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Systematic Quality Improvement on a Piston Machining Line Using DOE and Test for Variance

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Abstract

The globalization of industry and the competiveness has driven every manufacturing organizations to produce defect less and high quality product to satisfy the demands of the varying world market. Therefore quality is the key parameter which plays a vital role in manufacturing industries and products are tested for quality, regulated and certified. Some of the machining lines of Piston Machine Shop (PMS) of Federal Mogul Goetze (India) Limited were experiencing problems with quality and leading to losses of which machining line-02 (ML-02) which runs continuously through all the year with a significant output was identified which has maximum rejection rate accounting to 15.67% among all the machining lines which was considerably higher for its production volume and therefore it was identified for quality improvement. The tools like SPC, DOE and test for variance were used for improving the quality of the pistons in the ML-02. The result obtained after implementing Oil cooling system and new statistical way of rejection entry showed that the percentage rejection rate of skirt diameter reduced from 2.56% to 1.33% and hence the total percentage rejection on ML-02 was reduced from 17.26% to 9.56%.

Keywords: *Quality improvement, SPC tool, DOE, Variance test.*

INTRODUCTION:

A piston is heart and main component of reciprocating engines, gas compressor, reciprocating pumps and pneumatic cylinders with other similar mechanisms [1].Federal Mogul Geotze (India) Limited (FMGL) is the largest manufacturer of pistons and piston rings, globally and has much cutting edge technology in the field of piston ring. The Piston Machine Shop (PMS) operates 17 production lines for producing different types of pistons. These production lines consist of both manual and automated workstations. It was observed that some of the production lines were encountering quality issues. Out of these lines some particular production lines dedicated for certain customers/piston types which run continuously in all three shifts throughout the year. Rejections in such lines were leading to heavier losses. Therefore this situation demanded for identifying and resolving quality issues on such production lines. The main scope of the project work involves performing systematic quality analysis on piston ML-02 in order to reduce the rejection rate and there by improve the quality. The works involves thorough study of ML-02 and identify the causes by using quality tools and techniques and validate the proposed solution for eliminating the causes for rejection. The scope also involves implementing the proposed solutions and validates the rejection rate and quality of the pistons by carrying out production runs after implementation.

A. SPC Tools of Quality

The SPC tools are simple statistical tools used for problem solving. The SPC tools of quality refers to the use of statistical methods for monitoring and maintaining the quality of the products and services [2]. They are also called basic tools of quality because they are suitable for people with minute appropriate training in statistics. These tools are used to give explanation regarding the massive majority of quality-linked issues. [3]

B. *DOE*

DOE is a sequence of tests which are conducted to measure response variables by varying the input variables and both physical processes and computer simulation models are tested through DOE [4]. DOE provides an influential way to accomplish improvements in process efficiency and quality of the product. From the manufacturer view point, this can minimize the number of required experiments by considering the several factors disturbing experimental out comes. [5, 6]

C. Process Capability Analysis

A process capability analysis is used to evaluate the capability of an in-control process and establishing the

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mean of the sample and standard deviation, when the data are taken from the normal distribution. [7, 8]

D. ***Test for Variance***

Test for variance is used for measuring effect of single parameter on the process parameters. [4]

II. PROBLEM DEFINITION

PMS consists of 17 different piston machining lines. Machining line-02 (ML-02) had the maximum output at an average of 810 numbers of pistons per shift and which runs continuously with single piston type manufactured for M/S Ashok Leyland. From the data available through studies conducted by Quality management department at PMS of FMGL, it was found that ML-02 had the highest rejection rate accounting to 15.67% among all the machining lines.

III. OBJECTIVES AND METHODOLOGY

A. ***Objective of Work***

The project work has following specific objectives.

1. Thorough study of existing manufacturing processes in ML-02.
2. Identifying the root causes affecting the rejection rate using SPC tools and techniques and proposes solutions to eliminate those causes.
3. Implementation of the proposed solutions and perform the quality checks for the purpose of validation.

B. Methodology

The project methodology involves study of existing manufacturing process in ML-02 to identify the root causes for rejections, perform process capability analysis, propose a solution for eliminating the causes for rejections and improve the quality. The methodology also involves implementing proposed solutions and check for quality for the purpose of validation. The project methodology is depicted in the Flow Chart, as shown in Figure 1.

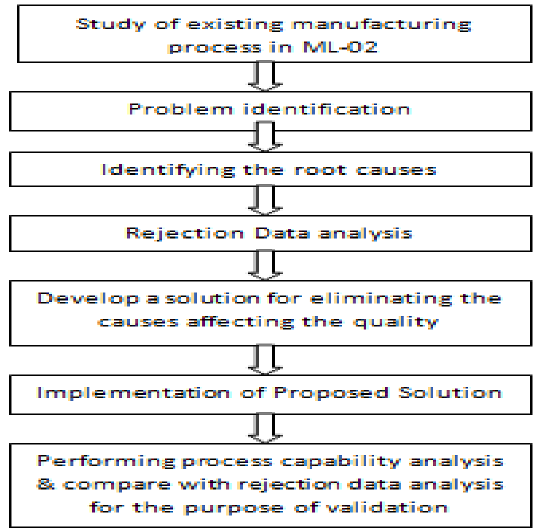

Figure 1 Flow chart depicting project methodology

IV. DATA COLLECTIO ON ML-02

The data of machining line-02 is collected from quality department of the company. Data regarding the number of operations in the machining line-02, the number of workers working in the line, hourly output, WIP between the operation and the number of rejections were collected. It is not possible to predict the rejection analysis by considering one month data. For studying rejection analysis at least two or more than two months data are required. Therefore November, December and January month data were chosen for rejection analysis. The total number of pistons produced and number of pistons rejected in ML-02 was collected for the month of November, December 2014 and January 2015 are presented in Table 1. By observing the table November month data is chosen for quality improvement. The types of defects and percentage of those defects for the month November, December and January 2014-2015 are represented in the Table 2.

Table 1: Month wise produced and rejected pistons in the ML-02, 2014-2015.

Sl. No.	Month	Total number of pistons machined	Total number good pistons	Total number of pistons rejected
1	November	51686	45194	6492
2	December	54026	46070	7956
3	January	52588	45586	7002
Total		158300	136850	21450

Table 2: % rejection of pistons in the ML-02 for the month Nov, Dec & Jan, 2015.

Sl. No.	Type of defectives	Rejection in no's	Percentage rejections
1	Skirt Diameter	4050	2.56
2	Damages	3540	2.24
3	Pin hole unclear	2331	1.47
4	Pin hole ovality	2100	1.33
5	Pin hole diameter	1630	1.03
6	OD unclear	1522	0.96
7	Compression height	1253	0.79
8	Machine bonding	1050	0.66
9	Surface treatment	863	0.54
10	Skirt diameter after coating	660	0.42
11	Circlip groove distance	620	0.39
12	Wall thickness	456	0.29
13	Coating thickness	325	0.21
14	Cavity finish	303	0.19
15	Pin hole alignment	294	0.19
16	Chamfer	258	0.16
17	Crown stamping	222	0.14

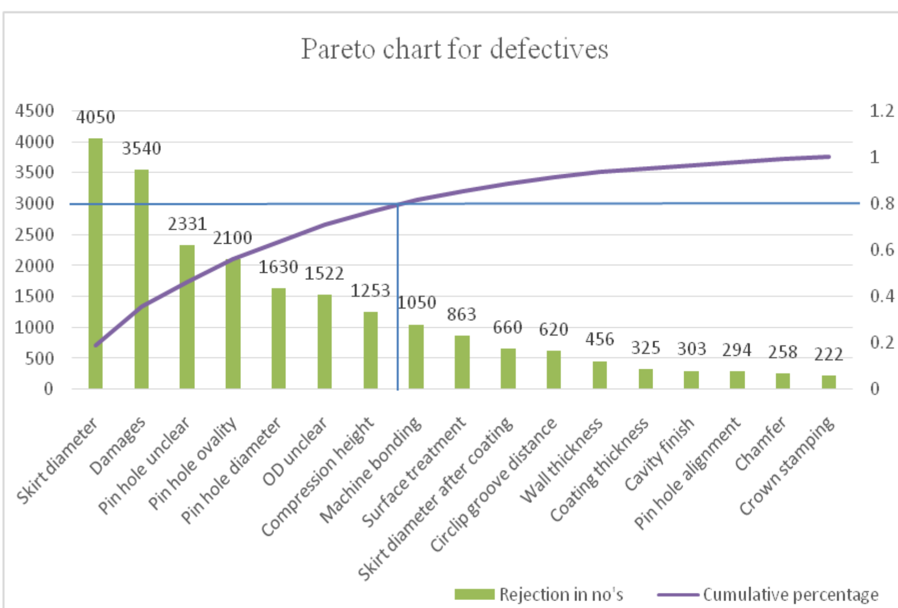

Figure 2 Defective pareto chart.

Figure 2 Defective pareto chart.

According to pareto principle or "80/20 rule", 80% of the problems created due to the 20% of the causes [9, 10, 11]. The 80/20 rule was established by drawing horizontal line from 80 percentage of cumulative percentage line and draw vertical line from a point where the curve and horizontal line crosses. This can be shown in Figure 2. The area which is left side of the line shows the 80% of the problems created due to the 20% of the causes. From the pareto graph it was observed that the causes like skirt diameter, damages, pin hole unclear, pin hole ovality, pin hole diameter, OD unclear, compression height and machine bonding create 80% of the problems in rejection rate in piston manufacturing of ML-02. From the pareto chart it was concluded that skirt diameter accounts accounting into 2.56% was caused more on rejection rate. Hence these two factors have been chosen for improvement of quality in the ML-02.

A. Analysis of Collected Capability Data For Skirt Diameter

Capability analysis of skirt diameter is done by taking 50 pistons having skirt diameter 89.95±10 mm in FD3 machine with equal interval of time. The pistons should be run within specified tolerance limit and measure and note down the skirt diameter tolerance values. Then divide 50 pistons readings into 10 subgroups and each sub groups having 5 pistons each.

Specifications for process capability analysis:

Machine – FD3, Operation – Skirt diameter (89.95±10 mm), Speed – 450 rpm, Feed- 0.25mm/rev, USL = 10microns (µ), LSL = -10 µ, Tolerance = 20µ.

Table 3: Analysis of capability data before implementation.

Sample no	**Time (minutes)**	**Skirt diameter tolerance observations (X), (µ)**					**Mean (X/5)**	**Range (Max-Min)**
		1	**2**	**3**	**4**	**5**		
1	9:10am	0	1	-1	2	0	0.4	**3**
2	9:20am	2	4	0	0	-3	0.6	7
3	9:30am	4	-15	8	4	-7	-0.2	23
4	9:40am	2	1	3	0	1	1.4	3
5	9:50am	-1	-1	0	-2	1	-0.6	3
6	10:00am	1	0	3	0	2	1.2	3
7	10:10am	-1	0	4	2	-2	0.6	6
8	10:20am	6	-2	5	4	2	3	8
9	10:30am	7	-18	5	2	-6	-2	25
10	10:40am	4	3	2	1	0	2	4
						$\bar{\bar{X}}$	0.54	
						$\bar{R}$		8.5

X bar Chart:

$\mathrm{UCL} = \bar{\bar{X}} + \mathrm{A2} \times \bar{R}$

= (0.54+ .577× 8.1) = **5.444**

$\mathrm{LCL} = \bar{\bar{X}} - \mathrm{A2} \times \bar{R}$

= (0.54 – 0.577×8.5) = **-4.364**

R bar chart:

$\mathrm{UCL} = \mathrm{D4} \times \bar{R}$

= 2.114 × 8.5 =**17.969**

$\mathrm{LCL} = \mathrm{D3} \times \bar{R}$

= 0×8.5 = **0**

Where,

UCL – Upper critical limit in microns.

LCL – Lower critical limit in microns.

A2 – Sample size – anti-biazing constant

D3, D4 – Constant taken from quality table.

$\bar{R}$ – Average of the sub-group range.

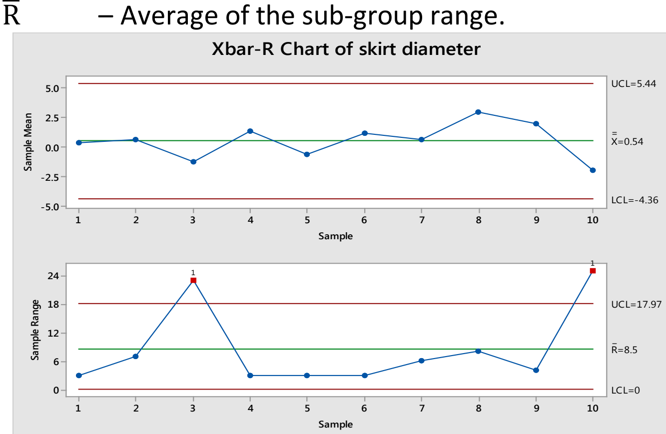

Figure 3 X bar-R chart before implementation.

Control charts are the one of the most significant and operational statistical tools for defining the process stability and variability [12]. The values from Table 3 are use in Minitab 17 software for constructing X bar - R chart. The Minitab 17 software used in X bar–R chart construction would take values of UCL, LCL, $\overline{\overline{X}}$ and $\overline{R}$ automatically. The X bar chart constructed using Minitab 17 software for skirt diameter variation having upper and lower values were 5.44µ and -4.36µ respectively and observed that all the values are within control limit. The center line used for estimating process average which has value of 0.54µ. In R chart the upper and lower control limits were found to be 17.97µ and 0 respectively and the center line used for evaluations of process variation which has value 8.5µ. It was found that some points of R chart were out of the control limit and showed that process is out of the control limit and shown in the Figure 3. This indicated the necessity for some corrective action to be taken to monitor the process.

Calculation of C_p:

$$\overline{\overline{X}} = \frac{\sum \text{of } \overline{X}}{10} = \mathbf{0.54}$$

$$\overline{R} = \frac{\sum \text{of} R}{10} = \mathbf{8.5}$$

$$\sigma = \frac{\overline{R}}{d2} = \frac{8.5}{2.33} = 3.64$$

$$Cp = \frac{\text{Tolerence}}{6\sigma} = \frac{20}{6\times 3.64} = \mathbf{0.81}$$

Calculation of C_{pk}:

$$Cpk = \min \text{ of } \left[\frac{USL - \overline{\overline{X}}}{3\sigma}, \frac{\overline{\overline{X}} - LCL}{3\sigma}\right]$$

$$= \{.766, 0.965\} = \underline{\mathbf{0.766}}$$

where

$\underline{C_p}$– Potential process capability index.

$\underline{C_{pk}}$– Real process capability index.

σ – Standard deviation.

$\overline{\overline{X}}$ – Mean of the skirt diameter tolerance observations.

$\overline{R}$– Average of the sub-group range.

R – Range of the sub-group.

D2 – Constant taken from the quality table.

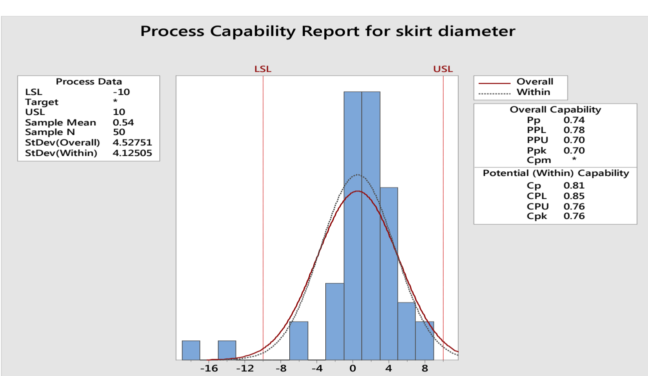

Figure 4 Process capability graph for skirt diameter.

Skirt diameter operation was processed in the FD3 machine. So before conducting it is necessary to study the process capability analysis of FD3 machine by estimating process capability index and real process capability index. In both C_p and C_{pk} cases 1.33 considered as minimum indices value. The process capability analysis was carried out in Minitab software. The C_p and C_{pk} values estimated from minitab were 0.81 and 0.766 respectively shown in the Figure 4. It was found that C_p and C_{pk} values were less than 1.33 specified indices value. Hence concluded that process is not controlled.

B. Identification of Causes

The variety of causes and parameters which lead to reduce in quality and cause rejections are determined and are shown in the form of cause and effect diagram. CED is a basic root cause approach tool where the general as well as unique causes are categorized in the direction of 4 M's i.e. material, man, machine and method [13, 14, 15, and 16]. The various possible causes which lead to rejection of skirt diameter are grouped into man, material, machine and method and that are represented in the form of cause and effect diagram. CED rejection due to skirt diameter has been shown in the Figure 5.

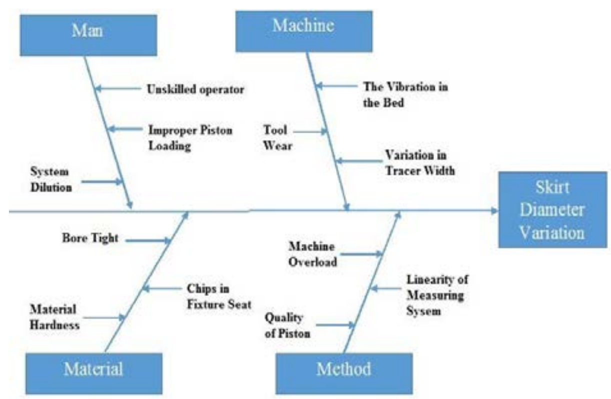

Figure 5 CED for rejection due to skirt diameter.

From the studies conducted on the production runs it was found that feed, variation in cam temperature, bore tight (fixture seat diameter) and type of tool were observed to causes defects in skirt diameter and thus those causes were selected for detailed analysis using DOE and Variance techniques.

A. Test for Variance

The effect of feed on skirt diameter was tested by using variance test .Feed is the relative velocity at which the cutter is advanced along the work piece, its vector is perpendicular to the vector of cutting speed. In FMGL for achieving good quality, 0.25mm/rev and 0.35mm/rev feed values are set for piston machining. So 0.25mm/rev and 0.35mm/rev feed values were chosen for conducting the variance test. 30 pistons were machined by setting 0.25mm/rev feed in FD3 machine and record the skirt diameter values. Similarly another 30 pistons were machined by setting 0.35mm/rev feed in FD3 machine and record the skirt diameter values. The tabulated values of skirt diameter values for feed of 0.25mm/rev and 0.35mm/rev is presented in the Table 4.

Table 4: Skirt diameter tolerance values

Sl. No	Skirt diameter tolerance values for different feed (μ)		Sl. No.	Skirt diameter tolerance values for different feed (μ)	
	0.25mm/rev	0.35mm/rev		0.25mm/rev	0.35mm/rev
1	2	0	16	2	1
2	5	0	17	-4	4
3	1	4	18	0	2
4	6	3	19	1	1
5	2	2	20	2	5
6	-1	4	21	3	2
7	4	6	22	3	-1
8	-2	-1	23	-1	6
9	-3	0	24	0	2
10	4	2	25	-3	-3
11	0	-3	26	3	-1
12	1	1	27	4	0
13	6	5	28	3	3
14	3	-4	29	-1	-2
15	5	-2	30	0	3

Test and CI for Two Variances: C1, C2

Method

Null hypothesis σ(C1) / σ(C2) = 1
Alternative hypothesis σ(C1) / σ(C2) ≠ 1
Significance level α = 0.05

Statistics

95% CI for

Variable	N	StDev	Variance	StDevs
C1	30	2.675	7.155	(2.194, 3.490)
C2	30	2.718	7.390	(2.254, 3.507)

Ratio of standard deviations = 0.984
Ratio of variances = 0.968

95% Confidence Intervals

Method	CI for StDev Ratio	CI for Variance Ratio
Bonett	(0.709, 1.352)	(0.503, 1.829)
Levene	(0.662, 1.404)	(0.438, 1.972)

Tests

Method	DF1	DF2	Test Statistic	P-Value
Bonett	1	—	0.01	0.916
Levene	1	58	0.03	0.869

The p-values of Bonett and Levene method obtained from the analysis were found to be 0.9 and 0.936. σ(1) and σ (2) represents the standard deviation of population 1 and 2 respectively.

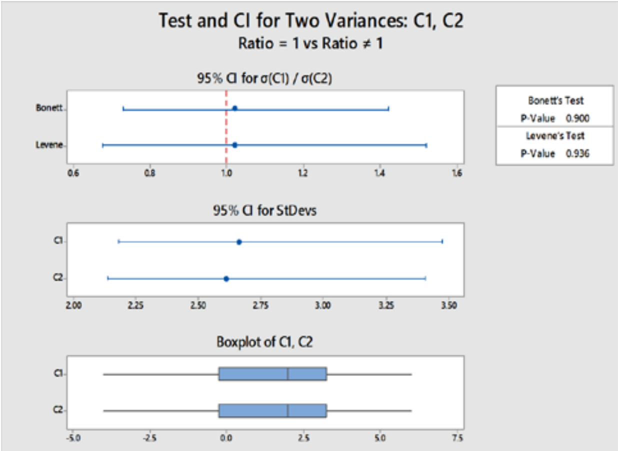

Figure 6 Standard deviation of two variances.

By observing the Figure 6, graphically it can be found that two variances (0.25mm/rev and 0.35mm/rev) are 95% accurate. The p-value of these two variances are 0.0900 and 0.936 for feed 0.25mm/rev and 0.35mm/rev respectively and p-value of these two variances were not less than 0.05 and therefore it was statistically proved that feed has no effect on skirt diameter.

B*. *Design of Experiments (DOE)

A full factorial design was used to measure the various combinations of the factor levels, 'RUN' is the each combination of the experiment and each measure as an observation. The experiment was conducted for 3 factors with 2 replicates, therefore 16 experiments runs should be conducted. The 2-level factorial is chosen for designing the factors. The factors like fixture seat diameter, cam temperature and type of tool are recorded with low and high levels and this is shown in the Table 5.

Table 5: Factors selected for DOE.

Factor	Name of the parameter	Type	Low	High
A	Fixture seat diameter	Numeric	-15	15
B	Cam temperature	Numeric	20	30
C	Type of tool	Text	Sadwick	Widia

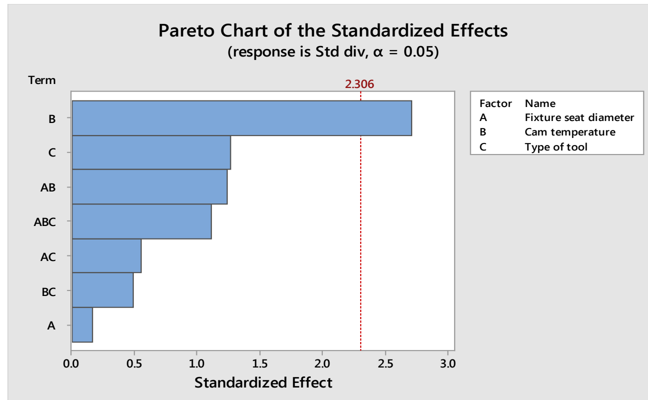

Figure 7 Pareto plot.

By The pareto chart shown in Figure 7, it was revealed that the cam temperature crossed the reference line therefore cam temperature was considered as significant effect. Also observed that the fixture seat diameter effect is least as it enlarges very less quantity.

Table 7: Analysis of variance (ANNOVA) table.

Sources	Degrees of freedom(DF)	Adj SS	Adj MS	F -value	P –value
Model	7	9.6297	1.37567	1.75	0.224
Linear	3	7.0346	2.34488	2.99	0.096
Fixture seat diameter	1	0.0201	0.02009	0.03	0.877
Cam temperature	1	5.7534	5.75336	7.33	0.027
Type of tool	1	1.2612	1.26118	1.61	0.241
2-way interaction	3	1.6177	0.53922	0.69	0.585
Fixture seat diameter*cam temperature	1	1.1952	1.19518	1.52	0.252
Fixture seat diameter*type of tool	1	0.2374	0.23745	0.30	0.597
Cam temperature*type of tool	1	0.1850	0.18502	0.24	0.640
3-way interaction	1	0.9774	0.97743	1.2	0.297
Fixture seat diameter* cam temperature*type of tool	1	0.9774	0.97743	1.24	0.297

In variance table the p-value as used to determine which effects are statically significant in the model. Here the p-value is recognized for the evaluation of the effect. By comparing p-value with α-level (α = 0.05), can determine the effect is significant or not. If the p-value is less than or equal to α, then it confirm that the effect is significant. If the p-value is greater than α, then it confirms that the effect is not significant. The analysis of variance table has been shown in the Table 7.

V. IMPLEMENTATION AND CORRECTIVE ACTION

The causes identified for the rejections due to skirt diameter were cam temperature, daily rejection entry of the pistons. These causes are eliminated by implementing proposed solutions.

A. Variation of Cam Temperature

In FD3 machine, cam is used for giving profile on the piston surface and shape of the cam will decides shape of the pistons. Different pistons having different types of cam and these cams are used in manual machining operation. Due to continuous machining cam surface gets heated and similarly during idle time (i.e. lunch break, machine set-up time and tea break) cam surface gets cooled. These variations of cam temperature results in the variation of skirt diameter values and causes defects on skirt zone. Before implementation of theFD3 machine is shown in the Figure 8.

Figure 8: Before implementation of oil cooling system.

Solution: In order to maintain the cam temperature at required level it was proposed to have a cooling system. A cooling system was proposed to have a sponge and oil tank. Sponge is attached to the cam surface and maintains the cam surface temperature. Sponge used in the oil cooling system was soaked to remove excess heat from the cam at every cycle. The oil tank which act as a reservoir for supplying oil to sponge. This system has the facility of continuous feeding of oil into the sponge through oil pipes which is attached to the oil tank. The implemented oil cooling system displayed in the Figure 9.

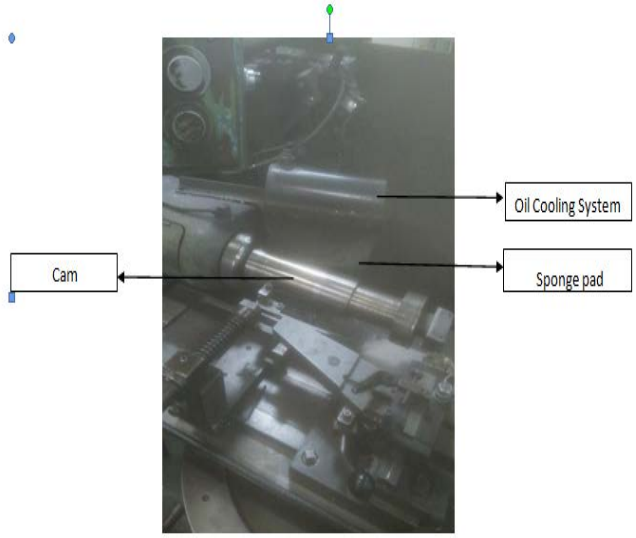

Figure 9 Implemented oil cooling system.

A. Daily Rejection Entry

In FMGL, every day the line engineer should visit to quarantine department, collect the defect pistons and recorded in the daily rejection entry sheet. In FD3 machine, there are two types of tools i.e. Poly Crystalline Diamond (PCD) and Carbide are used for skirt diameter operation. PCD tools used for machining of skirt zone and carbide tools for machining of crown and groove zone. Defects accounting due to both tools. So for skirt diameter defect, line engineer will measure the skirt diameter values and enter in the daily rejection sheet. But this method of recording the skirt diameter values are inconvenient technique for understanding in which area defects are more and which tool have to monitor.

Table 8: Daily rejection entry.

Piston No	D1 more	D1 less	Ring zone more	Ring zone less	D5 more	D5 less
1	12	-10	5	-35	20	-18
2	5	-25	14	-55	45	-15
3	10	-8	7	-45	25	-5

In the previous format there was no provision for recording daily rejection of the pistons. In new format was developed to collect the data on day to day basis which enables monitoring the rejections and process continuously. The proposed table and recorded information is given in the Table 9. From the implemented system it was cleared that line engineer will easily predict in which area defects are more and which tool has to monitor for machining.

Table 9: Statistical way of daily rejection entry.

FEDERAL MOGUL Machining Scrap Analysis for Skirt Diameter					
	Piston name:				
Area of rejection	01/01/15	02/01/15	03/01/15	04/01/15	05/01/15
D1 more					
D1 less					
Ring zone more					
Ring zone less					
D5 more					
D5 less					
Line engineer name					
Comments					
Sign					

VI. RESULTS AND DISCUSSIONS

This chapter deals with assessment regarding the entire project is done based on the reducing the rejection and improving the quality of the pistons.

The total number of pistons rejected after implementation was found to be 6114 out of 52585 pistons produced during the month of February 2015. The rejection data of pistons collected after implementation for the month of February 2015 is provided in the Table 10.

Table 10: Total number of pistons rejected in the month February 2015.

Total piston machined	Total number of good pistons	Total pistons rejected
52585	46471	6114

Out of piston defects rejections due to skirt diameter accounted for 702 rejections. The percentage of rejection for skirt diameter was 1.33%. The percentage of rejections after implementation for rejection due to skirt diameter is provided in the Table 11.

Table 11: Percentage rejection skirt diameter and damages in the month February.

Sl. No.	Type of defective	Rejection numbers	Percentage rejection
1	Skirt diameter	702	1.33

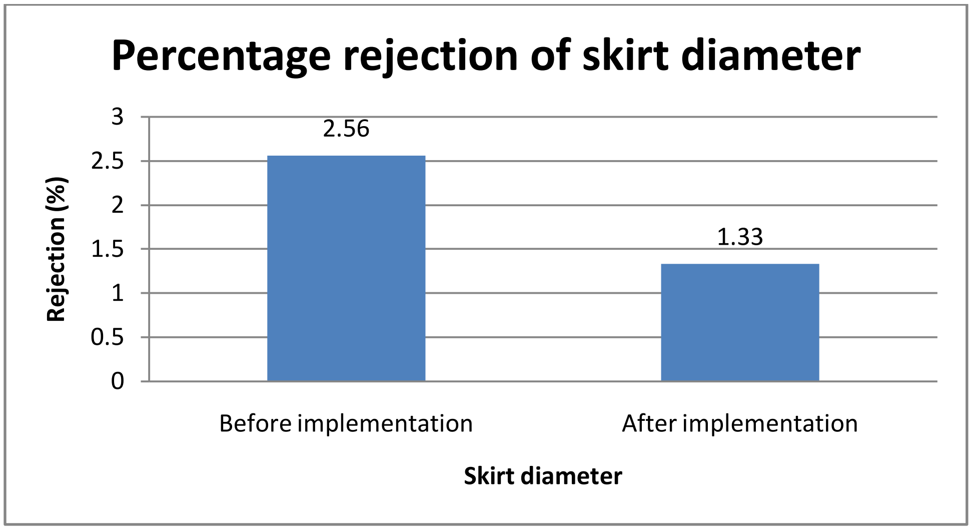

Figure 10 Percentage rejections of before and after implementation.

The rejections have reduced from an average of 2.56% before implementation to 1.33% after implementation of proposed solution for rejection due to skirt diameter. The rejection due to skirt diameter before and after implementation of proposed solution is given in the Figure 10.

Table 12: Month wise rejection of machining line-02 after implementation.

Sl. No.	Month	% of scrap
1	November	15.67
2	December	14.5
3	January	17.26
4	February	9.56

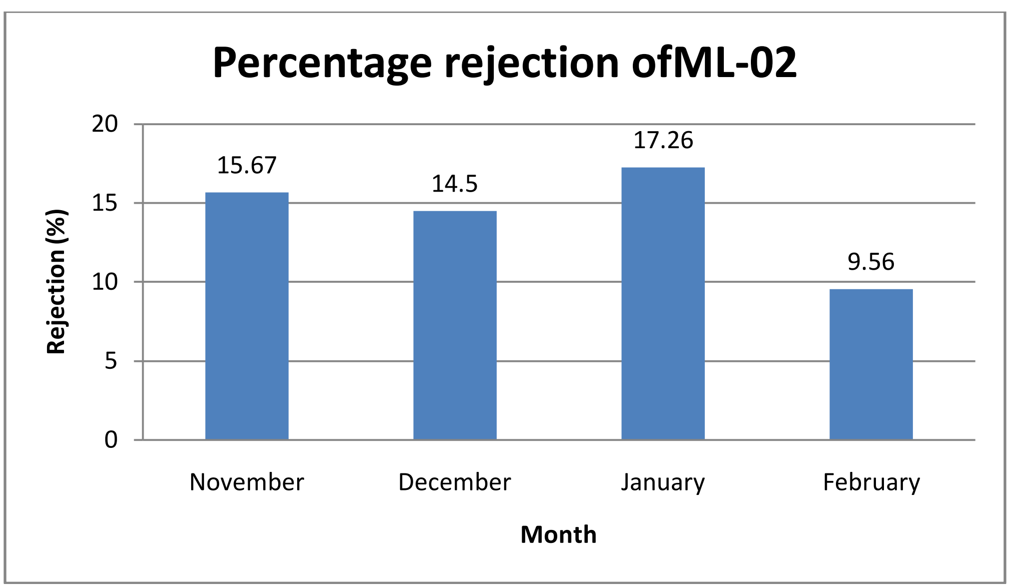

Figure 11 Month wise percentage rejection of ML-02.

The percentages of rejections after implementation of proposed system have reduced to 9.56% as compared to 17.26%, 14.5% and 15.67% for the month of January, December and November respectively before implementation. The percentage of rejections after implementation of proposed system is presented in the Table 12 and Figure 11.

VII. CONCLUSION

➢ Detailed study was conducted on ML-02 for the month of November, December and January was revealed that rejection due to skirt diameter accounted to 2.56% and 17 types of defects were identified. From the pareto chart constructed, it was found that rejection due to skirt diameter and damages was part of 20% of causes creating 80% of the problems as per 80/20 rule. Hence was chosen as factors to be improved.

➢ Out of the problems identified, skirt diameter was found to be highest rate with respect to their effect on quality and rejection. Skirt diameter accounts to 2.56% of the total rejection in machining line-02.

➢ The process capability analysis of skirt diameter tolerance observations was performed on FD3 machine before implementation of proposed solutions. The C_p and C_{pk} values were found to be 0.81 and 0.766 respectively which was less than the specified index value of 1.33 indicating that the process is not controlled.

➢ DOE and test for variance, root causes foe skirt diameter in piston is identified and validated through data analysis. Variation of cam temperature, chips in fixture seat and complexity in daily rejection entry were the reasons for the rejection. These rejections are eliminated by providing oil cooling system and statistical way of rejection entry.

➢ The percentage of rejection due to skirt diameter obtained for the month of February of implemented proposed solutions was reduced to 1.33% after implementation as compared to 2.56% before implementation.

➢ The total rejections in ML-02 obtained for the month of February of implemented proposed solutions was reduced to 9.56% from 17.26%.

A. Scope of future work

The quality improvement method implemented can be adopted for reducing /eliminating other types of defects identified in ML-02.

REFERENCES

1. Piston Manufacturing Processes Hand Book, FMGL.
2. Faheem Yosuf, Dr. Shahid Ikramullah Butt, Dr. Riaz Ahmed, Six Sigma Implementation to Reduce Rejection Rate of Pump Casting in local Manufacturing Company, ISOR Journal of Mechanical & Civil Engineering (ISOR & JMCE), Volume 7, Issue 4, July-Aug 2013.
3. Hairulliza Mohamad Judi, Ruzzakiah Jenal and Devendran Genasan, Quality Control Implementation in Manufacturing Companies: Motivating Factors and Challenges.
4. Mathews and Paul G, Design of experiments with MINITAB, published in 2014.
5. Dong-Woo Kim, Myeong-Woo Cho , Tae-Il Seo and Eung-Sug Lee, Application of Design of Experiment Method for Thrust Force Minimization in Step-feed Micro Drilling, ISSN 1424-8220 © 2008 by MDPI.
6. S. Suresh, Defects Reduction in Manufacturing of Automobile Piston Ring Using Six Sigma, Journal of Industrial and Intelligent Information Vol. 3, No. 1, March 2015.
7. Dulce MaríaRábago-Remy, Edith Padilla-Gasca and Jesús Gabriel Rangel-Peraza,Statistical Quality Control and Process Capability Analysis for Variability Reduction of the Tomato Paste Filling Process, research article, Rábago-Remy et al., Ind Eng Manage 2014.
8. GVSS Sharma and P Srinivasa Rao, Process capability improvement of an engine connecting rod machining process, Sharma and Rao Journal of Industrial Engineering International 2013.
9. Juran, Joseph M, "Quality Control Hand Book", 4th edition, New York, McGraw Hill Company, 1980.
10. Varsha M. Magar, Dr. Vikas B. Shinde, Application of 7 Quality Control (QC) Tools for Continuous Improvement of Manufacturing Processes, International Journal of Engineering Research & General Science, volume 2, Issue 4, June-July 2014.
11. Samadhan D. Bhosale, S.C. Shilwat, S. R. Patil, Quality improvement in manufacturing process using SQC tools, International Journal of Engineering Research & Applications, Volume 3, Issue 3, May-June 2013.
12. Mohamed Aichouni, *Member SQC,* On the Use of the Basic Quality Tools for the Improvement of the Construction Industry: A Case Study of a Ready Mixed Concrete Production Process, International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol:12 No:05.
13. V.G. Surange, M. Soković a, D. Pavletić , E. Krulčić, Six Sigma process improvements in automotive parts production, Jornal of Achievements in Materials and Manufacturing Engineering, VOLUME 19 ISSUE 1 November 2006.
14. Dr. D. R. Prajapati, Implementation of SPC Techniques in Automotive Industry: A Case Study,

International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 3, March 2012.

15. Mohiuddin Ahmed; Nafis Ahmad, An Application of Pareto Analysis and Cause-and-Effect Diagram (CED) for Minimizing Rejection of Raw Materials in Lamp Production Process, Management Science and Engineering, Vol. 5, No. 3, 2011.

16. Anirudha Joshi and PrithamKadom, Optimizing and Analysing Over through Design of Experiments.