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IMPROVE MACHINING PROCESS CAPABILITY BY USING SIX-SIGMA

Abstract: Six-Sigma is an improvement strategy for achieving customer satisfaction by reducing variation and thus producing products and services better, faster and cheaper. This study presents a Six-Sigma project of an automotive plant illustrating how the DMAIC methodology and statistical techniques were applied to resolve the issue of manufacturing process capability. This project has substantially benefitted the organization by reducing the variation of bore size of crank case, achieving zero rejection and improving the on time delivery. By using appropriate qualitative and quantitative tools in different phases of the DMAIC methodology, the critical output, key process inputs and root causes were identified, analyzed and validated. This project methodology can be used in general to reduce process variation for any other manufacturing processes as well, which will help in improving customer satisfaction.

Keywords: Six Sigma; DMAIC (Define – Measure – Analyze – Improve – Control), SIPOC; Critical to Quality (CTQ); Key Process Input Variable (KPIV); Repeatability, Reproducibility; Sigma Rating; Analysis of Variance (ANOVA).

1. INTRODUCTION

As customer expectation and competition continues to become more intense, organizations worldwide are under pressure to improve their operational performance to meet the customer and market expectations (Hammer, 2002). In the pursuit of improving operational performance leading to higher customer satisfaction, Six-Sigma has been recognized as a unified approach. The roots of Six-Sigma as a measuring standard of process variation can be traced back to Walter Shewart, who showed that three sigma from the mean is the point where a process require attention (Pande et al., 2000). Six-Sigma has been recognized as a systematic and structured

methodology for reducing defect rate by improving process capability (Harry, 1998). Motorola originally developed Six-Sigma in the 1980s and helped the company to win the Malcolm Baldrige Quality Award in 1988 (Coronado and Antony, 2002). There has been a significant increase in the application of Six-Sigma in industry over last 15 years because they have proven to be successful not only at improving quality but also at producing large cost benefits. Several companies, including Motorola, General Electric, Honeywell, Bombardier and Sony have reported significant benefits from Six-Sigma initiatives (Antony and Banuelas, 2001).

This paper details a Six-Sigma project which was implemented by using the

DMAIC roadmap in an automotive manufacturing plant in India. This particular project was undertaken in the machining

shop for the part crank case. The company was facing higher rejection at the honing operation of crankcase machining, seriously affecting the process yield. As a result the company was incurring loss at the current production rate apart from resulting customer dissatisfaction due to delay in on-time delivery of machined crank cases for further operation. A Six-Sigma project was, therefore, created that specifically focused on resolving the rejection of crankcase at honing operation.

1.1. QUALITY IMPROVEMENT METHODS AND SIX-SIGMA

Due to rapidly changing technology and business environments, the definition of quality improvement can include reducing process variability, improving product and service quality, decreasing cost, eliminating process waste and thus enhancing profitability and customer satisfaction. The quality improvement should be linked to a process, whether manufacturing or non-manufacturing, and capability of these processes markedly influences an organization's achievements. Consequently, controlling and improving processes continuously is a critical issue to enhancing organizations capability (Stewart and Spancer, 2006). Numerous process improvement methodologies have been widely adopted by various industries, such as, 5S, ISO 9000, total quality management (TQM) and lean (Stewart and Spancer, 2006). Numerous process improvement methodologies have been widely adopted by various industries, such as, 5S, ISO 9000, total quality management (TQM) and lean manufacturing. The 5S principles provide simple and systematic techniques for improving work and process environments, and then further influences

employee attitude towards work environment. The international quality management standard ISO 9000 is a widely accepted and implemented basic quality management system standard of an organization (Lin and Wu, 2005) which helped companies to effectively document the relevant system standards and implement it to maintain the processes effectively and efficiently. TQM is a customer oriented approach that uses statistical techniques, follows the plan-do-check-act (PDCA) cycle, implements measures and continuously improves processes in order to improve the product quality (Rounce, 1998). TQM focuses on satisfying customer needs, identifying problems, building commitment and involves employees for process improvement. Lean concept deals with methodology and tools for transforming processes to deliver customer value faster by improving work flow and eliminating waste (Motwani, 2003). The concept has been borrowed from Toyota Production System (just-in-time movement) and most of the automobile and its part manufacturing units in the World implemented the principle and was rewarded with excellent results. Although these different methodologies apply different tools and techniques, the fundamental principles are very much similar. The ultimate objective of all quality improvement methodologies is to identify customer needs and then satisfy these needs effectively and efficiently. A good quality improvement methodology must be able to promote and accommodate all factors directly or indirectly influencing process performance by using suitable techniques. The improvement methodology should provide a systematic and logical structure that utilizes tangible and intangible information to track root causes, improves or eliminates root causes, and monitors and sustains improvement. Six-Sigma is a highly disciplined and rigorous data analysis based improvement

approach for removing defects from products and redundancies from processes. Six-Sigma methodology demand detailed analysis, fact based decisions and an effective control of the improved process. Six-Sigma methodologies were originated as a set of practices designed to improve manufacturing processes; however, organizations realized the benefits of Six-Sigma, and its use is rapidly expanded to different functional areas such as marketing, engineering, purchasing, servicing, and administrative support (Ray and Das, 2009, 2010).

Six-Sigma was heavily inspired by six preceding decades of quality improvement methodologies such as Quality Control, TQM and Zero Defects based on the work of pioneers such as Shewhart, Deming, Juran, Ishikawa, Taguchi and others (Feigenbaum, 1986; Juran, 1988). Six-Sigma is a scientific and statistical quality assessment for all processes in the organization through measurement of quality level, which provides the opportunity and discipline to eliminate mistakes, improve moral and thus reduce cost (Park, 2002). In Six-Sigma, a defect is defined as any process output that does not meet customer specifications, or that could lead to creating an output that does not meet customer specifications. Six-Sigma seeks to improve the quality of process outputs by identifying and removing the causes of defects (errors) and minimizing variation in manufacturing and business processes (Antony and Banuelas, 2001). It uses a set of quality management methods, including statistical methods, and creates a special infrastructure of people ("Black Belts", "Green Belts", etc.) within the organization. Each Six-Sigma project, carried out within an organization, follows a defined sequence of steps and has quantified targets. These targets can be financial (cost reduction or profit increase) or whatever is critical to the customer of that process (cycle time, safety, delivery, etc.).

In practice, the principal focus of Six-Sigma is to decrease potential variability in processes and products using a continuous improvement methodology, which proceeds through the DMAIC phases (Antony and Banuelas, 2001). Six-Sigma focuses on improving quality by helping an organization to produce products and services better, faster and cheaper (Mahanti and Antony, 2005). Park (2002) has stated that Six-Sigma is a scientific and statistical quality assessment for all processes through measurement of quality level which provide the opportunity and discipline to eliminate mistakes, improve morale and saves money. Doing things right and keeping those consistent are the ideas behind Six-Sigma. Therefore, an organization needs to have linkage of bottom line benefits to the Six-Sigma projects as the Six-Sigma drive for process improvement takes place project-by-project basis (Juran, 1989) by following these principles.

- Identify the process for improvement. Every output is the result of a process. To improve quality of output, improve the process.
- All processes have inherent variability.
- Data is used to understand the variability and the sources thereof, and drive process improvement decisions.

The DMAIC framework of Six-Sigma is a serial analytical and statistical method for eliminating process variations and obtaining breakthrough improvements in products and service quality (Harry, 1998). It is a project-driven scheme that employs a well-structured methodology, called DMAIC, comprising of the five phases: *Define, Measure, Analyze, Improve* and *Control*. The DMAIC project methodology has five phases:

- *Define* the problem, the voice of the customer, and the project goals, specifically.

- *Measure* key aspects of the current process and collect relevant data.
- *Analyze* the data to investigate and verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered. Seek out root cause of the defect under investigation.
- *Improve* or optimize the current process based upon data analysis using techniques such as design of experiments, pokayoke or mistake proofing, and standard work to create a new, future state process. Set up pilot runs to establish process capability.
- *Control* the future state process to ensure that any deviations from target are corrected before they result in

defects. Control systems are implemented such as statistical process control, production boards, and visual workplaces and the process is continuously monitored.

The details of the five phases of the Six-Sigma DMAIC methodology are introduced as follows.

2. DEFINE PHASE

This phase defines the goals and boundaries of an improvement project in terms of customer requirements or business requirements and the process delivering these requirements (Porter, 2001).

SUPPLIER	INPUT	PROCESS	OUTPUT	CUSTOMER
Purchase	Input Crankcase	Tool Setting	Machined Crankcase	Next Operation
Maintenance	Machine	↓ Job Loading		
Self	Honing Head	↓		
Self	Operator	↓ Machine Parameter Setting		
QA	Inspector	↓		
QA	Calibrated Instruments	↓		
Maintenance	Consumables and Air Supply	Manufacturing		
QA	Forms and Tags	↓ Inspection of Parts		

Table 1- Process Mapping of Honing Process

The main activities of define phase are the following:

1. Define the project boundary (process and machine)
2. Identify and define Critical to Quality (CTQ).

One of the major objectives of any Six Sigma project is to improve the selected process performance. At Define phase, the process is identified, which will be improved to reduce the defect rate with appropriate scope and boundaries. The process thus identified is given in Table 1. The high-level process mapping helps to define the project boundary (start and end), can identify where to collect data and clarify the scope. It also identifies the resources required to carry out the project / improvement. Based on the above objective and process definition, the CTQ for the project is selected. By measuring and monitoring the CTQ, the process quality and control can be ensured. In this particular project, the CTQ selected is the bore size with the specification of (111.257 - 111.277 mm).

The objective of this project is to reduce operational scrap of crankcase by improving the process capability of bore size. A project charter was then defined which states the project description, objectives, scope, potential benefits, team members, schedule and support required. With the above analysis and definitions, the project moves to the Measure phase of the DMAIC journey.

3. MEASURE PHASE

The Measure phase of a Six Sigma project deals with the following

- Data collection plan and identification of stratification factors.
- Measurement system analysis to validate the measurement uncertainty (if any) of the current measurement system.

- Collection of existing data on liner bore size (if available) or collection of fresh data.
- Analysis of liner bore size data for Sigma Level calculation.
- Initial Process Analysis based on the Stratification factors.

It is essential for every Six Sigma project to prepare a Data Collection Plan, which will clarify the following:

- Recording what data to be collected reminds what to be accomplished.
- The data type will guide what analysis to be performed.
- An operational definition defines how exactly data to be collected and recorded.
- Ensure consistency of data collected over different time points and by people.

At present the company is using a single spindle honing machines with indexing table, which is equipped with the following features to achieve the required surface finish and bore size after the operation.

- Double expansion honing head is used for rough and finish honing.
- Rough honing expansion is controlled by stepper motor and finish honing expansion is controlled by hydraulic motor.
- Bore size is controlled with the help of continuous air sizing by a transducer, which receives required air supply through a FRL (Filter Regulator Lubricator). The FRL unit ensures that the transducer receives air which is free from dust particles, moisture, abrasive materials etc. The transducer ensures that the pressure with which working parts of the honing tool are pressed against the bore wall is controlled during machining. The pressure per unit area of the working parts can thereby be kept constant or specifically varied, irrespective of the surface configuration of the bore wall. For this purpose, the honing machine

includes a feed mechanism and electronic control device for predetermining the pressure of the working parts against the bore.

- Temperature controllers are used for controlling temperature of cutting oil and hydraulic oil.
- Each crankcase is having six bores, which are machined in single setting by each machine.

To formulate a data collection plan for the above process, a brain storming session was conducted by involving personnel from QA, Production, Maintenance, Safety and Design. The following data collection plan, as given in Table 2, was evolved for the project.

Before collecting data on bore size, it was decided to validate the measurement system. At present 2 inspectors are measuring the bore size by using a bore dial. It was decided to study the contribution of measurement system variation in the form of repeatability and reproducibility present in the process. Repeatability of a measurement system is the variation due to the measuring device observed when the same part is measured repeatedly with the same device, whereas reproducibility is the variability in measurements due to operators and the operator by part interaction. The Gage

Repeatability and Reproducibility (R and R) studies determine how much of the observed process variation is due to measurement system variation and it should be less than 30% of total to be acceptable (MSA Reference Manual, AIAG, 2010). The R and R study was conducted by selecting parts (6 nos.) at random and measured by two inspectors, each twice. The study results were analyzed by the ANOVA method, which breaks down the overall variation into three categories: part-to-part, repeatability and reproducibility; and further breaks down reproducibility into its operator and operator by part components. Apart from calculating R and R%, the value of the Number of Distinct Categories (NDC) was also calculated. The NDC value of a measurement system represents the number of non-overlapping confidence intervals that will span the range of product variation. It can be also thought as the number of groups within the process data that the measurement system can discern. This value of NDC is calculated by the following formula

$$ndc = \frac{(sd)part}{(sd)gage} * 1.41$$

Source	Degrees of Freedom (df)	Sum of Squares	Mean Sum of Squares	F ratio	p value
Part No	5	0.005017	0.0001003	65.08	0
Inspector	1	0.000002	0.000002	1.32	0.302
Part No x Inspector	5	0.000008	0.0000015	1.05	0.43
Repeatability	12	0.0000175	0.0000015		
Total	23	0.000529			

Table 3 - Two-Way Analysis of Variance (ANOVA) Table with Interaction

The data was analyzed by Minitab software and the results of the analysis are furnished next (ref. Figure 1 and 2). The analysis of variance (ANOVA) was carried out to find the difference between inspectors, significance of repeatability error and the interaction between part and inspector.

The ANOVA in Table 3 clearly indicates that there is no significant difference between inspectors; no repeatability error as well as no interaction between part and inspector exists (Montgomery, 1991). The *p* value is associated with the *F* statistic value. The *p* value will indicate the probability of observing an *F* statistic as large as or larger than the calculated one, assuming

that all groups under that source of variation share the same mean.

Source of Variation	Standard Deviation (sd)	Study Variation (6*sd)	% Study Variation
Repeatability	0.0012177	0.0073	23.77
Reproducibility	0.0002158	0.0013	4.21
RandR	0.0012367	0.0074	24.14
Inspector	0.0002158	0.0013	4.21
Part-to-Part	0.0049714	0.0298	97.04
Total Variation	0.0051229	0.0307	100

Table 4 - Summary of Gage R and R Study.

DATA		OPERATIONAL DEFINITION OF MEASURE			
What Data	Data Type	How Measured	Related Conditions to Record	Sampling Notes	How / Where Recorded (Check Sheet)
Liner Bore Size	Continuous	Bore Dial	Bore Name (6 nos. – 1,2,3,4,5,6)	30 components produced and measured at all 6 Bore Positions for the finished bore size.	Check Sheet

Table 2 - Data Collection Plan

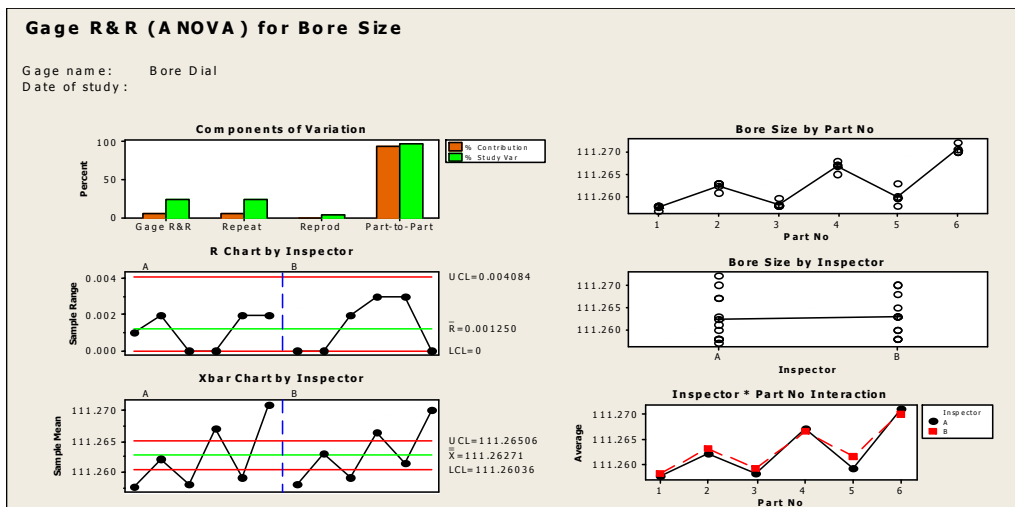


Figure 1 - Gage R and R Study Results for Bore Dial

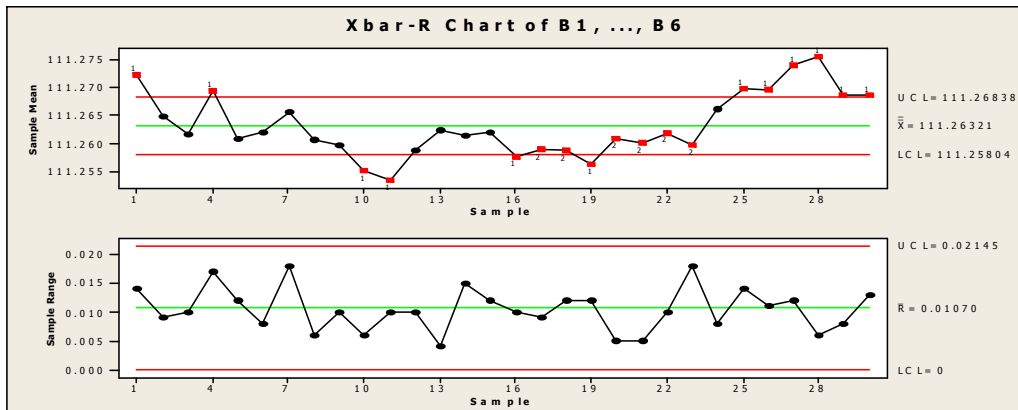


Figure 2 - \bar{x} and R Chart for Crank Case Bore Size produced in Honing Machine

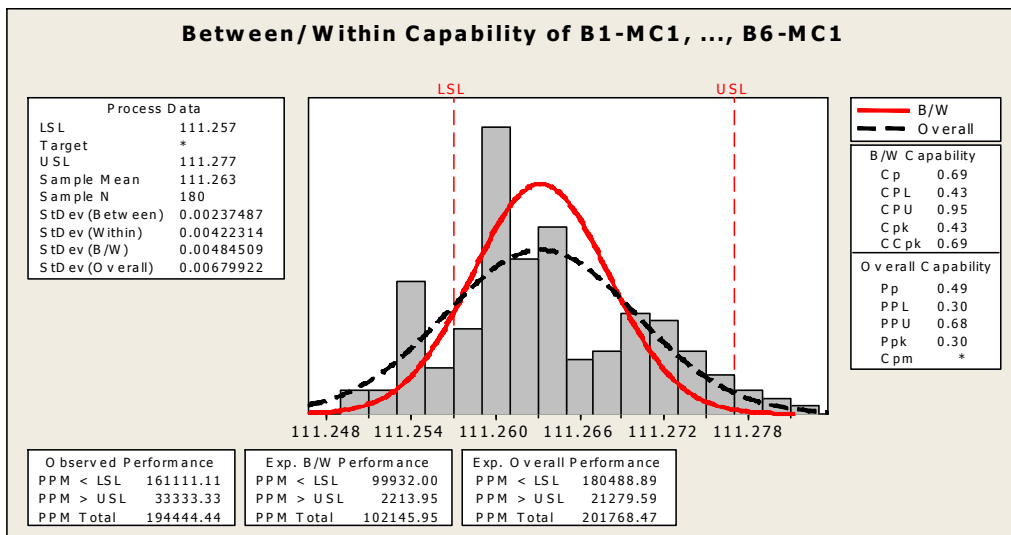


Figure 3 - Process Capability Analysis of Bore Size of Crank Case

A small p ($< \alpha = 0.05$) implies that the assumption of all groups sharing the same mean is probably not true. The summary of the analysis is presented in Table 4.

The percent of the study variation for each component is calculated by dividing the standard deviation for each component by the total standard deviation. The percentages in this column do not add (ref. Table 4) to 100. Also the observed value of NDC was equal to 5, where the acceptable value is 4 or more. From the above table (ref. Table 4) it is clear that most of the study variation is accounted

for distinguishing from part to part, which is the purpose of a measurement system.

After validating the existing measurement system, it was decided to collect data from the current process to estimate sigma level of bore size. Based on the above data collection plan, 30 crankcases were manufactured and measured for bore size. The data thus collected was chronological with a subgroup of size 6, as in each Crankcase, there are 6 bores. The data thus collected were analyzed by using \bar{x} -R chart technique to identify presence of any

assignable causes present in the current process.

The Figure 2 indicates that the crankcases produced in are affected by the presence of assignable causes affecting the process average. This fact was discussed with the engineers in the company to identify the assignable causes. It was observed by the team that while producing 30 crankcases, no special cause(s) were recorded by the process team. In the absence of any identifiable special cause, the above variation of the process is treated as the variation due to chance causes only. It was decided next to estimate the process capability and calculation of initial Sigma-Level of the process, which are presented in Figure 3.

The crankcases produced in the machine depict the process problem for the CTQ bore size, unidentifiable assignable causes affecting process average and with the initial sigma level of 2.32.

4. ANALYSIS PHASE

In the Analysis phase, the following relation is established through data analysis,

$$y = f(x)$$

Where y is the CTQ (bore size) and x 's are the validated root causes from the process. The Analysis phase of a Six-Sigma project deals (Stamatis, 2004) with the following

- Identification of suspected stratification factors and causes, known as x 's.
- Collect data on x 's and y together and establish the relation between them.

At this phase of the project it is essential to find out the main causes responsible for bore size variation. A brainstorming session was conducted to identify the stratification factors and causes which are potential for bore size variation. The causes thus identified are presented in the form of an Analysis Tree

in Figure 4.

The data of bore size collected at the measure phase was analyzed to identify the difference of bore size from bore-to-bore (1 to 6). The data was analyzed by one-way ANOVA and the result of the analysis is given in Table 5.

Source	Degrees of Freedom (df)	Sum of Squares	Mean Sum of Squares	F ratio	p value
Bore No	5	0.0000836	0.0000167	0.36	0.878
Error	174	0.0081864	0.0000469		
Total	179	0.008252			

Table 5 - One-Way Analysis of Variance (ANOVA) for Bore Size

Sl. No.	Cause	Specification	Observation	Remarks
1	Oil Temperature	10° less than ambient temp.	Oil temp observed for 5 shifts and found to be varying	May be a Probable Cause
2	Low Oil Level	3/4 th of oil tank level	Checked for a week and found ok	Not a Root Cause
3	Machining Allowances	50 to 75 Microns.	Checked for 2 days and found to be with in tolerance.	Not a Root Cause
4	Feed Rate	15 to 30 steps / second	By altering the feed rate within specification, variation in bore size observed.	May be a Probable Cause
5	Cutting Speed	170 to 190 rpm	By altering the cutting speed, no variation in bore size observed.	Not a Root Cause
6	Stroke Speed	50 to 60 strokes / min	By altering the stroke speed no variation in bore size observed.	Not a Root Cause
7	Concentration of Diamond Honing Sticks	Min 60%	Diamond stick were checked and found ok	Not a Root Cause
8	Bonding Quality	Metal Bond	Checked and found ok	Not a Root Cause
9	Grit Size	D 213	Checked and found ok	Not a Root Cause
10	Air Nozzle Diameter	1.2 mm	Checked and found ok.	Not a Root Cause
11	Improper Size Setting	As per Standard Operating Procedure.	Being followed correctly	Not a root cause
12	Air Pressure	2 to 3 Bar	By altering the air pressure within specification, variation in Bore size observed.	May be a probable cause
13	Dia over Guide Ledges	111.160mm / 111.180mm.	Checked and found under size	May be a probable cause

Table 6: Results of GEMBA Study

It is clear from the above analysis that there is no significant difference ($p > 0.05$) in bore size from position to position. It was decided by the team to investigate all the suspected causes for their presence in

the process by observing them in the workplace. The results of the investigation

are summarized in Table 6.

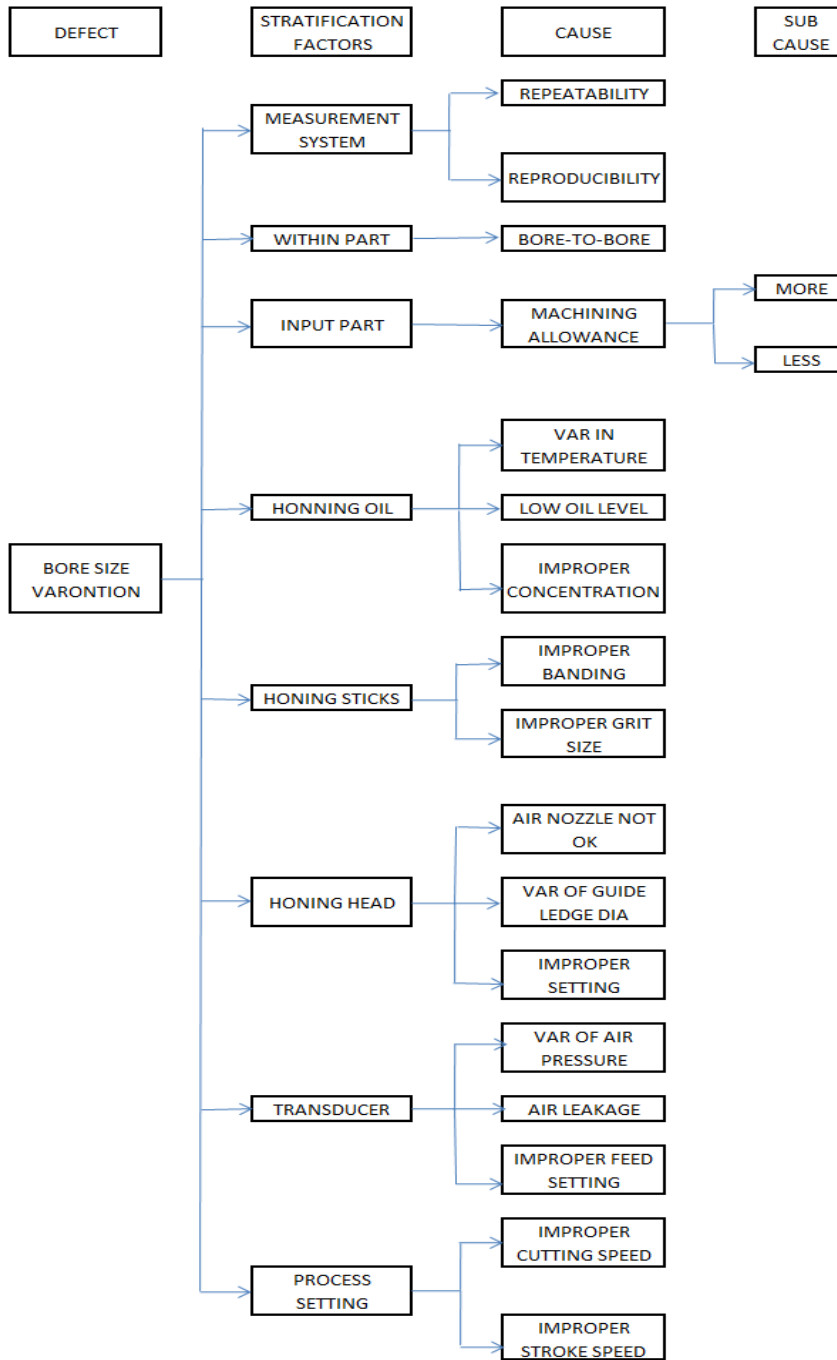


Figure 4 - Tree Diagram of Causes of Bore Size Variation

The root causes for variation in the bore size as identified from the work place variation are following

1. Guide.
2. Ledges.
3. Oil Temperature variation.
4. Feed Rate variation.
5. Air Pressure variation.

In the Measure phase of this project it was observed from the \bar{x} -R chart analysis that though there are out of control situations in the \bar{x} -chart, but no assignable causes could be identified. Probably the assignable causes are variation of the above root causes within their respective specifications.

6. IMPROVE AND CONTROL PHASE

The optimal solutions for improving the mean of the bore size and reducing variation are determined and confirmed in the Improve phase. The Analysis phase could reveal four key process input variables (KPIV) responsible for variation in bore size. The Improve phase considers the KPIVs identified and develops and selects solutions to eliminate the effect of these causes by optimizing them effectively. This stage of the Six-Sigma project involves:

1. Identification of Factor and Levels
2. Planning and Conduct of Experiments
3. Analysis of Results
4. Identification of Optimum Setting.
5. Trial Run and Sigma-Level Calculation.

A design of experiment technique was employed to identify the optimum setting of the KPIVs. The factors and the corresponding levels to be considered in the experiment are given in Table 7.

CODE	FACTOR	LEVEL 1	LEVEL 2
A	Air Pressure	2.25	3
B	Honing Oil Temperature	25	35
C	Feed Rate (Steps/Sec)	15	25

Table 7 - Factor and Levels for the Experiment

The experiment was conducted by using full factorial experimentation techniques, in which all main effects and two factor interactions were considered.

One of the root causes, variation over Guide Ledges diameter was not considered in the experiments, but it was ensured that the diameter is corrected before the experiments were conducted, such that it does not add to the variation in the bore size during experimentation. It was decided to manufacture 5 crank cases for each experiment. In each crank case there are 6 bores, therefore, for each experiment there will be 30 readings (5 crank cases, in each 6 bore sizes). The objective of the designed experiments was to reduce within piece variation (bore to bore in a crank case), between piece variations (crank case to crank case) and also to achieve the target bore size (nominal the base). The experiments were conducted after randomizing the trial runs and the results from each experiment were documented. The above experimental data were summarized to calculate the mean bore size for each crankcase, $\log_{10}S_p^2$ for within piece (crank case) variation and $\log_{10}S_b^2$ for between piece (crank case) variations.

The above data were subjected to the following analysis

1. Analysis of variance of the mean bore size for each crank case.

2. Analysis of variance of within piece variation ($\log_{10}S_1^2$)
3. Analysis of variance of between piece variance ($\log_{10}S^2$).

The mean bore size data was analyzed by ANOVA methodology and the result of the analysis is given in Table 8.

Source	Degrees of Freedom (df)	Sum of Squares	Mean Sum of Squares	F ratio	p value
Air Pressure	1	0.0001043	0.0001043	10.05	0.003
Oil Temperature	1	0.0000004	0.0000004	0.04	0.843
Feed	1	0.0000652	0.0000652	6.28	0.017
Air Pr x Oil Temp	1	0.0000161	0.0000161	1.55	0.221
Air Pr x Feed	1	0.0000051	0.0000051	0.49	0.489
Oil Temp x Feed	1	0.0000117	0.0000117	1.12	0.297
Error	33	0.0003426	0.0000104		
Total	39	0.0005454			

Table 8 - ANOVA of Mean Bore Size Data

It is clear from the above analysis that the mean bore size of crank case is affected by air pressure and feed rate setting as the respective p values are less than 0.05. The level averages of mean bore size was plotted (*ref.* Figure 5) to select the best level of significant factors.

The within crank case variation (bore-to-bore) was analyzed by ANOVA methodology and the result of the analysis is given in Table 9.

It is clear from the above analysis that the within piece variation of bore size of crank case is affected by only oil temperature. The level averages of bore size was plotted (*ref.* Figure 6) to select the best level of oil temperature.

Similarly, to study the between crank case variation for bore size, ANOVA analysis is conducted and the results of the analysis is given in Table 10.

No factor is significantly affecting the between crankcase to crankcase variation as p values of all suspected main effects

and their interaction effects are found to be more than 0.05. The summary of the ANOVA analysis is given in Table 11.

Source	Degrees of Freedom (df)	Sum of Square	Mean Sum of Square	F Ratio	P Value
Air Pressure	1	0.0402	0.0402	0.31	0.579
Oil Temperature	1	0.3994	0.3994	3.11	0.087
Feed	1	0.2162	0.2162	1.69	0.203
Air Pr x Oil Temp	1	0.0592	0.0592	0.46	0.502
Air Pr x Feed	1	0.0003	0.0003	0	0.964
Oil Temp x Feed	1	0.0239	0.0239	0.19	0.669
Error	33	4.232	0.1282		
Total	39	4.9711			

Table 9 - ANOVA of Within Crankcase Variations of Bore Size

Source	Degrees of Freedom (df)	Sum of Squares	Mean Sum of Squares	F ratio	p value
Air Pressure	1	0.0109	0.0109	0.07	0.833
Oil Temperature	1	0.071	0.071	0.47	0.618
Feed	1	0.036	0.036	0.24	0.711
Air Pr x Oil Temp	1	0.2443	0.2443	1.61	0.425
Air Pr x Feed	1	0.0841	0.0841	0.56	0.592
Oil Temp x Feed	1	0.0011	0.0011	0.01	0.947
Error	1	0.1514	0.1514		
Total	7	0.5987			

Table 10 - ANOVA of Between Crankcase Variations of Bore Size

Sl. No.	Factor	Mean Bore Size	Within Piece Variance (Bore - to - Bore)	Between Piece (Crank Case - to - Crank Case)	Best Setting
1	Air Pressure	Affect Significantly	No Significant Effect	No Significant Effect	3
2	Honing Oil Temperature	No Significant Effect	Affect Significantly	No Significant Effect	25
3	Feed Rate (Steps/Sec)	Affect Significantly	No Significant Effect	No Significant Effect	25

Table 11 - Summary of ANOVA analysis for Bore Size

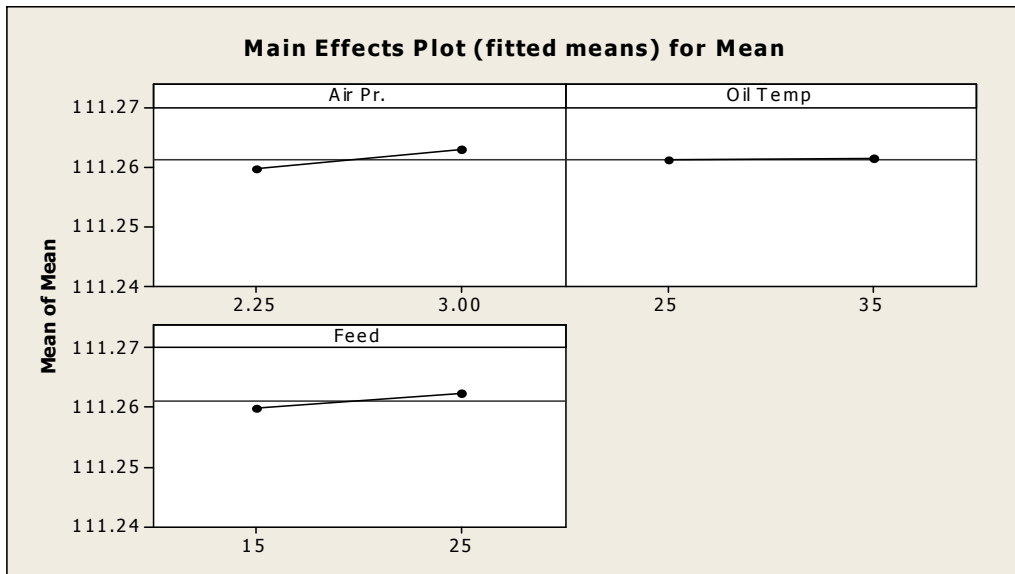


Figure 5- Level Averages of Factors for Mean Bore Size

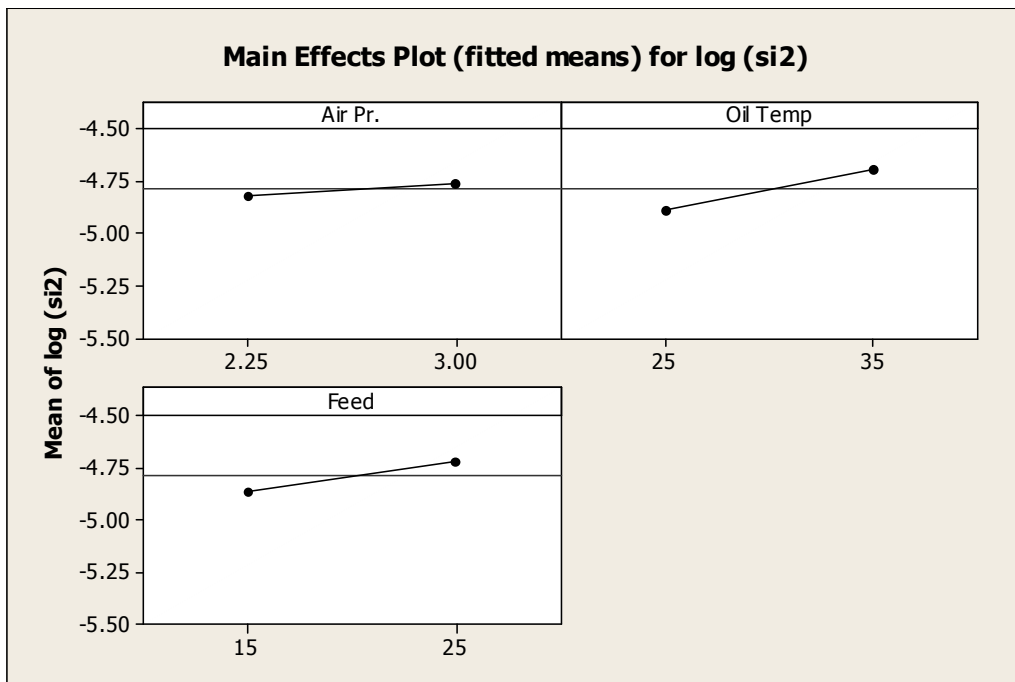


Figure 6 - Level Averages of Factors for Bore Size

The honing process parameters were set as per the optimum combination of the significant KPIVs and 8 crankcases were manufactured and measure for bore size

for each of the 6 bores. The process was set by using a new honing tool and as well as by using an used honing tool, which is almost at the end of its life, as it is a

known fact that as the life of the honing tool reduces, it affect the process capability. The results of the process

capability studies are given in Figure 7 and 8.

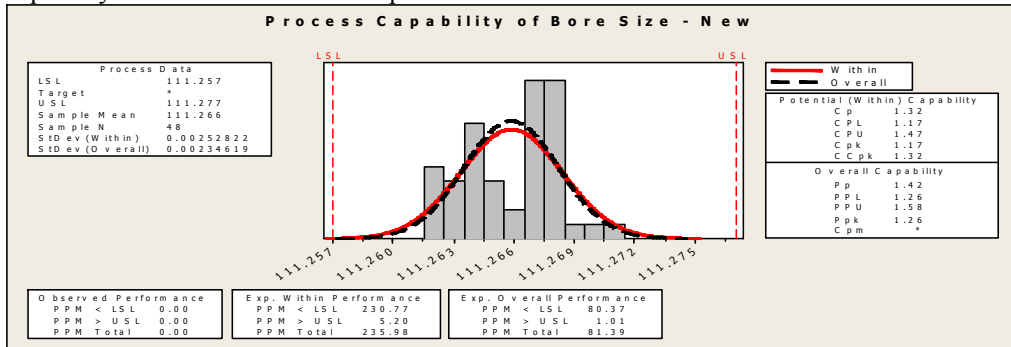


Figure 7 - Process Capability of Bore Size by using a New Honing Tool

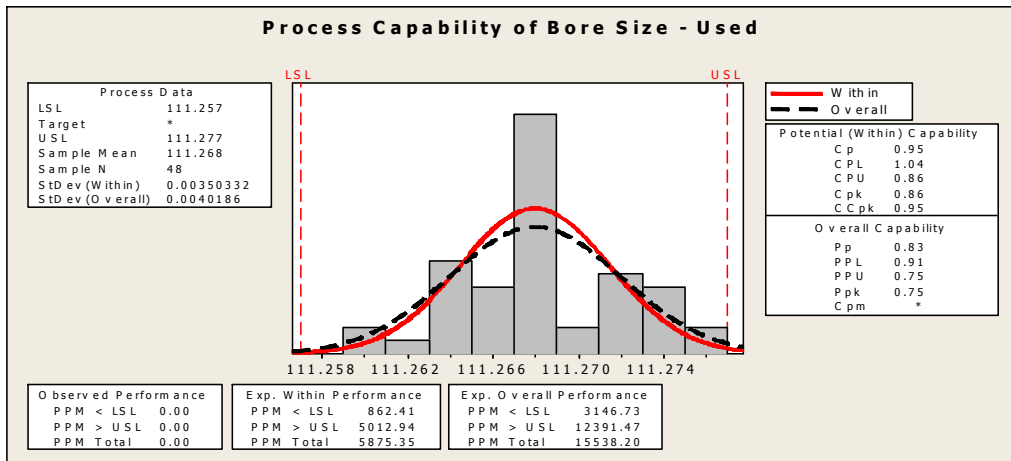


Figure 8 - Process Capability of Bore Size by using a Used Honing Tool

Sl. No.	Performance Measure	Before Improvement	After Improvement	
			New Honing Tool	Used Honing Tool
1	Ppm	201768	82	15538
2	Sigma Level	2.32	5.27	3.65

Table 12 - Sigma Level of Bore Size before and after Improvement

The summary of the improvement thus achieved in improving process capability of bore size of crank case is given in Table 12.

The main objective of control phase of a Six-Sigma project is to ensure that the changes are permanent and the gain obtained from the project remains permanent. Hence, at this stage, the

optimum process conditions are documented in the manufacturing process control plan document and implemented in the system to make the changes irreversible. All root causes identified during Analysis phase and their optimum condition as identified in the Improve phase are documented at control phase for the purpose of process monitoring and

control.

The result thus obtained by this project is a multifold reduction of process ppm of bore size, which is the main objective of any Six-Sigma project. Apart from improvement of process capability, the project also saves Rs. 10 million per annum at the rated production. It was also established by this project that throughout the life of the honing tool there will be no rejection of crankcase due to bore size problem anymore.

7. DISCUSSION

This case illustrates the application of Six-Sigma to resolve the problem of manufacturing process variation affecting bore size of crankcase. The DMAIC approach of Six Sigma is a systematic methodology utilizing training, measurement and data analysis tools to identify the root causes and eliminate these causes by improving the current process and thus achieving better results. The qualitative and quantitative tools helped to identify, prioritise and validate the possible root causes and their interrelationship to the CTQ's (y). Specifically, Six-Sigma DMAIC methodology allows effective problem definition, allows for use of data rather than trials and conjecture during critical decision making, helps study team to think about the process, and provides an approach for managing real improvement. It describes how the project was specified, how the tools were employed in the different phases to identify, improve and control the correct sources of variation

resulting into scrap and rework. This study demonstrates a project in which DMAIC scheme with logical analysis, statistical validation, design of experiments and hypothesis testing were employed to identify the KPIVs that affect the process capability of bore size. This project has substantially benefitted the organization by reducing the bore size variation of crankcase, making the loss due to rejection and rework to zero and finally improving customer satisfaction by supplying better quality product.

This paper will be of interest to academic researchers and practical managers. It describes the justification and selection of the project, how the tools and techniques of DMAIC methodology were employed in the different phases and how the improvement actions were implemented. This project methodology can be used to solve any process issue resulting in improving business results and finally improve customer satisfaction. However, people can modify the detailed contents and tools according to the organizational condition, selection of variables for analysis and availability of data.

Additional benefits were observed in this work, including the employee participation in Six Sigma project. The management was impressed with the analysis generated by the Six Sigma project. To make the Six Sigma principle a culture of the organization, a guideline was developed to ensure that problem solving of similar nature should be tackled in similar fashion.

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