Six Sigma Implementation to reduce rejection rate of Pump Casings at local Manufacturing Company

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Abstract: *Six Sigma is being Implemented all over the World as a successful Quality Improvement Methodology. This article provides a description of Six Sigma Project implemented at Local manufacturing Company. The Company Manufactures Pump Casings where it was receiving high nonconformance rate that resulted in to Rejection of Product. This study deals with Six Sigma DMAIC methodology implementation and gives a frame work of how the non-conformance rate was first monitored and then brought in to acceptance limits. A complete Coverage of the statistical analysis performed during the study is given and results are shown to describe that how Six Sigma helped the Project members to Improve Quality of Pump casings at manufacturing facility.*
Keywords: *Statistical Process Control (SQC), Process Capability Indices, Six Sigma, Variable control chart, Pareto charts, Standard deviation, Critical to Quality (CTQ), Analysis of Variance (ANOVA), DMAIC, Total quality Management (TQM)*

I. Introduction

In this Era of changing customer needs and demand of highly reliable products have pushed many manufacturing companies to adopt Total Quality Management (TQM) principles. Globalization and extension of Product Market has also increased the need of Quality Products at Reasonable cost to Customers. To respond to these Demands many Companies are implementing different Quality Management Principles at their manufacturing facilities such as ISO 9000, Just in Time (JIT), Lean Manufacturing, and Kaizan etc. A new and Improved Quality Improvement Approach called Six Sigma is also becoming Popular in Controlling the Defect rate and managing the Quality as overall Process Function.

The roots of Six Sigma as a measurement standard can be traced back to Carl Frederick Gauss (1777-1855) who introduced the concept of the normal curve. Six Sigma as a measurement standard in product variation can be traced back to the 1920′s when Walter Shewhart showed that three standard deviations from the process mean is the point where a process requires correction. Many measurement standards (Zero defects etc.) Later came on the scene but credit for coining the term "Six Sigma" goes to a Motorola engineer named Bill Smith. (Incidentally, "Six Sigma" is a federally registered trademark of Motorola).

In the early and mid-1980s with Chairman Bob Galvin, Motorola engineers decided that the traditional quality levels; measuring defects in thousands of opportunities didn't provide enough granularity. Instead, they wanted to measure the defects per million opportunities. Motorola developed this new standard and created the methodology and needed cultural change associated with it. Since then, hundreds of companies around the world have adopted Six Sigma as a way of doing business.

II. Overview of Statistical Quality Control (SQC)

Quality may be defined as that characteristic which Renders a product or service as having "fitness for Purpose or use". There are different reasons why a Product may have poor quality. Statistical Methods play a central role in Quality improvement Efforts and recognized as an efficient and powerful tool in dealing with the process control aspects (Montgomery 2003).

Statistical Quality Control (SQC) is the term used to describe the set of statistical tools used by quality professionals. SQC is used to analyze the quality problems and solve them. Statistical quality control refers to the use of statistical methods in monitoring and maintaining of the quality of products and services. All the tools of SQC are helpful in evaluating the quality of services. SQC uses different tools to analyze quality problems. Descriptive Statistics, Statistical Process Control (SPC) and Acceptance Sampling are the major SQC Techniques used in Improving Quality of Processes.

2.1. Concept of Variation

Variation is part and parcel of life. The concept of Variation states that no two products will be perfectly identical even if extreme care is taken to make them Identical in some aspect. The variation in the quality of Product in any manufacturing process results because of two reasons namely, Chance cause and

Assignable Cause. A process that is operating with only chance causes of variation is said to be in a state of control with minor variations in the process. The major objective of SPC is to quickly detect the occurrence of assignable causes so that investigation of process and corrective action may be taken before many non-conforming units are manufactured. Finally the eventual goal of SPC is the elimination of variability in the processes.

2.2. Process Capability

The Process Capability studies are helpful in analyzing the quality and efficiency of the process. The Process Capability analysis has been widely adopted as the ultimate measure of Performance to evaluate the ability of a process to satisfy the customers in the form of specifications (English et al 1993).

The Process Capability study helps in designing the product, deciding the acceptance limits of the process and operators in the operations management (Feigenbaum 1994). The evaluation of process capability is an important step in process quality improvement (Juran 1991). It is customary to take the Six Sigma Prime spread in the distribution of the product Quality Characteristic as a measure of process capability. In Process Capability study of particular process, Six Sigma Prime spread is compared with the difference of Upper Specification Limit (USL) and the Lower Specification Limit (LSL). The following are the three possible cases.

1. 6s ` > (USL – LSL): In this case, the process spread is greater than the tolerance. So the process is incapable of meeting the Specification.

2. 6s `= (USL – LSL): In this case, the process spread is exactly equal to the tolerance. So the process is exactly capable of meeting the specifications.

3. 6s ` < (USL – LSL): In this case, the process spread is less than the tolerance. So the process is capable of meeting the specifications.

2.3. Process Capability Indices

It is frequently convenient for Engineers to have a simple and quantitative way to express process capability. One way to do so is through process capability indices. Process capability indices (PCI) are powerful means of studying the process ability for manufacturing a product that meets specifications (Chen et al 2001). PCI is defined as the ratio of tolerances to the process spread. Equation (1) describes the way to calculate PCI.

Process Capability Index (PCI) = (USL – LSL)/6s   (1)

Where PCI is process Capability indices, USL is upper specification limit, LSL is lower specification limit and 6s is the six sigma abbreviation.

2.4. Six Sigma

It is the set of practices originally developed by Motorola to systematically improve process by eliminating defects. Defect is defined as non-conformity of a product or service to its specification. Like its previous quality improving methodologies six sigma focuses on the following points.

- A continuous effort to reduce variation in process outputs is essential to business success.
- Manufacturing and business processes can be Measured, Analyzed, Improved and Controlled.
- In order to achieve best Quality Improvement results, role of upper management is very critical.

The term Six Sigma refers to a highly capable process that can produce products within specifications. Process that achieves Six Sigma levels produces only 3.4 defective Products per million opportunities. Main focus of Six Sigma is to improve all key processes of manufacturing setup and takes quality as a function of Processes Capability to produce items with in specification.

Six Sigma mainly uses two main methodologies one is called Define, Measure, Analyze, Improve and Control, usually known as DMAIC and other is Define, Measure, Analyze, Design and Verify, known as DMADV. Both the methodologies are based on Edwards Deming's, Plan-   Do-Check-Act cycle. DMADV is used for creating new processes to produce products with minimum defect rate.

Other methodologies that are being used during six sigma implementation are given as.

- DCCDI (Define, Customer, Concept, Design And Implement)
- CDOC (Conceptualize, Design, Optimize and Control)
- DCDOV (Define, Concept, Design, Optimize and Verify)
- DMADOV (Define, Measure, Analyze, Design, Optimize and Verify)
- DMEDI (Define, Measure, Explore, Develop and Implement)
- IDOV (Identify, Design, Optimize and validate)
- IIDOV (Invent, Innovate, Develop, Optimize and validate)

DMAIC methodology has been used as effective methodology in before mentioned organization; details of this methodology are given as.

2.5. Define, Measure, Analyze, Improve and Control (DMAIC)
Basically this methodology comprises of following five key points.
- Define the process improvement goals that are aligned with the customer demands and company's strategy.
- Measure the current process and make a strategy for making further improvement.
- Analyze to verify the relationship and causality of factors. Determine what the relationship is and attempts to ensure that all the factors have been considered.
- Improve and optimize process based on findings of analysis phase using different techniques.
- Control to ensure that any variances are corrected before they result in defects.

2.6. DMAIC Implementation at Pump Casing manufacturing company
DMAIC is chosen as potential methodology for implementation at pump casings manufacturing company. At this company quality management systems like ISO 9000 are already implemented that's why quality improvement focus is to only reduce nonconformities. Figure 1 describes the five phases of DMIAC that are implemented at manufacturing facility with different statistical techniques.
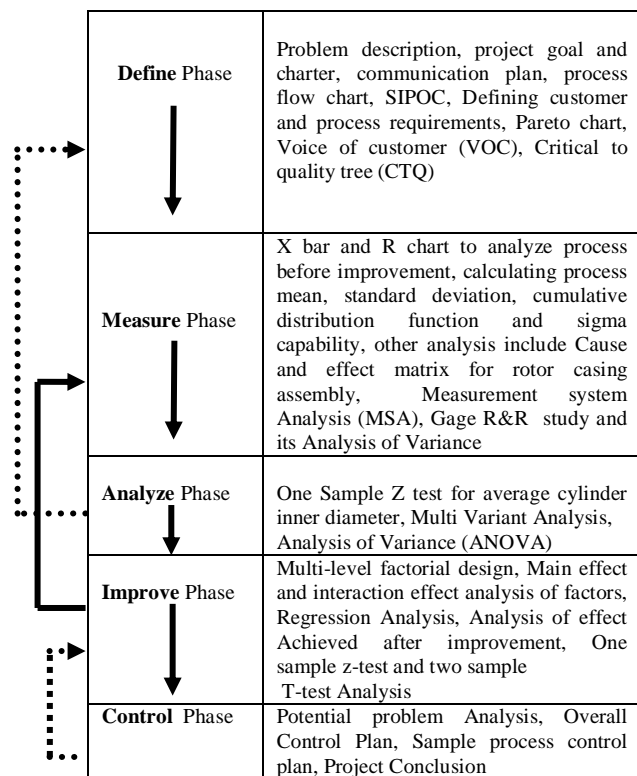
Define Phase	Problem description, project goal and charter, communication plan, process flow chart, SIPOC, Defining customer and process requirements, Pareto chart, Voice of customer (VOC), Critical to quality tree (CTQ)
Measure Phase	X bar and R chart to analyze process before improvement, calculating process mean, standard deviation, cumulative distribution function and sigma capability, other analysis include Cause and effect matrix for rotor casing assembly, Measurement system Analysis (MSA), Gage R&R study and its Analysis of Variance
Analyze Phase	One Sample Z test for average cylinder inner diameter, Multi Variant Analysis, Analysis of Variance (ANOVA)
Improve Phase	Multi-level factorial design, Main effect and interaction effect analysis of factors, Regression Analysis, Analysis of effect Achieved after improvement, One sample z-test and two sample T-test Analysis
Control Phase	Potential problem Analysis, Overall Control Plan, Sample process control plan, Project Conclusion

Figure 1. DMAIC Flow Chart

III.   Define Phase
It is the first stage of Six Sigma DMAIC project, the phase determines the objectives and scope of the project and it defines the problem & communicates the problem to others.

3.1. Problem Description
Company ABC is a manufacturing organization that produces pump casings and different sub-assemblies related to Pump. For the few weeks company is receiving high rejection rate in pump casings, this results in high rework rate and due to which higher production time is spent and also credibility of the company and profits are being affected.

Approximately 25% pump casings produced by manufacturing facility are either required to be reworked or rejected at final inspection (Rework and rejection are both considered as defects), this was found when the last two lots were sampled for inspection.

3.2. Project Goal and Charter

Management of the company wanted a detail process study of different sections of manufacturing Facility. For this purpose a project team was made whose primary responsibility was to identify the key factors playing role in rejection and rework and then to take certain improvement measures to reduce the rejection rate. Table 1 clearly defines the Project Team Charter. Clearly the project goal is to reduce Current rejection rate from 25% to 1% (acceptance limit).

Table 1. Project Team Description

Project Team Charter	
Team Members Status	**Involvement in Project**
Sponsor and Champion	Define, Project Charter, Project Closure
Black Belt	Project Implementation
Production Department	Improve and Control
Quality control Head	Data collection and Analysis
Project Title: Implementation of Six Sigma to reduce rejection rate of Pump Casings. **Subject Matter Experts**: Black Belt, Champion Six Sigma. **Stake Holders**: Employees of Company, Production Department, and quality control Department.	
Project Milestones	
S.NO.	**PHASE**
1	Define
2	Measure
3	Analyze
4	Improve
5	Control

3.3. Communication Plan for DMAIC Project

Table 2 shows the complete communication plan for Project.

Table 2. Communication Plan for Six Sigma Project

What	To whom	When	Who	How	Where
Project meetings	Project team invitees	Every Thursday	Black belt	Via mail	Conference room
Minutes of meetings	Distribution list	Next day of meeting	Black belt	Via mail	Office of black belt
Team work	Project team	As per requirement	Black Belt	Via mail	Office of black belt
Status reports	Customer	Every Friday	Black Belt	Via mail	Office of black belt

3.4. SIPOC for Pump Casings

Supplier, Inputs, Processes, Outputs, Customers i.e. SIPOC is a process improvement and analysis tool that summarizes the input and output of one or more processes. This tool helps to sum up the inputs and outputs of a certain process according to the customer point of view that helps to analyze the requirements of each process in one table format.

For the current facility the SIPOC is shown in Table 3. From the current system study it was revealed that Pump casings key supplier is material store accompanied with manufacturing shops. Inputs to the process are manufacturing process parameters and piece of bars in rectangular and cylindrical form. Complete process details and outputs along with customers are shown in Table 3.

Table 3. SIPOC for Pump Casing

Suppliers	Inputs	Processes	Outputs	Customers
Material store Welding section, Milling section, Turning section, Drilling section	Piece of round/ rectangular bar, Tool angle, Tool, Feed, Depth of cut, Coolant flow	Facing, Turning, Taper turning, Boring, Threading, Milling, Drilling, Welding, Assembly.	Rotor cylinder, Pads with holes, Padded Rotor cylinder, Nozzle end, Front Stopper, Chuck Ring, Hexagonal section of nozzle end, Assembled rotor casings	Inspection and quality department, Assembly section, Manufacturing shops, End users

3.5. Process flow chart for Pump casings

Complete flow chart of the manufacturing process at manufacturing facility of pump casings was developed and shown in Figure 2. This chart provides good understanding of process and material flow.
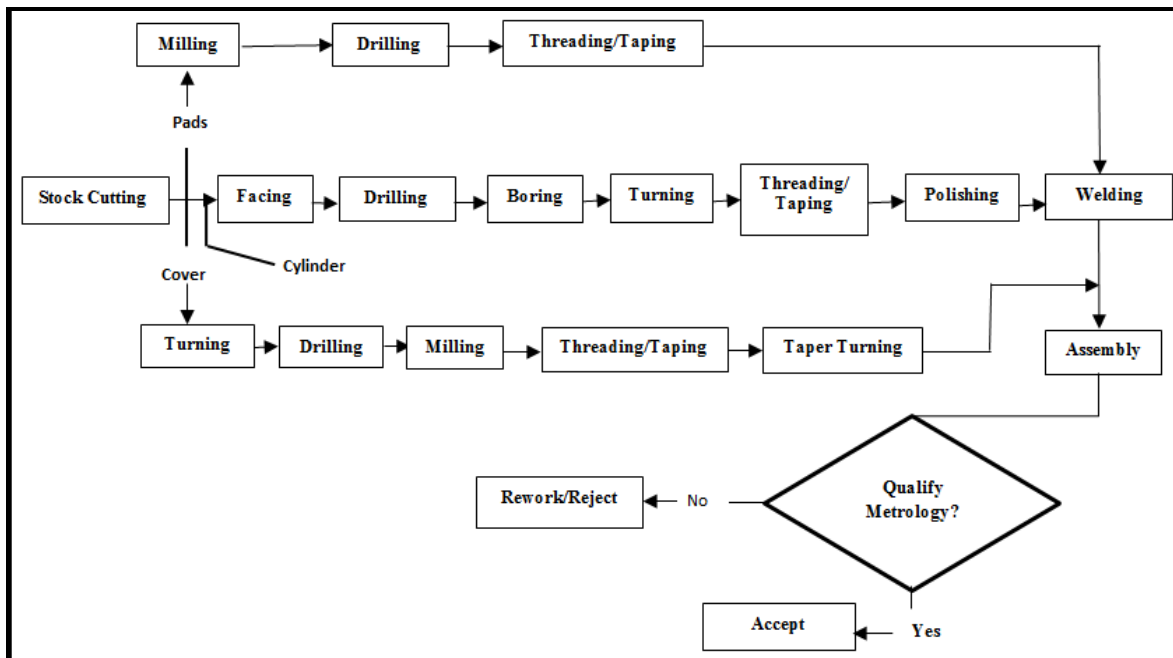

Figure 2. Pump Casing's Process Flow Chart

3.6. Defining Process boundaries and customer Rrequirements

Main manufacturing processes are setup to process three items named as cover, cylinder and pads. Complete flow diagram is illustrated in Figure 3. According to detailed study of the processes it was revealed that chamber inner diameter, nozzle throat diameter and some other defects were contributing to high nonconformance rate . Figure 3 shows a Pareto chart which summarizes the key defects in process outputs, this show that chamber Inner Diameter accounts for 71.4% of total defects and comes to be potential Key Process Input Variables (KPIV) to be addressed.
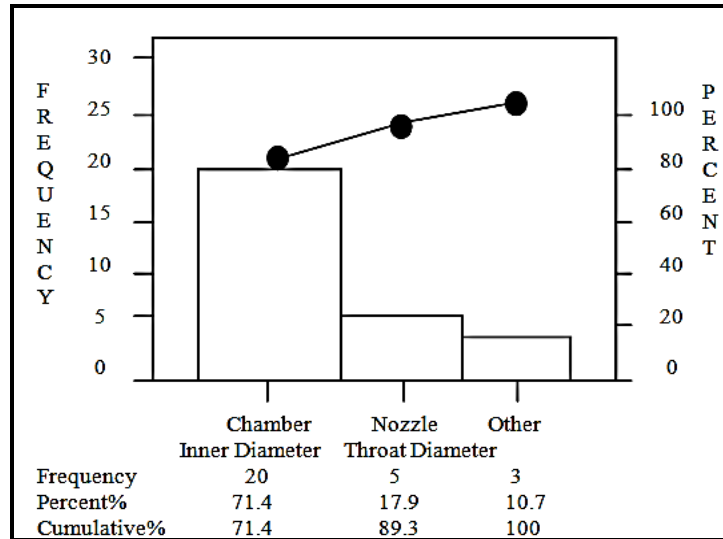
Figure 3. Pareto chart for defects monitoring

Customer data i.e. Voice of Customer (VOC) revealed that internal customers are being affected by the defects rate of Chamber inner diameter that accounts for major portion of defects as explained in Figure 3. Thus Critical To Quality (CTQ) tree can be established based on voice of customer and project objectives. Figure 4 shows the CTQ tree based on the voice of customer
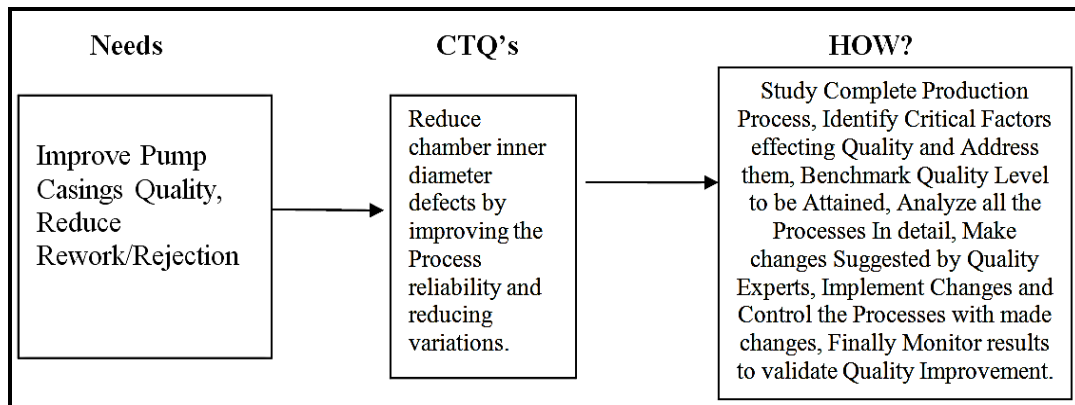

Figure 4. Critical To Quality (CTQ) Tree

IV.   Measure Phase

The primary requirement of this phase is the complete process map of manufacturing process that is given in Figure 2 of define phase. Measure Phase focuses on the following points about Six Sigma Project.

4.1. Determines What to Measure

The Six Sigma project team needs to come out with an explicit list of vital inputs, desired outputs and process metrics that they are planning to track. This decision has large scale implications on the performance of the project and is usually taken by the Project Leader on the basis of data provided by the Six Sigma team and the Process Owner.

4.1.1. Determine How to Measure

There have been many cases of measurement bias in Six Sigma history. The bias may have its roots in the complexity of the calculation, the wrong method of data collection or the bias of the person performing the exercise.

4.1.2. Manage the Measurement Process

One of the biggest challenges of this phase is to validate the fact that the measurement system in place is good for the purpose. This challenge has been discussed in detail in the section titled Measurement Systems Analysis.

4.1.3. Calculating the Current Sigma Levels
A common practice in the measure phase is to put a figure in front of the losses that the organization is currently facing due to inefficient processes. This helps the management to evaluate the process and the Six Sigma team can bargain for more resources to successfully implement the project.

4.2. Current Base line for the Process
Mean of cylinder inner diameter = 50.4512mm
Standard deviation = 0.0708445mm
Upper specification limit = 50.6 mm
 lower specification limit = 50.4 mm

4.2.1 Cumulative Ddistribution Function of sample taken
Normal with mean =50.4512mm and standard deviation = 0.0708445mm.
Cumulative Distribution Function

x	$P(X<=x)$
50.4	0.234929
50.6	0.982152

4.2.2. Defective parts per million opportunities (DPPMO)
Equation 2 gives us the formula to calculate defective parts per million opportunities.

DPPMO = (% of parts less than 50.4) + (%of parts greater than 50.6)/1, 000000   (2)

Using Equation 2 the defect percentage is calculated as.

= (0.234929) + (1-0.982152)/1000000
= 252,777
= 25.27%

4.2.3. Inverse Cumulative Distribution function
Normal with mean = 0 and standard deviation = 1

Inverse Cumulative Distribution Function

$P(X<=x)$	x
0.252777	-0.665776

Measure of distance from the mean of sample (Z-score) is calculated to be = 0.665776
Process Capability index (Cpk) is calculated to be
= 0.665776/3
= 0.2219
Sigma capability = Z-score + 1.5   (3)
Using equation 3 sigma capability for current process before improvement is calculated to be = 2.16

4.3. Cause and Effect matrix for Pump casing Assembly
Cause and effect matrix for pump casings was made in detail and relationship between process inputs and outputs is described. From Table 4 it is clear that depth of cut, feed rate and tool angle are the important factors affecting the quality of pump casings.

Table 4. Cause and Effect Matrix (C&E)

Rating of Iimportance to Customers	7	8	8	7	7	9	9	9	
S/N	1	2	3	4	5	6	7	8	
Process output / Process input	A	B	C	D	E	F	G	H	Total
Depth of cut	9	9	9	9	9	9	9	9	576
Feed	0	0	3	3	3	3	3	3	147
Tool Angle	1	3	1	3	3	3	1	3	144
Tool	1	3	1	1	1	3	1	1	98
Speed	1	1	1	3	3	1	1	1	92
Coolant Flow	0	1	1	1	1	3	1	1	75
Material Type	1	1	1	1	1	1	1	1	64

Where A= cylinder length, B= cylinder inner diameter, C = cylinder wall thickness, D = cylinder front prepped, E = cylinder rear prepped, F = Nozzle throat Diameter, G = D-Nozzle Outer diameter, H = D-Nozzle angle.

4.4. Measurement System Analysis [MSA]

The next step in measurement phase is measurement system analysis. Basic measurement tool is Venire caliper. Two measurement analysis techniques named Gage Linearity and bias Study and Gage R and r study were used and details are given.

4.4.1. Control Charts

In statistical process control XBar and R charts are type of control charts that are used to monitor samples data when data is collected at different intervals. Usually standard Deviations are monitored by Range chart commonly known as R chart and sample mean is monitored by X-bar chart.

In Figure 5 the XBar-R chart shows that process is out of control with maximum observations out of limits. Also a certain pattern is followed by the data points which may be due to machine error or operators shift change. Reasons of out of Control manufacturing process are given in Analyze Phase of the Project.
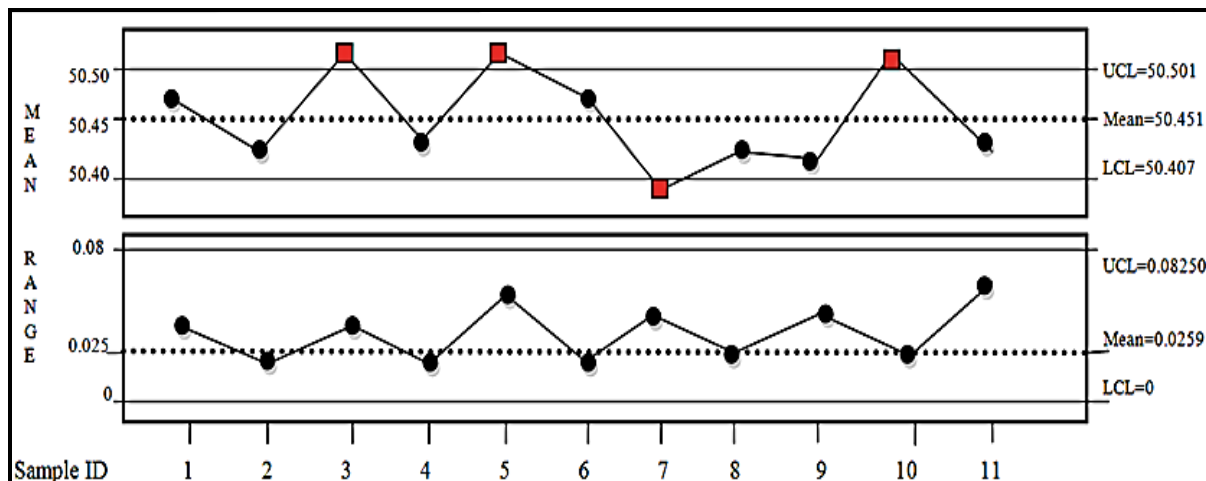

Figure 5. Xbar-R chart of cylinder inner Diameter before improvement

Table 5. Gage Linearity Analysis

Predictor	Coefficient	SE Coefficient	P
Constant	0.01434	0.01442	0.324
Slope	0.0000145	0.0001223	0.906
S	0.070711	R-sq	0.0%
Linearity	0.0000051	%Linearity	0.0

Table 6. Gage Biasness Analysis

Reference	Bias	%Bias	P
Average	0.0156667	4.4	0.017
1.5	-0.031666	8.9	0.445
25	0.0675000	19.1	0.004
80	0.0125000	3.5	0.006
150	0.0216667	6.1	0.012
200	0.0083333	2.4	0.001

Results shown in Table 5 and 6 provides enough evidence that bias of the instrument is constant over its measuring range and the gage measures constantly regardless of the part size.

4.5. Gage Repeatability and Reproduce ability (R&R) Study-ANOVA Method
Another study of the measurement system was made by analysis of variance of gage. Complete data of the analysis is Table 7 and 8.

Table 7. Two-Way ANOVA Table with Interaction

Source	DF	SS	MS	F	P
Part ID	9	1.4244	0.158271	2347.9	0.00
Operator	1	0.00003	0.0000	0.4	0.54
Part ID*Operator	9	0.00061	0.000067	2.25	0.03
Repeatability	40	0.0012	0.000030		
Total	59	1.42627			

Table 8. Gage R&R Analysis

Source	VarComp	%Contribution (Varcomp)
Total Gage R&R	0.0000425	0.16
Repeatability	0.0000300	0.11
Reproducibility	0.0000125	0.05
Operator	0.000000	0.00
Operator*Part ID	0.0000125	0.05
Part-To-Part	0.0263673	99.84
Total Variation	0.0264098	100.0

Source	St Dev	Study Variation	%study Variation	Tolerance
Total Gage R&R	0.006517	0.033562	4.01	6.71
Repeatability S	0.005477	0.028208	3.37	5.64
Reproducibility	0.003531	0.018186	2.17	3.64
Operator	0.00000	0.00000	0.0	0.00
Operator*Part ID	0.003531	0.018186	2.17	3.64
Part-To-Part	0.16238	0.836257	99.92	167.25
Total Variation	0.162511	0.836931	100.0	167.39

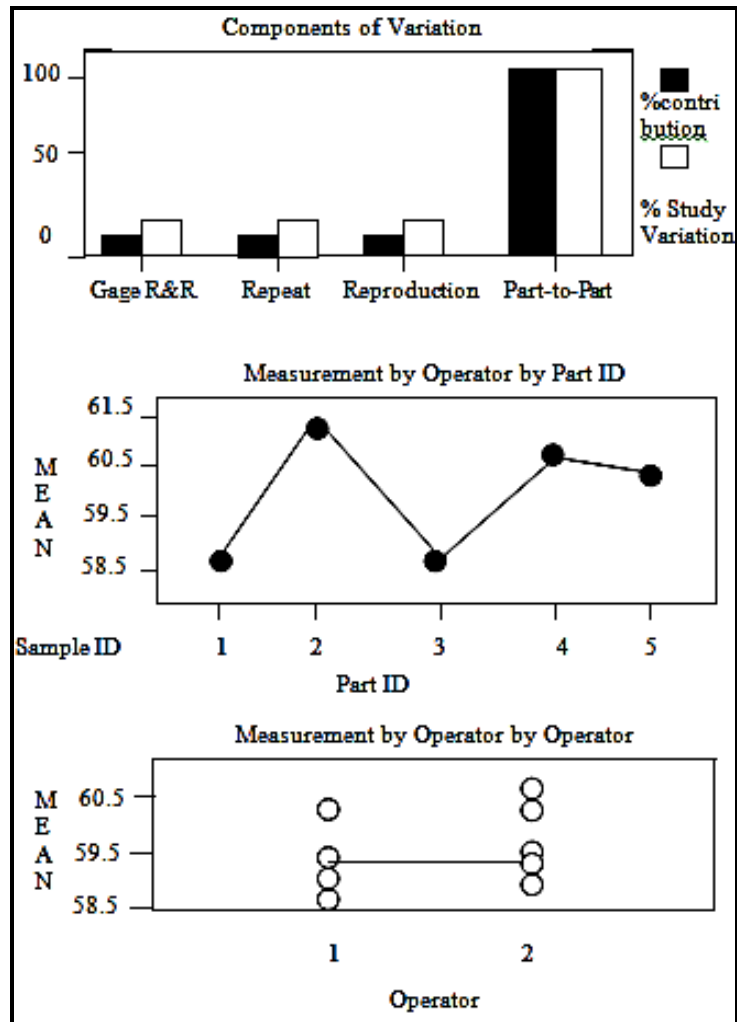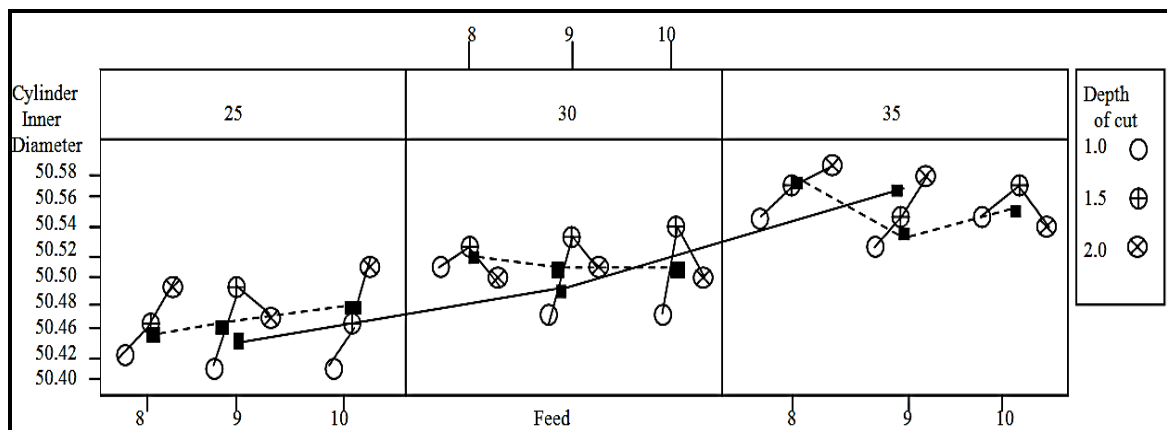**No. of Distinct Categories** = 35

Figure 6. Gage R&R (ANOVA) for Measurement

By the complete ANOVA study and Gages run chart and R&R chart analysis shown in Figure 6 it is clear that percentage contribution of repeatability and reproducibility is very minimum and these are not making significant impact in variation data. Main cause of variation is found to be part to part variation.

Figure 7. Multi-Vari Chart for Cylinder Inner Diameter by Depth of Cut-Tool Angle

By Table 8 it is clear that Measurement Gage
%contribution is 0.16<1,
%study variation = 4.01 < 10%,
%Tolerance = 6.71 < 10%,
%Distinct categories = 35>10
Hence the measurement system is acceptable and reliable for measurement purpose.

V.   Analyze Phase

This phase focuses on analyzing the cause of defects defined in the before mentioned project phases. The first analysis was made on cylinder inner diameter. Table 9 shows One sample z test performed to check whether average inner cylinder diameter was 50.4512 or not.

Table 9. One-sample Z-Test of Cylinder inner diameter.

Factor	Type	Levels	Values
Depth Of cut	random	3	1.0, 1.5, 2.0
Feed	random	3	8,9,10
Tool angle	random	3	25, 30, 35

Source	DF	SS	MS	F	P
Depth of cut	2	0.015528	0.0077	14.23	0.00
Feed	2	0.005140	0.0002	0.470	0.62
Tool angle	2	0.162343	0.08117	148.75	0.00
Error	74	0.040380	0.00054		
Total	80	0.287650			

S = 0.0233598   R-sq. = 81.54 % R-sq. (adj.) = 80.05%

As given in Table 9 the P-Value of 1 is greater than alpha = 0.05, the decision is not to reject null hypothesis. There is strong evidence that the average cylinder inner diameter is 50.4512 mm. Next in the analyze phase is Multi-vari Analysis that was performed with three variables i.e. depth of cut with three settings 1.0,1.5,2.and tool angle with settings 25,30,35 degrees and feed rate with settings 8,9 and 10mm per minute. Figure 7 shows the Analysis. The settings of variable that gave best responses are

- Depth of cut = 1 mm
- Feed = 8 mm/min
- Tool angle = 35 degrees

Next in the analyze phase is ANOVA performed on cylinder inner Diameter versus Depth of cut, Feed, Tool Angle. Exhibit Table 10 shows complete Analysis data.

Table 10. Analysis of Variance of Cylinder Inner Diameter

Factors   2   Replicates: 3
Base runs 9   total runs   27
Base blocks1   Total Blocks   1
Number of levels: 3, 3

Factor	Type	Levels	Values
Depth of Cut	fixed	3	1.0, 1.5, 2.0
Tool angle	fixed	3	25, 30, 35

Source	DF	AdjSS	Adj MS	F	P
Depth of cut	2	0.01111	0.00555	11.2	0.001
Tool angle	2	0.073563	0.036781	74.11	0.626
Tool angle* Depth of cut	4	0.010148	0.000253	5.11	0.006

Error	18	0.008933	0.000496
Total	26	0.103763	

S = 0.0222777   R-sq. = 91.39%   R-sq. (adj) = 87.56%

From data given in Table 10 it is clear that depth of cut and tool angle has significant effect over the response variable whereas feed has no significant effect. Hence these variables were considered in the improve phase for improving the response variables.

VI.   Improve Phase

Key findings from the analyze phase are that depth of cut and tool angle have the significant effect on the cylinder inner diameter. This was further analyzed by Multilevel factorial design in Table 11 in which cylinder inner diameter was tested against different levels of tool angle and depth of cut data obtained is given in Table 11.

Table 11. Analysis of variance of Cylinder Inner Diameter using adjusted SS for tests

Factors   2   Replicates: 3
Base runs 9   total runs   27
Base blocks1   Total Blocks   1
Number of levels: 3, 3

Factor	Type	Levels	Values
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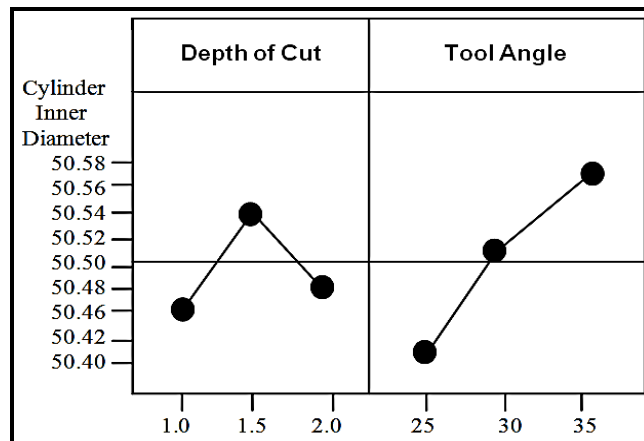S = 0.0222777   R-sq. = 91.39%   R-sq. (adj) = 87.56%

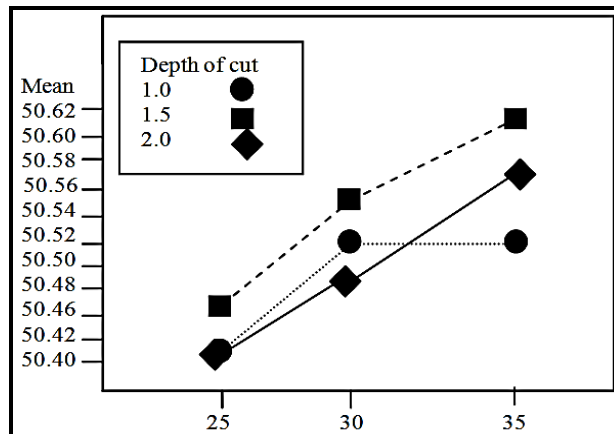**Figure 8.** Main Effect Plots for Cylinder Inner Diameter

Figure 9. Interaction Plot (Data Means) for Cylinder Inner Diameter

Figure 8 and 9 show the main effect and interaction effect of depth of cut and tool angles. Form plots it is clear that depth of cut, and the interaction have significant effect on the response variable best results are obtained for the settings:
- Depth of cut = 1.5 mm
- Tool angle= 30 degrees

Regression analysis was also made to get the correlation between different response variables. The regression equation is given by equation 4.

Cylinder inner diameter = 50.1 + 0.0058* depth of cut + 0.126 *Tool angle   (4)

Table 12. Multiple Regression Analysis

Predictor	Coef	SE Coef	T	P
Constant	50.0974	0.042	1192.23	0.00
Depth of cut	0.00583	0.01244	0.47	0.642
Tool angle	0.01258	0.001244	10.12	0.000

S = 0.0304622   R-sq. = 75.7%   R-sq. (adj) = 74.2%

Table 13. Analysis of variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	2	0.095528	0.047764	51.3	0.000
Residual Error	33	0.030622	0.000957		
Total	35	0.125831			

Using the multiple regression analysis in Table 12 and 13 it is clear that tool angle has significant effect on response variable whereas depth of cut has also an effect but not to significant. This is further confirmed by the best subset regression considering the maximum r-sq and minimum mallows c-p criteria, tool angle has the most effect and the interaction has the significant effect on the second number. The settings obtained from the analyze phase were implemented and data was monitored for some time.

6.1. Analysis of the effect achieved after improvement
Mean of cylinder inner diameter = 50.4972mm
Standard deviation of cylinder inner diameter= 0.032479mm

6.1.1. Cumulative distribution function of sample taken
Normal with mean =50.4972mm
Sstandard deviation = 0.0324795mm
Cumulative distribution function

x	P(X<=x)
50.4	0.001383
50.6	0.999225

6.1.2. Defective parts per million opportunities (DPPMO)
Using formula given in equation 2, DPPMO is given as
= (0.001383) + (1-0.999225)/1000000
= 2,158
= 2.158%

6.1.3. Inverse Cumulative Distribution function
Normal with mean = 0mm and standard deviation = 1mm

P(X<=x)	x
0.002158	-2.85409

Measure of distance from the mean of sample (Z-score) is calculated to be Z-score = 2.85409
Process Capability index (Cpk) is calculated to be
Cpk = 2.85409/3 = 0.951363
Using equation 3, Sigma capability for current process before improvement is calculated to be

Sigma capability = Z-score + 1.5
= 2.85409 +1.5
= 4.354

6.2. Ensuring the sampling errors with test of Hypothesis
To ensure that average cylinder inner diameter is 50.4972 or not a one sample Z test was performed. Exhibit 23 shows findings as follows:
- Ho: μ=50.4972 (claim) and
- H1: $\mu \neq$50.4972

Table 14. One-sample Z: Cylinder Iinner diameter

Test of mu = 50.4972 vs. not = 50.4972
The assumed standard deviation = 0.0324795

Variable	N	mean	stdev	SE Mean	95%CI	Z	P
Cylinder inner D	36	50.49	0.03	0.0054	(50.48, 50.50)	0.0	0.9

As given in Table 14 the P-value of 0.997 is greater than α = 0.05 the decision here is not to reject the null hypothesis. there is enough evidence to support the claim that the average cylinder inner diameter is 50.4972.

6.3. Testing difference between two Means (Large independent systems)
- Ho: μ1 = μ2 and
- H1: μ1 ≠ μ2 (claim)

6.3.1. Two sample T-Test and CI: Cylinder inner diameter
Table 15 shows test results.

Table 15. Two sample T-Test

	N	Mean	StDev	SEMean
Cylinder Inner D	50	50.4512	0.0708	0.010
Cylinder Inner D	36	50.4972	0.0325	0.0054

Difference =
 mu (cylinder inner Dia. Before Imp) –   (Cylinder Inner Dia. After Imp)
Estimate of difference : -0.046022
95% CI for difference : (-0.068718, -0.023326)
T-Test of difference = 0 (vs. not =): T-Value = -4.04
P-Value = 0.000, DF=73.

In Table 15 the P value of 0.00 is less than alpha=0.05 so the decision is to reject the null hypothesis. There is enough evidence to support the claim that the two means are not equal. There is significant difference in cylinder inner diameter before and after process improvement.

VII.   Control Phase

Tables 16 and 17 show the overall control plan for the Project. Overall control plan includes three phases. First one is solution implementation Phase, in this phase settings of DMAIC Implementation phase were carried and observed for 2 months and were communicated to Project sponsor, process owner and Quality control head. Main objective of this phase is to monitor the process and decide whether the process is settled down and has absorbed the changes by giving the required results or it does not continue to give the improved results because of some other factors setting's that might be overlooked in the Improve Phase.
 Next is training Phase which includes training of working staff as well as process owners and Quality Head to make them able to provide improved results if working conditions are slightly changed e.g. induction of new Machine in Assembly line or workers shift changes etc. Cost and benefits analysis is the last and project conclusion Phase, that was done after solution was Implemented and observed for 2 months.
Process Control plan is given in Table 17. It includes control of Pump Casings Inner diameter boring Control.
Machine used is turning and 100% inspection was carried on to observe this Process In detail. XBar and R charts were used to observe processes deviation and Mean shifts.
By observing XBar-R chart in Figure 10 it is clear that the process is well in control i.e. the variation with in groups is controlled. There are no points in X-bar chart that are more than 3 standard deviation away from Process Mean, also R chart shows that variation of process is well under control.

Table 16. Overall control plan

S/No.	Description	Communicated to	Approximate duration
1.	Solution implementation schedule	Sponsor, process owner, Qc head	02 months
2.	Training	Process owner, Qc head	02 weeks
3.	Cost and Benefits Analysis	Sponsor	Was carried Out after Implementing the solution and running the process for 2 months

Table 17. Sample process control plan

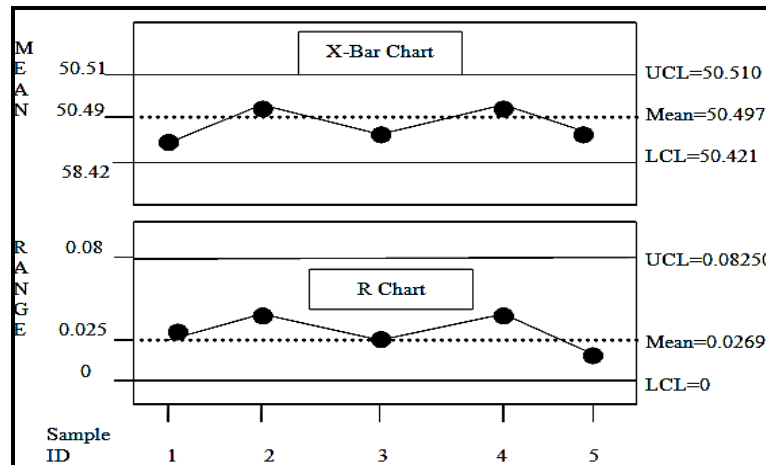| Process/ operation description	Machine	Jigs, tools, Fixtures for manufacturing		Methods		
		Category	Number	Spec. limit	Sample size	Control method
Inner Dia. Boring	Turning	Jig	T/jig/ 002	100% inspection	5	X-bar, R-charts

Fig.10. XBar-R chart of cylinder inner Diameter after improvement

VIII.   Conclusion

Local pump casing manufacturing facility was receiving high defect rate due to which quality of the production lots was being effected and customer complaints had to be addressed. This was turning in to high financial loses to the company. An effective quality improvement technique called Six Sigma was decided to be implemented in the facility.

At this stage the defect rate was 25.27% with sigma capability of 2.16. Pareto charts defined that chamber inner diameter defects were more than 71.4% of the total defects and was potential KPIV to be addressed. Further analyses cleared that depth of cut; feed rate and tool angle were contributing in defect rate. After carrying out detailed analysis of the process ,tool settings came out as main reason for this defect rate. feed rate had not significant effect as compared to depth of cut and tool angle. Best results were achieved at:

- Feed rate = 8mm/min
- Depth of cut = 1.5 mm
- Tool angle = 30 degrees

Some jigs and fixture were required to achieve the above settings during production of rotor casings. These were designed and manufactured and then were Incorporated to reduce setups times and eliminate adjustments.

After getting the right settings from the analyze phase these settings were implemented and results achieved were in favor of good quality of products. Further results were monitored and controlled and finally defect rate observed is 2.158% with sigma capability of 4.354.

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