Using QC Tools To Investigate The Problem Of Rejection Of Piston Rings - A Case Study Of Engine Component Manufacturing Organization

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Abstract : One of the leading engine components manufacturing company located in Ghaziabad city of Uttar Pradesh, India, producing pistons, piston rings, piston pins, and engine valves faced lot rejection during internal quality checks in a specific model of piston rings because of 'radial down or radial over' problem. The QC tools integrated with the core tools of the automotive sector have been used on DARE methodology to solve the problem. PFMEA for diagnosing and defining the reason for failure followed by Flowchart, Histograms, Pareto Analysis, Fishbone Diagram, Run Chart, and Process Capability analysis were used to counter the problem. The value of Cpk was improved for the process from 0.68 to 2.45 after using the methodology resulting in a reduction in rejection by 99.26 percent.

Keywords : Quality Control tools, DARE, FMEA, Cpk, BS-VI, Piston Rings, etc.

1 INTRODUCTION

Piston rings in an engine play a crucial role by sealing the combustion chamber and minimizing the loss of gases to the crankcase. This not only helps in enhancing the transfer of heat from pistons to the wall of the cylinder but also helps to maintain the required oil quantity causing optimal consumption of oil, controlling the emissions. The radial thickness of such rings becomes a vital parameter in meeting the emission norms of BS-VI. The radial thickness of the rings controlled in this study is required to be maintained between specification limits of 2.9 +0.15 -0.1. The narrow tolerance value for the manufacturing process is required for the optimum working of the rings. The effect of manufacturing errors in piston rings has been detailed by Anatasios Zavos and Pantelis George (2015) in their study over the waviness and straightness of piston rings [1]. C. Mukhopadhyay and H Nataraja (2004) in their study on improving the quality of the piston ring advocated the use of QC tools [2]. Six Sigma, Cost of Poor Quality, FMEA, DOE, etc. had been used by S. Suresh et al, in an attempt to reduce the rejection rate of piston rings [3]. The importance of dimensional accuracy has been stressed in a study on assessing the risk of defects in casted piston rings using FMEA in the year 2017 [4]. Such similar studies have also been carried on a larger scale by researchers for reducing the defects in car body panel [5] and bicycle industry [6]. The QC tools are also of equal importance for the service-based industry like banking and academia wherein these tools have been put to use by researchers for improving the competitiveness [7], [8] The DARE methodology of defining, analyzing, report making, engaging for implementing recommendations and evaluating the results has been used for the study of interest. DARE is a recent methodology being practiced by process consultants for improving the performance of an organization holistically by focusing on 3 Ps of the system, the process, the product, and the people. On encountering the problem of lot rejection of piston rings, a systematic study using the QC tools with DARE methodology was carried out. To understand the gravity of the problem of 'over or under thickness' of piston rings, failures caused by it and its effect, a detailed PFMEA was made as shown in table 1. This concluded that the problem needs immediate attention to resolve. Pareto Analysis of month-wise rejection data of the rings was done to understand the main cause of rejection. Subsequently, a detailed process flow of manufacturing of rings was studied and a process flowchart was created. This helped in critically understanding the process parameters of production of the rings which was essentially required to prepare the fishbone diagram later. Run charts to understand the pattern of defects were then made and analyzed. The help of another QC tool called Ishikawa diagram was taken to search out for the reasons of the prime defect seen from Pareto analysis. Based on this an action plan was developed to mitigate the problem. But before implementing the action plan process capability analysis of the existing process was carried to compare it with the process capability attained after implementing the action plan developed.

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2 METHODOLOGY

The DARE methodology shown in figure 1, as quoted earlier, is a recent technology being used by process consultants specifically designed to improve the system holistically in the dimensions of 3 Ps – Process, Product and People.

Figure 1: DARE Methodology

The methodology is similar to the DMAIC cycle of 6sigma and a comparison of both the methodologies has been presented in table 1. As evident from Table 1, the DARE cycle defines the problem by investigating it at the very time of defining by collecting required data using core tools like FMEA saving one step from the DMAIC Cycle. Also, the last two phases of the DMAIC cycle are clubbed in the DARE cycle in the form of engaging and evaluating.

Phase	DMAIC	Explanation	Tools	DARE	Explanation	Tools
Phase 1	Define	Identifying problem	7 QC tools	Define	Identifying and recording problem	7 QC tools, PFMEA
Phase 2	Measure	Data Collection	Check Sheets	Analyze	Data analysis	Histograms, Scatter Diagram, Run Charts, Control Charts, Pareto Diagrams, Fishbone Diagrams
Phase 3	Analyze	Data Analysis	Histograms, Scatter Diagram, Run Charts, Control Charts, Pareto Diagrams, Fishbone Diagrams	Report	Reporting the solutions	Histograms, Cause and Effect Diagram, Flowcharts,
Phase4	Improve	Improving the process by implementing the observations received during data analysis	DOE, PDCA, FMEA	Engage and Evaluate	Implementing reports and evaluating the outcomes	PPAP, APQP, MSA, FME, Control Charts, Action Plans, PDCA, DOE, SOPs, Lean Process tools
Phase 5	Control	Implementing and controlling the process	Control Charts, SOPs	-------		

Table 1: *Comparison of DMAIC and DARE methodologies and tools typically used in each phase*

The DARE methodology used for this study is stage-wise detailed along with the tools that are used in the respective phases.

Phase 1: Defining the problem

To define the problem precisely, month-wise lot rejection data of piston rings were studied for the last three months with the help of histograms shown in figure 2. Subsequently, Pareto Analysis as shown in figure 3 was carried to understand the major reason for the rejection.

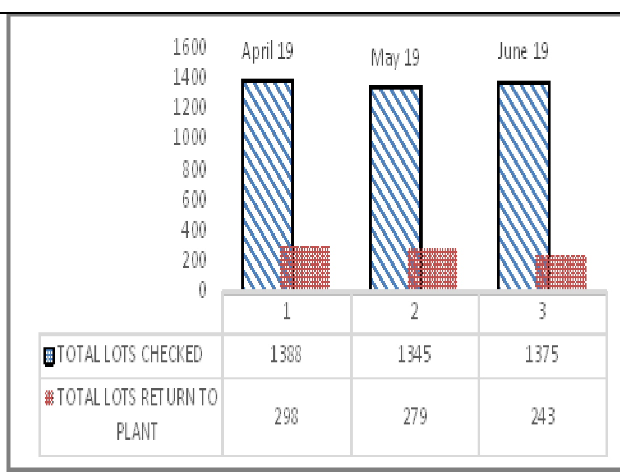

Figure 2: Histograms to analyze the month-wise rejection of piston rings

The histograms showed that almost consistently more than 250 lots were rejected every month out of around 1400 lots checked per month. This was a big rejection number. Next, it was intended to understand that, howsoever big number this is, but is it required controlling this and what can be the effect of these rejections. For this, a PFMEA was developed for piston rings shown in table 2.

Defect	Type of ring	Location	Acceptance criteria	Severity	Occurrence	Detection	Risk priority number
Crack	All chrome ring	OD/ID/Face	No pass	7	4	4	112
Cavity	All chrome ring	ID/Face	In one ring max 4 cavity	2	5	2	20
Shrinkage	All chrome ring	ID	Max 0.2mm, max t/10 depth	1	6	6	36
Bad face	All chrome ring	Face	No pass	3	6	4	72
Tool mark	All chrome ring	OD/ID/Face	No pass	6	7	3	126
Scratch	All chrome ring	OD/ID/Face	Max width 0.1 mm	4	6	4	96
A dent or hit mark	All chrome ring	Face	Max width t/3	3	7	6	126
Chrome Chipping	Top chrome ring	OD chamfer	Gap chamfer of 0.2mm	4	3	5	60
Gap broke on OD	Chrome oil & chrome ring	OD gap	Max 0.2mm	5	8	2	80
Gap broke on ID	Chrome oil & chrome ring	ID gap	Max 0.3mm	2	6	2	24
Gap leakage	Chrome ring	OD	Max b/3 land width	2	4	7	56
Patch mark	Chrome ring	OD	No pass	5	4	4	80
Re-honing	Chrome ring	OD	No pass	4	3	5	60
Pitting	Chrome ring	OD	No pass	6	2	5	60
ID land width	Oil chrome ring	ID	Max diff. T/6	3	5	6	90
OD groove vibration	Chrome oil & chrome ring	OD	No pass	5	4	4	80
OD/ID unturned	Plain ring	OD	No pass	4	2	1	8
Gap misalignment	All chrome ring	OD	The gap to ring dist.t/3	2	3	2	12

Contact more or less	Taper chrome ring	OD	According to the drawing	4	6	5	120
Vibration & chattering	Chrome ring	OD/ID	No pass	5	3	3	45
De-chrome	Chrome ring	OD	No pass	2	4	1	8
OD/ID lining	Chrome ring	OD/ID	No pass	4	7	2	56
Granular plating	Chrome ring	OD	No pass	2	3	1	6
Parkerizing spot	Plain ring chrome ring	Face	No pass	2	2	1	4
Sand-blasting	Plain ring chrome ring	OD	No pass	2	5	2	20
Dull od	Chrome ring	OD	No pass	2	4	1	8
Radial down/high	All chrome ring	OD/ID	No pass	4	7	9	252

Table2: *PFMEA of Piston rings*

It was observed from the PFMEA that the defect of having the radial thickness high or less from the required value attracts an RPN number of 378, which was the maximum of all, and required immediate attention. Further, Pareto Analysis of the problem shown in figure 3, also indicated the fact that more than 80% of the rejection was due to this problem.

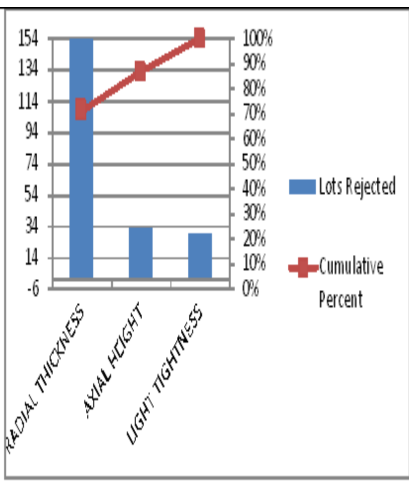

Figure 3:Pareto Analysis for reasons of rejection of piston rings

Phase 2: Analyzing the data

In phase 1, Histograms, PFMEA, and Pareto Analysis helped in defining the problem of controlling the radial thickness of the rings. In the second phase, it was required to analyze the problem in detail, for this a process flowchart of the production of the piston rings was made as shown in figure 4. This helped in understanding the process parameters related to the radial thickness.

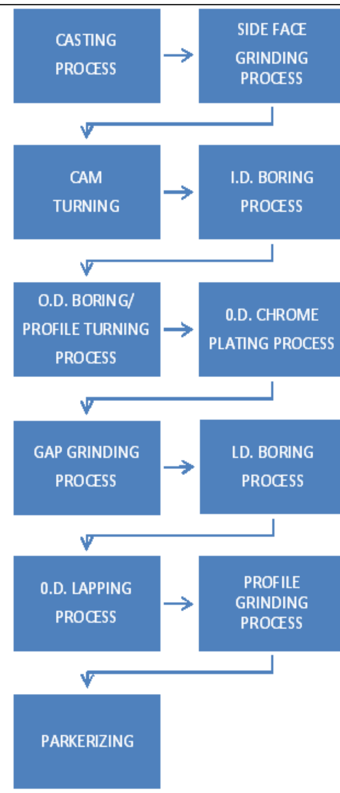

Figure 4: Process flowchart of piston ring production

The 4th step of ID Boring in the sequence corresponds to the radial thickness formation and it can be understood that having a defective ring at this stage causes succeeding steps to over-process the defects. An additional stage of inspection of the thickness was introduced here to avoid this over-processing of defects. Subsequently, a run chart for the thickness parameter of the piston rings of 3 randomly chosen batches was made as shown in figure 5. The policy was to reject the complete lot on having a maximum 1 defective piece.

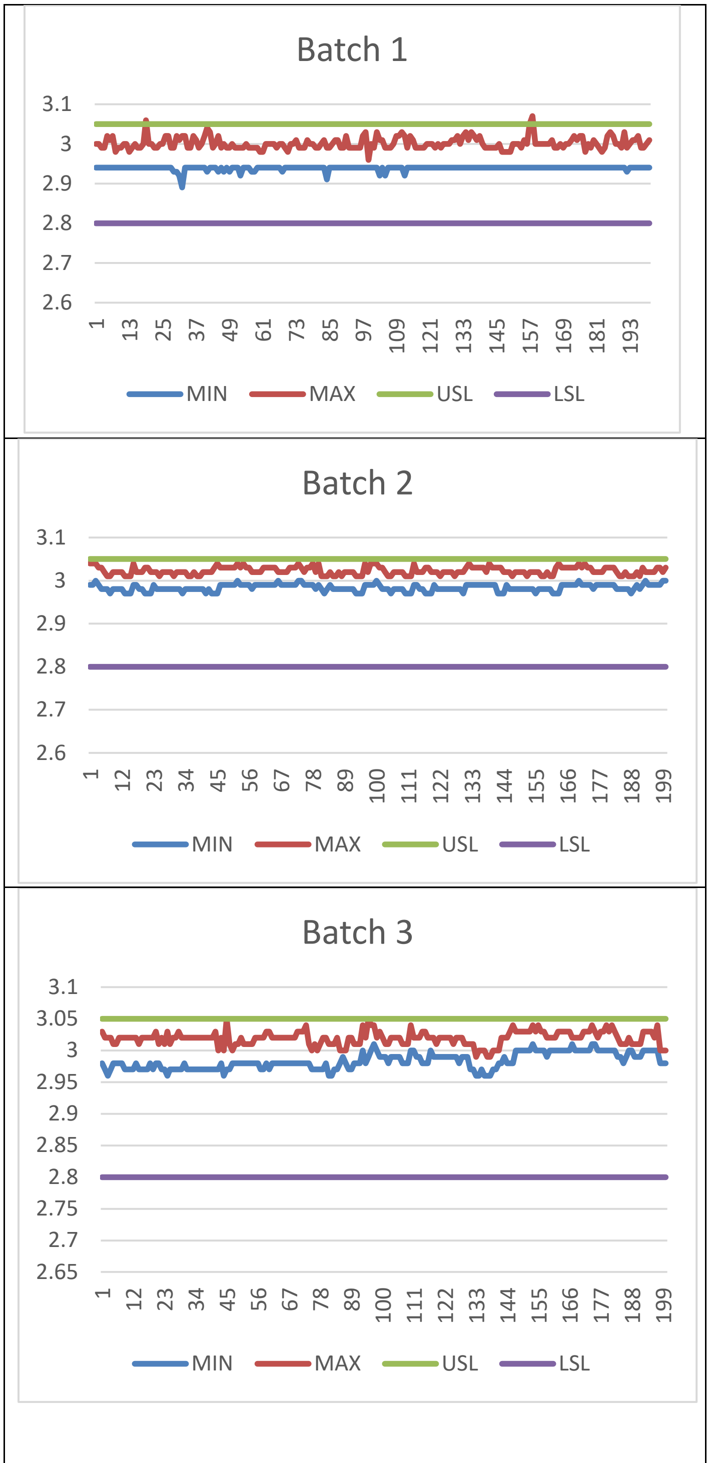

***Figure 5**: Run chart of 3 random batches of ring*

	Batch 1	Batch 2	Batch 3
Cp	1.25	1.73	1.93
Cpk	0.80	0.68	0.75

Table 3: Process capability

Many out of upper specification limits components were produced in the batch 1. While in batch 2 and 3, components very close to upper specification limits were produced. It was evident from the analysis that a lot of unacceptable components were being produced. The minimum process capability indices, Cp and Cpk for the process as shown in table 3 were 1.25 & 0.68 for batch 1 and 2 respectively, which is way less than the proposed value of 1.67.

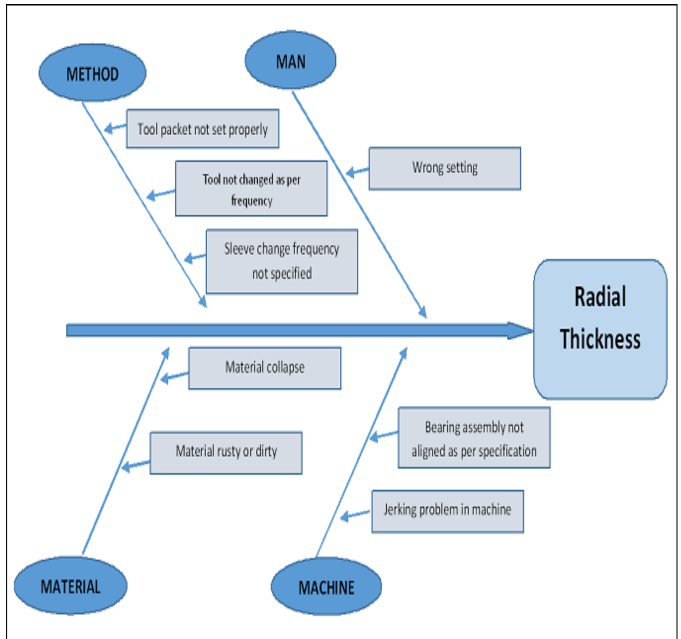

Figure 6: Root cause analysis of radial thickness

Further Ishikawa diagram for root cause analysis was made to hunt the possible causes of the problem of out of specification limit of radial thickness shown in figure 6.

Phase 3: Reporting the solution

Based upon the analysis carried out in phase 2 an action plan was developed to mitigate all the possible problems seen in root cause analysis. Table 4 shows the action plan reported for solving the problem.

S. No.	Probable cause	Action plan	Responsibility
1	Bearing assembly not aligned as per specification	Doing the accuracy check and correcting it. Setting a schedule for periodic check-in in the future.	Circle leader-Quality
2	Jerking problem in machine	Matching the slide with the help of the maintenance department and give training	Circle leader-Quality
3	Tool packet not set properly	Training the operator for error-free setup	Circle leader-Quality

4	Tool not changed as per the frequency	Training the operator for identifying a worn-out tool by visual and physical inspection	Circle leader-Quality
5	Sleeve change frequency not specified	Specifying the sleeve change time	Circle leader-Quality
6	Material rusty or dirty	Add a new step before the boring operation to check rings for rust and dirt then boring clean rings only	Circle leader-Quality
7	Material collapse	Rings must be checked for any collapse after the operation before boring	Circle leader-Quality
8	Wrong setting	Training the operator for error-free setup	Circle leader-Quality

Table 4: Action plan

Phase 4: Engage and Examine

The suggested action plan was implemented for engaging the people of the organization and for examining the effectiveness of the action plan the process Cp and Cpk value of the process after implementing the action was calculated for three batches chosen at random. The values obtained shown in table 5 improved process capability.

3 RESULTS

The run chart of the process for the three batches chosen at random after implementing the action plan is shown in figure7. Table 5 shows the improved values of C_p and C_{pk} obtained after implementing the action plan.

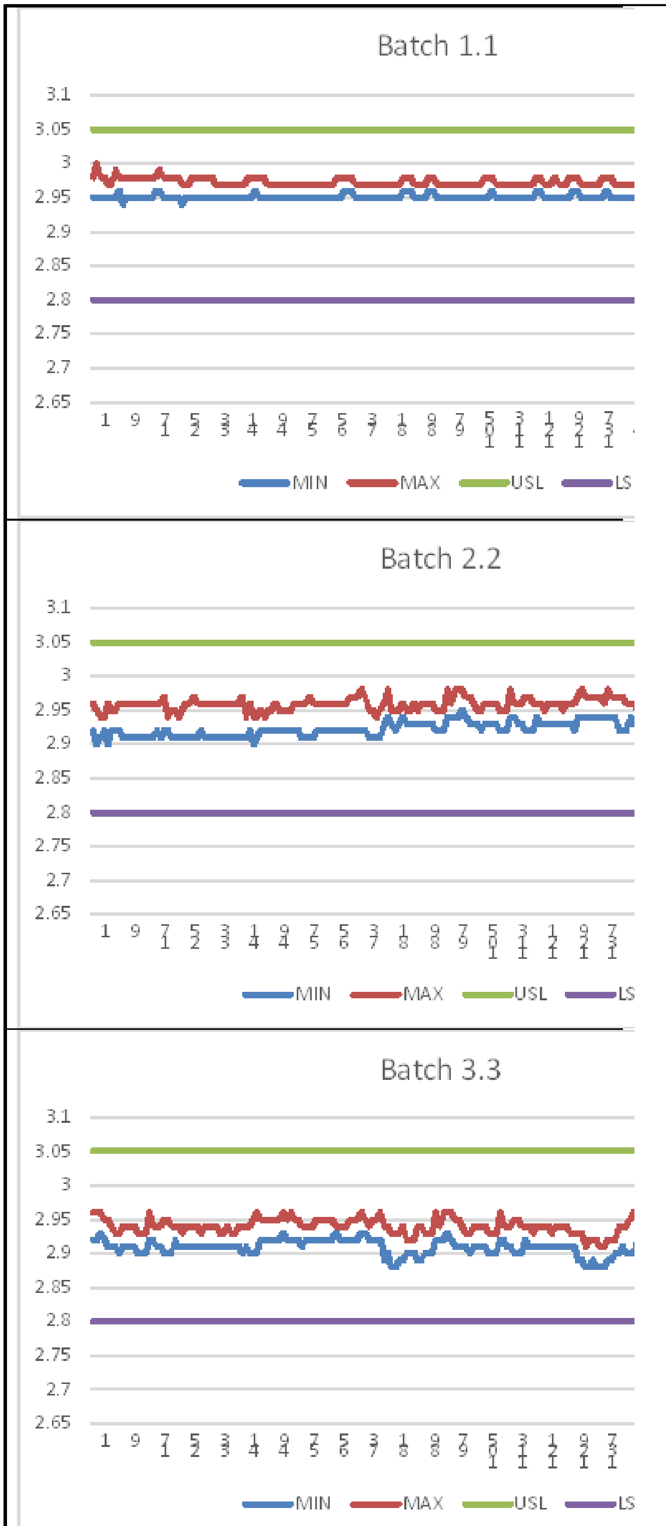

Figure 7: The run chart for the process

	Batch 1	Batch 2	Batch 3
Cp	3.47	2.07	2.22
Cpk	2.45	1.77	2.19

***Table 5**: Process capability after implementation of the action plan*

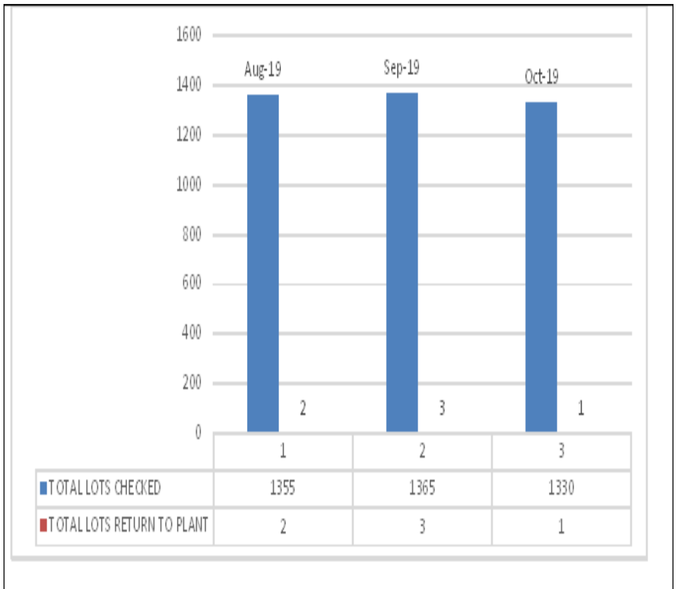

Figure 8: Histograms to analyze the month-wise rejection of piston rings

4 CONCLUSION

The value of Cpk has considerably improved and reached in acceptable limits of more than 1.67. The systematic approach towards solving problem by amalgamating the QC tools like Pareto Analysis, Ishikawa Diagram, Histograms, Run Charts, Flow Charts and core tools like FMEA, Action Plan, etc. through the phases of DARE methodology has helped in improving the process capability and reduced the rejection rate of the lots of the piston rings. A comparison of the DARE cycle with the DMAIC cycle exhibits that the DARE cycle is yet another methodology inspired by the DMAIC cycle providing efficient ways of problem-solving.

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