Six Sigma – A New Direction to Quality and Productivity Management

Tushar N. Desai and Dr. R. L. Shrivastava

Abstract - **The fast changing economic conditions such as global competition, declining profit margin, customer demand for high quality product, product variety and reduced lead–time etc. had a major impact on manufacturing industries. To respond to these needs various industrial engineering and quality management strategies such as ISO 9000, Total Quality Management, Kaizen, Just–in–time manufacturing, Enterprise Resource Planning, Business Process Reengineering, Lean management etc. have been developed. A new paradigm in this area of manufacturing strategies is Six Sigma. The Six Sigma approach has been increasingly adopted world wide in the manufacturing sector in order to enhance productivity and quality performance and to make the process robust to quality variations.**

This paper discusses the quality and productivity improvement in a manufacturing enterprise through a case study. The paper deals with an application of Six Sigma DMAIC(Define–Measure-Analyze-Improve-Control) methodo -logy in an industry which provides a framework to identify, quantify and eliminate sources of variation in an operational process in question, to optimize the operation variables, improve and sustain performance viz. process yield with well-executed control plans. Six Sigma improves the process performance (process yield) of the critical operational process, leading to better utilization of resources, decreases variations & maintains consistent quality of the process output.

Index Terms – **DMAIC, Process yield, Six Sigma, Total Quality Management.**

I. INTRODUCTION

A. Total Quality Management

Within the last two decades, Total Quality Management (TQM) has evolved as a strategic approach in most of the manufacturing and service organizations to respond to the challenges posed by the competitive business world. Today TQM has become a comprehensive management strategy which is built on foundation of continuous improvement & organization wide involvement, with core focus on quality. TQM is a process of embedding quality awareness at every step of production or service while targeting the end customer. It is a management strategy to embed awareness of quality in all organizational processes. By pursuing the process of continuous improvement and never-ending improvement the companies can outdistance their competitors by enticing the customers with high quality products at low price. TQM has culminated Six Sigma, Which targets 99.99927% defect free manufacturing.

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B. Six Sigma

Six Sigma is considered as a methodology of implementing TQM. Six Sigma is an innovative approach to continuous process improvement and a TQM methodology. Since quality improvement is the prime ingredient of TQM, adding a Six Sigma program to the company's current business system covers almost all the elements of TQM. Six Sigma has become a much broader umbrella compared to TQM.

Six Sigma Philosophy

Six Sigma is a business performance improvement strategy that aims to reduce the number of mistakes/defects to as low as 3.4 occasions per million opportunities. Sigma is a measure of "variation about the average" in a process which could be in manufacturing or service industry.

Six Sigma improvement drive is the latest and most effective technique in the quality engineering and management spectrum. It enables organizations to make substantial improvements in their bottom line by designing and monitoring everyday business activities in ways which minimizes all types of wastes and NVA activities and maximizes customer satisfaction. While all the quality improvement drives are useful in their own ways, they often fail to make breakthrough improvements in bottom line and quality. Voelkel, J.G. contents that Six Sigma blends correct management, financial and methodological elements to make improvement in process and products in ways that surpass other approaches.

Mostly led by practitioners, Six Sigma has acquired a strong perspective stance with practices often being advocated as universally applicable. Six Sigma has a major impact on the quality management approach, while still based in the fundamental methods & tools of traditional quality management (Goh & Xie, 2004).

Six Sigma is a strategic initiative to boost profitability, increase market share and improve customer satisfaction through statistical tools that can lead to breakthrough quantum gains in quality; Mike Harry (2000). Park (1999) believes that Six Sigma is a new paradigm of management innovation for company's survival in this 21st century, which implies three things: Statistical Measurement, Management Strategy and Quality Culture

Six Sigma is a business improvement strategy used to improve profitability, to drive out waste, to reduce quality costs & improve the effectiveness and efficiency of all operational processes that meet or exceed customers' needs & expectations (Antony & Banuelas, 2001). Tomkins (1997) defines Six Sigma as a program aimed at the near-elimi-nation of defects from every product, process and transaction. Snee (2004) defines Six Sigma as a business improvement approach that seeks to find and eliminate causes of mistakes or defects in business processes by focusing on process outputs that are of critical importance to customers.

Kuei and Madu (2003) define Six Sigma as:
Six Sigma quality = meeting the very specific goal provided by the 6σ metric and
Management = enhancing process capabilities for Six Sigma quality.

II. The DMAIC Six Sigma Methodology

The DMAIC methodology follows the phases: define, measure, analyze, improve and control. (Antony & Banuelas, 2002). Although PDCA could be used for process improvement, to give a new thrust Six Sigma was introduced with a modified model i.e. DMAIC.

The methodology is revealed phase wise (Fig. 1) which is depicted in A, B, C, D and E and is implemented for this project.

A. Define Phase

Development of a Project Charter

This phase determines the objectives & the scope of the project, collect information on the process and the customers, and specify the deliverables to customers (internal & external).

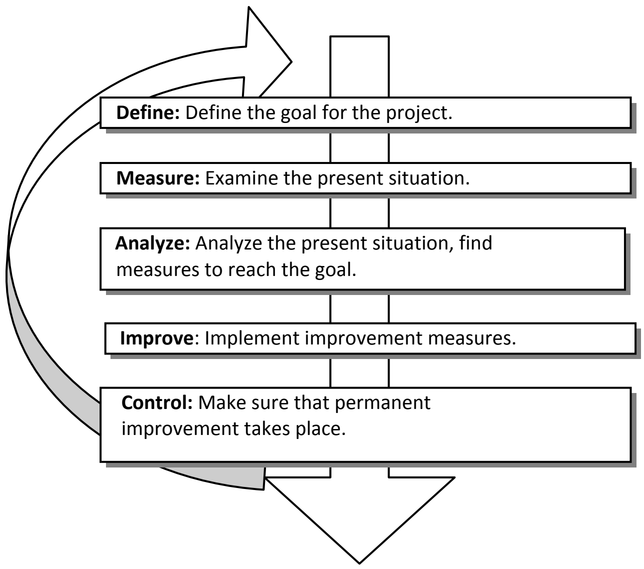

Fig.1 The DMAIC methodology (Pyzdek, 2003)

Creation of a Problem Statement

The operational process concerned is SAW Boom machine welding process. SAW Boom machine is used for welding of huge shells, containers, and pipes. Table 1 presents the SAW Boom machines' process yield as reviewed for the last one year.

TABLE-1 PROCESS YIELD OF SAW BOOM MACHINES

SAW Boom machine	Process yield
SAW A101	42.3 %
SAW A102	49.1%
SAW A103	59.3 %
SAW A104	55.7 %

SAW A101 Boom machine process yield is lowest in the given period; a Pareto chart illustrates this in Fig. (2). It was decided to increase this process yield. Table 2 presents the team charter for the project.

TABLE-2 PROJECT TEAM CHARTER

Project Team Charter	
Black Belt Name: Head – TQM Facilitation & Industrial Engineering Deptt.	**Champion Name :** GM, Operations
Project Start Date : August, 2006; Project Completion Date : Feb. , 2007	**Project Location :** A large scale manufacturing unit, Surat, Gujarat, India
Business Case: Improvement in SAW A101 Boom machine process yield will reduce COPQ, non-production idle hours, delay in delivery of jobs; which will satisfy the customers (internal & external), which will lead to improvement in quality, productivity & corporate health. **Project Title:** To improve SAW A101 Boom machine process yield. **Team Members :** Project student – M. Tech(Mech), Prof. T. N. Desai, Dr. R. L. Shrivastava and employees of the concern. **Stake holders :** Employees of TQM Facilitation & Industrial Engg. Deptt. **Subject Matter Experts :** Black Belt of Team, Head – TQM Facilitation & Industrial Engg Deptt., Sr. Managers **Project Milestones :** Define phase : Aug. 1 to Sept. 15, 2006 Measure Phase : Sept. 16 to Oct. 31, 06 Analyze Phase : Nov. 1 to Nov. 30, 06 Improve Phase : Dec. 1 to Jan. 31, 07 Control Phase : Feb. 1 to Feb. 28, 07	

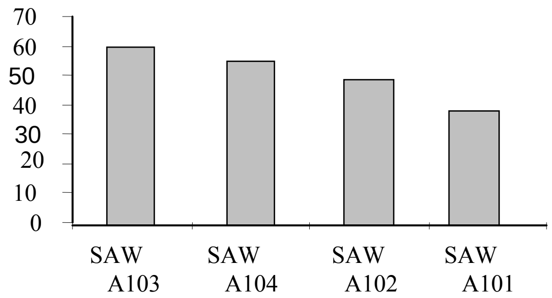

Fig.2 Pareto chart showing SAW Boom machines' process yield.

SIPOC Diagram

Fig. (3) describes the transformation process of inputs form suppliers to output for customers & gives a high level understanding of the process, the process steps (sub processes) and their correlation to each other.

Process Deliverables:
1. Reduction of non-production idle hours. 2. Reduction of COPQ. 3. Increase in SAW A101 boom machine process yield.

Principal Customers:
Internal customers are: 1. Project management group. 2. Manufacturing shops. 3. Inspection departments. External

customers are: 1. Clients / Third party Inspectors. 2. Customer Representatives.

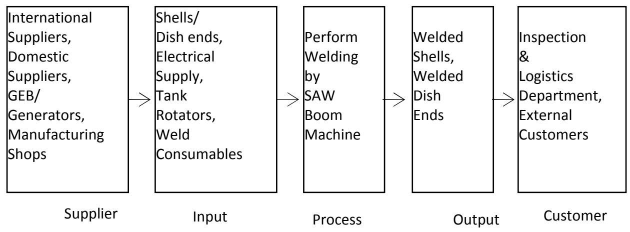

Fig.3 SIPOC diagram

Defining Process Boundaries and Customer CTQ requirements:
Process Boundaries - Process Start Point: - Un-welded Rolled shell from PFS shop, SWP & WPS of the job.
Process Stop Point: - Welded Shell which is ready for inspection clearance.

Customer CTQ Requirements
The customer data (VOC) revealed that internal customers are mainly affected by low SAW A 101 Boom machine welding process yield. CTQ characteristics are established and a CTQ tree (Fig. 4) is prepared on the basis of the VOC and project objective.

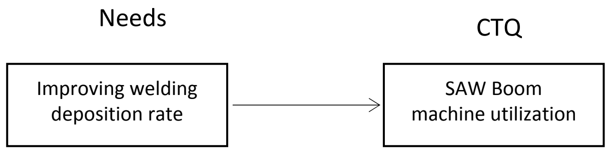

Fig.4 CTQ tree

B. Measure Phase

This phase presents the detailed process mapping, operational definition, data collection chart, evaluation of the existing system, assessment of the current level of process performance etc.

Process Mapping
The process map of the SAW Boom machine welding process (fig. 5) is prepared by visually studying the process and then mapping various sub-activities in it. This mapping helped to visualize and separate value-added activities from NVA activities and to isolate the hidden waste streams.

Operational Definition:-
Yield of SAW Boom machine process is defined as the ratio of net operating hrs to gross available hrs..

Type of Data
The type of data is continuous (variable).

Assessing current level of process performance (process sigma level)

$$\text{Yield of A101 SAW Boom machine welding process} = \frac{\text{Net operating hrs. (on job)}}{\text{Gross available hrs.}} = 2542/4112 = 61.8\%$$

From process-sigma conversion table, current process sigma level is *1.8* for process yield of 61.8%.

C. Analyze phase

This phase describes the potential causes identified which have the maximum impact on the low process yield, cause-and-effect diagram, Pareto analysis of the causes, the Why Why analysis, FMEA analysis which leaded to identify the vital few factors in order to identify the root causes of the defects / problems and helped to examine the processes that affect the CTQs and decide which X's are the vital few that must be controlled to result in the desired improvement in the Y's, this leaded to generate ideas for improvement.

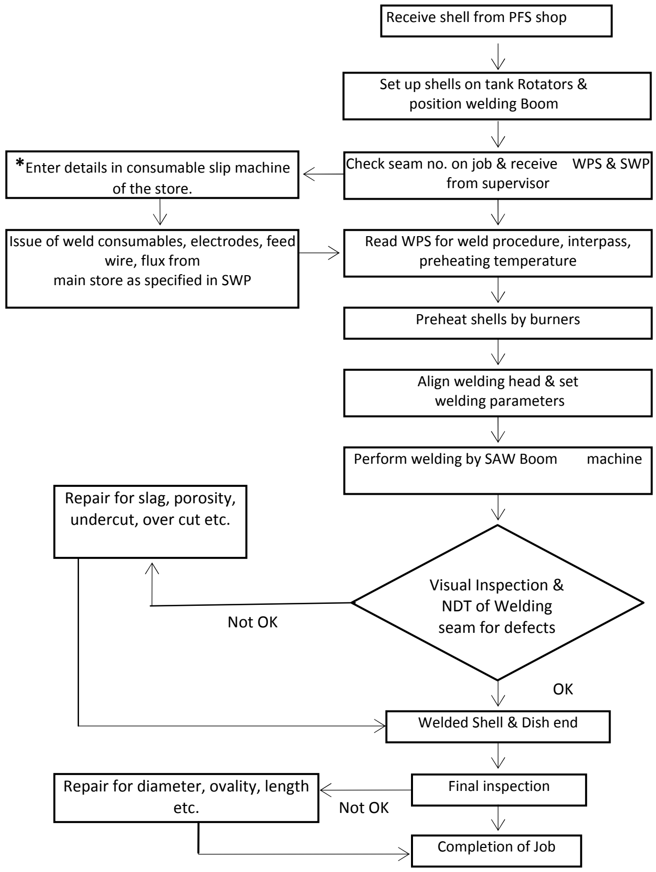

Fig.5 Process Map of SAW Boom machine welding process

Improved process map incorporates modification such as: the details are filled up through computer rather than manually (block marked with * in Fig. (5)).

Pareto chart

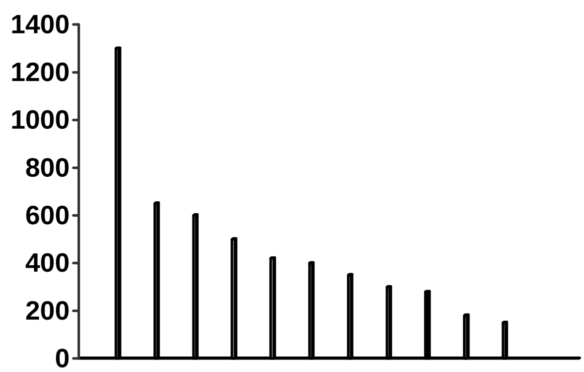

Fig.6 Pareto diagram illustrating the reasons for low yield for A101 SAW Boom machine welding process.

Fig. (6) represents a Pareto chart (Y-Axis: Hours) illustrating the reasons for the low yield of the process; which separate the vital few causes from trivial many. The graph is read from left to right and it starts with 1) lack of work, 2) breakdown hours, 3) set up time, 4) rework, 5) operator training, 6) operator absent, 7) preventive maintenance, 8) waiting for inspection/ instruments, 9) waiting for material, 10) no material handling equipment, 11) other reasons. The critical reason emerged is lack of work which depends mainly on scheduling of the activities. Another significant reason is breakdown hours of the machine. The relationship between CTQ and root causes is represented by Y = f (X1, X2, X3, …, Xn), Where, Y = CTQ, & $X_1, X_2, X_3, \ldots, X_n$ = Potential root causes.

Segregation of Causes

The initial causes are segregated into two categories: 1. Direct implementable causes. 2. Likely & controllable causes.

TABLE-3 PROCESS FMEA

Sr. No.	Potential Failure Mode	Potential Failure Causes	Potential Failure Effects	Severity	Occurrence	Detection	RPN
1	Improper gear alignment in gear box	Boom jerking in forward direction	Wear & tear of rack & pinion, poor bead finish	9	7	4	252
2	Motor of tank rotator is not synchronized	Eccentric load on roller of tank rotator	Fluctuation in rotational speed of job while rotating	8	9	2	144
3	Improper alignment of tank rotators' roller & uneven ovality of the job	Drifting of job while welding	Poor bead finish, drift of job away from welding head leading to stoppage in welding	9	10	6	540
4	Pinion damage	Speed variation in Boom	Stoppage in welding process	7	4	5	140
5	Waiting for spool	Spool not available	More consumption of time	4	9	2	72
6	Improper interpass cleaning, wrong bead placement, poor bead finish	Slag	Low strength welding leading to rework	8	8	8	512
7	Improper cleaning of weld, lower preheat temp. Use of cold flux, strong wind flow on arc, earthing clamp loose, use of lower current.	Porosity	Low strength welding leading to rework	8	8	9	576
8	Lower current, poor WEP/setup, higher voltage	Lack of fusion	Low strength welding leading to rework	7	8	8	448
9	Improper setting of shell's rotational speed; current, preheating temperature, voltage, etc. not as per WEP	Improper control over process parameters	Decrease in weld deposition	4	8	8	256

Direct implementable Causes- These are the causes for which the actual solutions can be implemented directly by the team & need no further analysis. These are *1*) improper lubrication of guide ways, *2*) waiting for flux, *3*) sudden eruption of sparks in welding operation, *4*) repositioning of start end of electrode strip, *5*) poor bead finish, *6*) shift take over/ hand over.

Likely & controllable Causes These causes are the causes that are within the control of the present boundaries of the team and need further analysis. These are *1*) lack of work, *2)* unavailability of material handling equipment, *3)* waiting for inspection, *4)* sticking of wire due to power failure, *5)* improper control of process parameters viz. rotational speed of shell, preheating temperature, voltage, current etc. are not as per WPS, *6)* non-uniform rotation of shell, *7)* drifting of job while welding, *8)* speed variation in boom, *9)* waiting for spool, *10)* slag, *11)* porosity, *12)* lack of fusion, *13)* forward jerking due to play in gear movement.

Cause and Effect diagram

A cause-and-effect diagram for low SAW Boom machine welding process yield presents a chain of causes & effects, sorts out causes & organizes relationship between variables. The cause-and-effect diagram prepared for the 22 initial probable causes identified can be viewed in Fig. (7).

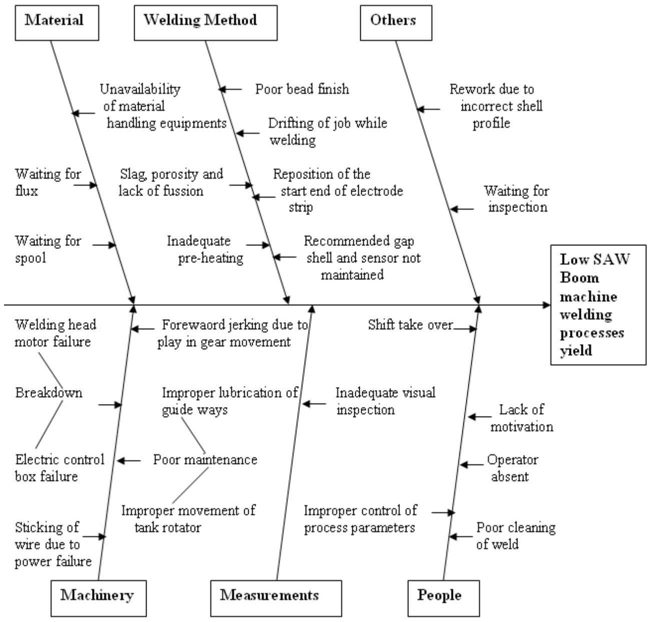

Fig.7 Cause & Effect diagram for low SAW Boom machine welding process yield

Why-Why analysis

Fig. (8) shows a why-why diagram which helped in identifying root cause of the problem.

Failure Mode and Effects Analysis (FMEA)

The major causes, prioritized on the basis of RPN, are porosity, drifting of job while welding, slag, lack of fusion, improper control of process parameters, etc.; which are responsible for low yield of the welding process.

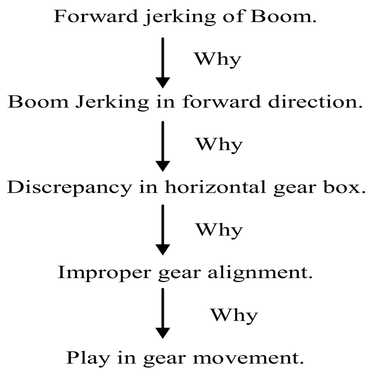

Fig.8 Why-Why analysis

D. Improve Phase

Target level of process performance (target Sigma level)

TABLE-4 SIGMA LEVEL CALCULATION

Improve SAW A101 Boom machine process yield	Current		Target	
	Process yield	Sigma level	Process yield	Sigma level
	61.8%	1.8	90.0%	2.78

The project team identified the risks for vital 'Xs' or input variables identified from various tools and took actions to optimize these input resources or the 'Xs' and thus developed process requirements that minimize the likelihood of those failures. The team members generated ideas for improving the process, analyzed and evaluated those ideas and selected the best potential solutions, planned and implemented these solutions.

Matrix diagram

A matrix diagram shown Fig. (9) is developed from the FMEA and other causes, which provided a picture of how well two sets of objects or issues are related and helped managers set priorities on plans and actions.

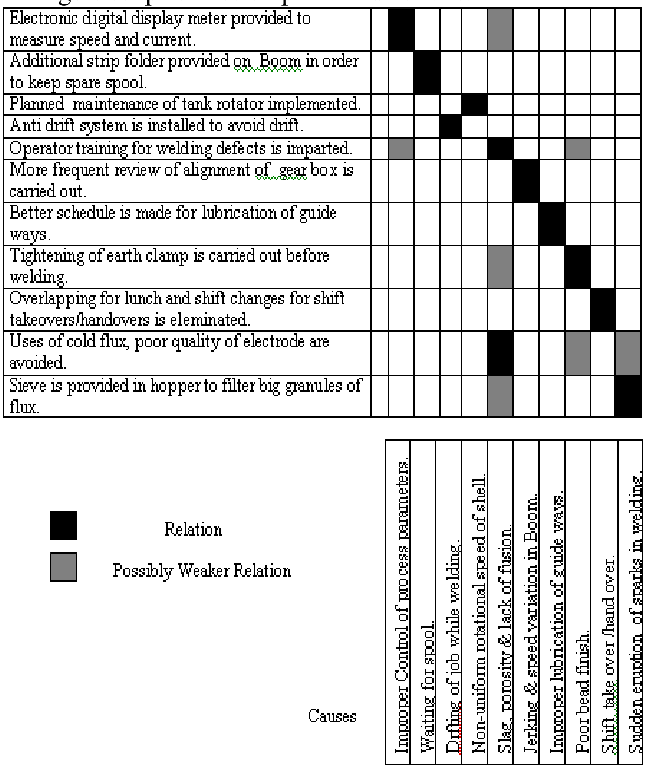

Fig.9 Matrix diagram with relationship between causes and measures.

Improvement Measures for Likely and controllable causes

Following improvement measures are implemented.

1. Additional strip folder is provided on the boom to keep a spare spool which avoided waiting for the spool. *2.* The uneven ovality at various ends of the shell and improper horizontal & diagonal alignments of the rollers of tank rotators are the major reasons for drifting of shell. To overcome problem of drifting, an anti drift system is developed and installed on tank rotator. *3.* A digital display meter is installed on the boom machine for controlling the process parameters such as rotational speed of shell, current, etc.; so that the supervisor of the machine can control these process parameters. *4.* Proper gear alignment of the horizontal gear box is carried out which eliminated disturbance of pinion and jerking of boom. Periodic review of the gear alignment in the gear box is also carried out. *5.* Presence of moisture, cold flux, dust, high voltage current, etc. are eliminated which reduced slag & porosity in welding. Operators are given training for overcoming defects in welding like slag, porosity, lack of fusion, etc. *6.* Planned maintenance schedule for tank rotators is implemented which avoided unsynchronisation of motors of tank rotators' rollers leading to proper rotation of tank rotators.

Production planning & control activities

Scheduling and controlling of operations, establishing job priorities and determining the sequence of jobs, Master Production Schedule, Materials Requirement Planning, detailed capacity planning, shop floor controls, provision of material handling equipments, resources allocation, etc are carried out.

Other quality management strategies

Philosophies and techniques for quality and productivity improvement such as: Zero defect programs, employee motivational strategies, preventive maintenance program, Kaizen-Gemba Kaizen, TPM, 5 S for workplace management and house keeping, operator training, change management, Quality Circles, TEI, Ergonomics, etc. are employed.

E. Control Phase

This is about holding the gains which have been achieved by the project team. Implementing all improvement measures during the improve phase, periodic reviews of various solutions and strict adherence on the process yield is carried out. The Business Quality Council (a group of Black Belt, Champion of team, Sr. Managers including project team members) executed strategic controls by an ongoing process of reviewing the goals and progress of the targets. The council met periodically and reviewed the progress of improvement measures and their impacts on the overall business goals.

III. Results and Discussion

The Six Sigma based methodology has been used to optimize the variables of SAW Boom machine operational process. The results obtained after implementing the improvement measures at various stages of the SAW Boom machine operational process are described below:

1. *Sigma impact* – The sigma level has been increased to 3(corresponding to improved process yield of 93%) from 1.8(previous process yield of 61.8%). The higher the sigma level, the better the process is performing and the lower the probability that a defect will occur. The DMAIC methodology of Six Sigma has resulted into a quantum improvement in Sigma value.

2. *Cost/benefit impact* – COPQ of A101 SAW Boom machine is reduced from Rs.1.42 million ($35,500) to Rs.0.22 million ($5,500) per annum. COPQ – the cost of doing things wrong – is reduced by identifying the visible and less visible costs of all the defects that exists in the processes, as well as identifying the NVA activities, and thereby eliminating costs of steps or processes that did not add value from the customers' perspective. A company that reduces its cost of doing business, meets the expectations of its customers more effectively and efficiently, inspires its employees, fosters a culture of dedication and pride, and earns a reputation for quality.

3. *Customer satisfaction impact* – Customer satisfaction is achieved by providing the products and service of right quality, in the right quantity at the right time, right place and right cost, fulfilling customers'(external as well as internal) stated and implied needs. By providing defect-free products and services of consistent performance and quality, the Six Sigma practice definitely enhanced the customer satisfaction.

4. *Time impact* – Considerable time is saved by eliminating non-production (idle) time and by not producing the defective product and by eliminating rework/reprocessing.
5. *Top line impact* – Organizational reputation in the market and society at large is improved by providing products and service of good quality without any deviation in terms of performance and reliability.
6. *Bottom line impact* – Six Sigma is a process control technique. By ensuring that the process is under control, the product can never be defective. Rejection or rework saved is straight away added to the bottom line in terms of profit of the organization and ROI.
7. *Improvement in yield/productivity* – Time saved in reworking is time utilized for effective production of products and services; which is added to the productivity. The yield or productivity is improved by optimum utilization of resources along with the reduction in wastages. Higher productivity lead to more production, lower cost of production and better quality and competitiveness in the marketplace.
8. Six Sigma has set a new direction for quality and productivity management. Six Sigma shifts the paradigm quality as the cause of good business performance and not the effect. Earlier all process and product improvement techniques were aimed at continuous improvement of quality. Six Sigma proves to be an effective strategy of finding solutions to eliminate the root causes (critical Xs) of performance problems in processes that already exist in the concern & thereby eliminating the unwanted defects (Ys) produced by the process. Six Sigma propagates that all-round quality performance is bound to result in the attainment of the desired business excellence in terms of reduction in cost of production, maximization of productivity, customers' (external as well as internal) satisfaction, profitability and ROI by achieving reduction in cost of production and processing by continuous process improvement, reduction and elimination of wastages, rework and excess consumption of resources.

IV. Conclusion

The process Sigma level through Six Sigma DMAIC methodology was found to be approaching 3 Sigma from 1.8, while the process yield was increased to 93% from a very low figure of 61.8%. This Six Sigma improvement methodology viz. DMAIC project shows that the performance of the company is increased to a better level as regards to: enhancement in customers' (both internal and external) satisfaction, adherence of delivery schedules, development of specific methods to redesign and reorganize a process with a view to reduce or eliminate errors, defects; development of more efficient, capable, reliable and consistent manufacturing process and more better overall process performance, creation of continuous improvement and "do it right the first time" mindset.

Six Sigma provides business leaders and executives with the strategy, methods, tools and techniques to change their organizations. Six Sigma as a powerful business strategy has been well recognized as an imperative for achieving and sustaining operational (process) effectiveness, producing significant savings to the bottom line and thereby achieving organizational excellence. If implemented properly with total commitment & focus, Six Sigma can put industries at the forefront of the global competition.

Scope for further improvement

The Sigma level achieved after implementation of DMAIC Six Sigma methodology can be further improved & new performance standards can be realized. Six Sigma methodologies expect that the new learning will be validated & evaluated with practice. It can be integrated effectively in the community of company employees for maintaining & further improving the improved performances.

Abbreviations

DMAIC : Define Measure Analyze Improve Control, VOC : Voice of Customer, CTQ : Critical To Quality, PFS : Pre Fabrication Shop, SAW : Submerged Arc Welding, SWP : Shop Weld Plan, WPS : Welding Procedure Specifications, SIPOC : Suppliers, Inputs, Process, Outputs, Control; RPN : Risk Priority Number, FMEA : Failure Mode Effects Analysis, NDT- Non Destructive Testing, NVA : Non value added, TPM : Total Productive Maintenance, TEI : Total Employee Involvement, COPQ : Cost of Poor Quality, ROI : Return on Investment.

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