A Ph. D. Synopsis

Implementation and Computation of Performance Excellence in Connecting Rod Manufacturing Industries

Submitted to

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1. Abstract :

The present work explains the solutions of ongoing industrial problems in details related to connecting rod manufacturing operations. The solutions of each problem may not be generalized. Every existing problem is having *Tailor Made Solution* (TMS). The probable diversified options for the solutions are identified and discussed with statistical measures. The necessary remedial measures are implemented for shop floor activities for individual case. The impacts of implemented actions for each case are discussed in details. The proposed solutions are justified by feedbacks of implemented action.

The existing problems are identified from Customer Complaints Redressal Form (CCRF), Rework analysis, Rejection report, In-process Inspection Report (IIR), Final Inspection Report (FIR), Doc Inspection Report (DIR), Patrol Inspection Report (PIR), Process Capability Study Report (PCSR) and on-going shop floor production report. Five problems are identified related to connecting rod manufacturing and solutions to be implemented for individual cases.

The solutions for on-going shop floor production issues are derived with various problem solving techniques. Brainstorming session, Cause and Effect Diagram (CED) (Fish Bone Diagram), Pareto Analysis, Failure Mode and Effects Analysis (FMEA), Kaizen, etc.; are used for Tailor Made Solution (TMS) of individual cases. The solutions proposed are implemented to solve the respective production issues.

Various Quality Improvement tools are employed in various industries by many experts in one or another form in manufacturing industries. The gap is identified that there is no generalized methodology to solve the on-going problem. There is a need to generate the general steps to identify the non-conformance potential and to implement the necessary actions. The significance of modification for the best option has been long recognized as a vital to both competition and survival in present competitive business world. There are numerous ways to identify improvement potential and implement the same with higher degree of impact.

2. Brief description on the state of the art of the research topic

The internal combustion engine parts manufacturer produces many part of engine. Main parts are crank shaft, connecting rod, cam shaft, piston, cylinder, piston ring, oil ring, gudgeon pin, etc. The scope is found in manufacturing processes of connecting rod. The connecting rod is one of the most critical components of Internal Combustion Engine. The connecting rod transmits reciprocating motion of piston in to rotary motion of crank shaft. Piston is a reciprocating element; crankshaft is a rotating element while the connecting rod is an oscillating element of the mechanism. The forging of connecting rod is followed by various machining operations. Numerous improvement potentials are hidden in connecting rod manufacturing operations that are solved day by day and implemented by the manufacturer as and when arisen.

The connecting rods are most usually made of steel for internal combustion engines, but can be made of aluminum (for lightness and the ability to absorb high impact at the expense of durability) or titanium (for a combination of strength and lightness at the expense of affordability) for high performance engines, or of cast iron for applications such scooters [1] [2]. Fracture splitting technology has been used in some types of connecting rod manufacturing. Compared with traditional method, it has remarkable advantages [3].

Analytical solutions of the problem of buckling of a compressed rod made of a shapememory alloy (SMA), that undergoes direct or reverse martensite phase transition under compressive stresses, are obtained with the use of various hypotheses [4]. An optimization study was performed on a steel forged connecting rod with a consideration for improvement in weight and production cost [5].

A failure investigation has been conducted of small end of the connecting rod. The fracture occurred because of multiple-origin fatigue failure. The machining or assembling process was responsible for the formation of the axial grooves [6]. Process Failure Mode and Effects analysis (p-FMEA) and Cause and Effect diagram (CED) prepared for connecting rod manufacturing process to solve the problem [7] [8].

An informal survey for comparison of manufacturing technologies in the connecting rod industry was conducted. For mass production, non-specialty vehicles, two main methods and materials of manufacture are crack-able forged powder connecting rods and crack-able wrought forged connecting rods. It was concluded that for larger engines with lower RPM, powder metallurgy was the dominant method of manufacture. As engines progress toward smaller sizes with higher RPMs, there is a need for connecting rods with increased fatigue resistance that can be manufactured economically [9].

A study performed in 1,200 Australian and New Zealand companies [10], investigating the effect of the different TQM (Total Quality Management) factors on operational performance, proved that strong predictors of operational performance are the so-called ``soft'' factors of TQM [11] [12]. A model for Quality assurance to be employed for mechanical assembly in shop floor. [13]. The similarities and differences between TQM, Six Sigma and lean are discussed including an evaluation and criticism of each concept [14] [15]. Overall excellence model is prepared for connecting rod manufacturing industries [16].

The present study is conducted at an SME based in Gujarat, dealing with the manufacturing of various auto parts of Compression Ignition Engine. The product connecting rod face few problems like dent marks in small end after manual de-burring operation, End Float, more rework and rejection at customer end due to big end bore diameter variation. All the problems are solved with *Tailor Made Solution* (TMS) up to considerable extent.

The boundary conditions represented in diagram 1, represents the justification for selection of present work. Performance Excellence can be employed in Service industries, forging industries, manufacturing industries, designing industries, power generation and transportation industries and in medical field. The present work is concentrated in manufacturing industries. After visiting many industries, it's found that there is scope for improvement in manufacturing industries using conventional machine where more burning issues are found as far as quality and quantity is concerned.

Diagram 1.Boundary Conditions



There are Twenty Three machining operations to be carried out on a forged connecting rod. Table 1 shows the sequence of manufacturing operations needed for final product.

Sr.	Name of Operation	Sr.	Name of Operation
10	Final Cap Facing	130	Bolt Hole Final Drilling
20	Rod Face Grinding	140	Bolt Hole Cotation
30	Small End Drilling	150	Deburring, Washing and Assembly
40	Small End Final Boring	160	Big End Final Boring
50	Small End Chamfer	170	Big End Chamfer
60	Round Rib Turning	180	Opening and Notch Milling
70	Rough Joint Face (Rod & Cap)	190	Deburring, Washing, Cleaning and Assembly
80	Final Parting Face (Rod & Cap)	200	Big End Rough Honing
90	Cap Groove Milling	210	Big End Final Honing
100	Final Spot Face (Rod & Cap)	220	Small End Bush Pressing and Oil Hole Drilling
110	Big End Locater Boring	230	Small End Bush Boring
120	Bolt Hole Pre Drilling		Final Inspection

Table 1: Connecting Rod Manufacturing Operations

The Constraints

The implementation of methodology for particular solution results in many hurdles for industries as it requires changes in on-going shop floor activities. Change is always rejected first time at any normal working environment. It is a great task to convince the people for alteration in their regular work. It's needed to justify the proposed alteration with many aspects including quality, quantity, cost, comfort and many other aspects. All the hurdles are solved using practical and tailor made approach for particular action.

There are few constraints as listed below to be considered while implementing the solution of any problem.

• It is not allowed to alter any design parameter of product as it is customer requirement. The product is manufactured as per customer drawing, hence it can't be altered.

- The manufacturing line of product should not be disturbed that may result in reduction in production quantity.
- To implement any alteration, the permission should be taken from top management with proper justification.
- The data and documentation of the organization should not be shared with any one without prior permission of management.
- The confidentiality of project work to be maintained as per the management policy.

Considering the above constraints in mind, the present work is selected as represented in boundary conditions.

3. Definition of the problem

Various cases are discussed and implemented with various aspects with due impact. The impact of implemented action is measured with few parameters. The parameters used to measure impact are rejection quantity per month, rework quantity per month and Customer satisfaction (customer complaint/s per month).

Following is the list of possible rejection parameters that may be faced in connecting rod manufacturing.

- 1. Big End Bore Diameter variation
- 2. Small End Bore Diameter variation
- 3. Center Distance variation
- 4. Bend (Axial mis-alignment of both bores)
- 5. Twist(Angular mis-alignment of both bores)
- 6. Rod Face Flatness
- 7. End Float
- 8. Rod Rib Diameter
- 9. Cap Face Width
- 10. Circularity of Big End Bore
- 11. Circularity of Small End Bore
- 12. Bolt Hole Tight
- 13. Notch Missing

- 14. Dent Marks in Small End
- 15. Rod Width
- 16. Oil Hole diameter
- 17. Cap face Taper
- 18. Rod face Taper
- 19. Big End chamfer diameter
- 20. Cap Rib Dimension
- 21. Notch dimensions
- 22. Bolt Hole Center Distance
- 23. Bolt Hole Diameter variation
- 24. Rod Spot Face dimensions
- 25. Surface Finish in Big End Bore
- 26. Surface Finish in Bush

Rejection parameters mentioned from 1 to 6 are critical parameter for connecting rod. For these parameters, 100% inspection may be carried out of any batch once in a month.

Problem Discussion I

This case represents the method to compute Overall Equipment Effectiveness (OEE) in connecting rod manufacturing operations. The OEE sheet enables companies to get a quick assessment of their operations performance. The OEE sheet discussed is a powerful tool to assess the current state and to plan the future state of enterprise operations. This sheet is employed in a connecting rod manufacturing industries to provide decision-makers with sufficient input to identify improvement targets and revise the ongoing operations strategy. The use of OEE sheet is demonstrated and some insights are extracted and mentioned regarding the sheet's applicability for different types of manufacturing processes.

The data sheet prepared indicates the gray area of the shop floor. There is need to emphasize on the last manufacturing operation i.e. bush boring and bush pressing. Quality of this operation is lower as compared to other operations. This is because of more rework needed in this operation to have desired quality. The team of manufacturing unit target to improve this aspect as it is one of the most crucial step.





The team initiated in-depth study of bush pressing and bush boring operation that includes many parameters. The fish bone diagram prepared for this operation and appropriate corrections implemented to have better quality at this stage.

Problem Discussion II

The product, connecting rod faced the problem of dent marks in small end after manual de-burring operation and uneasiness to insert the gudgeon pin in small end at the time of assembly. The solution of problem is taken for the present case study. The scope for improvement potential is studied and necessary corrective measures are to be taken with the help of a kaizen approach. The critical success factors to be identified for kaizen approach [17] [18]. The present approach is checked for continuous improvement in the ongoing process with the help of cost benefit analysis.

The brain storming exercise was conducted by an interdisciplinary team of engineers at the company in order to identify potential factors that could influence the problem. The team assessed number of factors and proposed to add bush bore chamfering operation with pillar drilling machine. It eliminates manual de burring operation. The proposed solution needs to analyze with various factors like cost analysis of new machine, fixture design, man power, space, measuring instrument, gauge, tooling requirements; etc. The analysis is made for feasibility of proposed solution in detail and concluded for necessary actions.

KAIZEN SHEET

Part Name : Connecting Rod	Kaizen Idea : Avoid Manual process	Level-2	
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Counter Measure: The small end bush bore chamfering on pillar drilling machine is started in place of the manual de-burring done after bush boring. It gives better concentricity, easy insertion of pin in small end, no dent marks and avoids manual work.



Figure 2. De burring operation (Manual) Before implementation

Figure 3. Small End bush chamfering
After implementation

Analysis

- Sharpe edges generated after bush boring operation. Hence, Burrs are removed by manual de-burring operation.
- Possibility of dent marks on inner bore.
- Irregularity may possible on the edge.
- Uneasiness to insert the gudgeon pin in small end of connecting rod at the time of assembly.
- + Sharpe edges removed by Small End Bush Chamfer on pillar drill machine.
- + Better quality of edge.
- + No dent marks.
- + Reduces manual work.
- + Easy insertion of gudgeon pin in small end at the time of assembly.

FEASIBILITY OF PROPOSED SOLUTION

The addition of small end bush bore chamfering operation in production line affects numbers of other factors. It disturbs many aspects including costing, layout, machine and fixture requirement, tooling, etc. The initial investment in terms of machine cost and fixture cost, tool cost, man power cost, space utilization, measuring instrument, etc are justified to the management. The implemented action shows improvement in quality of small end bush bore. It shows reduction in customer complaint due to easy insertion of gudgeon pin in small end at the time of assembly of piston and connecting rod at the customer end. The assembly line also reported reduction in assembly time due to implemented action.



Figure 4. Pillar drilling machine



Figure 5. Fixture for implemented action

The kaizen approach presented in this case, shows improvement in quality in terms of many aspects. The dent marks in small end is eliminated and assembly of pin become faster and easier as compared to previous method.

Problem Discussion III

The primary purpose of this case study is to utilize six sigma capabilities to solve the technical problem. The study specifically examines one of the shop floor chronic quality issues to maintain the End Float in a connecting rod during the manufacturing process. DMAIC Six Sigma process is an effective and novel approach for the machining and fabrication industries to improve the quality of their processes and products [19] [20]. Using Six Sigma methodology, this study leverages various Six Sigma tools such as "Fish bone diagram, histograms, control charts and brain storming" to provide the platform for necessary actions [21] [22]. The analysis resulted in a number of findings and recommendations. The fixture of one of the machining operations needed to be redesigned and altered. The solution for the problem has been discussed and implemented that reduces rejection quantity and hence improves the customer satisfaction.

Majority of the rejection taken place because of the distance between center of bolt hole and the rod face. It was noticed that this distance measured higher in one side and lower in another side. To study the possible reason for this cause, the fixture of the bolt hole drilling machine needed to be inspected. A small monotonic change in the fraction of nonconforming process needs to be identified at the early stage for better result [23]. The fixture of the bolt hole drilling machine checked for number of parameters that includes surface roughness, taper ness, distance between locators of small end bore and big end parting face and vibration possibilities during machining operation.

For drilling operation, the big end face of the rod was located on the surface of the fixture. It was observed that the surface of the fixture used in drilling operation was tapered. This taper ness came into effect only when extreme conditions match. When the taper ness of rod co insides with the taper ness of the fixture plane, the ultimate effect of the taper ness on the rod drilling nullifies or reduces. When the taper ness of rod and fixture plane become of the same type, then the combined effect increased up to considerable amount. The linear diagram is shown in Figure 6. The possibility for this occurrence looks to be little, but it does matters for the studied rejected components.





Figure 6: Taper ness of the Big End Face of Rod and Surface plane of Fixture (Not to scale)

There are two possible corrective measures to overcome the problem. The first one is to alter the fixture plate, as it is tapered. The second is to ensure that the taper ness of rod must co inside with the taper ness of the fixture plane. This can be performed by measuring the taper ness of the rod face by dial indicator and locating the rod face accordingly on the fixture locator. The second solution is to be adopted locally for temporary solution. Hence, there is need to alter the taper ness of fixture either by fully changing the fixture or providing the packaging to the taper side.

Problem Discussion IV

This case covers the statistical control of customer defined critical parameter i.e. bend and twist of connecting rod. The connecting rod is subjected to alternative stress tensile and compressive; it is designed for compressive stress as it is higher at the time of power stroke. Bend and Twist are two dimensional parameters of connecting rod that represents the axial misalignment of axis of both the bores of connecting rod. Various methods are used in industry for the inspection of these parameters. Some methods are discussed in details and readings of these two parameters are taken. A program is prepared to calculate process capability indices to assure the dimensional quality. The value of these indices represent that the process is under statistical control. The Statistical Process Control analysis is conducted for these critical parameters of the connecting rod. The \bar{x} and R chart is prepared for continuous monitoring of the process. This chart also indicates the trend of the process and hence the chance of rejection can be interpreted [24] [25]. The cause and effect diagram for Bend and Twist variation is shown in Figure 7.



Figure 7. Cause and Effect Diagram for Bend and Twist

Problem Discussion V

The effect of temperature variation at the time of manufacturing of the connecting rod affects the dimensional quality of the product. The case study for the rejection of a lot from customer end is analyzed. A big lot was rejected from customer end because of the oversize of various parameters of big end bore. The problem is discussed in detail with the readings of the parameters. Two methods are described to overcome the problem. The correction factor is found out by taking various readings of the dimension at various temperatures. The other method is suggested to use the master piece of the similar material and calibrate the gauge at regular interval. The first method needs regular computation, whereas the second method needs frequent

checking of gauge with master piece as and when temperature variation is noticed. Hence, first method is temporary solution and second method is permanent solution.

Torque value at the time of assembly of connecting rod also having impact on bore diameter variation as represented in Figure 8.

4. Objective and Scope of work

The objectives for present work are

- To identify the improvement potential in manufacturing processes of connecting rod.
- To maintain customer satisfaction with the implementation of Quality Control tools.
- To solve shop floor issues related to Connecting Rod manufacturing operations.
- To implement Performance Excellence in Connecting Rod Manufacturing Industries.

5. Original contribution by the thesis

The solution of case studies represented in present work can be generalized with the following steps. Any shop floor issue related to connecting rod manufacturing can be solved by using these steps.

- P-PAP (Type 1): The first step is to prepare report of Production Part Approval Process Type 1. Check alignment (straightness) of the fixture with respect to reference plane. Any deviation more than allowable limit lead to inaccurate output. Take appropriate action to eliminate such deviation.
- 2. **P-PAP** (Type 2): Prepare a report of Production Part Approval Process Type-2. Measure the spindle axial alignment with respect to reference surface. Do necessary alteration if deviation is more than allowable range.
- 3. Gauge R & R Study (MSA): Check the measuring instruments and gauge with master calibration unit. (Measurement System Analysis, Gauge Repeatability and Reproducibility Study)
- Interact with Operator and Inspector for the fitness to do work with STAR technique. (Situation, Task, Action and Result) [26] [27]
- 5. Check the Patrol Inspection and Dock Inspection Reports.
- 6. Prepare First Article Inspection Report (FAIR) and may alter the frequency.
- 7. **FMEA** : Do Failure Mode and Effects Analysis for the case if needed. Prepare chart of readings. Try to find out the trend of Non-conformance. e.g. Tool change frequency, coolant temperature, operator, inspector, instrument, etc. (To find the impact of respective factor responsible for Non-conformance)

6. Methodology of Research, Results / Comparisons

The present work is applied research and not fundamental research. It deals with the solution of ongoing problem facing an industry. Fundamental research is concerned with generalizations and formulation of a theory. The central aim of applied research is to discover a solution for some practical problem [28]. A sample of graphs is shown to represent the improvement in various parameters.

7. Achievements with respect to objectives

There is reduction in rejection, rework and customer complaints. The sample is as shown in graph. Five case studies discussed in present work are solved using various techniques. It ultimately results in customer satisfaction. The objectives are fulfilled as stated.

8. Conclusion

The TMS (Tailor Made solution) is used to solve the shop floor ongoing issues. The generalization of such TMS is discussed so that it can be used for other chronic issues. The reduction in rejection, rework and customer complaints shows the impact of implemented actions. All the improvement actions discussed are implemented with management permission. Future scope of present work and supplementary improvement potential is stated that is highly significant for the people involved in connecting rod manufacturing. It also encompasses the employability of various quality assurance aspects and their implementation with due impact.

9. Copies of papers published and a list of all publications arising from the thesis

Following papers are published / presented at national/international level journals/conferences.

- Sonigra S. S., Qureshi M. N. (2015). Implementation of Bush boring chamfer to avoid manual de-burring in Connecting Rod: A Kaizen Approach. International Conference of AMPD 2015, SVNITSurat, 10-11 January 2015, (pp. 280-284).
- Sonigra S. S., Qureshi M. N. (2014). Computation of Overall Equipment Effectiveness in Connecting Rod Manufacturing Operations. *The IUP Journal of Mechanical Engineering, IUP India, Vol. VII, No.3, (pp.49-60).*
- Sonigra S.S., QureshiM.N., LohiaA.A.(2013). Review of Implementation of Overall Excellence Model in select manufacturing industries. Asian Academic Research Journal of Multidisciplinary, ISSN:2319-2801, Vol.1, Issue 16, (pp.348-363).
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10. Patents (if any)

Not applied for any patent.

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