Defects Reduction in Manufacturing of Automobile Piston Ring Using Six Sigma

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***Abstract*—Six Sigma is one of the best emerging approaches for quality assurance and management in automobile parts manufacturing. In this research, Quality Management tools such as COPQ analysis, Data Analysis, Pareto charts, Cause and Effect diagrams, Process Capability Study, Failure Mode Effects Analysis (FMEA), Design of Experiments (DOE), Visual and Control Charts etc. are used in defining the problems in order to find the root causes for the problem and carrying out experiments in order to suggest improvements, through which the company could bring in Quality and Stability in their process. Two main reasons that strongly effect the product rejections are discovered. The new improved process is validated through a Pilot batch run. Using the six sigma method, the rejection percentage is reduced by 13.2% from the existing 38.1% of rejection. Further improvement in the rejection is expected in the long run after the continuous implementation of all the solutions.**

***Index Terms*—six sigma, piston rings, cost of poor quality, pilot batch**

I. Introduction

Rejections in manufacturing processes occur mainly due to proper systems not being in place. Even though recycling of rejected components is common these days, rejections in every process are a waste which adds up to a company's net loss especially in mass produced product layouts where components travel through a series of operations to be a final product. Hence the whole process should be made foolproof. Piston Ring manufacturing travels through a series of manufacturing processes to become the end product used in the automotives. Hence Quality Control at each station needs to be emphasized to achieve high output. Measures of preventing rejected parts from travelling to the next station should also be in place to ensure that time is not spent processing an already rejected part.

Cost of Poor Quality is "all the costs that would disappear if your manufacturing process was perfect. This includes all appraisal, prevention, and failure costs. The cost of poor quality is accounted as the annual monitory loss of an industry on its balance sheet. Apparently the cost of poor quality is not concerned with the quality only but cost of waste associated because of poor performance and process along with serious impact on companies market and good will" [1]. Tools and methodology within Six Sigma deal with overall costs of quality, both tangible and intangible parts, trying to minimize it, while, in the same time, increasing overall quality level contributing to company business success and profitability [2]. Table I indicates the proportional reduction in the Cost of Poor Quality in accordance to the reduction in the number of defective parts which is achieved through increase in process control.

This paper involves the research on the factors causing rejection of piston rings in the Automobile Piston Ring Manufacturing industry using a Six Sigma Methodology for Problem solving and control. Measurement system analysis is carried out to compare the existing systems with the control plans and the Standard Operating Procedures in place. Data analysis is done at each machine in the production line to find out the contribution of each machine in the rejection. Process Capabilities of the machines are analysed and the causes leading to the rejections are listed.

TABLE I. Six Sigma Philosophy of Cost of Quality [1]

Process Sigma Levels	Defects Per Million	COPQ as % of Sales
2	308,537 (non-competitive)	Not applicable
3	66,807	25-40%
4	6,200	15-25%
5	233	5-15%
6	3.4 (world Class)	<1%

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II. The Six Sigma Methodology

Six Sigma is a business or engineering management approach that is applied in establishments to drive and also continuously maintain transformational growth in the establishment. The Six Sigma approach focuses on realigning the process, based on the variations-those affect the process outputs- between the expected results and the actual results. The realignment process is done after a series of data collection and data analysis. Statistical Process Control tools are applied in measuring the variations in the process. Six sigma acts as an indicator that projects the variations in the process. Once the process variation is determined, quality control tools are used to narrow down to the causes that lead to the variations or the effects.

Manufacturing and mechanical engineering principles are then applied in rectifying the errors and improving the process. A Pilot batch of production is then run to measure and further amend the improvements. The Demings cycle approach – Plan, Do, Check, Act – method is utilized in the Pilot run.

The basis of the Six Sigma methodology is the DMAIC cycle. It consists of five stages: define, measure, analyze, improve, and control [3] as in Fig. 1.

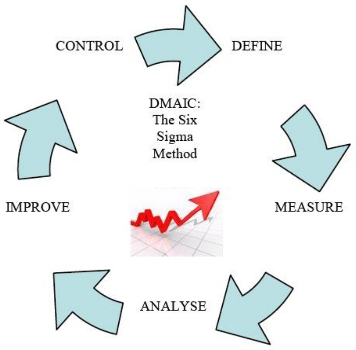

Figure 1. Six sigma approach [3]

Figure 2. Schematic diagram of piston ring

A study on the Piston Ring Tribology is presented, in which is described, the requirements to be met by the Piston ring as a dynamic seal for linear motion that operates under demanding thermal and chemical conditions [4]. The different types of pistons rings like the chrome plated, plasma coated, plain rings, oil control rings and the scraper rings are used depending on the application. The schematic diagram of automobile piston ring is shown in Fig. 2. Several wear resistant Mo blended coatings for application to the piston rings have been presented [5]. Molybdenum Plasma coated Piston Rings are manufactured through a series of operations listed in the Fig. 3.

Plasma Spraying is a kind of Thermal spraying technique in which heated and melted materials are sprayed onto a surface for coating. The purpose of Plasma Spraying is for surface protection against corrosion, erosion and wears. The materials that are used for coating the surface are metals, alloys, ceramics and composites etc. During Plasma spraying, a gas is heated to very high temperatures and fed out as a plasma jet through a gun with a nozzle. The coating materials mentioned above are then fed into the plasma jet where they melt and then adhere to the surface being coated [6]. The coating thickness may range from 20 microns to few millimeters.

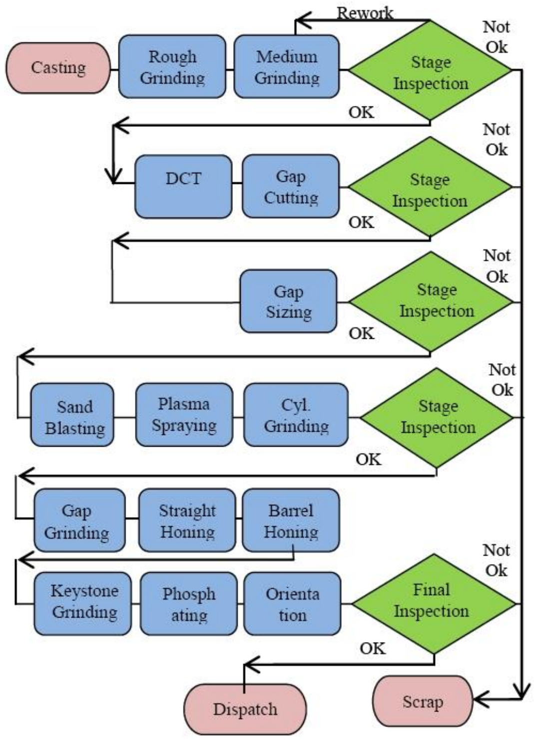

Figure 3. Process flow of molybdenum coated piston rings

Plasma Spraying is a widely used process to improve the surface of piston rings, as this process of thermal spraying has a high spray rate and deposition. The molybdenum coatings produced by atmospheric plasma spraying have a high resistance to wear [7].

A. Problem Define Phase

Fig. 4 shows the historical data of the rejection quantity of Molybdenum coated piston rings. The yield through the Manufacturing process of the Plasma Spray Molybdenum coated Piston rings in the Ring Plant is found to be 61.9% during the year of evaluation which means that the rejection rate was 38.1% .The problem identified here, is the high volume of rejections in the Ring plant for the Molybdenum coated pistons Rings.

This study aims to find out the problems in the manufacturing line of the Molybdenum coated Piston rings which comprises of around 20 stations that each ring passes through to take form of the final product, as shown in the Process flow chart in Fig. 3. The 38.1 % rejection accounts to 513,247 numbers of rings that have been rejected out of the 1,348,147 rings machined during the year of evaluation.

Manufacturing cost per ring = $ 1.2 (minimum diameter product)

COPQ = No. of rings Rejected × Price per ring
COPQ = 513247 × 1.2
COPQ = $ 615896

The COPQ being a very high amount, it is decided that the project be undertaken as a measure to reduce the cost of poor quality borne by the company.

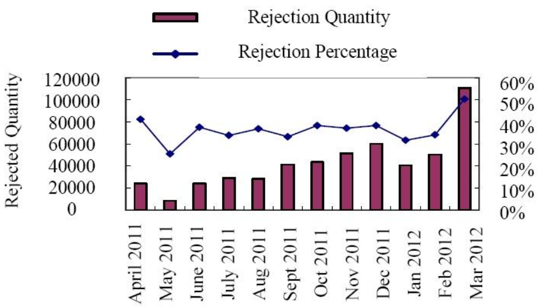

Figure 4. Historical data on the rejection quantity and % of molycoated piston rings

B. Measurement System Analysis – Measure Phase

The measure phase helps in measuring the existing system and establish valid and reliable metrics to help monitor progress towards the goals defined in the previous step. Measurement System Analysis of the Manufacturing Process is carried out to compare the Standard Operating Procedures (SOP's) with the actual procedures being followed, the reason for deviation if any, sampling details, measuring instruments and their Calibration frequencies etc.

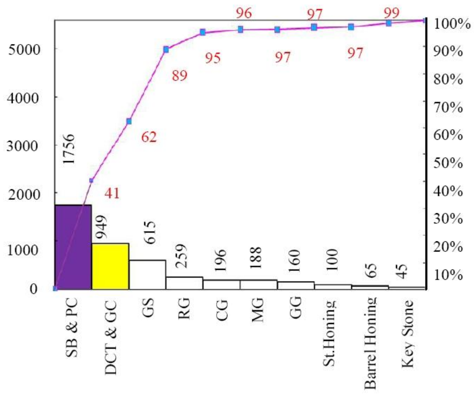

Figure 5. Pareto on the rejections at each station

Through the Data analysis, the number of rejections made at each machine as shown in Fig. 5. The major contributors for rejections are identified to be the Plasma Spray Section (which comprises both the Sand Blasting and the Plasma Spray Machines) and the Double Cam Turning Machine (DCT). The Process Capability study and the Cause and effect analysis are carried out for the two processes.

Variations were observed in the diameters of the rings along the length of the mandrel after the Spraying process and the causes were listed under the sub categories of Man, Machine, Method and Material. At the Double Cam Turning it was found that the diameters and the radial thickness of the rings after turning were oversize and the causes for this were also listed out under the four sub categories as mentioned above.

C. FMEA – Analyze Phase

FMEA is carried out for both the processes to find out the vital causes among the many causes listed in the cause and effect analysis. The vital causes for plasma spraying are listed as per its descending order of Risk Priority Number (RPN). The causes so found are as follows.

- Poor roughness at the Sand blasting
- Staggering Gun Movement
- Poor storage of mandrels
- Run out
- Occurrence of unmelts
- Irregular Coating thickness
- Machine Knowledge among operators
- Gap chip off
- Outer Diameter Edge Breakage

The vital causes for double cam turning are,

- Tool wear
- Non -segregation of abnormal blanks
- Machine condition
- Visual Inspection before operation
- Irregularities in the ring blanks
- Rings assortment
- Machine Cleaning
- Measuring Knowledge

Solutions are suggested for the above causes in the Improve phase.

D. Improve Phase

Improvements are carried out based on previous findings of the analyze phase.

1) Design of Experiments
2) Other Methods
    - Brainstorming
    - Creative Thinking
    - Bench marking
    - Alternate Selection Matrix
3) Basic tools
    - Mistake Proofing
    - Visual Standards
    - Cause and Effect
    - Process Mapping

Here we use all the above said tools to sort out solutions for the problems found out through the Analyse phase. But the most widely used tool is the Design of Experiments (DOE). It is a test or a series of tests which are intentionally performed on input variables in a system to see the effect in response variable.

Poor roughness at the sand blasting was found to be a major cause of concern that caused the variations in the ring diameter after coating. The basic science behind this is that when the surface roughness is not sufficient, there will be poor bonding of the sprayed coating on the walls of the rings. The quality and the grade of sand used for sand blasting were studied due to the poor roughness caused by it in the sand blasting section. The sand variety presently being used was Brown 46 Grit. A different variety of sand, the EK 36 grit is suggested based upon benchmarking with counterparts in Germany. They claimed that the surface roughness Ra value is tested to be higher for this new variety.

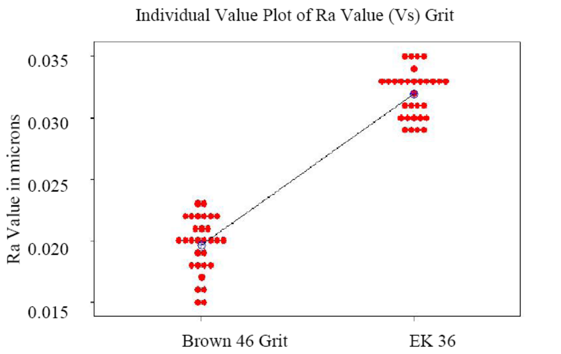

Figure 6. Relationship between Ra value and different grit size of sand

The new variety is tested practically for which 30 samples each was sand blasted with the existing sand variety namely the Brown 46 Grit and the proposed sand variety EK36 Grit. Samples were taken and roughness values were checked. Fig. 6 shows the relationship of roughness and grit sizes of the sand varieties. It states that EK 36 grit sand as suggested by the experts has given an average Ra value of 31 microns when compared to the Brown 46 Grit that gave a Ra value of only 19 microns. Hence the sand variety at the sand blasting is proposed to be changed in order to get a better surface roughness which will help in improving the bonding quality of the coated material.

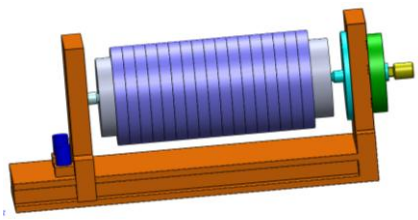

Figure 7. Mandrel stacked with rings

Additionally, run out error is also discovered at the sand blasting and the Plasma spraying sections. The piston rings are stacked on mandrels and held in between centers for both the sand blasting and the Plasma Spraying Machines as illustrated in Fig. 7. Often there occurs run out in the rotary motion due to which it can be observed that the mandrel wobbles about the center axis instead of being concentric to it. This causes irregular Blasting as well as sprayed surfaces.

A fixture carrying a plunger dial is shown in Fig. 8. It is designed to check the run out of the mandrels at the two machines. The fixture will be placed on the machine bed and the run out will be checked with respect to the bed and the machine centres. It is a typical plunger dial attachment with its base modified to suit the machines

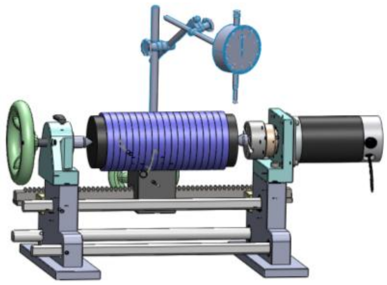

Figure 8. Solution for checking run out

The major cause for the rejections at the DCT machine was found to be due to the tool wear. It is observed that after cutting a certain number of rings the Cutting tool gets worn out thus causing the parts to be oversized and rejected.

Another problem observed was that when the tool loses its cutting efficiency, it produces a burnished surface on the rings while machining. This implies that the load multiplies on the rings since the cutting edge is blunt. This multiplication of load causes deformation of the rings which cannot be judged even with the control rings.

Control rings are the inspection gauges used for checking the diameter and the gap after DCT. This effect on the rings at the DCT machine is transferred later in the honing stage where the rings are squeezed into the sleeves and reciprocated up and down for a long time in the sleeves along with fine abrasives for honing [8]. At this stage the irregularity in the form caused at the DCT machine will effect in the edge of the ring at the gap getting chipped off.

In order to ensure that worn out tool is not used for machining, a DOE study was carried out to find out the optimum number of rings that could be machined with the help of a single tool edge or in other words to optimize the tool edge life.

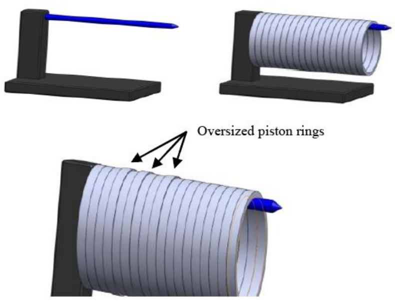

Figure 9. Piston ring alignment

It should be noted that the ring blanks are aligned using an aligning device as shown in Fig. 9. This device aligns around 60 rings at a time and these 60 rings are clamped together on the DCT machine for turning and the same setting is passed over to the Gap Cutting machine for gap cutting. Hence it is sure that if rejected the whole 60 numbers get rejected.

In DCT, as per the Control Plan, the tool is supposed to be changed after machining 25 Packets (1 packet consists of 60 rings). It is noticed that all the tools lose their cutting edge well before machining 25 packets. This happens due to the indefinite shape of the castings which imparts intermittent shocks to the tool during machining. The worn out tools are still used which either results in dimensional rejections or deformation in the shapes due to the poor cutting ability of the tool which also causes chatter marks on the rings. It is also noticed that less care is taken by the fixture which also causes the above said problem of excess cut taken by the tool.

DOE was carried out by setting a new tool and then judging its tool life. 10 samples out of 1st packet of 60 rings were inspected and similarly from the consecutive packets of 60 each. It is observed through the DOE as shown in Fig. 10, that 1260 rings can be machined with the same tool edge such that the dimensions do not go beyond the USL. The rings machined till about 1100 stay well within the control limits.

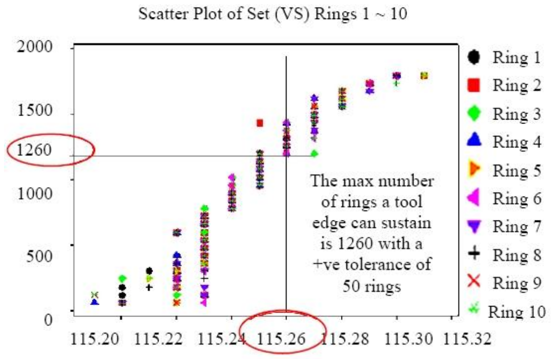

Figure 10. DOE for Tool Life optimization

Hence the optimum number of rings to be machined by a single tool edge, of the present tool being used, is 1100 which means that the tool edge has to be indexed or changed after 19 packets of 60 each (at feed = 0.125m/min and RPM = 125). An alternative approach for the same is to carry out more experiments with better tools and also by experimenting on the feed of the tool and speed of rotation of the rings in order to reach at an optimum blend of parameters.

The above derived results are only for the particular type of ring that has been selected for this project. To find out the optimum tool edge life for the other types of rings, the above mentioned process has to be deployed to the other types of rings. Once the optimum tool edge life is ascertained for all the types of rings a control chart can be displayed at all the DCT machines so that the operator knows when to change or index the tool.

Improvements of plasma spraying processes are as follows

1) The Staggering movement of the gun is reduced by deploying collapsible metal guards on the Guide rails in order to cover them from the powder particles during spraying and by lubricating the guides.
2) Racks and Trolleys are designed and fabricated to avoid the scratches and dents on the mandrels and the rings during handling and storage.
3) It is noticed during spraying process, the spray material enters the gaps in the rings which, upon release of the rings after spraying from the mandrels, causes a chip off at the gaps of the rings as shown in Fig. 11. This is found to be due to the sudden impact or the spring back effect caused on the rings on the release from the clamped position. It is suggested that the pneumatic press be replaced by a hydraulic press in order to regulate the speed of release of the rings. However, this suggestion is not been implemented as better solutions are still being thought of to curb this issue.
4) A rougher variety of sand to increase the roughness at the sand blasting process is implemented by purchasing the EK36 Grit instead of the Brown 46 Grit being used in the past. This has also been tested to prove right by conducting a DOE at the station which has been shown in the improve phase. The sand change frequency of 200 mandrels is also implemented.

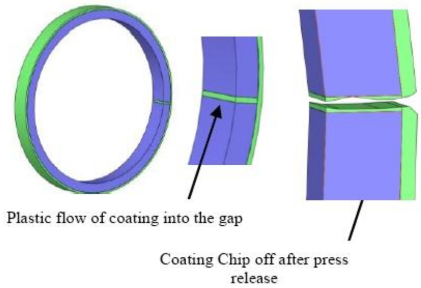

Figure 11. Illustration of edge breakage

Improvement steps for double cam turning process are

1) Through a DOE analysis the optimum number of packets that can be turned with the tool edges are determined as was explained in the Improve phase. The result is implemented for the particular type of ring taken for the experiment and this project. Similar experiment is to be carried out for all the other types of rings to find out the optimum number of packets that can be machined by a single too edge.
2) It was suggested that the foundry process be controlled in order to reduce porous blanks and blanks with indefinite shapes. Such blanks cause heavy damage to the tools as the indefinite shaped blanks have more cutting stock than the rest in the packet and it is not always easy to detect these blanks. A separate project is taken up by the foundry to control the rejections of the ring blanks due to the foundry process.
3) The operators and the stage inspectors are given proper training in order to prevent irregular and porous blanks from going through the machining process. It is to be noted that certain rings have pores inside them which may come into light only after machining Suggestions are also made to purchase scanning machines with the help of which the cracks and pores within castings can be diagnosed and segregated.

The process is run using a pilot batch of 1000 rings. Prior to running the Pilot the manufacturing staff is informed of the changes made in the process and the operators are trained in order to run the process the way it has been changed. New tools are set at the DCT machines and the pilot is run. 28 rings were rejected at the Stage inspection before DCT due to irregularities (Cracks, pores, indefinite shapes).The rejections noticed at the DCT section were the rings that were rejected due to the pores and cracks that were found in the rings after machining. 100% visual inspection was done prior to and after every operation to ensure that no rejected part goes to the next station for processing. A stage wise change or improvement in the rejection rates compared to the base values that were taken at the initial stages in the Measure Phase is illustrated in the Table II below.

TABLE II. COMPARISON OF REJECTION RATES

Stepwise Change in the Rejection Rates		
Machine	Rejection Rate (Before)	Rejection Rate (After)
DCT	26%	17%
Plasma Section	45%	38%

A Process capability Study for the Plasma spray section and the DCT is again carried to validate the results and compare them to the process capabilities of these machines before the implementation. Out of 1000 units 30 samples are taken for checking the process capabilities of the two machines for their respective CTQ dimensions. The process capabilities were found to have improved, the details of which are given in the Project Summary Scorecard in Table III.

TABLE III. PROJECT SUMMARY SCORECARD

PROJECT SUMMARY SCORE CARD	
Project Aim: To reduce rejections in the Manufacturing process of Molycoated Piston Rings	
Project Goal : 15 percent reduction in the rejection	
Rejection percent= 38.1	Estimated rejection percent =23.1
Number of rejected parts = 513,247	Simulated number of rejected parts = 335,688
COPQ = $ 615,896	Estimated COPQ = $ 402825
Cp Plasma = 0.45	Cp Plasma = 0.96
Cp DCT = 0.49	Cp DCT = 1.16
Estimated cost benefits of the Project = $213,071	
Achieved goal : 13.2 % reduction in the reject	

E. Control Phase

The control phase of Six Sigma is used to develop and implement process control plan to ensure sustenance of the improved process. It is to make sure that the process stays in control after the solutions have been implemented. The control phase helps in quickly detecting the out of control state and determines the associated special causes so that actions can be taken to correct the problem before non conformances are produced.

In this case the Control phase can be functional only after all the solutions are implemented. A few more pilot runs have to be carried out to know the stability of the process. Once the process is in control, control measures need to be taken to maintain the process as desired in long run. A control plan need to be formulated to maintain all the improvements made. The existing control systems and procedures of the process must incorporate the control of X's (Variables) and finally the responsibility of ensuring that the control plan is followed must be transited from the project leader to the process owner.

III. DISCUSSION AND CONCLUSION

The following steps need to be taken in order to further reduce the rejections in the process

- Foundry process to be improved to avoid the irregular shaped and porous rings from being cast.
- Experiments to be carried out to select a better tool or process parameters (Feed and RPM) in order to sustain the tool for larger number of packets without being worn out.
- Productivity of the CNC DCT's to be improved to eliminate the usage of conventional DCT's.
- Scanning machines to be installed in order to detect porous and cracked rings from moving to the next station after casting.
- Process capability Study to be done for the remaining machines that have not been addressed in this project, causes of rejections to be analysed and solved using the same method being used in this project.
- Many more Pilot runs to be carried out to check the stability of the improved process.
- The operators to be trained to incorporate the changes in the process so that the process is controlled.

This paper involves the study on the factors causing rejection of piston rings in the Automobile Piston Ring Manufacturing industry using a Six Sigma Methodology of Problem solving and control. Measurement system analysis is carried out to compare the existing systems with the control plans and the Standard Operating Procedures in place. Data analysis is done at each machine in the production line to find out the contribution of each machine in the rejection. Process Capabilities of the machines are analyzed and the causes leading to the rejections are listed.

It is noted that the Double cam turning Machine caused rejections in the initial stages as the tools were getting worn off, due to the non segregation of irregular piston blanks and also the non optimization of Cutting Tool Life. The cutting tool life is optimized using the Design of Experiment quality tool and visual standards are displayed to segregate the irregular piston blanks before machining. Similar study is done at the Plasma Coating section comprising of the Sand blasting and the Plasma coating processes. The major causes for rejection are, (1) run out of mandrels carrying the rings causing uneven roughness; (2) the staggering movement of the spray gun also causing irregular thickness of the sprayed Molybdenum coating and (3) poor storage of mandrels during the process. As solutions, shields are provided at the guide rail of the spray gun to prevent dust particles from sticking to the guide rails causing staggered movement of the spray gun. Better storage methods are introduced and instruments to control the run out of mandrels in between centers are also introduced in the machine set up stage.

APPENDIX A QUALITY ENGINEERING ACRONYMS

CTQ -Critical to Quality
COPQ -Cost of Poor Quality
CP -Process Capability
DMAIC -Define-Measure-Analyze -Improve- Control
DOE -Design of Experiments
FMEA -Failure Mode Effects Analysis
PPM -Parts Per Million
RPN -Risk Priority Number
SOP -Standard Operating Procedure
USL -Upper Specification Limit

APPENDIX B ENGINEERING ACRONYMS

BH -Barrel Honing
CG -Cylindrical Grinding
CNC -Computer Numerical Control
DCT -Double Cam Turning
GC -Gap Cutting
GG -Gap Grinding
GS -Gap Sizing
KSG -Key Stone Grinding
MG -Medium Grinding
PS -Plasma Spraying
RG -Rough Grinding
RPM -Revolutions Per Minute
SB -Sand Blasting
SH -Straight Honing

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