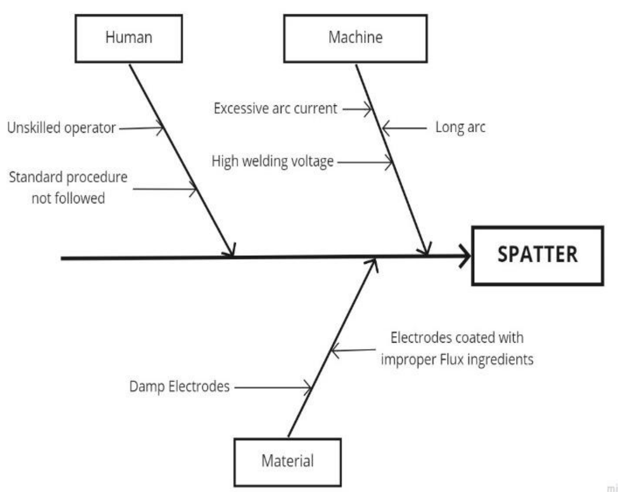

Figure 4: Fishbone diagram for Spatter Defect

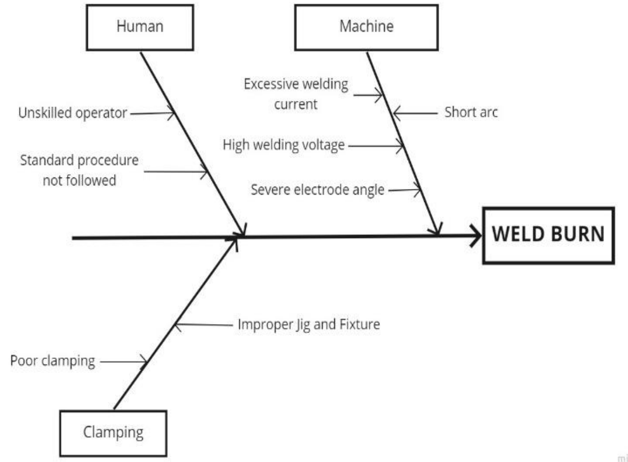

Figure 5: Fishbone diagram for Weld Burn Defect

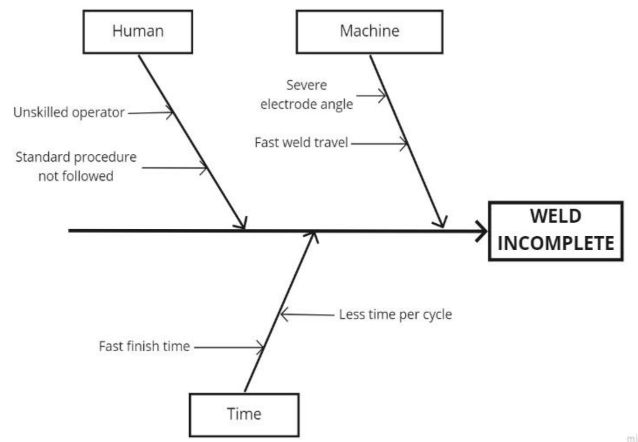

Figure 6: Fishbone diagram for Weld Incomplete Defect

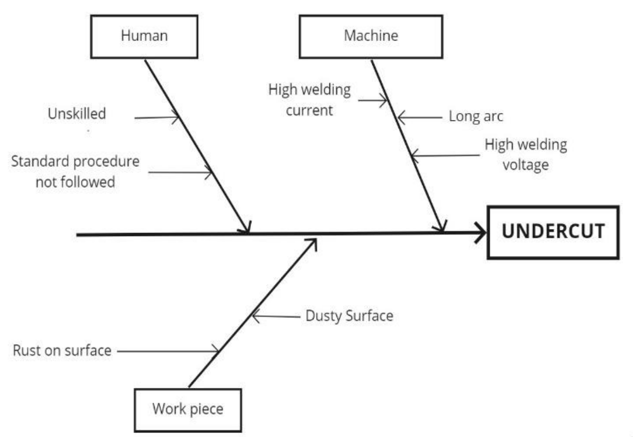

Figure 7: Fishbone diagram for Undercut Defect

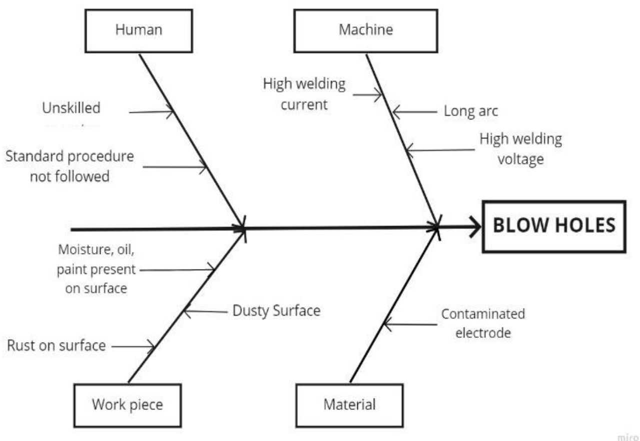

Figure 8: Fishbone diagram for Blow Holes Defect

This signifies the initial point of root-cause analysis. As a sensible answer to the question following answers were produced:

1. standard working procedure not followed,
2. imprecisely angled and tightened water tube pipework,
3. imprecise measurements,
4. imprecise stencil-based working table,
5. low-quality material,
6. environment effect,
7. human factor
8. Incorrect Welding parameters

The upper-stated answers signify the likely causes of the dimensional deviation. The main job of this stage is to decrease the number of possible defects to a reasonable few. This decrease can be conducted by multiple voting methods. The answers that remain after the multiple voting are also the possible reasons for defects and not the definite ones. The tool that could help in a pursuit for the most likely cause of the defects in the 5 WHY diagram. After the multi-voting session, the list of potential causes had been reduced to the following causes:

1. incorrect welding parameters
2. imprecise stencil-based working table
3. human error

Each of the responses from the list had been exposed to the question: Why? For every Why four or five answers were produced.

The conclusions in descending order represent below listed features:

1. incorrect welding parameters
2. imprecise stencil-based working table
3. unskilled operator
4. standard working procedure not followed
5. low-quality material
6. imprecise measuring
7. environment effect

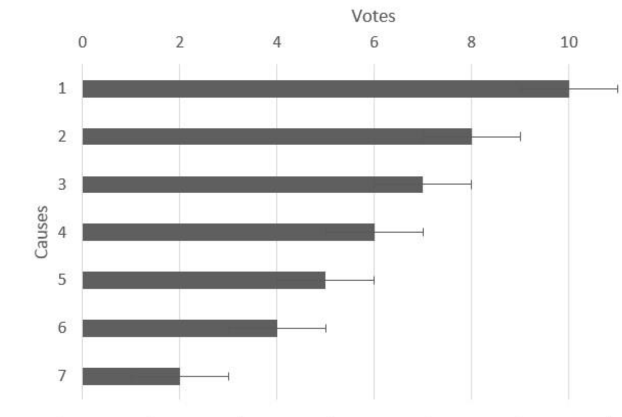

Figure 9: Results of multi-voting session

Thus, for example, by answering the question: "Why does the incorrect welding parameters effect on occurring of defects?" we got the following answers:

1. high welding voltage
2. improper welding current selection,
3. severe electrode (welding) angle
4. bad cooling,
5. Long arc length

The same procedure is used for other two causes:

imprecise stencil-based working table and human error

Next step in the 5 WHY process is to take the component that aspires the most likely as the root cause and try out the 5 WHY procedure. Among the three possible root causes, improper welding current selection represents the most likely root cause. When the root cause of the defect is found, we carry on the analysis by replying to the following type of questions: "Why does the improper welding current selection effect the defects produced?" The next solutions were collected:

1.Unskilled labor
2.Thickness determination error in plate and pipe
3.Improper voltage

For instance, in the stage of finding the root cause, the most probable error caused by the determined root cause needs to be recognized. This identification is also led by using multiple voting. These steps need to be reiterated until the occurrence of duplication of the answers or until we get to the point where no more rational questions could be created.

D. Improve

The experimental values of process factors were found to be unsuitable for the manufacturing process of the boiler, including fabrication. Additional studies about defects show that the defects arising during manufacturing can be decreased by changing the process parameters to some magnitude. The following three tables show the process parameters variation to reduce the defects. Table no.2,3,4 give the enhanced values of process parameters.

Parameters	Range
Current for plate welding	100-150 A
Current for pipe/tube welding	75-100 A
Voltage	440 V AC
Workshop luminosity	2000-3000 LUX
Electrode and workpiece gap (for 12-15 mm plate)	3.125-3.75 mm
Electrode and workpiece gap (for 3 mm pipe)	2.125-3.125 mm
Welding angle (fillet weld)	40-45 deg
Welding angle (pipe/tube)	40-45 deg
The result due to these changes is satisfactory	

Table 2: Process Parameters Iteration 1

Parameters	**Range**
Current for plate welding	200-250 A
Current for pipe/tube welding	175-200 A
Voltage	440 V AC
Workshop luminosity	5000-7000 LUX
Electrode and workpiece gap (for 12-15 mm plate)	3.125-3.75 mm
Electrode and workpiece gap (for 3 mm pipe)	2.125-3.125 mm
Welding angle (fillet weld)	40-45 deg
Welding angle (pipe/tube)	30-35 deg
The result due to these changes is good	

Table 3: Process Parameters Iteration 2

Parameters	**Range**
Current for plate welding	200-250 A
Current for pipe/tube welding	150-175 A
Voltage	440 V AC
Workshop luminosity	5000-7000 LUX
Electrode and workpiece gap (for 12-15 mm plate)	3.125-3.75 mm
Electrode and workpiece gap (for 3 mm pipe)	2.125-3.125 mm
Welding angle (fillet weld)	40-45 deg
Welding angle (pipe/tube)	30-35 deg
The result due to these changes is excellent	

Table 4: Process Parameters Iteration 3

E. Control

In the concluding step of the method, the arrangement of constant improvement needed to be assured. It was suggested to use the calculation of control limits. During the improvement course, all the events were being repeatedly documented according to the response plan. The significance of the response plan is that it creates a durable plan for action for all members of a process.

III. CALCULATION AND RESULTS

The Six Sigma was calculated as follows:

Defects per Million Opportunities (DPMO)

$$= \frac{\text{Total no.of defects found in a sample}}{\text{Total no.of defects opportunities in a sample}} * 100000$$

Sr. No.	Defects	Quantity		
		Outer shell	Chamber	Tubes
1	Spatter	102	117	129
2	Weld burn	12	9	45
3	Weld incomplete	46	33	21
4	Welding undercut	17	35	15
5	Blow holes	19	10	9

Table 5: Quantity of defects after implementation of Six Sigma

Calculating from the above data and formula, we have achieved a sigma level of 3.98

IV. CONCLUSION

The execution of this project has been measured as successful because the critical factor for the process was established and organized. Therefore, the organized plan was updated, and new operating environments with standard operating procedures (SOP) for the production process of the water tube steam boiler have been established. The baseline of the project was 3.62 sigma level and the gain of 0.36 sigma that represents the elimination of 10,390 defects. It is imperative to mention that the organization management was very helpful and positive with the project team. Finally, Six Sigma implementation can be helpful in decreasing the defective units or improving the organization quality and personal development

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