Implementation and Computation of Performance Excellence in Connecting Rod Manufacturing Industries

A Thesis submitted to Gujarat Technological University

For the Award of

Doctor of Philosophy

in

Mechanical Engineering

by

Sunilkumar Sureshchandra Sonigra

Enrollment No. : 119997119012

Under supervision of

Dr. M. N. Qureshi

GUJARAT TECHNOLOGICAL UNIVERSITY

AHMEDABAD

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DECLARATION

I declare that the thesis entitled **“Implementation and Computation of Performance Excellence in Connecting Rod Manufacturing Industries”** submitted by me for the degree of Doctor of Philosophy, is the record of research work carried out by me during the period from **October 2011** to **October 2016** under the supervision of **Dr. M. N. Qureshi**, Associate Professor - Mechanical Engineering Department, Faculty of Technology and Engineering, The M. S. University of Baroda, Vadodara and **Dr. Kash A. Barker**, Professor, Oklahoma University, Oklahoma, USA, and this has not formed the basis for the award of any degree, diploma, associate ship and fellowship, titles in this or any other University or other institution of higher learning.

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I certify that the work incorporated in the thesis titled as **Implementation and Computation of Performance Excellence in Connecting Rod Manufacturing Industries** submitted by Mr. **Sunilkumar Sureshchandra Sonigra** was carried out by the candidate under my supervision/guidance. To the best of my knowledge: (i) the candidate has not submitted the same research work to any other institution for any degree/diploma, Associateship, Fellowship or other similar titles (ii) the thesis submitted is a record of original research work done by the Research Scholar during the period of study under my supervision, and (iii) the thesis represents independent research work on the part of the Research Scholar.

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Name of Supervisor: **Dr. M. N. Qureshi**

Place: Ahmedabad

Seal:

Annexure - VII

Thesis Approval Form

The viva-voce of the Ph.D. Thesis submitted by Shri **Sunilkumar Sureshchandra Sonigra** (Enrollment No. **119997119012**) entitled **Implementation and Computation of Performance Excellence in Connecting Rod Manufacturing Industries** was conducted on …………………….., (day and date) at Gujarat Technological University.

(Please tick any one of the following option)

☐ We recommend that he be awarded the Ph.D. degree.

☐ We recommend that the *viva-voce* be re-conducted after incorporating the following suggestions.

(briefly specify the modifications suggested by the panel)

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(The panel must give justifications for rejecting the research work)

-- Name and Signature of Supervisor with Seal

-- External Examiner -1 Name and Signature

-- External Examiner -2 Name and Signature

-- External Examiner -3 Name and Signature

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 probably diversified options for the solutions are identified and discussed with statistical measures. The necessary remedial measures are executed for shop floor activities for the individual case. The impacts of implemented actions for each case are discussed in details. The proposed solutions are justified by the feedback 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. The 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. There are numerous ways to identify improvement potential and implement the same with the higher degree of impact.

The thesis addresses five major questions in connecting rod manufacturing industries (1) Higher rejection in bush boring operation (2) dent marks in the small end (3) End float variation (4) Bend and Twist (5) Big End bore diameter variation of connecting rod.

Acknowledgement

I am very much thankful to respected Sirs, Dr. M. N. Qureshi, Dr. G. D. Acharya and Dr. M. G. Bhatt for their continuous encouragement, guidance and tremendous support. I am also thankful to respected Sir, Dr. Kash A. Barker, for invaluable guidance with International Exposure for my work. The studies described in this thesis were performed at Rajkot base Manufacturing Industries. While conducting this research project I received support from many people in one way or another, without whose support, this thesis would not have been completed in its present form. It is my pleasure to take this opportunity to thank all of you. I would like to apologize to those I do not mention by name here; however, I highly valued your kind support.

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Last but not least, my parents and my family members Neha, Devam, Diva… … … I have no word to say…

And above of all, to the supreme power who is the originator of all these occurrences, we call as GOD for my entire life.

S. S. Sonigra

Date : 02.02.2017

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List of Abbreviations

APQP	:	Advanced Production Quality Planning
CA	:	Corrective Action
CBA	:	Cost Benefit Analysis
CCRF	:	Customer Complaint Redressal Form
CD	:	Center Distance
CED	:	Cause and Effect Diagram
CTQ	:	Critical to Quality
DIR	:	Dock Inspection Report
DPMO	:	Defects Per Million Opportunity
FIR	:	Final Inspection Report
FMEA	:	Failure Mode and Effect Analysis
FPA	:	First Piece Approval
IIR	:	In-process Inspection Report
ISO	:	International Standardizations for Organization
LCL	:	Lower Control Limit
LSL	:	Lower Specification Limit
LTL	:	Lower Tolerance Limit
MSA	:	Measuring System Analysis
OEE	:	Overall Equipment Effectiveness
PA	:	Preventive Action
PCI	:	Process Capability Index
PCSR	:	Process Capability Study Report
PDI	:	Pre Dispatch Inspection Report

PIR	:	Patrol Inspection Report
P-PAP	:	Production Part Approval Process
PPM	:	Parts Per Million
QA	:	Quality Assurance
QC	:	Quality Control
QS	:	Quality Standards
SPC	:	Statistical Process Control
SPG	:	Special Purpose Gauge
SPM	:	Special Purpose Machine
SQC	:	Statistical Quality Control
STAR	:	Situation, Task, Action and Result
TMS	:	Tailor Made Solution
TPM	:	Total Productive Maintenance
TQC	:	Total Quality Control
TQM	:	Total Quality Management
UCL	:	Upper Control Limit
USL	:	Upper Specification Limit
UTL	:	Upper Tolerance Limit
WCM	:	World Class Manufacturing
ZD	:	Zero Defect

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CHAPTER – 1

Introduction

The present work deals with the solutions for an immediate problem facing an industrial organization. Hence, it comes under the category of Applied Research. The principal aim of applied research is to discover a solution for some practical problems [1]. The problems arise in the industry day by day with numerous of varieties and diversities. These problems are solved with some concealed approaches to retain secrecy policy.

1.1 Motivation

It is needed to materialize the hidden approaches conducted in industries for the solution of existing problems. There is a need to generalize the structure that can be useful for solving any industrial challenge. The generalization and implementation of various Tailor-Made Solutions are discussed in details with the appropriate outcome in the present work.

The visit and interaction with various industries were conducted at the initial stage. The reviews of concerned persons lead to identifying the need for some firm groundwork. It is concluded to participate with them for in-depth study with technical aspects of day to day activities. There are so many hidden constraints while working on the shop floor of any organization. All those aspects are discussed in details in the present work.

Initially, the approach of management towards the modification found to be challenging. It is obvious that employment of modification becomes challenging at any workstation. The commitment of top management towards continuous improvement imparted lots of encouragement to perform in-depth work and achieve the assigned duty. The management permitted working with certain conditions as per company policy. The initial success in a minor work becomes the great motivation for further work.

1.2 Background

The significance of modification for the best option has been long recognized as a vital to both competition and survival in the present competitive business world. There are numerous ways to identify improvement potential and implement the same with the highest degree of impact. Various tools used to express the enhancement potential in industries are ISO:9000 (International Standardization for Organization), QS:9000 (Quality Standard), Quality Circles, Zero Defect (ZD), Six Sigma, TQM (Total Quality Management), WCM (World Class Manufacturing), Kaizen (workplace improvement), Lean manufacturing, TPM (Total Productive Maintenance), TQC (Total Quality Control) and much more.

There has been significant research carried out to improve shop floor production activity with due impact. Various aspects are implemented in many organizations to express the improvement. After implementation of these aspects, there are equal chances of success and failure. The success of any action purely depends on the elementary aspects employed for implementation. There should be micro analysis at every step of actions for real impact of success. The area of present work is based on these aspects. The research gap is identified in this field to express the impact of the implemented action.

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 probably diversified options for the solutions are identified and discussed with statistical measures. The necessary remedial measures are implemented for shop floor activities for an individual case. The impacts of implemented actions for each case are discussed in details. The proposed corrective action plan is justified by feedback of implemented action.

The existing problems are identified from study of Customer Complaints Redressal Form (CE), 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), Pre-Dispatch Inspection (PDI) Report 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 problems raised during shop floor production are derived with various problem-solving techniques. The brainstorming session, Cause and Effect Diagram (CED) (Fishbone 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.

1.3 Boundary Condition

The boundary conditions represented in Fig. 1.1 represent 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 the 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 the conventional machine where more burning issues are found as far as quality and quantity is concerned.

The internal combustion engine parts manufacturer produces many parts of an engine. Main parts are a crankshaft, connecting rod, camshaft, piston, cylinder, piston ring, oil ring, gudgeon pin, etc. The scope is found in manufacturing processes of the connecting rod. The connecting rod of Internal Combustion Engine is one of the most critical components of the mechanism.

The function of the connecting rod is to transmit the reciprocating motion of a piston into rotary motion of the crankshaft. The 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. There are many hidden improvement potentials in connecting rod manufacturing operations, which are solved day by day as and when arisen.

Performance excellence in connecting rod manufacturing includes uses of CNC machines; layout modification of manufacturing line, weight reduction, reduction in wastage, modification in manufacturing processes, reduction in rejection or rework, reduction in the customer complaint, etc.

The present work is performed at manufacturing industries based in Gujarat, dealing with the manufacturing of various auto parts of Internal Combustion Engine. The connecting rod faces few problems like dent marks in the small end after the manual deburring operation, End Float, more rework and rejection at customer end due to the variation in big end bore diameter. All the problems are identified and solved with *Tailor-Made Solution* (TMS) up to the considerable extent.

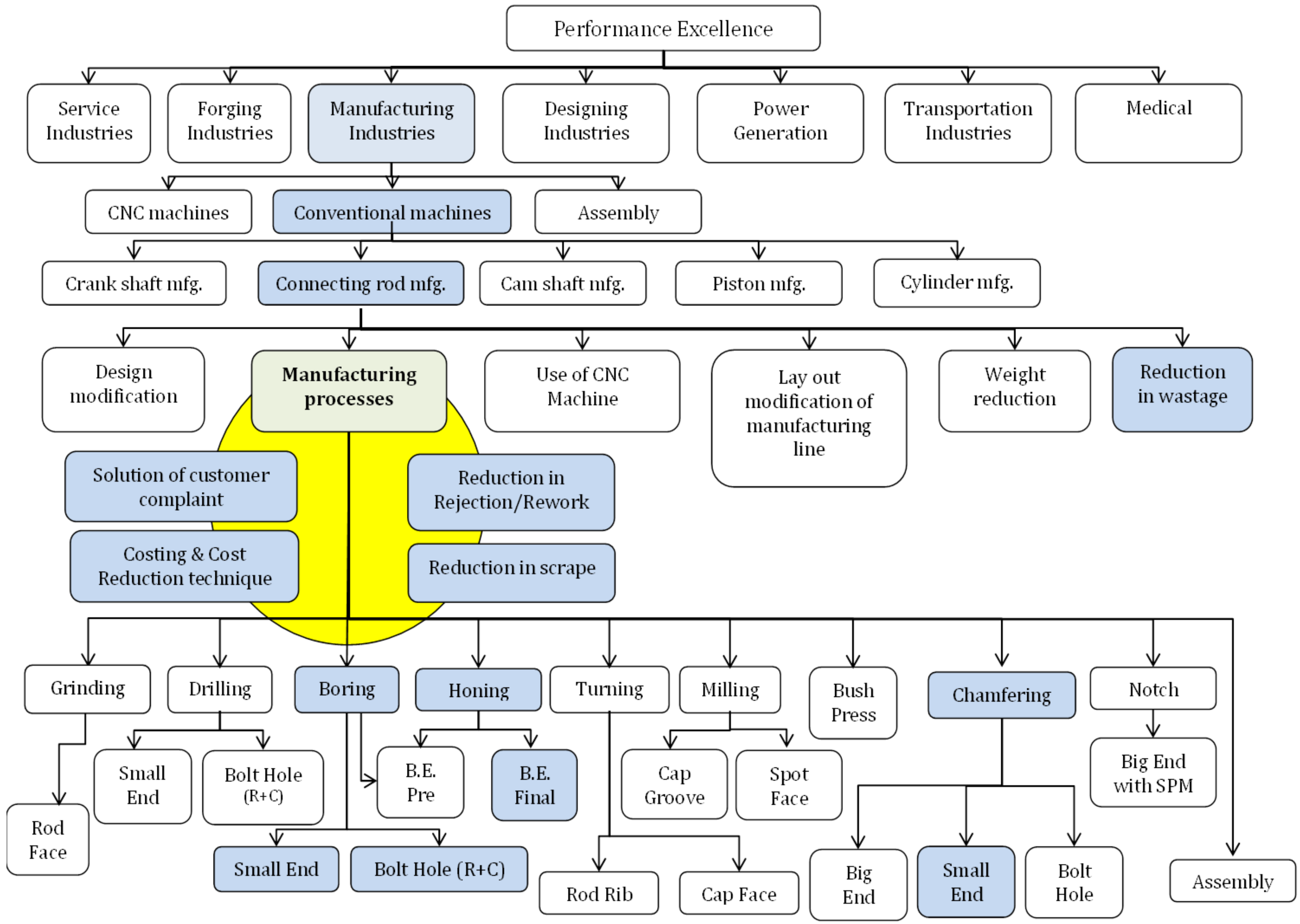


FIGURE 1.1: Boundary Conditions

1.4 The Constraints

The implementation of the methodology for a particular solution results in many hurdles for industries as it requires changes in on-going shop floor activities. Change is always rejected at the first time for 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 a particular action.

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

- It is not allowed to alter any design parameter of the product as it is the customer requirement. The product is manufactured as per customer drawing, hence it can't be altered.
- The manufacturing line of the product should not be disturbed, which may result in the reduction in production quantity.
- To implement any alteration, the prior permission should be taken from top management with proper justification.
- The data and documentation of the organization should not be shared anywhere without prior permission of management.
- The confidentiality of the 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 Fig. 1.1.

There are Twenty Three machining operations to be carried out on a forged connecting rod. Table 1.1 shows the sequence of manufacturing operations needed for the final product. Advanced Product Quality Planning (APQP) for the product was conducted earlier by the company people before starting the production. APQP is a structured method of defining the steps necessary to ensure that a product satisfies the customer requirements.

TABLE 1.1 : Connecting Rod Manufacturing Operations

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

1.5 Contribution by literature

The present work is applied research and not fundamental research. It deals with the solution of the 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 [1].

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

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.

1. **P-PAP** (Type 1): The first step is to prepare a report of Production Part Approval Process Type 1. Check alignment (straightness) of the fixture with respect to the reference plane. Any deviation more than allowable limit leads 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 the reference surface. Do necessary alteration if the deviation is more than allowable range.

3. **Gauge R & R Study (MSA)**: Check the measuring instruments and gauge with a master calibration unit. (Measurement System Analysis, Gauge Repeatability and Reproducibility Study)

4. Interact with Operator and Inspector for the fitness to do work with STAR technique. (Situation, Task, Action and Result) [2] [3]

5. **Reports**: 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 the 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 the respective factor responsible for Non-conformance)

1.6 Research Objectives

The objectives for present work are

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

1.7 Structure of the Thesis

Structure of the Thesis

Chapter 1 gives a brief description of the research work. It includes background and motivation for present work. The boundary conditions are represented along with the pre-defined constraints for present work. It also covers the research objectives and original contribution by the thesis.

Chapter 2 covers the Literature review related to present work and research gap identified after rigorous literature survey. The Research methodology employed is also discussed in details in this chapter.

Chapter 3 presents the method for computation of Overall Equipment Effectiveness (OEE) in connecting rod manufacturing processes. The OEE sheet enables companies to attain a rapid assessment of their operations performance. It highlights the gray area of the shop floor. The OEE sheet discussed is a dominant tool to evaluate 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 adequate input to identify improvement objectives and review the ongoing operations strategy. The use of OEE sheet is demonstrated and some perceptions are extracted and mentioned regarding the sheet's applicability for different types of manufacturing operations.

Chapter 4 The purpose of this chapter is to identify and outline the application of Kaizen approach on the shop floor of manufacturer of the connecting rod. After a bush boring operation, in Small End of connecting rod, pillar drill is used to eliminate dent marks and burrs, as a replacement for manual de-burring operation. It reduces manual work with better concentricity of small end and improves the quality of product up to a considerable extent. Assembly of gudgeon pin in the small end of connecting rod becomes easier as compared to the previous method due to chamfered end. The efforts made by teamwork to employ kaizen concept is documented and discussed in details.

Chapter 5 covers the discussion and solution of a technical problem identified from customer complaint redressal form . The study examines one of the shop floors long-lasting quality issues to maintain the End Float in a connecting rod during the manufacturing process. This study leverages various Six Sigma tools such as "Fishbone diagram, histograms, control charts and brainstorming" to provide the platform for essential actions. The analysis resulted in a number of findings and recommendations. The corrective actions for the problem are discussed and implemented which improves the customer satisfaction and reduces the rejection quantity. The fixture of one of the manufacturing operations needed to be redesigned and altered. The future scope of present work includes preparation of a model which correlates the interrelationships of the factors affecting the quality of the product as discussed in the brainstorming session and shown in the fishbone diagram.

Chapter 6 covers the statistical control of customer defined critical parameter i.e. axial alignment (bend and twist) of connecting rod. The connecting rod is one of the most important elements of the internal combustion engine. As it is subjected to alternative stresses, 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, which represents the axial misalignment of the axis of both the bores of a 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 assure the dimensional quality in which the process capability index (PCI) is calculated. The value of these indices represents 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 with the help of which the chance of rejection can be interpreted.

Chapter 7 discusses the effect of temperature variation at the time of manufacturing of the connecting rod. Temperature variation 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 the 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 masterpiece of the similar material and calibrate the gauge at regular interval. Failure Mode and Effects analysis are conducted to identify the rejection potential.

Chapter 8 identifies the bore diameter variation analysis with a brainstorming sheet. The solution is discussed in details with four iterations. Process Capability Study reports (PCSR) are prepared after iterations and the reason for causes are discussed. The reduction is noticed in big end bore diameter variation after proposed alteration.

Chapter 9 includes about Computation of Performance Excellence, Conclusion and Future Scope of the thesis. The method to compute performance excellence is discussed in details. It represents the impact of implemented action. The performance parameters like rejection quantity, rework quantity and customer complaints per month are considered to compute the performance excellence.

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. Future scope of present work and supplementary improvement potential is stated which 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.

CHAPTER – 2

Literature Survey and Problem Identification

In a reciprocating piston engine, the connecting rod connects the piston and crank pin. Together with the crank, they form a simple mechanism that converts reciprocating motion into rotating motion. As a connecting rod is rigid, it may transmit either a pushing force or a pulling force and so the rod may rotate the crank through both halves of a revolution. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required for pushing force [4].

2.1 Review of Research Work

The internal combustion engine parts manufacturer produces many parts of an engine. Main parts are the crankshaft, connecting rod, camshaft, piston, cylinder, piston ring, oil ring, gudgeon pin, etc. The scope is found in manufacturing processes of the connecting rod. The connecting rod is one of the most critical components of Internal Combustion Engine. The connecting rod transmits the reciprocating motion of the piston into rotary motion of the crankshaft. The piston is a reciprocating element; crankshaft is a rotating element while the connecting rod is an oscillating element of the mechanism.

Internal Combustion Engine is assembled with a number of components. Each component is also constituted by a number of parts. The final product is assembled according to the assembly process plan.

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.

Performance Excellence Process would allow determining where improvements could be made to save money and increase the quality of a product. According to NIST (2011) the term 'performance excellence' refers to an integrated approach to organizational performance management that results in (1) delivery of ever-improving value to customers and stakeholders, contributing to organizational sustainability; (2) improvement of overall organizational effectiveness and capabilities; and (3) organizational and personal learning [5] [6].

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 [7] [8]. Fracture splitting technology has been used in some types of connecting rod manufacturing. Compared with the traditional method, it has remarkable advantages [9].

Analytical solutions of the problem of buckling of a compressed rod made of a shape-memory alloy (SMA), that undergoes direct or reverse martensite phase transition under compressive stresses, are obtained with the use of various hypotheses [10]. An optimization study was performed on a steel forged connecting rod with a consideration for improvement in weight and production cost [11].

A failure investigation has been conducted for the 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 [12]. Process Failure Mode and Effects analysis (p-FMEA) and Cause and Effect diagram (CED) prepared for connecting rod manufacturing process to solve the problem [13] [14].

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 [15].

A study performed in 1,200 Australian and New Zealand companies [16], 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 [17] [18]. A model prepared for Quality assurance and to be employed for mechanical assembly on the shop floor. [19]. The similarities and differences between TQM, Six Sigma and lean are discussed including an evaluation and criticism of each concept [20] [21].

The DMAIC approach is used to analyze the manufacturing lines of a brake lever at an automotive component manufacturing company [22]. The DMAIC approach is also adopted to solve the bolt hole center distance and crank-pin bore honing operations of the connecting rod manufacturing process [23]. Six-sigma methodology is employed in the flywheel casting process that includes process map, cause and effect matrix and Failure Mode and Effects Analysis (FMEA) [24].

In an enterprise, its actions and thinking should be oriented on processes, which are included in the quality management system. Therefore, the quality of the product is not only a result of the production process, but of the whole chain of processes. Using the statistical process control (SPC) in metallurgical enterprises allows for measuring, researching, estimating and controlling one or a few parameters of the product [25].

2.2 Research gap

The quality improvement aspects are employed in various manufacturing industries to attain the mitigating situation. The need is identified to have the generalization of the steps followed to implement a structured approach. Any challenging problem can be solved using organized approach. The master key to any burning challenge can be prepared with simplification of resolution. The great improvement potential is identified in the connecting rod manufacturing processes.

Other than internal combustion engine, the connecting rod is also useful in various mechanisms. It is an oscillating element, also used in reciprocating compressor, reciprocating pump and steam engine.

2.3 Research Methodology

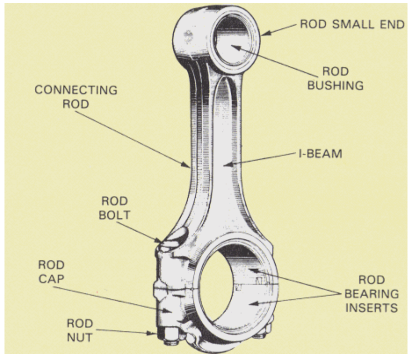
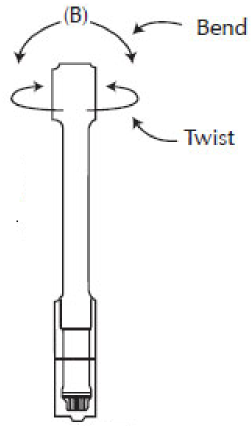
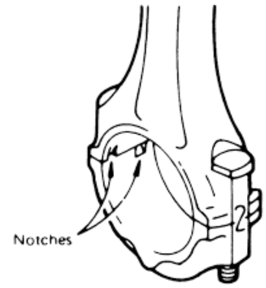
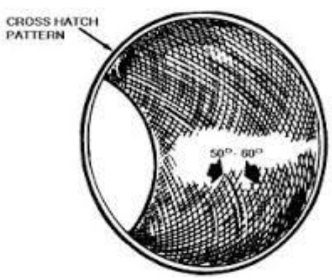
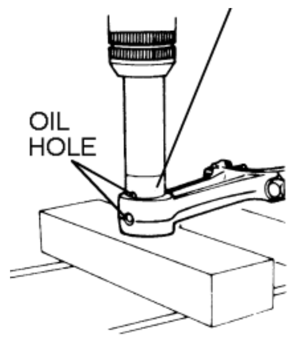
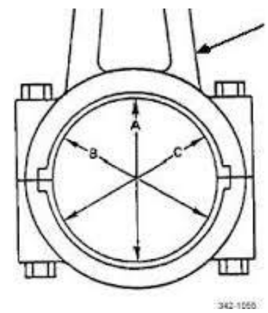
The present work is an Applied Research and it utilized the unstructured approach of inquiry mode. The central aim of applied research is to discover a solution to the practical problems, whereas basic research is directed towards finding information that has a broad base of applications and thus, adds to the already existing organized body of scientific knowledge [1].

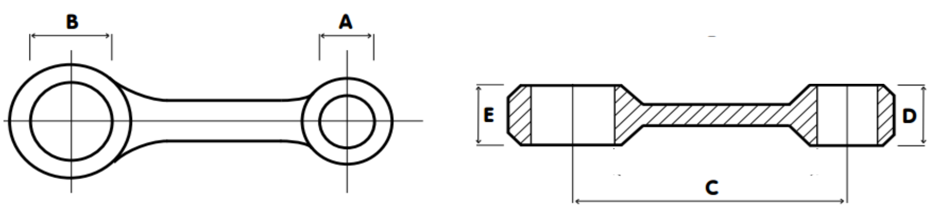
2.4 Definition of problem

The list of possible rejection parameters that may be faced in connecting rod manufacturing is represented in Table 2.1. The majority rejection parameters are variation in dimension. Some rejection parameters are related to poor surface finish, axial misalignment, irregular honing pattern, magnetism and improper packing.

TABLE 2.1 : Rejection Parameters during connecting rod manufacturing

Sr.	Parameter	Sr.	Parameter
1	Big End bore diameter variation	18	Rod Face Taper
2	Small End bore diameter variation	19	Rod Face Surface Finish
3	Center Distance variation (C.D. variation)	20	Square ness of Small End face with respect to Big End Bore
4	Bend (Axial mis-alignment of both bores)	21	Big End Chamfer Diameter
5	Twist (Angular mis-alignment of both bores)	22	Big End Chamfer angle
6	End Float more/less	23	Parting face Finish Rod and Cap
7	Big end bore width	24	Cap rib dimension
8	Rib diameter variation	25	Rod spot face dimension
9	Honing pattern in big end bore	26	Rod Spot face surface finish
10	Big End Bore Ovality	27	Bolt Hole Center Distance
11	Surface Finish in Big End Bore	28	Bolt Hole Diameter
12	Surface Finish in Small End Bore	29	Notch Length Rod & Cap
13	Big End bore Taper	30	Notch Depth Rod & Cap
14	Small End bore Taper	31	Notch Width Rod & Cap
15	Oil Hole Diameter in Small End	32	Magnetism
16	Cap Face Taper	33	Visual Inspection
17	Cap Face Surface Finish	34	Packing

 a. Connecting rod parameters	 b. Bend and twist	 c. Notches in big end bore
 d. Honing pattern in big end bore	 e. Oil hole in small end	 f. Ovality of big end bore



A : Small end bore diameter variation
B : Big end bore diameter variation
C : Center distance variation
D : Small end thickness variation
E : Big end thickness variation

FIGURE 2.1 : Rejection parameters in connecting rod

Rejection parameters mentioned from Sr. 1 to 6 are the customer defined critical parameters for connecting rod and 7th parameter i.e. big end bore width variation, is the manufacturer defined critical parameter. For these parameters, 100% inspection may be carried out of any batch once in a month.

The connecting rod should be properly demagnetized after all machining operations. it should also be passed in visual inspection and packed three pieces in one box.

The connecting rod manufacturing process faces the problems like End Float, dent marks in the small end after a manual de-burring operation, more rework and rejection from customer side due to big end bore diameter variation, bolt tight at the time of assembly and dis-assembly, etc.

The problems are identified and solved using various problem-solving techniques. The Statistical Process Control Analysis to be conducted and reports are prepared after implementation of suggested solutions.

Major rejection parameters with corrective action, specification, inspection method and frequency are represented in Table 2.2.

TABLE 2.2 : Details of Major rejection parameters

Sr.	Major Rejection parameters	Shop floor Corrective actions (CAs)	Inspection Method	Specification in mm		Range	Inspection Frequency
				LSL	USL		
1	Big End bore diameter variation[CP]	Rework with honing for undersize bore and rejection for oversize bore	Pneumatic Air Gauge, Bore Gauge	60.833	60.846	0.013	1 pc / 2 Hr
2	Small End bore diameter variation[CP]	Rework with bush boring for undersize bore and rejection for oversize bore	Pneumatic Air Gauge, Bore Gauge	37.738	37.788	0.05	1 pc / 2 Hr
3	Center Distance variation[CP]	For Longer C.D., Rod and Cap dis-assembled and contact surfaces are milled. for Shorter C.D., Bush is re-fitted and Small End bush boring to be done.	Mechanical SPG calibrated with Master (Special Purpose Gauge)	223.812	223.863	0.051	1 pc / 2 Hr
4	Bend[CP]	Small End Bush boring	Pin, Dial gauge, Height gauge, V-block	0.000	0.020/40 mm	-	1 pc / Hr
5	Twist[CP]	Small End Bush boring	Pin, Dial gauge, Height gauge, V-block	0.000	0.020/40 mm	-	1 pc / Hr
6	End Float more/less[CP]	Rod face grinding operation is done/Cap face milling to be done.	Filler gauge	0.448	0.602	0.1545	2 pc / Hr
7	Big end bore width[CP-M]	Rod face grinding operation to be done.	Mechanical Dial with comparator	39.375	39.434	0.059	1 pc / 4 Hr
8	Rib diameter variation	Rib turning of Rod to be done.	Snap Gauge set with GO and NO GO	88.040	88.110	0.07	1 pc / 2 Hr
9	Honing pattern in big end bore	Re-honing to be done manually.	Visual Inspection	Crossed Honing pattern		-	1 pc / Hr
10	Big End Bore Ovality	Torque Wrench calibration to be done in First and Second assembly	Pneumatic Air Gauge	8.3 kg m		-	1 pc / Hr
CP : Critical Parameters (Customer defined) CP-M : Critical Parameter (Manufacturer defined)			LSL : Lower Specification Limit USL : Upper Specification Limit				

CHAPTER – 3

Computation of Overall Equipment Effectiveness for Connecting Rod Manufacturing Operations

3.1 Introduction

This chapter covers 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 leading 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 in one example considered from a reputed connecting rod manufacturing company, and some insights are extracted and mentioned regarding the sheet's applicability for different types of manufacturing processes.

The **Overall equipment effectiveness** (OEE) is a hierarchy of metrics developed by Seiichi Nakajima in the 1960s to evaluate how effectively a manufacturing operation is employed and utilized. An OEE System is a powerful tool which is the best used to light up our understanding of the production process and identify opportunities to initiate improvements. The results are stated in a generic form which allows comparison between manufacturing operations in different units or manufacturing units in different industries. It is not an absolute measure but it reflects the comparative performance with each other. It is used to identify scope and direction for process performance improvement. OEE was not designed to make comparisons from machine-to-machine, plant-to-plant, or company-to-company, but it has evolved to these common levels of misuse.

If the cycle time is reduced, the OEE will increase, as more products are produced in lesser time but it is always not true. The reduction in cycle time may have an adverse effect on the quality of the product. If the adverse effect on quality is more than the improved effect due to time saving, OEE leads towards reduction.

There may be more interrelationships between many other factors. The reduction in cycle time may have influence over rejection or rework quantity. The tool wear, initial cost, machine wear and many other factors may alter if more products are produced in lesser time. Hence all impacts to be combined for computation of OEE to be a common platform for all the operations evaluation [26].

Another example is if one manufacturing operation produces better quality at the cost of time, there may be an alteration in OEE. It depends on the impact of a change in quality and change in time over the process. The improvement in quality is higher as compared to increase in time lead towards higher OEE, but improvement in quality is lower as compared to increase in time lead towards the reduction in OEE value.

3.2 Review of other research

Overall Equipment Effectiveness is a matter of prime interest for researchers for the management of asset performance. Managing the asset performance is critical for the long-term economic and business viability. To integrate a whole organization, where free flow and transparency of information is possible; and each process is linked for integrating to achieve the company's business goals is a real challenge.

A relationship analysis between Overall Equipment Effectiveness (OEE) and Process Capability (PC) measures to be conducted [27]. Process Capability uses the capability indices (CI) to help in determining the suitability of a process to meet the required quality standards. Although the statistical value of process capability indices C_p and C_{pk} equal to 1.0 indicates a capable process.

The generally accepted minimum value in the manufacturing industry of these indices is 1.33. The results of the investigation challenge the traditional and the prevailing knowledge of considering this value as the best PC target in terms of OEE. This provides a useful perspective and guides to understand the interaction of different elements of performance and helps managers to take better decisions about how to run and improve their processes more efficiently and effectively.

A measure of Six Sigma process capability using extant data from the OEE framework is introduced. Similarly, indicators of plant reliability, maintainability and asset management effectiveness were calculated taking extant data from the OEE framework [28]. The ability to compare internal performance against external competition and vice versa is argued as being a critical attribute of any performance measurement system. OEE is used to track and trace improvements or decline in equipment effectiveness over a period of time [29].

The competitiveness of manufacturing companies depends on the availability and productivity of their production facilities [30]. Due to intense global competition, companies are striving to improve and optimize their productivity in order to remain competitive [31]. This would be possible if the production losses are identified and eliminated so that the manufacturers can bring their products to the market at a minimum cost. This situation has led to a need for a rigorously defined performance measurement system that is able to take into account different important elements of productivity in a manufacturing process.

The industrial application of OEE, as it is today, varies from one industry to another. Though the basis of measuring effectiveness is derived from the original OEE concept, manufacturers have customized OEE to fit their particular industrial requirements. Furthermore, the term OEE has been modified in literature to differentiate other terms with regard to the concept of application. This has led to widening the concept of OEE to many measures. This includes total equipment effectiveness performance (TEEP), production equipment effectiveness (PEE), overall plant effectiveness (OPE), overall throughput effectiveness (OTE), overall asset effectiveness (OAE) and overall factory effectiveness (OFE).

Major six big losses from a palletizing plant are discussed in a brewery which affects OEE [32]. The most successful method of employing OEE is to use cross-functional teams aimed at improving the competitiveness of business [33]. Two industrial examples are discussed of OEE application and analyzed the differences between theory and practice [34]. A framework proposed for classifying and measuring production losses for overall production effectiveness, which harmonizes the differences between theory and practice and makes possible the presentation of overall production/asset effectiveness that can be customized with the manufacturers needs to improve productivity.

When machines operate jointly on a manufacturing line, OEE alone is not sufficient to improve the performance of the system as a whole. A new metric OEEML (overall equipment effectiveness of a manufacturing line) for manufacturing lines and an integrated approach to assessing the performance of a line is presented [35]. OEEML highlights the progressive degradation of the ideal cycle time, explaining it in terms of the bottleneck, inefficiency, and quality rate and synchronization-transportation problems.

3.3 Objectives of OEE

- To identify a single asset (machine or equipment) and/or single stream process related losses for the purpose of improving total asset performance and reliability.
- To provide the basis for setting improvement priorities and beginning root cause analysis.
- To develop and improve collaboration between asset operations, maintenance, purchasing and equipment engineering to jointly identify and eliminate (or reduce) the major causes of poor performance.
- To identify hidden or untapped capacity in a manufacturing process and lead to balanced flow.
- To identify and categorize major losses or reasons for poor performance.
- To track and trend the improvement, or decline, in equipment effectiveness over a period of time.

3.4 Implementation

Overall equipment effectiveness (OEE) is related measurements that report the overall utilization of facilities, time and material for manufacturing operations. It directly indicates the gap between the actual and ideal performance. It quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run.

OEE analysis starts with Plant Operating Time which is the amount of time the facility is available and open for equipment operation. Planned Production Time, excludes Planned Shutdown Time from Plant Operating Time. Planned Shutdown time includes all events that should not be included in efficiency analysis because there is no intention of running production. The events like scheduled maintenance breaks and the planned period where nothing is to be produced are considered in planned shutdown time.

The OEE measure is defined as the ability to run equipment at the designed speed with zero defects. In order to maximize OEE, the major losses should be reduced. The literature review on OEE evolution reveals a lot of differences in the formulation of equipment effectiveness. The main difference lies in the types of production losses that are captured by the measurement tool. Though the original OEE tool identifies six major losses in a production setup, other types of losses have been found to have a significant contribution to the overall production loss.

OEE breaks the performance of a manufacturing unit into three separate components. The components are Availability, Performance and Quality. These components are measurable and point to an aspect of the process that can be targeted for improvement. OEE can also be applied to any individual work center or production unit or plant level. It also allows knowing very specific analysis like shift, particular part number or any of several other parameters. The ideal value of OEE would be 100%, but achieving value up to 80 % is quite remarkable.

3.5 OEE factors and Computation sheet

Three measurable components for the calculation of OEE are as follows.

1. Availability = $\frac{Operating\ Time}{Planned\ Time}$

It represents the percentage of scheduled time that the operation is available to operate. It also takes into account the fraction of Down Time Loss. It covers equipment failures, unavailability due to accidental reasons and change over time and material shortages. Changeover time is a form of downtime which may not be possible to eliminate but can be reduced up to a considerable extent. Availability is a pure measurement of Uptime that is designed to exclude the effects of Quality, Performance and Scheduled Downtime Events.

2. Performance = $\frac{Ideal\ Cycle\ Time}{Operating\ Time}$

It represents the speed at which the Work Center runs as a percentage of its designed speed. It takes into account Speed Loss, which includes any factors that cause the process to operate at less than the maximum possible speed when running. It covers operator efficiency, variation in feeds, substandard materials and machine tool wear. Ideal Cycle time is the minimum cycle time that the process can be expected to achieve in optimal circumstances. It is also called as Theoretical Cycle Time or Design Cycle Time. Performance is a pure measurement of speed that is designed to exclude the effects of Quality and Availability.

3. Quality = $\frac{(Total\ production - Defectives)}{Total\ Pieces\ produced}$

It represents the good units produced as a percentage of total units produced. It takes into account Quality Loss, which accounts for produced pieces that do not meet quality standards, including pieces that require rework. Quality is a pure measurement of Process Yield that is designed to exclude the effects of Availability and Performance.

OEE = Availability x Performance x Quality

Hence, OEE considers all three factors i.e. availability, performance and quality. These three measures indicate the degree of conformation to output necessities. OEE gives one magical number which is a measure of usefulness and effectiveness. It includes three numbers which are all useful individually as the circumstances vary from day to day. It also helps to visualize performance in modest terms. This is in agreement with the definition in literature that OEE measures the degree to which the equipment is doing what it is supposed to do base on availability, performance and quality rate. OEE percentages are useful when tracking and trending the performance effectiveness (reliability) of a single piece of equipment or single-stream process over a period of time.

Determining how management intends to use the OEE score is a very important reflection in the planning process for executing an OEE System. If the score is used as a mean to penalize or reward, the staff may be encouraged to manipulate the data, which will dilute the impact of potential assistances from OEE. It is, therefore, necessary to focus one's attention beyond the performance of individual equipment toward the performance of the whole manufacturing works. The ultimate objective of any factory is to have a highly efficient integrated system and not brilliant individual equipment [36].

The details are prepared as shown in Table 3.1, for machining operations of a product to compute OEE to enlighten the working environment of shop floor activities.

TABLE 3.1 Computation Sheet of OEE for each operation

1	Shift Length	10	Hours =	600	Minutes		
2	Short Breaks	2	Breaks @	15	Minutes Each =	30	Minutes Total
3	Meal Break	1	Break @	60	Minutes Each =	60	Minutes Total
4	Planned Production Time = Shift Length – Break=					510	Minutes
5	Operating Time = Planned Production Time - Down Time						
6	Good pcs = Total pcs – Rejected pcs						

Operation No.	Operations	Down Time	Planned production Time	Operating Time	Availability (%)	Time per pc. (sec.)	Ideal Rate pcs/hr	Total pcs produced/hr	Performance (%)	Rejection/Rework	Good pcs	Quality (%)	OEE (%)
10	Cap Facing	75	510	435	85.29	40	82	60	73.17	5	55	91.67	57.2
20	Rod Face	80	510	430	84.31	45	73	55	75.34	4	51	92.73	58.9
30	Small End Drilling	56	510	454	89.02	45	73	52	71.23	5	47	90.38	57.3
40	Small End Boring	65	510	445	87.25	70	47	35	74.47	4	31	88.57	57.6
50	Rod Rib Turning	70	510	440	86.27	67	49	39	79.59	5	34	87.18	59.9
60	Rough Joint Face	75	510	435	85.29	70	47	38	80.85	3	35	92.11	63.5
70	Final Joint Face	70	510	440	86.27	95	34	27	79.41	4	23	85.19	58.4
80	Cap Groove	75	510	435	85.29	82	40	33	82.50	4	29	87.88	61.8
90	Spot Face (R+C)	80	510	430	84.31	61	54	44	81.48	5	39	88.64	60.9
100	Bolt Hole Rough Drilling	78	510	432	84.71	38	86	71	82.56	7	64	90.14	63.0
110	Bolt Hole Final Drilling	80	510	430	84.31	35	94	81	86.17	9	72	88.89	64.6
110	Bolt Hole Final Drilling	80	510	430	84.31	35	94	81	86.17	9	72	88.89	64.6
	Quotation												
	Assembly-1												
120	B.E. Pre boring	85	510	425	83.33	70	47	40	85.11	6	34	85.00	60.3
130	B.E. Final boring	80	510	430	84.31	40	82	70	85.37	6	64	91.43	65.8
140	B.E. Chamfer	85	510	425	83.33	40	82	71	86.59	8	63	88.73	64.0
	Dismental												
150	Notch (SPM*)	75	510	435	85.29	22	149	121	81.21	11	110	90.91	63.0
	Assembly-2												
160	B.E. Rough Honing	80	510	430	84.31	42	78	69	88.46	8	61	88.41	65.9
170	B.E. Final Honing	90	510	420	82.35	33	99	79	79.80	8	71	89.87	59.1
180	Bush Pressing	75	510	435	85.29	51	64	55	85.94	14	41	74.55	54.6
180B	Bush Boring	75	510	435	85.29	51	64	55	85.94	14	41	74.55	54.6

*SPM : Special Purpose Machine

Equations:

A. Availability = $\frac{Operating\ Time}{Planned\ Time}$ x 100 %

B. Performance = $\frac{Actual\ produced\ Quantity}{Ideal\ production\ Quantity}$ x 100 %

C. Quality = $\frac{(Total\ production - Defectives)}{Total\ Pieces\ produced}$ x 100 % = $\frac{(Good\ pcs\ produced)}{Total\ Pieces\ produced}$ x 100 %

D. Overall Equipment Effectiveness = Availability x Performance x Quality

3.6 Analysis

The data sheet prepared indicates the gray area of the shop floor. There is a need to emphasize the last manufacturing operation, i.e. bush boring and bush pressing. The 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 targets to improve this aspect as it is one of the most crucial steps.

The team initiated the deep study of bush pressing and bush boring operation which includes many parameters. The fish bone diagram prepared for this operation as shown in Fig. 3.1. The following actions were taken and appropriate corrections implemented to have better quality at this stage.

- Alignment (straightness) of the fixture checked and found correct.
- The spindle axial alignment checked and corrected with necessary action.
- Tool wear measured for a lot size and suggested to alter the tool change frequency as the previous one was inadequate.
- Measuring instrument checked with master calibration unit and found correct.

Operator interviewed for his fitness to the work and asked for necessary improvement.

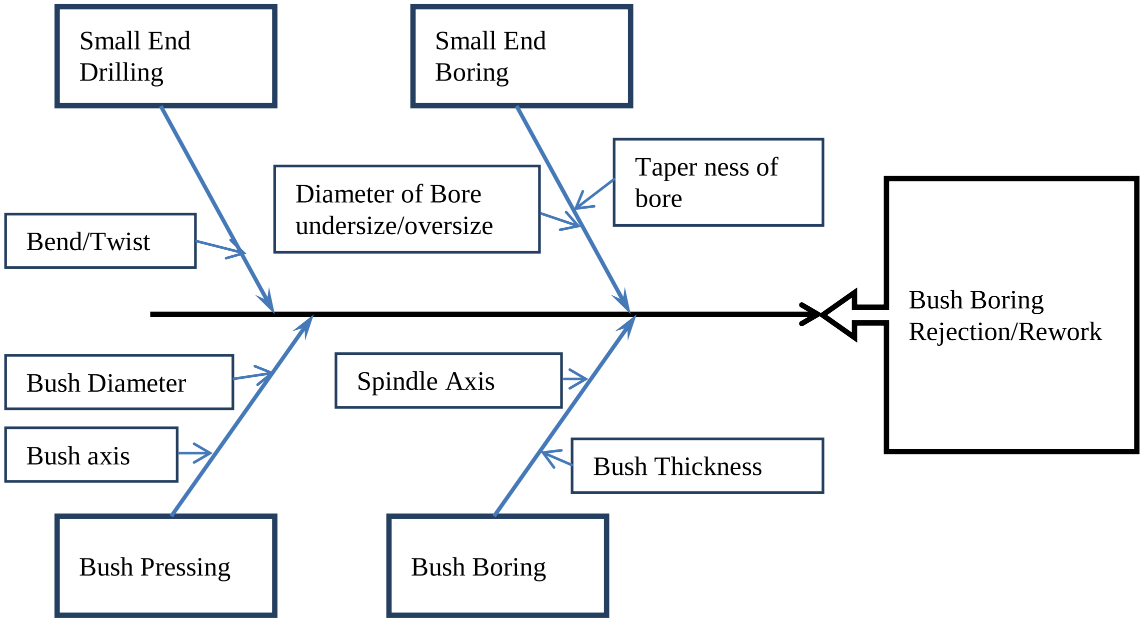


FIGURE 3.1 : Fishbone diagram showing rejection potentials

3.7 Results and discussion

The tool change frequency altered from 500 pcs to 400 pcs in bush boring operation. The impacts of employed actions are represented in the graph. There is a reduction in variation in the center distance parameter (Fig. 3.2 and 3.3). There is a reduction in rework (Fig. 3.4), rejection (Fig. 3.5) and customer complaints (Fig. 3.6) for this parameter.

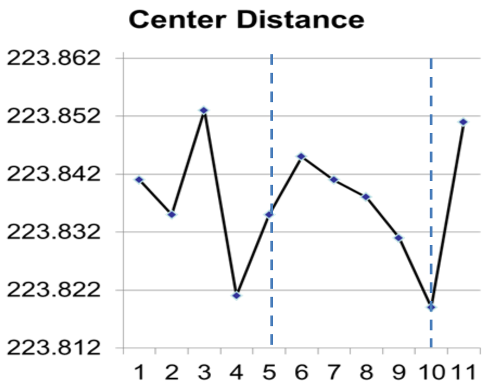


FIGURE 3.2 : Variation in Center Distance before implementation (More variation)

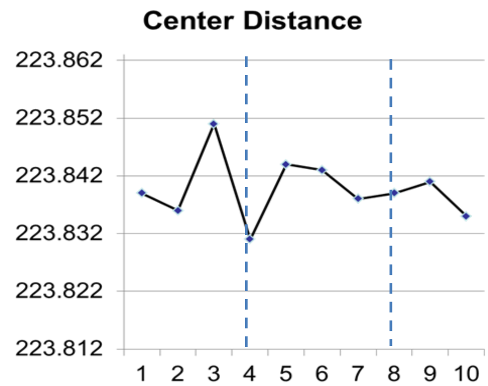


FIGURE 3.3 : Variation in Center Distance After implementation (Less variation)

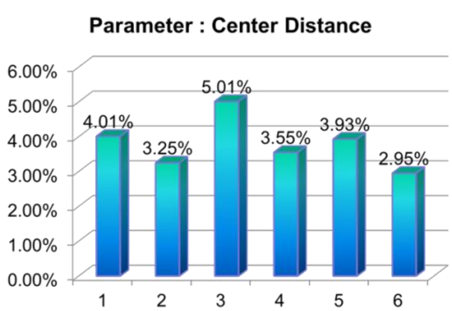


FIGURE 3.4 : Rework % (monthly)

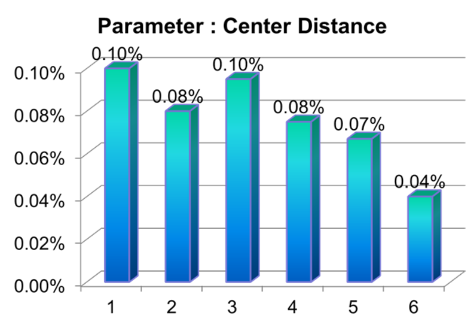


FIGURE 3.5 : Rejection % (monthly)

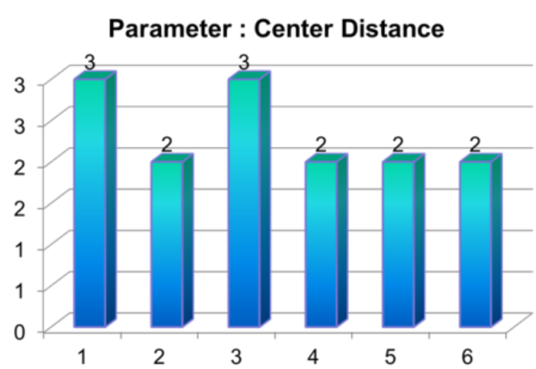


FIGURE 3.6 : Customer Complaints (monthly)

3.8 Limitations for using OEE system

- The percentage calculation of OEE is statistically cannot be said valid. A calculated OEE percentage assumes that all equipment-related losses are equally significant and any improvement in the value of OEE is a positive improvement for the whole plant. This may not be true for all the cases. For example, the calculated OEE percentage does not consider that two percent improvement in quality may have a bigger impact on the business than does a two percent improvement in availability.

- Calculated OEE is not valid for benchmarking or comparing various processes, assets or equipment. It is a relative measure of a specific single asset effectiveness associated with it over a period of time. However, OEE can be used to compare identical equipment in identical situations producing identical output.

- The calculated OEE cannot be used as a corporate level measure. It is just an estimated measure of selected equipment effectiveness only.

- Also, it does not measure maintenance effectiveness because most of the loss factors are not under the direct control of the maintainers.

3.9 Summary

OEE System identifies the problem area and accurately the symptoms of each problem. However, the real opportunity lies in the ability to determine the root causes for each loss, and then to implement effective corrective actions to abolish them. OEE Systems can also be used to gather supplementary data, create and report against improvement plans/agendas, and verify or authenticate the actions taken to resolve the issues identified.

To achieve a successful implementation and to optimize the success of an OEE System, organizations must focus to ensure an assurance to practice it as a fundamental, organization-wide tool to drive continuous improvement in an effective mode. OEE can be applied to manufacturing, petrochemical processes and environmental equipment. Overall, OEE can be visualized in a single statement as, *Implementation of OEE System can be compared to* *switching on the light in a darkened chamber. Nothing has changed, but the things can be seen more clearly.*

CHAPTER – 4

Implementation of Bush Boring Chamfer to avoid manual De-burring in connecting rod: A Kaizen Approach

4.1 Introduction

Numerous organizations have adopted the practice of Kaizen as a mean for obtaining the alternatives for continuous improvement. Many articles have addressed the implementation of Kaizen in different industries.

The purpose of the present work is to identify and outline the application of Kaizen approach on the shop floor of connecting manufacturing operations. After the bush boring operation, in Small End of connecting rod, pillar drill is used to eliminate dent marks and burrs, as a replacement for manual de-burring operation. It reduces manual work with better concentricity of small end and improves the quality of product up to a considerable extent.

Assembly of gudgeon pin in the small end of connecting rod becomes easier as compared to the previous method due to chamfered end. The efforts made by teamwork to employ kaizen concept is documented and discussed in details. Future scope of present work and supplementary improvement potential is stated which is highly significant for the people involved in connecting rod manufacturing.

4.2 Literature Review

Kaizen in one of the most important methodologies used to manage continuous improvement in maquiladora industry located in Ciudad Juarez, Chihuahua, Mexico; however, it is frequently implemented without obtaining the expected results. The survey was validated using a rational validation, judge validation, and statistical validation using the Cronbach alpha index. The result indicated that seven factors are the most important: education and training in operators, communication process, documentation and evaluation of projects results, human resources integration, management commitment and customer focus [37]. Management commitment and education are the main factors that guarantee the success of kaizen implementation programs, but that is moderated by a good communication for having good operational process performance for better workers and customer satisfaction [38].

Kaizen is a way of thinking and managing. Its essence is the continuous improvement of processes in an enterprise through small steps performed by all employees. Processes of implementing new ideas are more efficient when it is supported with kaizen activities. It is a slower but permanent improvement of things, starting from simple improvements of tools and working methods, finishing with the improvement of whole processes performed by all employees achieved with small steps in a way that does not require considerable investments.

A continuous improvement is a tool used by Toyota production system (TPS) and is also called kaizen. It is not only the process of fostering creativity, raising the spirit and forming energy, but it is also the best tool for creating value problems quickly. However, the most effective way to achieve the above is to improve endlessly and train employees to improve the enterprise and make it the culture of the enterprise. Continuous improvement needs to form across function groups to improve certain areas and identify the process or problem. Its operation includes educational training, understanding problems, evaluating problems, brainstorming, execution, standardization, achievement record, post event handling and reporting [39].

Improving individual operation yield is an important way to increase the system yield. Studies in this field try to stabilize the process either by finding root causes of variation and eliminating them or by making the process insensitive to external agitations [18].

4.3 Research Methodology

The aim of present work is to implement the new idea to replace manual operation with drilling machine for better concentricity and consistency. Hence, it is an *Applied Research* used for a solution of an immediate problem facing an industry. The observations were taken according to definite pre-arranged plans and involve experimental procedure. The controlled observations data is collected and documented for analysis. Such observations have a tendency to supply formalized data upon which generalizations can be built with some degree of assurance [1].

In machining, the objects in quality control are geometrical dimension, tolerance, surface finish, and relative tolerances on individual part. In mechanical assembly, the quality control is oriented to confirm the correct relations between a group of parts or components and the precisions with multi-dimensions, shapes, or relative position tolerances [19].

The methodology employed in present work is purely shop floor base activity. The case study discussed for implementation, cannot be generalized for other work as it is completely *Tailor-Made Solution* (TMS). It has focused on a practical description of Kaizen approach in the production line.

4.4 Problem Statement

The product, connecting rod faced the problem of dent marks in the small end after manual de-burring operation (Fig. 4.1) and uneasiness to insert the gudgeon pin on the small end at the time of assembly. The solution of the 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 present approach is checked for continuous improvement in the ongoing process with the help of cost-benefit analysis (CBA).

The brainstorming 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 a number of factors and proposed to add bush bore chamfering operation with pillar drilling machine as shown in Fig. 4.2. It eliminates manual de-burring operations. The proposed solution needs to analyze various factors like cost analysis of new machine, fixture design, manpower, space, measuring instrument, gauge, tooling requirements; etc. The analysis is made for the feasibility of proposed solution in detail and concluded for necessary actions.

4.5 KAIZEN SHEET

Part Name : 2.2 L Hino Con Rod	Level-2
Kaizen Idea : Avoid Manual process	
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 the pin in small end, no dent marks and avoids manual work.	
Analysis - Sharpe edges generated after the bush boring operation. - Burrs are removed by manual de-burring operation. - A possibility of dent marks on inner bore. - Irregularity may possible on the edge. - Uneasiness to insert the gudgeon pin in the 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 the small end at the time of assembly.

FIGURE 4.1 : Manual De-burring operation (Before implementation)

FIGURE 4.2 : Small End Bush Chamfering with Pillar Drill (After Implementation)

4.6 Feasibility of proposed solution

The introduction of small end bush bore chamfering process by pillar drilling machine (Fig. 4.3) in production line results in numbers of other factors. It disturbs many aspects including costing. The initial investment in terms of machine cost and fixture cost, tool cost, manpower cost, space utilization, measuring instrument, etc are justified to the management. The fixture is prepared for the proposed action plan as shown in Fig. 4.4. The implemented action shows improvement in the quality of small end bush bore. It shows the reduction in customer complaint due to easy insertion of gudgeon pin in the small end at the time of assembly of the piston and connecting rod at the customer end. The assembly line also reported the reduction in assembly time due to implemented action.

FIGURE 4.3 : Pillar Drilling machine

FIGURE 4.4 : Fixture for implemented action

4.7 Concluding Remarks

The purpose of this chapter is to describe the implementation of continuous improvement in connecting rod manufacturing operation. The kaizen approach presented shows improvement in quality in terms of many aspects. The dent marks in the small end are eliminated and assembly of pin becomes faster and easier as compared to the previous method. Further research in this area will need to focus on the practical experience of other aspects of other manufacturing operations.

Indeed, the concept of kaizen is outstanding road-maps, which could be used in order to strengthen the practices within an organization. Even if some of the other concepts have been accused of being management trends, it is the authors' interpretation that organizations continuously need to work with customer-orientated activities in order to survive; irrespective of how these activities are labeled today and in the future.

CHAPTER – 5

Control Variation in End Float Parameter with the Application of Six Sigma Tools

5.1 Introduction

Six Sigma tools are widely used by a number of reputed industries to solve the burning issues of the shop floor. The manufacturing of product involves the number of operations, quality of which affects the quality and performance of the final product. There is a scope to interrelate these operations' quality and their effect on the final product. The control of the operations at individual stages results in better outcome. This chapter proposes the proper implementation of various Six Sigma tools to solve the longer existed problem named as End Float of connecting rod.

5.2 Literature review

The number of companies has developed and implemented Six Sigma approaches. At Samsung, Six Sigma projects usually focus on either redesigning processes and systems or improving performance levels of existing systems [40]. Honeywell is known for the extensive application of lean methodologies, which has become a major tool in their Six Sigma implementation. Honeywell developed a proprietary Six Sigma approach called Six Sigma Plus which links lean manufacturing concepts and tools [41].

A key element of General Electric's approach to Six Sigma is tailoring underlying methodologies to specific needs and characteristics of its business units. The company has taken the generic Six Sigma methodology for process innovation and has tailored their specific needs of system design and implementation as well as product development activities.

Six Sigma Quality quantitatively means that the average review process generates 3.4 defects per million units – where a unit can be anything ranging from a component to a line of code or an administrative form. This implies that nearly flawless execution of key processes is critical to achieving customer satisfaction and productivity growth [42]. The Six Sigma initiatives in TCS-GEDC (The Global Engineering Development Center of Tata Consultancy Services) started in 1998, and, since then, 11 Six Sigma projects have been completed and five are in progress. These projects include Improvement of Schedule Compliance, Quality Compliance, Input Quality, Error Reduction, Cycle Time Reduction and Design Improvement.

Motorola was the first company to launch a six sigma program in the mid-1980s. In 1988, Motorola received the Malcolm Baldrige National Quality Award, which led to an increased interest of six sigma in other organizations. Today, a number of global organizations have developed six sigma programs of their own and six sigma is now established in almost every industry [21]. Six sigma could also be described as an improvement program for reducing variation, which focuses on continuous and breakthrough improvements. Improvement projects are driven in a wide range of areas and at different levels of complexity, in order to reduce variation. The main purpose of reducing variation on a product or a service is to satisfy customers.

Six Sigma is a tool which is widely used in the industrial and service organizations to enhance quality and reduce costs. The concepts are also applicable to distance education with certain modifications [43].

In the process of mechanical assembly, the assembly relationship in orientation, position, geometrical dimensions, and matching between parts and components should be built first, and these relations should be in accordance with the design requirements. The objectives of quality control (QC) in mechanical assembly can be considered to match the product design in the logical relationship between parts and components, and the precisions of geometric relations. The unstable factors and their variation existing in the assembly process may lead to high risk of serious quality problems and make the objects of assembly quality assurance out of specifications [44]. The quality problems can be categorized as the logical relationship failure, precision failure, and non-technical failure [45].

In machining, the objects in quality control are geometrical dimension and tolerance, surface finish, and relative tolerances on individual part. In mechanical assembly, the quality control is oriented to confirm the correct relations between a group of parts or components and the precisions with multi-dimensions, shapes, or relative position tolerances [19]. So the relative regulations and methods should be employed in mechanical assembly.

The quality of the final products highly depends on the quality of assembly operations and process [46]. However, the mistakes and errors in assembly processes are high sources of defects and erode margins of products. So some valuable theoretical models and technological measures have been brought forward based on the researches in this area recently. An algorithm is presented to propagate and control variation in mechanical assembly of automobile assembly by the state transition model approach [47].

Normal process variations are divided into common variation and special variation [48]. Common variation mainly arises from common causes, which is also called chance or random variation. It involves a different view of factors in an in-control process. In a manufacturing process, raw material lot-to-lot variability and operator-to-operator variability are the likely common causes. In a business process, day-to-day variability and department-to-department variability are more likely to be considered as the common causes [39]. The Special variation comes from non-human factors, such as the wear and tear of tools, lack of adjustment in equipment, bad quality material etc., or human factors, such as negligence, tiredness and incorrect operation. This is also called assignable variation.

5.3 Six Sigma frame work

Mathematically Six Sigma represents six standard deviations (plus or minus) from the arithmetic mean. As a measurement of quality Six Sigma means the setting of a performance level that equates to no more than 3.4 Defects Per Million Opportunities (DPMO) or 3.4 defect Parts Per Million (PPM) Opportunities. Six Sigma is an approach that takes a whole system approach for improvement of quality and customer service so as to benefit the ‘bottom line’.

The Six Sigma concept matured during the mid-eighties and grew out of various quality initiatives. Like most quality initiatives Six Sigma requires a total culture throughout an organization whereby everyone at all levels has a passion for continuous improvement with the ultimate aim of achieving virtual perfection. To know if Six Sigma has been achieved needs a common language throughout the organization (at all levels and within each function) and common uniform measurement techniques of quality. The overall Six Sigma philosophy has a goal of total customer satisfaction [49].

Six Sigma is an organized structure to diminish variation in organizational processes by using improvement specialists and performance metrics with the aim of attaining strategic objectives. Companies may choose variations of this base definition when implementing Six Sigma in order to customize it to their situation. Contingency theory implies that the base definition will not fit every company, but nonetheless, it is a starting point for research and implementation [50].

'Six Sigma is an organized and systematic method for strategic process improvement that relies on statistical methods and the scientific method to make melodramatic cutbacks in customer defined defect rates'. The simplest definition for Six Sigma is to eliminate waste and to mistake proof the processes that create value for the customer. The elimination of waste led to yield improvement and production quality; higher yield increased customer satisfaction.

A model which correlates the interrelationships of the factors affecting the quality of the product as discussed in the brainstorming session and shown in fishbone diagram need to be prepared for continuous improvement of the product quality. The approach is proposed for the allocation of tolerance to different parts, to minimize the manufacturing cost and satisfy the assembly function [51] [52].

The optimization objectives and constraints for concurrent tolerance design for manufacture and assembly are discussed, and the key technologies for concurrent tolerance design with game theory are investigated, including the strategy set division, payoff calculation, and Nash equilibrium evolution [53].

5.4 Problem Statement

The organization studied was an SME based in Rajkot, Gujarat, dealing with the manufacturing of various auto parts of Compression Ignition Engine. The product connecting rod faced the problem of End Float for a very long time. The problem was taken for the present case study. The scope for improvement potential was to be studied and necessary corrective measures were to be taken with the implementation of Six Sigma tools.

5.4.1 Meaning of End Float

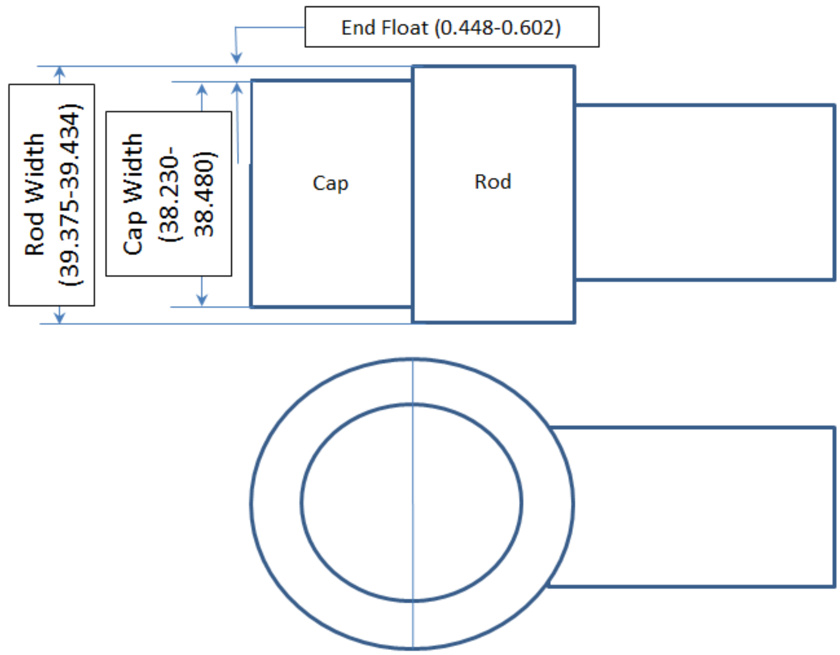
Normally, the thickness of the rod face and cap face is same in connecting rod but in some design of the connecting rod, there is the difference in the thickness of rod and thickness of the cap. In the big end face of connecting rod, the cap is assembled with nuts and bolts. The thickness of big end face of connecting rod is more than the thickness of cap face. Due to the difference in the thickness, there is a gap between the planes of rod face and cap face. The gap needs to be maintained half on both the sides of the connecting rod. This is called as End Float of connecting rod as represented in Fig.5.1.

5.4.2 Computation sheet of End Float

Mathematically, End float can be calculated as shown in Table 5.1. Lower dimension and Upper dimensions of Rod's face and Cap width decides the value of End Float. The maximum and minimum values of this parameter occur in extreme conditions of Rod face width and Cap width.

TABLE 5.1 : Computation Sheet of End Float

Parameter	Lower Dimension A (mm)	Upper Dimension B (mm)	Mean $\frac{(a+b)}{2}$ (mm)	Range (b-a) (mm)
Rod face width R	39.375	39.434	39.4045	0.059
Cap width C	38.230	38.480	38.355	0.250
Total Difference (R_{min} - C_{min})	1.145	-	-	-
Total Difference (R_{max} - C_{max})	-	0.954	-	-
Total Difference (R_{min} - C_{max})	0.895	-	-	-
Total Difference (R_{max} - C_{min})	-	1.204	-	-
Total Range of End Float	0.895	1.204	-	-
One side difference	0.448	0.602	0.52475	0.154



All dimensions are in mm
Not to scale

FIGURE 5.1 : End float of connecting rod (diagrammatic presentation)

5.5 DMAIC:

The project team followed five phases and key tools used in each phase are as listed bellow:

1. Define: Pareto Analysis; Project Charter.
2. Measure: Descriptive Statistics; Process Capability Analysis.
3. Analyze: Detailed Process Map; Fish-Bone Diagram.
4. Improve: Experimentation; New Process.
5. Control: Statistical Process Control.

The five Six Sigma phases (Define, Measure, Analyze, Improve and Control) are discussed in details (Fig. 5.2).

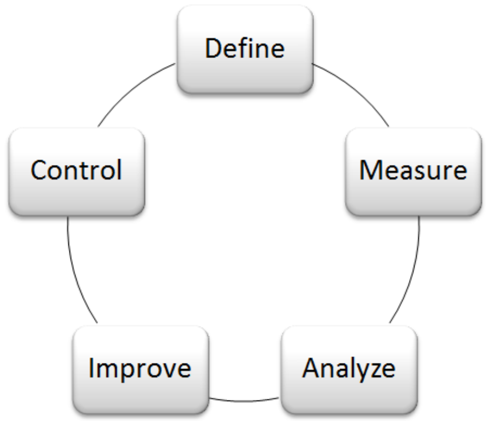


FIGURE 5.2 : Six Sigma Process

5.5.1 Define Phase

This is the first phase in Six Sigma project. This phase is defined by the following questions.

1. Who are the customers and what are their priorities?
2. Where are their problems?
3. Which do we attack first?

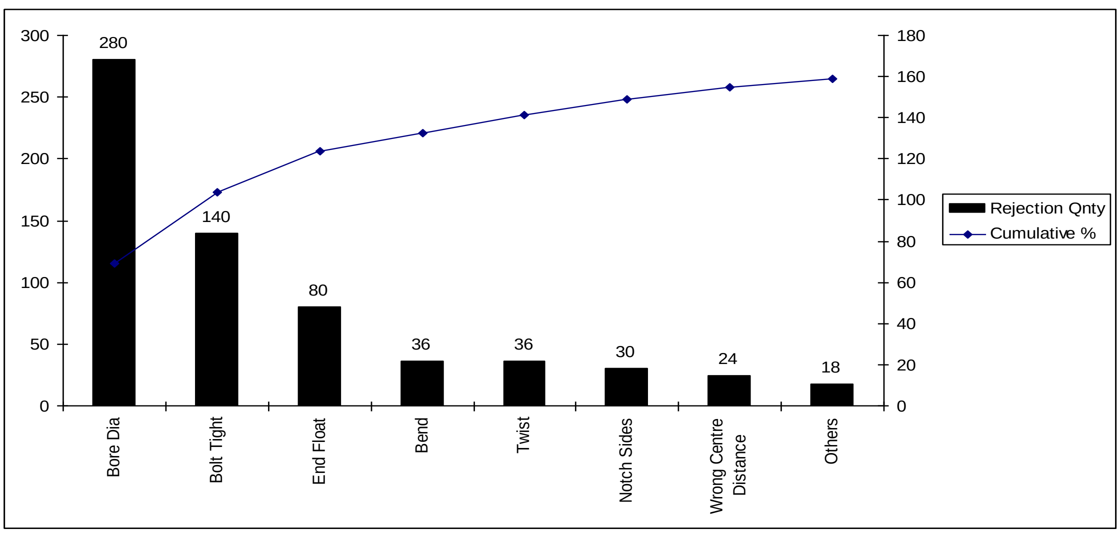
The subsequent process is the customer of the earlier process. The product or process to be improved is identified and recognized. Customer needs are identified and translated into Critical to Quality Characteristics (CTQ's). The problem or goal statement, the project scope, the role of team members and milestones are developed. A high-level process is mapped for the prevailing method. It also uses Pareto analysis to identify and prioritize projects that will be worked on as part of continuous improvement process in the company.

Pareto Analysis: The manufacturing of connecting rod includes many machining operations. After a long study, the major quality problems related to connecting rod manufacturing is studied and the database is prepared for various problems. The company has done excellent continuous improvement program for the manufacturing of various automobile components to be manufactured in a very large quantity. The company is now starting to look at the tools available in Six Sigma process to further its continuous improvement efforts.

There are many parameters to be controlled for achieving the quality of a product. The connecting rod manufacturing includes nearly 23 manufacturing operations. All the operations need to have proper attention for a quality product. A little deviation of one parameter at the early stage may cause higher deviation of other parameter/s at later stages. This product (i.e. connecting rod) is also having a number of parameters to be controlled within the specified limit, not be rejected at any stage. Hence, the database of major rejection parameters is prepared and the possible causes for the same need to be analyzed.

The Pareto chart shows the top seven rejection parameters of connecting rod Fig. 5.3. It indicates that the major rejection of the connecting rod occurs because of big end bore diameter variation. The second major problem of bolt tight is raised in the current year and the third one, i.e. end float has existed for many years and should be significantly decreased, if not eliminated. Due to the second major problem, the functionality of the component is not affected but the problem occurs at the time of assembly of the engine.

Once the assembly is prepared, the problem gets nullified whereas the third one causes the functional problem of the engine. Because of the end float, it was noticed by the customer that there is a significant increase in the frictional power loss. Hence, the area of focus for this project is the issue of end float of the connecting rod.



5.3 : Pareto Chart

It is the goal of the project team to eliminate the cause of the top three quality issues in each area on an annual basis. So over the multiple years, the majority of the quality issues can be solved.

5.5.2 Measure

The key internal processes that influence the CTQs (Critical to Quality) are identified and the defects generated relative to the identified CTQs are measured. It helps in creating the capability of given process and ascertaining existing performance levels. The objective of the measurement stage is to find out the magnitude of the problem and collect data to discover the few vital root causes. At this stage cause and effect relationships should be established. During the measurement process, the critical to quality (CTQ) characteristics which have an impact on the outcome would be selected.

The quality issue selected for the present work is End Float, which refers to maintain the gap between the plan of the connecting rod face and cap face in the final assembly of the connecting rod. The issue of End Float accounted for 20 % of the quality issues. It is measured for each part using a set of filler gauge. The big end rod face was supported on the surface plate and gauge passed from the gap between rod face and the surface table. The dial indicator arrangement can also be done for end float measurement. The difference between the dial reading taken at rod surface and cap surface indicates double the value of the end float. The second method is lengthy as compared to the first method as it uses only filler gauge.

The parameter End Float is affected by many manufacturing operations. Hence, to maintain this parameter within the required range, it is required to look after many manufacturing operations. A single control activity can’t control the multiple correlative manufacturing operations in the process. So the logical relations of control activities should be considered, and the united control activities should be carried out. The quality control activities usually include checking the conformity of quality characteristics against inspection specification, collecting and recording sampling data, monitoring the state of process characteristics, and so on.

5.5.3 Analyze

The objective of this phase is to understand why defects are generated. Brainstorming and statistical tools are used to identify key variables (X's) that cause defects. The output of this phase is the explanation of the variables that are most likely to affect process variation. The data is analyzed to find out the potential sources of variation and reduce the number of process variables to be acted on in the improvement phase. This is the stage at which new goals are set, and the route maps created for terminating the gap between current and target performance. The analysis also includes identifying root causes and arranged areas for improvement.

The brainstorming exercise was conducted by an interdisciplinary team of engineers at the company in order to identify potential factors that could influence the problem of end float. The team assessed a number of factors and finally reduced them to five key factors. The key factors are shown by fishbone diagram in Fig. 5.4. Following are the main factors which affect this problem.

1. Misalignment of the bolt hole axis.
2. Higher or lower widths of the rod during Rod face grinding operation.
3. Cap facing operation towards extreme dimension.
4. Taper-ness of rod face and cap face higher than the allowable limit.
5. The distance between the center of the bolt hole and the face of rod/cap out of allowable limit.

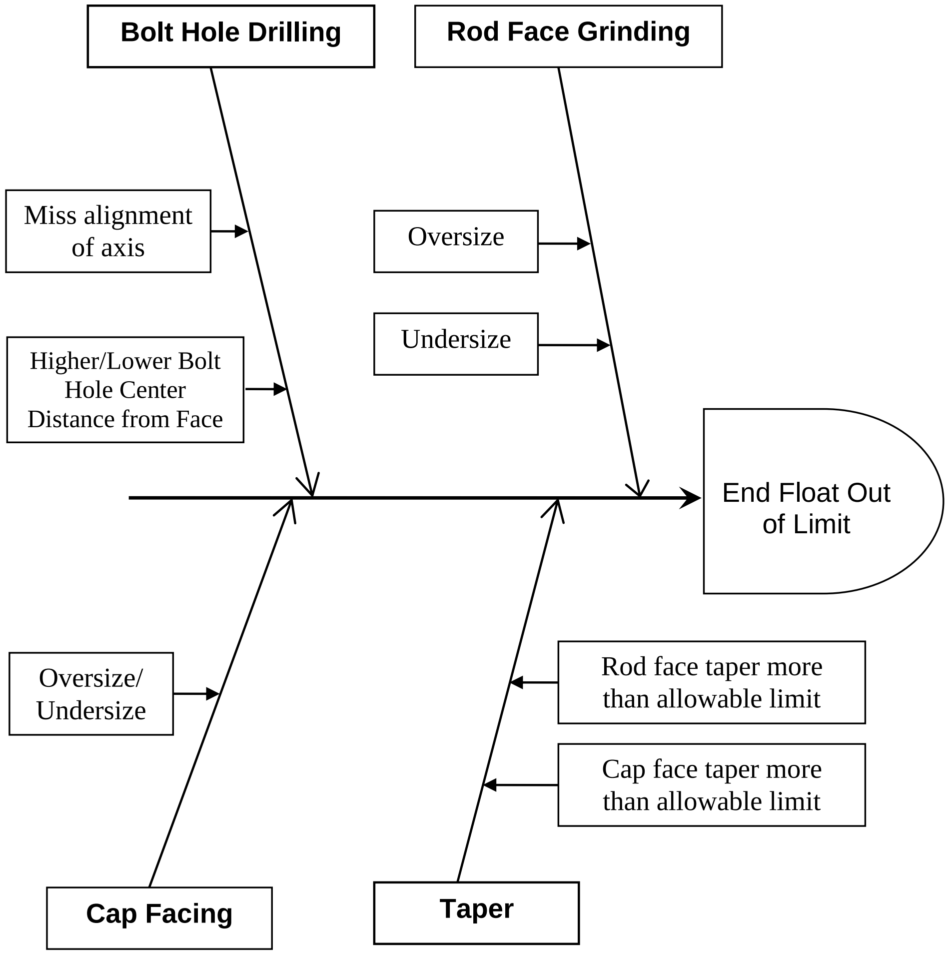


FIGURE 5.4 : Cause and Effect Diagram for End Float

5.5.4 Improve

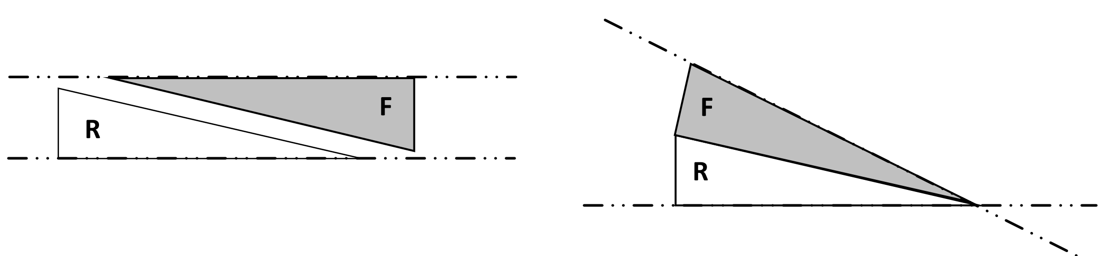
The objective of this phase is to confirm the key variables and quantify the effect of these variables on the CTQs. It also contains identifying the extremely acceptable ranges of the key variables, confirming the measurement systems and modifying the existing process to stay within these ranges. This is the stage where the root cause of the problem is removed and the corrective actions are standardized. The proposed solutions are confirmed and implementation strategy is worked out. To ensure that the corrective actions are effective, they are tried out in a prototype before commencing on concluding improvement. This is the stage where the ground work is translated into action. The output is measured continuously to monitor the extent of improvement along the CTQ parameters.

The five major key variables listed above are analyzed for rejected components. The majority of the rejection took place because of the distance between the center of the bolt hole and the rod face. It was noticed that this distance measured higher on one side and lower on another side. To study the possible reason for this cause, the fixture of the bolt hole drilling machine needed to be inspected.

The fixture of the bolt hole drilling machine checked for a number of parameters which includes surface roughness, taper-ness, the distance between locators of small end bore and big end parting face and vibration possibilities during the 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 the considerable amount.

The linear diagram is shown in Fig. 5.5. The possibility of this occurrence looks to be little, but it does matters for the studied rejected components.



a. Both taper planes co insides (Cumulative effect reduces taper ness)

b. Both taper planes are of same kind (Cumulative effect increases taper ness)

R : Rod face of Big End **F** : Fixture surface

FIGURE 5.5 : Taper ness of Big End Face of Rod and Surface of Fixture (Not to scale)

There are two possible corrective measures to overcome the problem. The first one is to alter the fixture plate which is tapered as shown in Fig. 5.6. The second is to ensure that the taper-ness of the 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 the temporary solution. Hence, there is a need to alter the taper-ness of fixture either by fully changing the fixture or providing the packaging to the tapered side.

FIGURE 5.6 : Fixture alteration proposed for solution

5.5.5 Control

In the control stage, the new process – conditions are documented and incorporated into systems so that the improvements remain sustained. Hence, the objective of this phase is to ensure that the modified process now enables the key variables to stay within the maximum acceptable range, using tools like Statistical Process Control (SPC) or control charts or simple checklists.

The control plan is composed of quality control activities in each manufacturing operations. The control essence is that different activities that have the different effect on manufacturing quality are controlled by different control tactics and measures. It is needed to execute a very long exercise when this parameter deviates from its mean value. There are many techniques to measure these parameters which include the usage of filler gauge. The *GO* and *NO GO* concept is used to check whether the parameter is within the limit or not.

The fixture of the bolt hole drilling machine changed and the tolerance for the taper-ness for the fixture plane redesigned and calculated for an extremely tapered face of the rod. After implementing the new fixture, a batch of the products taken for machining operation and extremely tapered rod faces taken for bolt hole drilling. The end float of the rods with tapered faces measured which found to be within the allowable limit. A checklist for fixture inspection prepared and the new taper-ness allowances checked for the control of the process.

5.6 Return on quality

In order to change the fixture, it must be determined that the benefits from the newly designed fixture outweigh the costs. Assuming the new fixture achieves the intended goals, the rejection due to end float reduced up to 20% of total rejection quantity and 0.8 % of the total production quantity. The savings will be recognized on approximately 10000 parts per month which equate to a monthly savings of (Rs. 10000x0.8x250=) Rs. 20000 and annual savings of Rs. 240000. The cost of new fixture is Rs. 5000/- which is to be recovered within a period of less than one month of the time.

5.7 Conclusion

It is recommended that the company move forward with the new fixture design. It is also recommended that the company implement a checklist to monitor the amount of taperness of the new fixture plane. The thrust on Six Sigma Quality has helped in creating and sustaining customer focus in the company leading to improved customer satisfaction as indicated in the feedback from the customer. At the same time, active participation of the team members from all levels in the Six Sigma projects has evolved a culture of effective and creative team work. This project has demonstrated the power of six sigma process to solve the problems that appeared unsolvable. The company had been suffering from the problem of end float for very long years. The corrective actions to be identified, tested and ready for implementation.

The end float problem to be resolved by altering the taperness of the fixture plane which locates the big end rod face. The second solution discussed, can also be implemented if the taperness value of the fixture plane checked higher than the newly designed tolerance.

The quality of the final product should not merely rely on the general inspections due to the complexity of unstable factors in manufacturing process. The errors or variation caused by those factors could be accumulated gradually in the process and thus avoid serious troubles in the following stages.

The six sigma process is an excellent fit for the fabrication and machining industries. It is implemented in present case with structured approach. Any company that needs solutions for quality related problems should benefit from this process. Companies will be most likely to succeed if their top-level management is supportive of a continuous improvement culture. Companies should also choose projects that can be measured and that potentially have a good return on quality.

CHAPTER – 6

Quality Assurance of Axial Mis-alignment (Bend and Twist) of Connecting Rod

6.1 Introduction

The connecting rod is the intermediate member between piston and crankshaft. Its primary function is to transmit the push and pull from piston pin to crank pin. Thus it converts the reciprocating motion of a piston into the rotary motion of crank. These are generally manufactured by a drop forging process. The small end is lined with a gun metal bush. The brasses in the big end are of C.I. or Cast Steel and are lined with white metal. Main parts of Connecting rod are Rod, Cap, Nuts (2 Nos.), Bolts (2 Nos.) and small end bush shown in Fig.6.1.

6.2 Theoretical Background

Forces acting on the connecting rod

1. Force on piston due to gas pressure and inertia of the reciprocating parts.
2. The force due to the inertia of connecting rod (Inertia bending force).
3. The force due to the friction of the piston rings and of the piston.
4. The force due to the friction of the piston pin bearings and crank pin bearing.

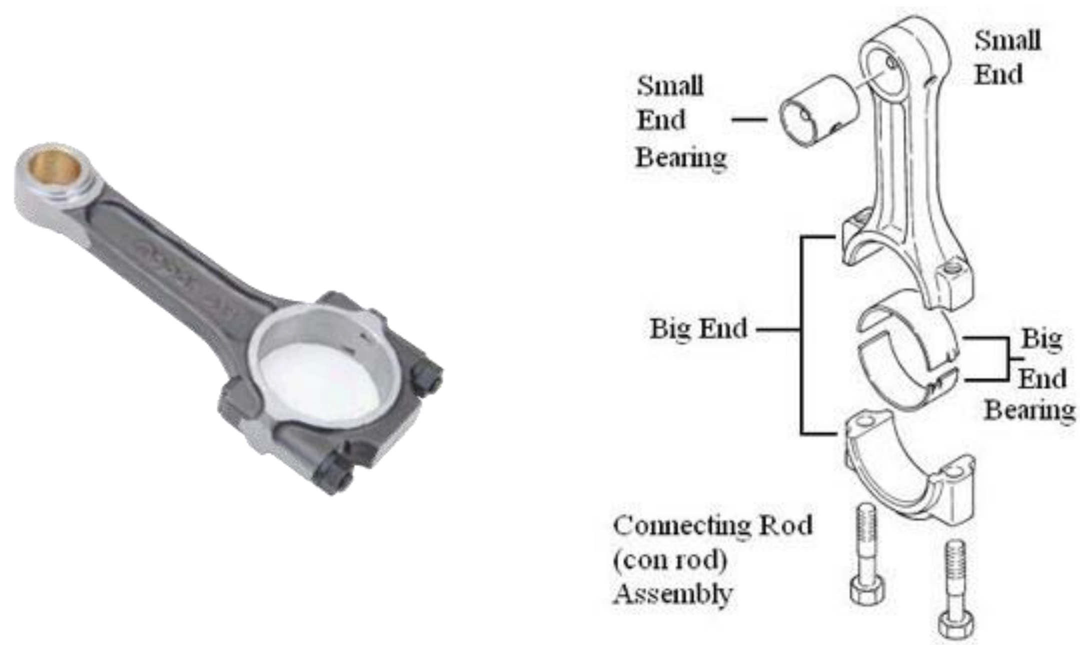


FIGURE 6.1 : Connecting Rod assembly with press fitted brass bush, Cap, Nuts and Bolts

The connecting rod is considered as column pillar as it is subjected to cyclic compressive and tensile load which is acting in an axial direction. During the suction stroke, the rod is subjected to the partial tensile load. During the compression stroke, the rod is subjected to the partial compressive load. When power stroke occurs, again the rod is subjected to high compressive load and during exhaust stroke; a small amount of compressive load is there. So cyclic loading occurs with the connecting rod. For the design consideration, compressive failure should be considered which occurs during power stroke as it is higher as compared to other three strokes.

1. The connecting rod is subjected to alternating direct compressive and tensile forces.
2. Compressive forces are much higher than tensile forces; so cross section of connecting rod is designed as strut and Rankine’s formula is used.

Due to axial load, the rod may buckle as shown in Fig. 6.2 and Fig. 6.3. Consider, the connecting rod as both the ends hinged about X axis for buckling and both ends are fixed about Y axis for buckling.

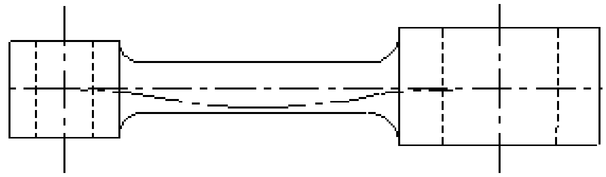


FIGURE 6.2 : Buckling of Connecting Rod about Y-axis (Both ends fixed L_{eq} = *l*/2)

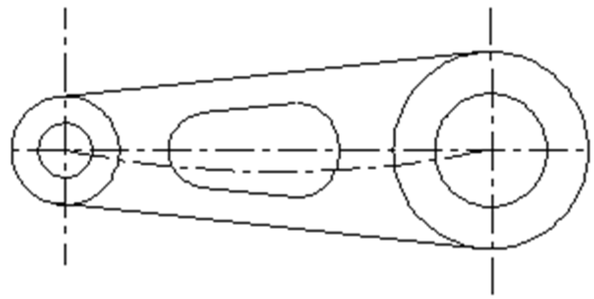


FIGURE 6.3 : Buckling of Connecting Rod about X-axis (Both ends hinged L_{eq} = *l*)

According to Rankine's formula,

W_B about X axis =[σ_c x A] / [1 + a { L_{equ} / K_{xx} }^{2}] , for $L_{eq} = l$; both ends hinged. (1)

W_B about Y axis = [σ_c x A] / [1 + a { L_{equ} / K_{yy} }^{2}], for $L_{eq} = l/2$; both ends fixed. (2)

Where, L_{eq} = Equivalent length of connecting rod.

a = Rankine's constant = $\frac{1}{1600}$ for C.I.

= $\frac{1}{7500}$ for M.S.

= $\frac{1}{9000}$ for Wrought Iron

To have an equal strength of connecting rod in buckling about both axis, the buckling load must be equal.

i.e. $\frac{[\sigma c \text{ x } A]}{[\ 1 + a\{\ L\ /\ Kxx\ \}2]} = \frac{[\sigma c \text{ x } A]}{[\ 1 + a\{\ L\ /\ Kyy\ \}2]}$

$$\frac{[\sigma c \text{ x } A]}{[\ 1 + a\{\ l\ /\ Kxx\ \}2]} = \frac{[\sigma c \text{ x } A]}{[\ 1 + a\{\ l\ /(2\ \ Kyy)\ \}2]}$$

$$K_{xx}^{\ 2} = 4\ K_{yy}^{\ 2}$$

$$\mathbf{I_{xx} = 4\ I_{yy}} \qquad (3)$$

Hence, connecting rod is 4 times stronger in buckling about Y axis than about X axis.

If $I_{xx} < 4\ I_{yy}$ then buckling will occur about X axis.

if $I_{xx} > 4\ I_{yy}$ then buckling will occur about Y axis.

Connecting rod is designed for $I_{xx} = 3$ to $3.5\ I_{yy}$ (it is designed for buckling about X axis.) for this condition, the most suitable cross section is I section, as discussed below.

$I_{xx} = [4t \times (5t)^3] / 12 - [3t \times (3t)^3/12 = 419 \times t^4 / 12$

$I_{yy} = [5t \times (4t)^3]/ 12 - [3t \times (3t)^3]/12 = 131 \times t^4 / 12$

$$\mathbf{I_{xx} = 3.2\ I_{yy}} \quad \textbf{(4)}$$

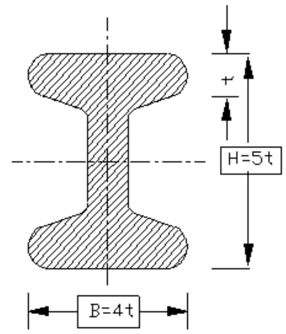


FIGURE 6.4 : I-section of Connecting Rod

Dimensions of I section is decided by considering the buckling of the connecting rod about X axis as shown in Fig. 6.4 (Both ends hinged).

6.3 Bend and Twist of Connecting rod and its measurement methods

Bend and Twist are defined as the angular misalignment of the two axes of the connecting rod that is the axis of big end diameter and the axis of small end diameter. Both the axis should be completely parallel in all three views. Because of manufacturing limitations, some misalignment is tolerated up to the allowable limit. Measurement of Bend and Twist is specified in terms of θ_{bend} and θ_{twist} as shown in Fig. 6.2. The misalignment in Front View, as shown in Fig. 6.2 is defined as Bend and the misalignment in Side View is defined as Twist of connecting rod. These parameters are measured on the shop floor in terms of mm (generally, micron) per mm of length.

There are many methods to measure Bend and Twist of connecting rod. Each method is having its own benefits and drawbacks. At this point, four methods are discussed to measure these parameters.

6.3.1 Method 1: To measure Bend and Twist with two pins

The pin is inserted in both the ends of connecting rod. The diameter of both the pins is equal to the mean diameter of big end and small end. The length of both the pins is longer than the thickness of the connecting rod ends. The extended length of the pin is used to take readings. The big end pin is to be held on the V block, and small end pin remains free in the small end.

With the help of the height gauge, readings of the big end pin are taken and the difference is noted down as the reading D_1. Because of the straightness of the pin, and V block, generally D_1 value is zero. Then after the reading of the free end of the small end pin is taken. The difference is noted down as the reading D_2. The difference of D_1 and D_2 indicates the misalignment of the axis of the rod ends.

This method requires two pins of diameters equal to the diameter of the ends. The limitation of this method is also there. The measurement done by this method consumes more time and good skill is required for measurement. The problem of scratch marks in the inner bore of the rod ends is possible while inserting the pins in the rod ends. It also requires skill and practice to insert the big end pin in the big end bore which may be tightened at the time of insertion of the pin in the big end.

Also, two pins of specified diameters are required, which can be used for this diameter bore, only. So initial investment required is more as compared to other methods. It is also not advisable to use this method for single piece measurement, as two pins would not be useful for any other purpose. This method is suitable where mass production is there and sampling inspection is carried out. It takes nearly two minutes to measure one piece by a trained and skilled inspector. This method is much accurate, as it directly measures misalignment between two axes; whereas other methods consider some reference planes.

6.3.2 Method 2: To measure Bend and Twist with V-block

This method is quicker and easier than others. The rod big end face is held on V block. Small End is free in the air in an upward position. After holding big end face on V block, the pointer of height gauge is moved in small end bore from one face to another face. The deviation in pointer reading indicates the value of misalignment of the axis. By shifting connecting rod position from vertical to horizontal, the twist can be measured.

In this method, the big end face is taken as reference. Bend and Twist measured by this method may differ from other methods. Taper in big end face is counted in this method. So measured value is not accurate, but the difference in the readings is very small. This method is widely used for mass inspection as it does not require greater skill and the measurement process is much faster.

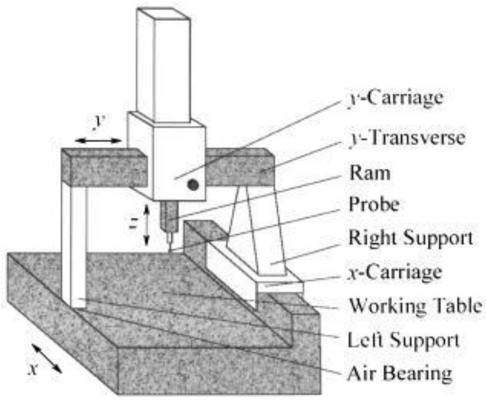
This method uses only conventional measuring devices and no need to use the pin or any other special purpose gauges. Another advantage as compared to the first method is that there is no any problem like scratch marks in bore because the pin is not required to be inserted in any end. Only pointer of height gauge dial moves along the bore which does not make any scratch marks inside the bore. The honing pattern can also be maintained inside the bore which may be disturbed due to insertion of the pin.

This method can be used for continuous inspection also which is an added advantage.

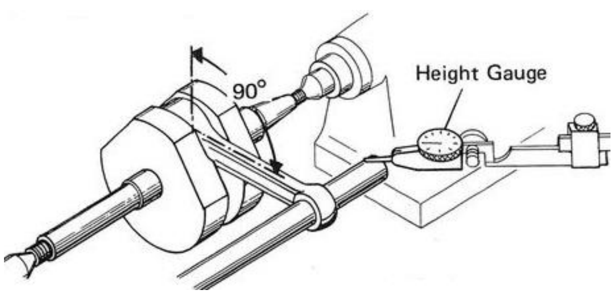
6.3.3 Method 3: Measurement with Co-ordinate Measuring Machine

CMM can be used to measure these parameters. The connecting rod is held on CMM table and the pointer is moved in both the bores. The pointer picks up four or five points in one plane and another four or five points in another plane. By considering these points, it creates a cylindrical shape based on input points. After defining the cylinder, it locates the axis which is the axis of big end bore. Same way small end bore axis is also defined by defining the small end bore cylinder. The parallelism of both the axis is calculated by programming of CMM and misalignment in Front View indicates bend and misalignment in Side View indicate twist.

Parameters measured by this method are highly accurate. This method considers big end and small end bore as references. Taper-ness of big end face does not affect the values of bend and twist. This method also requires good skill. Only well-trained inspector can do measurement by this method. The initial investment is also higher as CMM is the precise and costly instrument.



a. Measurement with Co-ordinate Measuring Machine



b. Measurement with single pin and height gauge

c. Measurement with Special Purpose Gauge

FIGURE 6.5 : Measurement of bend and twist of connecting rod

This method can’t be used for mass inspection. Only one or two components can be inspected per batch production. It also takes more time as compared to 2nd method. Only additional advantage of using this method is that it also measures many other parameters simultaneously. CMM also measures big end diameter, small end diameter, ovality of both the bores in upper plane and lower plane, the center distance between two ends along with bend and twist.

6.3.4 Method 4: Measurement with Special Purpose Gauge

Special purpose gauge can be used to measure various parameters of connecting rod. This gauge may have a mechanical sensor or a pneumatic sensor. In mechanical sensors, movement of pointer decides the size of the bore and in the pneumatic sensor, the pressure difference is calibrated and it decides the dimensions.

This method can be used for mass inspection. The accuracy and precision of this method are also very good and there is no need of having the skilled manpower in this method. The inspection time is also lesser as compared to other methods.

Only single drawback of this method is that it requires higher initial investment. The gauge designed for the inspection of the connecting rod cannot be used for inspection of other components of different dimensions.

During Bush boring operation, care is taken to control bend and twist of the connecting rod. X_{avg} and R charts are prepared for continuous monitoring of the parameters. With the help of this graph, the trend of the process can be obtained and quality can be assured.

6.4 Interpretation of readings and proposed Action Plan

The Statistical Process Control is carried out for the critical parameters of the connecting rod in order to maintain and assure the dimensional quality. The study is carried out by taking the reading for a particular parameter while the machining operation is going on. The sequential readings are to be taken and noted down in the format. Then after the average range $\mathbf{R_{avg}}$ and the average of all the readings is to be calculated i.e. $\mathbf{X_{avg}}$. The formula to calculate the value of C_p and C_{pk} are as follows.

$X_{avg} = \frac{\Sigma X}{n}$

Range $R = X_{max} - X_{min}$

Average Range $R_{avg} = \frac{\Sigma R}{n}$

Upper Control Limit for X is $UCL_x = \bar{X} + A_2 \times \bar{R}$

Lower Control Limit for X is $LCL_x = X_{avg} - A_2 \times \bar{R}$

Upper Control Limit for Range $UCL_R = D_4 \times \bar{R}$

Lower Control Limit for Range $LCL_R = D_3 \times \bar{R}$

From SPC manual the value of A_2, D_3 and D_4 to be taken. The values are as follows

$A_2 = 0.73$, $A_3 = 2.06$, $D_3 = 2.28$, $D_4 = 0.00$, $\sigma = \frac{\bar{R}}{A3}$

$$C_p = \frac{[UTL - LTL]}{6\ \sigma}$$

$$C_{pk} = \frac{[UTL - \bar{X}]}{6\ \sigma} \quad \text{and} \quad C_{pk} = \frac{[\bar{X} - LTL]}{6\ \sigma}$$

C_p and C_{pk} are process capability indices. C_p represents the potentiality of the process to be capable of the production and C_{pk} represents whether the process is under the statistical control or not.

UTL is Upper Tolerance Limit and LTL is Lower Tolerance Limit specified in the drawing by the customer.

There are two values of C_{pk}. We have to consider only the lower value. It indicates that how much the process deviates from the mean value. If the process is shifted towards the UCL the value of one C_{pk} will be higher and value of another C_{pk} will be lower. Same is true for the opposite case. So the process should remain near to the mean.

6.5 Process Capability Study Reports

TABLE 6.1: Process Capability Study Report for Bend

PROCESS CAPABILITY STUDY REPORT

PART NAME:	**Con Rod**	INSTRUMENT USED:	V Block, Pins, Height Gauge
PART NO.:		LEAST COUNT:	0.001 mm
CUSTOMER NAME:	M/s. Simpson	M/C NO.:	17-08-00
OPERATION NAME:	Small End Bush Boring	MACHINE NAME:	Profitech
PARAMETER:	**Bend**	OPERATOR NAME:	Nayan Sahu
DATE:		STUDIED BY :	Sunil

SUB-GROUP	READINGS 1	2	3	4	$\bar{X}$	R	RESULTS				
1	-0.001	0.001	0.000	-0.001	0.000	0.002	$\bar{\bar{X}}$	0.0010	CONTROL LIMITS:		INTERPRETATION
2	0.000	-0.001	0.002	-0.001	0.000	0.003	$\bar{R}$	0.0021	UCLX	0.0025	**Cp<1.00**
3	0.001	0.002	0.001	-0.001	0.001	0.003	UTL	0.0100	LCLX	-0.0005	1. Process is not capable
4	0.004	0.003	0.005	0.004	0.004	0.002	LTL	0.0000	UCLR	0.0047	-try to shift the job to
5	-0.004	-0.003	-0.002	-0.001	-0.003	0.003	σ	0.00100	LCLR	0.0000	another process with
6	0.004	0.003	0.005	0.003	0.004	0.002	**Cp**	**1.6613**	A2	D4	adequate capability
7	0.004	0.004	0.003	0.002	0.003	0.002	**Cpk**	**2.9792**	0.73	2.28	-try to improve capability
8	0.004	0.003	0.004	0.003	0.004	0.001		**1.6700**			**Cp=1.00**
9	0.003	0.005	0.003	0.004	0.004	0.002					1. Process is just capable
10	-0.002	-0.003	-0.004	-0.003	-0.003	0.002	Comments (If any):				**Cp>1.00**
11	0.004	0.003	0.004	0.004	0.004	0.001					1. Process is quite capable
12	0.001	0.003	0.001	0.001	0.002	0.002					**Cp>1.67**
13	-0.003	-0.003	-0.005	-0.005	-0.004	0.002					1. Process is capable
14	0.001	0.002	0.003	0.002	0.002	0.002					**Cpk<1.67**
15	-0.002	0.000	-0.001	-0.001	-0.001	0.002					1. Machine setting required

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Cp	**1.70**	**1.77**	**1.83**	**1.90**	**1.70**	**1.71**	**1.66**					
Cpk	1.690	1.700	1.750	1.840	1.690	1.670	1.670					

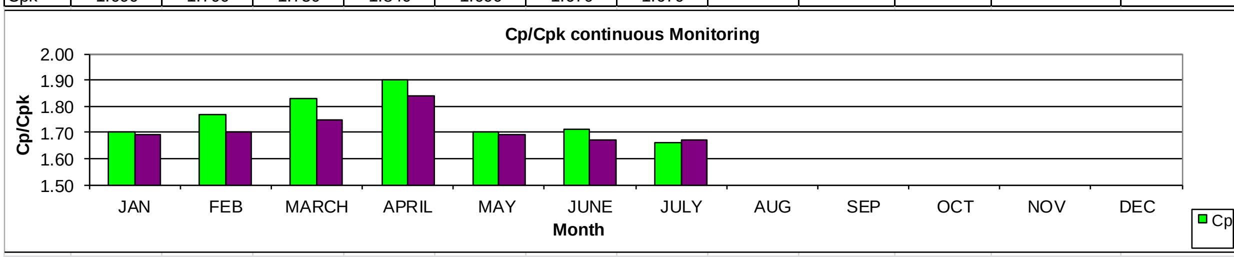


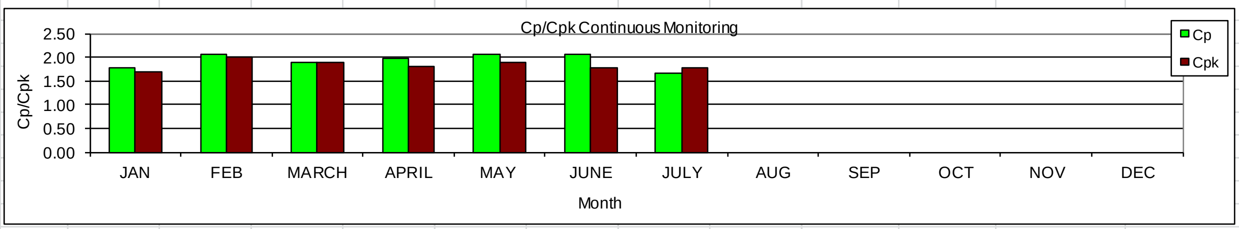
Table 6.2 : Process Capability Study Report for Twist

PROCESS CAPABILITY STUDY REPORT

PART NAME:	Con Rod	INSTRUMENT USED:	V Block, Pins, Height Gauge
PART NO.:		LEAST COUNT:	0.001 mm
CUSTOMER NAME:	M/s. Simpson	M/C NO.:	17-08-00
OPERATION NAME:	Small End Bush Boring	MACHINE NAME:	Profitech
PARAMETER:	**Twist**	OPERATOR NAME:	Nayan Sahu
DATE:		STUDIED BY :	Sunil

SUB-GROUP	READINGS 1	2	3	4	$\bar{X}$	R	RESULTS				
1	-0.002	-0.003	0.001	0.001	-0.001	0.004	$\bar{\bar{X}}$	0.0014	CONTROL LIMITS:		INTERPRETATION
2	0.003	0.002	0.002	0.002	0.002	0.001	$\bar{R}$	0.0021	UCLX	0.0029	**Cp<1.00**
3	0.003	0.002	0.005	0.005	0.004	0.003	UTL	0.0100	LCLX	-0.0001	1. Process is not capable
4	0.002	0.005	0.003	0.003	0.003	0.003	LTL	0.0000	UCLR	0.0047	- try to shift the job to
5	-0.002	-0.003	-0.002	-0.002	-0.002	0.001	σ	0.00100	LCLR	0.0000	another process with
6	0.001	0.002	0.002	0.002	0.002	0.001	**Cp**	**1.6613**	A2	D4	adequate capability
7	0.002	0.003	0.003	0.002	0.003	0.001	**Cpk**	**1.8700**	0.73	2.28	-try to improve capability
8	-0.005	-0.002	-0.003	-0.003	-0.003	0.003		**1.7700**			**Cp=1.00**
9	0.003	0.002	0.002	0.002	0.002	0.001					1. Process is just capable
10	0.002	0.005	0.002	0.002	0.003	0.003	Comments (If any):				**Cp>1.00**
11	0.005	0.005	0.005	0.005	0.005	0.000					1. Process is quite capable
12	-0.001	0.003	0.002	0.003	0.002	0.004					**Cp>1.67**
13	0.003	0.003	0.004	0.002	0.003	0.002					1. Process is capable
14	-0.002	-0.002	-0.002	-0.002	-0.002	0.000					**Cpk<1.67**
15	0.003	0.002	0.002	-0.001	0.002	0.004					1. Machine setting required

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Cp	**1.77**	**2.06**	**1.90**	**1.98**	**2.06**	**2.06**	**1.66**					
Cpk	*1.7*	2.0	1.9	1.8	1.9	1.8	1.8					



6.6 Discussion of implemented action

The value of C_p and C_{pk} should be more than 1.66 in order to assure the dimensional quality. If the value of $C_p < 1.00$ the process is not capable for the production. Try to shift the job to another process with the adequate capability or try to improve capability.

If the value of $C_p = 1.00$ the process is just capable for the production.

If the value of $C_p > 1.00$ the process is quite capable.

If the value of $C_p > 1.67$ the process is perfectly capable for the production to be carried out.

If the value of $C_{pk} < 1.67$ there is a requirement of the machine setting and fixtures to be modified.

If both the value of the C_p and C_{pk} comes out to be more than 1.67, then there will be a chance of rejection up to 0.03 %. And the reliability of the process reaches up to 99.97 %.

Bend and Twist have allowable dimension +/- 0.010/50 mm. Hence the value of bend and twist should be within +0.01 mm to -0.01 mm per 50 mm length. For SPC analysis, if the readings are noted down in a simple way like 0.004, 0.007, 0.005, etc, then the value of C_{pk} will be very lower and the interpretation of the result is wrong. While doing the measurement of these parameters, we should consider negative value. So readings should be like +0.002, -0.004, +0.005, -0.008. To put an appropriate sign, one side bend/twist should be considered as positive and the other side should be considered as negative. The sign convention to be decided by the inspector which should be maintained the same throughout the experiment.

The objective of SPC analysis is to find out the trend of the manufacturing operation. As to assure the health of the human heart, Electro Cardio Graphy (ECG) is helpful to the doctors. Same as that, the X_{bar} and R chart are the ECG of the process. Lesser the uneven fluctuation in ECG tells about better the health of heart and more the uneven fluctuation in ECG tells about the weaker heart. For the X_{bar} and R chart, the process should be as smooth as possible to have better dimensional quality.

This method is used to catch the trend of the manufacturing operation and we assure about its quality. This method gives the quality assurance (QA) in terms of statistical output.

SPC analysis of various critical parameters of connecting rod is done during manufacturing to assure Statistical Quality Control (SQC). The critical parameters may be customer defined or may be manufacturer defined as represented in Table 2.1.

6.7 Points to be considered while conducting SPC analysis

While conducting the readings for SPC analysis, following points to be considered.

- Write all the readings in the sequence. For doing this, the inspector has to be with the machining operation and as one piece machined, it should be measured.

- Do measurement of the parameter at the same point for all the components. Means that if the diameter is measured perpendicular to the parting line of the connecting rod and cap, every time the diameter should be measured at that point only.
- The measuring instrument used should not be changed at any interval. Throughout the readings taken, any single measuring instrument should be used. The changing in the measuring instrument may result into the instrument error occurrence in the overall readings.
- The inspector should also not be changed during the readings.
- The operator of the machine should also remain same for all the readings.
- If any considerable atmospheric change is noticed during the SPC study, all the readings should be canceled. And again the readings should be taken at the same atmospheric condition. Alteration in temperature or humidity may have the adverse effect on the result. Hence, constant temperature and constant humidity is also desirable condition.
- The method is used to find out the trend of the machine, so to locate the trend of the machine, graphical representation gives a better idea of the analysis.

6.8 Conclusion

The misalignment of the axis of the connecting rod plays a vital role in the performance of the I C Engine. Hence the parameters like bend and twist are to be controlled at the time of manufacturing operations. Many methods are there to measure these parameters.

According to our analysis, the value of C_p and C_{pk} comes out to be within the limit i.e. C_p, C_{pk} >1.67. Thus, the process of Bush boring operation is under statistical control for these two parameters bend and twist. The measurement of these parameters should be done by a single inspector at the same position. The measuring instrument, machine operator, fixture, method of inspection must not be altered while doing Statistical Process Control Analysis. If any of these is altered, the analysis must be done again from the first reading.

Statistical Process Control analysis of the critical parameters is required to be maintained every month. If any deviation is to be noticed because of any changes proposed as mentioned above, there is a need to do the SPC analysis again and again till the value of the C_p and C_{pk} comes into the desirable range of 1.67.

CHAPTER – 7

Examining the Influence of Temperature Variation on the Dimensional Variability of Connecting Rod during Manufacturing

7.1 Introduction

The atmospheric conditions of the shop floor are also to be considered by Quality Control Engineer to maintain the dimensional quality of various manufacturing operations. For any material, it is a general rule that it expands as temperature increases and it contracts when temperature reduces. This rule is exceptional for water between temperature limit of 0°C to 4°C. The raw materials for connecting rod do not have an exception like this. So while manufacturing of the connecting rod, as its temperature increases, certain dimensions increases. For manufacturing people, it is the duty to maintain the designed dimension of the connecting rod as per assigned drawing.

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 the lot from customer end is taken. The big lot was rejected from customer end because of the oversize of the various parameters. The problem is discussed in detail in 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.

7.2 Literature Review

A complex mechanical part is produced through many machining stages. That is, a machining process is typically a discrete and multi-stage process with multivariate quality attributes [54] [55]. There are various kinds of factors which can fluctuate quality attributes of a workpiece at a current stage, such as fixture error, machine tool error and workpiece error from the previous stage. It can be seen that the final quality of a product is an accumulation of process quality from its all machining phases.

Normal process variations are categorized as special variation and common variation. The special variation comes from non-human factors, such as the wear and tear of tools, bad quality of material, lack of adjustment in equipment, etc., or human factors, such as tiredness, negligence and incorrect operation. This is also called assignable variation. Common variation mainly arises from common causes, which is also called chance or random variation.

When a signal is detected by control charts, a search begins to identify and eliminate the sources of this signal. Knowing when a process has changed is very helpful for this purpose. The unknown special point that the process changed for the first time is referred to as change point [56]. The design and development of an expert system for on-line detection of various control chart patterns is prepared to enable the quality control practitioners to initiate prompt corrective actions for an out-of-control manufacturing process [57].

7.3 Problem Statement

The customer of the connecting rod rejected a very big lot of supplied product because of the oversized dimension of the product of certain parameters. The inspection report of the rejected components showed that the size of the bore and center distance is more than the specified limits. The majority of the readings were towards the higher side of the dimension or more than the upper limit. The reason behind this phenomenon is required to be studied and appropriate corrective actions need to be taken.

It was observed that the atmospheric temperature at the time of manufacturing of the connecting rod varies from 20°C to 45°C. The instrument used for inspection, measures different values of the same parameters at different temperatures. The inspection person may reject the measured dimension at one temperature and may not reject the measured dimension at another temperature. The temperature when the components measured for the quality check was higher than the temperature of the shop floor where the product was manufactured and inspected.

It was noted that both the bores of the connecting rod expand as the temperature increases as shown in Table 7.1. The Big End Diameter and Small End Diameter of the connecting rod show higher values at a higher temperature as shown in Fig. 7.1. The higher value of the diameter leads the component to be rejected as per quality standard. This type of rejection is not actual rejection but only rejection takes place because of temperature variation. The Center Distance of the connecting rod (i.e. Length of the connecting rod) is also affected by temperature variation. Higher temperature shows higher center distance and vice versa as shown in Fig. 7.2.

7.4 Readings at various temperatures

TABLE 7.1 : Readings at various temperature

Sr.	Temp. °C	Connecting Rod 1			Connecting Rod 2		
		Big End Dia. (60.820-60.833) Mm	Small End Dia. (30.665-30.690) mm	Center Distance (223.812-223.863) mm	Big End Dia. (60.820-60.833) mm	Small End Dia. (30.665-30.690) mm	Center Distance (223.812-223.863) Mm
1	15	60.810	30.651	223.800	60.801	30.660	223.792
2	20	60.816	**30.666**	223.809	60.807	**30.675**	223.801
3	25	**60.821**	**30.670**	**223.821**	60.812	**30.679**	223.811
4	30	**60.824**	**30.675**	**223.830**	**60.820**	**30.684**	**223.821**
5	35	**60.828**	**30.681**	**223.841**	**60.822**	**30.690**	**223.830**
6	40	**60.832**	**30.684**	**223.849**	**60.827**	30.694	**223.840**
7	45	60.835	**30.689**	223.864	**60.832**	30.698	**223.853**
8	50	60.841	30.696	223.873	60.838	30.703	223.864

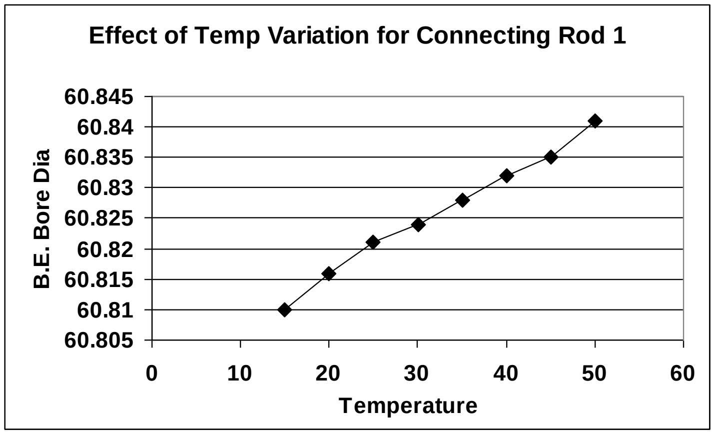


FIGURE 7.1 : Temperature variation effect on Big End Bore Diameter

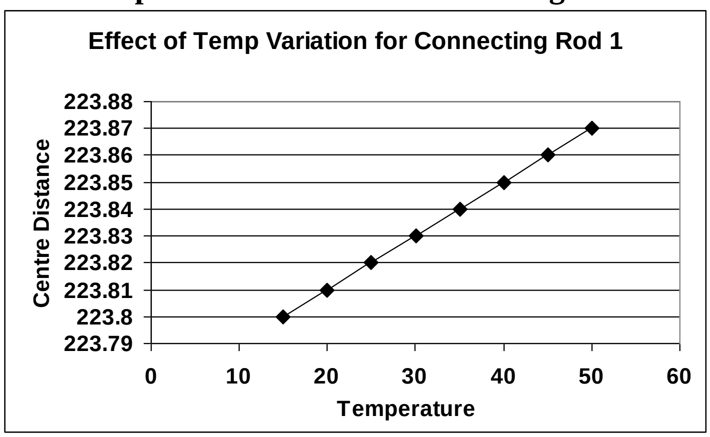


FIGURE 7.2 : Temperature variation effect on Center Distance

These readings are taken for a particular connecting rod. The readings are taken just by varying temperature and rest all the parameters maintained constant. The inspector, measuring instrument, the point of measurement, workpiece, method of measurement, etc remained same for above readings.

7.4.1 Co-efficient of thermal expansion

The values of Co-efficient of thermal expansion can be computed from the above readings. In present case it can be computed from the readings of center distance as about 1.6222 mm/K. It can't be compared with big end bore diameter and small end bore diameter as it is radial expansion.

It is observed from the table that for a particular range of the temperature, the parameter is within the specified limit. For lower temperature, the parameter is smaller and for higher temperature, the parameter is higher. The darken readings are within the acceptable range. The reading for the first piece shows that reading within the temperature range of 25 °C - 40 °C is accepted and the reading for the second piece shows that the reading within a temperature range of 30 °C - 35 °C is accepted. This kind of problem is faced for other parameters also for all other pieces.

7.5 Proposed Action Plan

The identified problem is solved with the possible corrective action plan. The study is conducted to overcome the problem. There are two ways to solve the problem. The first method is to manufacture three masterpieces which are having the minimum, maximum and exact value of the parameter. The calibration of the pneumatic pressure gauge requires three points which are obtained by three master rings (Master rings are used in case of Diameter readings).

In the case of mechanical gauge, only one master ring is required. In mechanical gauge, there is a linear relationship between the movement of the plunger and readings, whereas, in pneumatic gauge, there is no linear relationship between actual reading and pressure variation. Hence three master rings are required for calibration of the pneumatic gauge. The relationship between master dimension and pointer deflection for both types of the measuring instruments is represented by the graph as in Fig. 7.3a and Fig. 7.3b.

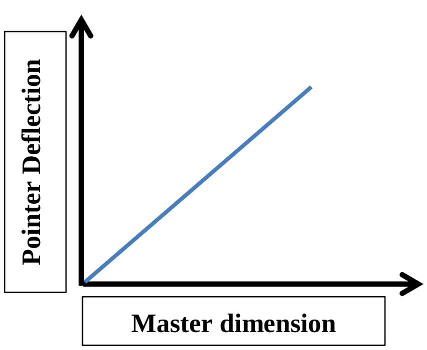


FIGURE 7.3a : Mechanical Gauge readings with masterpiece

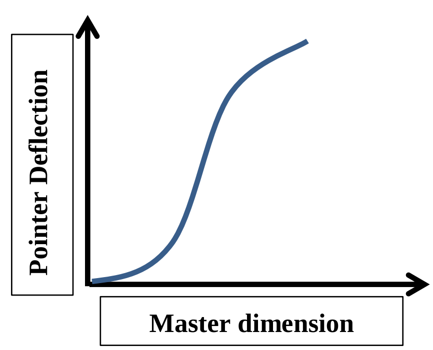


FIGURE 7.3b : Pneumatic Gauge readings with masterpiece

The material of the masterpieces is not same as the material of the connecting rod. Hence the rate of expansion of both the materials is recorded and according to the rate of expansion, the acceptable range for a particular temperature is found out. An exercise is to be conducted and the table is prepared for the proposed action plan.

The chart and table are prepared to show the relationship between temperature variation and the value of the parameter. With the help of the relationship, the measured dimension is checked and decided about its acceptance or rejection. The correction factor is to be calculated for easiness to the inspector as shown in Fig. 7.4 and Fig. 7.5. The correction factor can be used for a particular parameter only. The correction factor for bore diameter cannot be used for center distance. The correction factor for a particular parameter is counted as shown in Table 7.2

TABLE 7.2 : Correction Factor at various temperature

Sr.	Temp. °C	Correction Factor °C		
		Big End Dia. (mm) (60.820-60.833)	Small End Dia. (mm) (30.665-30.690)	Centre Distance (mm) (223.812-223.863)
1	15	+ 0.018	+ 0.020	+ 0.041
2	20	+ 0.012	+ 0.015	+ 0.032
3	25	+ 0.007	+ 0.011	+ 0.020
4	30	+ 0.004	+ 0.006	+ 0.011
5	35	0.000	0.000	0.000
6	40	- 0.004	- 0.003	- 0.008
7	45	- 0.007	- 0.008	- 0.022
8	50	- 0.013	- 0.015	- 0.032

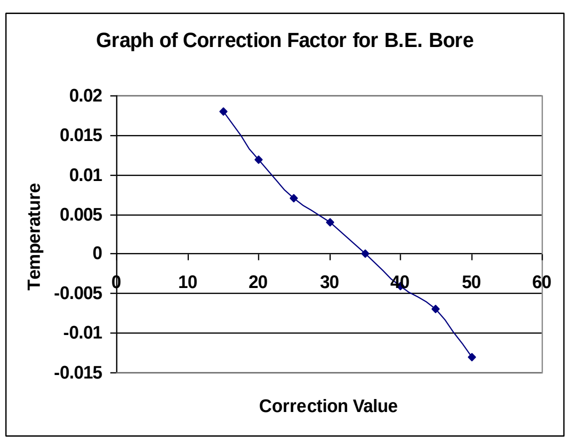


FIGURE 7.4 : Big End Bore Diameter correction factor

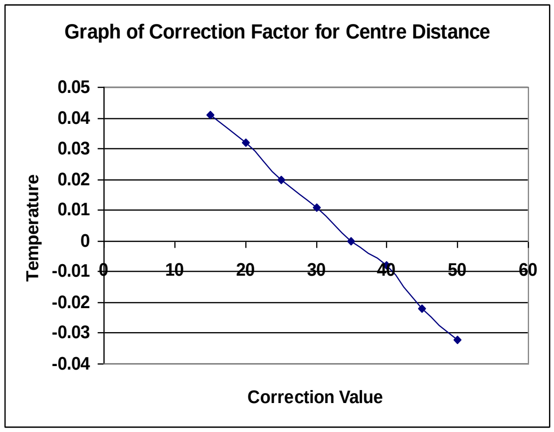


FIGURE 7.5 : Center Distance correction factor

In the present case, the correction factor is decided considering the base temperature as 35 °C. This temperature is taken as it is the average temperature of the shop floor, where the components are manufactured.

In this method, the masterpiece is used for longer time and there is no need to change a masterpiece once it is used. The surface of a masterpiece, which comes into contact with the plunger, is hardened such that because of simultaneous contact, the dimension does not vary.

In the second method, the material of the masterpiece is taken same as the material of the connecting rod. In the case of mechanical gauge, one masterpiece and in the case of pneumatic gauge, three masterpieces are prepared. In this case, the size of the masterpiece also varies with temperature variation. The masterpieces dimensions are assured at the required temperature. As the temperature increases, the sizes of the master also increase.

As and when temperature variation is noticed, it is recommended to calibrate the measuring instrument with the masterpiece. As the master ring dimension increases due to temperature rise, the instrument also calibrates itself according to that value. So the effect of temperature variation nullifies itself.

If the instrument is not calibrated with the master, then it will measure the dimension of the parameter higher than the range and the quality standard will reject that workpiece. But because of the calibration of the instrument, it shows the dimension within the range. Hence, it is not needed to use any correction factor but needs to set the measuring device with the master when temperature change takes place.

7.6 Conclusion

The effect of temperature variation is highly considerable for the precise dimensional quality of the product. This exercise should be done for other parameters also where the effect of temperature is major for dimensional control. The parameters like Bend and Twist are not much affected by temperature variation.

CHAPTER – 8

Solving the Problem of Big End Bore Diameter variation

8.1 Introduction

The manufacturing of connecting rod involves the number of operations. The quality of each operation affects the performance and quality of connecting rod. There is a scope to correlate these operations' quality and their effect on the final product. The control of the operations at individual stages results in better outcome. This chapter proposes the proper implementation of DMAIC to solve the longer existed problem of big end bore diameter variation in connecting rod manufacturing operation.

The development and application of quality assurance system help companies to better organize their operations by proper process documentation. The clear definition of responsibilities and duties to employees and departments reduce the hurdles observed for improvement and progress. Many strategies are widely used by a number of reputed industries to solve the burning issues of the shop floor.

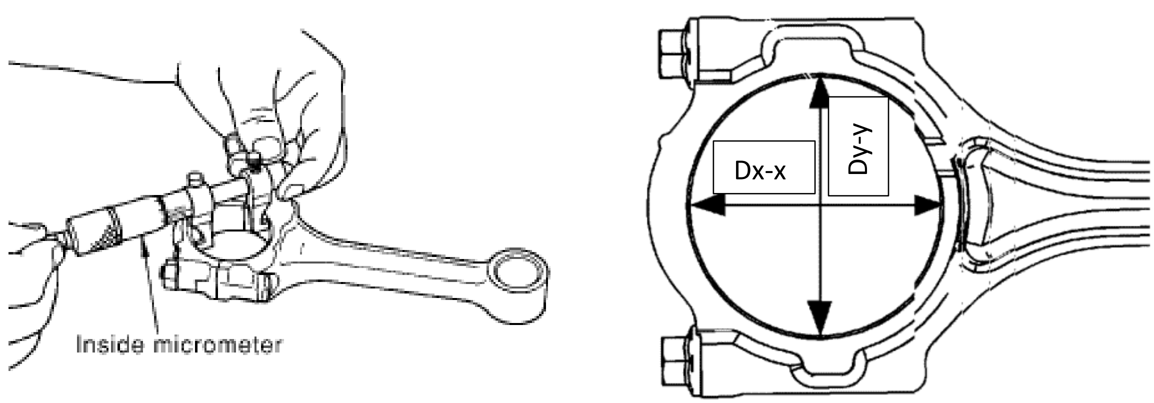
8.2 Literature Review

The simplest definition for Six Sigma is to eliminate waste and to mistake proof the processes that create value for the customer. The elimination of waste led to yield improvement and production quality; higher yield increases customer satisfaction. To maintain optimal quality characteristics in the defined specification limits is a vital decision for any industry and service system [58]. To avoid nonconformity in outputs, the stream of variations and their potential causes must be identified so that the response variables fall into desirable limits across the manufacturing or service chain [59].

8.3 The Problem Statement

The present case represents the study about big end bore diameter variation. It is observed that the variation in big end bore diameter shown higher variation than allowable limit (variation more than 0.013 mm). After inspection of a batch, undersized components to be sent for rework to a honing operation and oversized components are rejected. Undersized components can be cured but oversized components become un-curable. The honing operation is carried out manually. So the tendency of an operator remains to work in the undersize zone. It results in more rework and it ultimately increases in quality loss.

The scope for improvement potential to be studied and necessary corrective actions were suggested. The steps generalized for the solution are followed and p-FMEA (product Failure Mode and Effects Analysis) is conducted to prepare the corrective action plan.



a. Using inside micrometer b. Circularity of bore

FIGURE 8.1: Big end bore diameter measurement

8.4 Measurement report

The report of rejected pieces prepared as shown in Table 8.1. It clearly indicates the majority rejection occurred to those work-pieces, which were reworked. The tendency of an operator in manual honing operation, to work towards lower side is the major reason for higher rework.

The parameter Big End bore diameter is affected by many manufacturing operations. Hence, to maintain this parameter within the specified range, it is required to look after many manufacturing operations. A single control activity cannot control the multiple correlative manufacturing operations in the process. So the logical relations of control activities should be considered, and the united control activities should be carried out.

TABLE 8.1 : Readings of Big End Bore Diameter

Part Name : Connecting Rod (S3 series)			UTL = 60.8460 mm	
Instrument Used : Air Guage (L.C. = 0.001mm)			LTL = 60.8330 mm	
Name of Operation : Final Honing			Machine No.	23a (Mns)
Sr.	**Traceability No.**	**Bore Diameter D_{x-x} (mm)**	**Bore Diameter D_{y-y} (mm)**	**Remarks**
1	2398	60.842	60.840	
2	2240	60.838	60.839	Reworked
3	2320	60.835	60.837	
4	2243	60.839	60.843	Reworked
5	2199	60.837	60.837	Reworked
6	2300	60.840	60.838	
7	2234	60.839	60.840	Reworked
8	2248	60.838	60.839	Reworked
9	2349	60.838	60.841	
10	2401	60.842	60.841	Reworked
11	2233	60.839	60.839	
12	2303	60.838	60.837	Reworked
13	2287	60.842	60.839	
14	2307	60.839	60.839	Reworked
15	2319	60.838	60.839	Reworked
16	2409	60.839	60.837	
17	2425	60.837	60.838	Reworked
18	2375	60.839	60.842	Reworked
19	2280	60.839	60.838	
20	2291	60.839	60.838	
Special Note: - The parameter to be measured along parting face is D_{x-x} and measured along rod axis is D_{y-y}. (Figure 8.1) - Air gauge is calibrated with 3 master calibration ring at a frequency of 50 pcs. The diameter of master calibration rings are 60.8330 mm, 60.8400 mm and 60.8460 mm.				

8.5 Analysis of brainstorming report

The objective of the brainstorming session is to understand why defects are generated. Brainstorming and statistical tools are used to identify basic variables that cause defects. The data is analyzed to find out the potential sources of variation and reduce the number of process variables to be acted on in the improvement phase.

The brainstorming exercise was carried out by an interdisciplinary team of engineers at the company. The report of exercise is used to identify potential factors that could influence the problem of big end bore diameter variation. The team assessed a number of factors and finally reduced them to five key factors. The key factors are shown by fishbone diagram in Fig. 8.2. The main factors that affect the bore diameter variation are listed below.

1. Oversize or undersize of big end pre-boring operation.
2. Misalignment of the axis of big end final boring operation.
3. Uncontrolled tool wears during final boring operation.
4. Rod face width oversize/undersize/taper after rod face grinding operation.
5. Oversize or undersize bore after the manual honing operation.

8.6 Fishbone diagram

Fishbone diagram

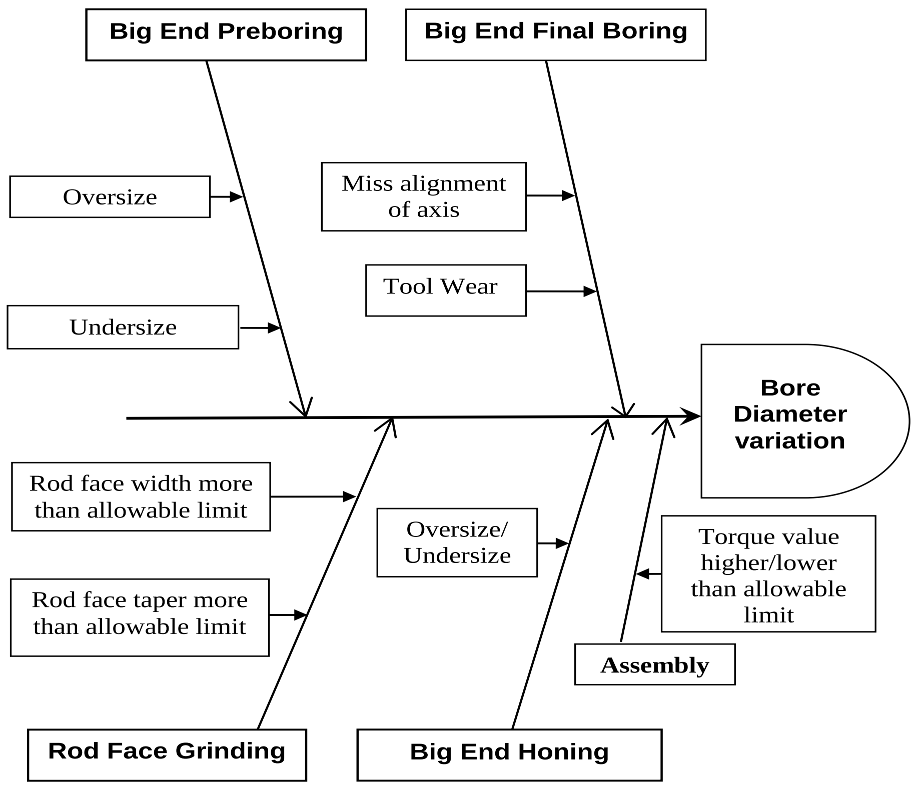


FIGURE 8.2 : Fish Bone Diagram for Bore Diameter Variation

TABLE 8.2 : Brain-storming Computation sheet

Rank	**Cause**	**Operator 1**	**Operator 2**	**Supervisor**	**QC Engineer**	**QC Head**	**Production Head**	**Researcher**	**Inspector**	**Jr. Supervisor**	**Total**
1	Torque value in Assembly	9	10	9	9	9	9	10	8	7	80
2	Ovality of bore after final boring	9	7	7	9	9	8	9	8	7	73
3	Big End Pre boring oversize	8	9	8	7	9	9	7	8	7	72
4	Big End Pre boring undersize	8	9	10	7	10	9	9	7	9	68
5	Rod face width variation	7	8	7	8	9	8	8	7	5	67
6	Rod face Taper	5	8	9	8	6	9	6	6	6	63
7	Axial Misalignment in boring	6	7	9	9	5	6	7	6	7	62
8	Tool wear	6	7	8	8	7	5	7	5	8	61
9	Big end honing oversize	8	8	5	4	5	7	6	4	3	50
10	Big end honing undersize	7	8	7	4	5	3	8	4	3	49
11	Improper Fixture Setup Process	6	6	7	3	3	5	6	3	5	44
12	Unskilled Operator	4	6	5	3	5	6	4	3	6	42

13	Machine Worktable Flatness	5	4	5	3	5	5	6	2	5	40
14	Inexperienced Operator	5	5	4	6	2	3	5	2	4	36
15	Machine Incapability	3	3	4	3	5	4	6	3	3	34
16	Lack of Inspection	4	5	3	2	4	2	6	2	4	32
17	Hardness Of Material	4	4	3	5	3	2	3	4	4	32

8.7 Discussion of proposed Action Plan

The five major key variables listed above analyzed for rejected components. The majority rejections were taken place due to oversize of the bore diameter. To study the possible reason for this cause, the fixture of the pre-boring operation, rod face grinding operation and big end final boring operation needed to be inspected. Following actions initiated for all machining operations.

8.7.1 Production Planning Approval Process (P-PAP) Type 1: Check Alignment (straightness) of the fixture for all the machining processes. The report found within the defined range.

8.7.2 Production Planning Approval Process (P-PAP) Type 2: Measure the spindle axial alignment. The report for P-PAP (Type 2) shown that the parameters are within the prescribed limit.

8.7.3 Gauge R & R Study (MSA): It helps to investigate about following three aspects. Whether the measuring system variability is small compared with the process variability. How much variability in the measuring system is caused by differences between operators? Whether the measurement system is capable of discriminating between different parts. A Gauge R & R study indicates whether the inspectors are consistent in their measurements of the same part (repeatability) and whether the variation between inspectors is consistent (reproducibility).

8.7.4 STAR technique: Interact with Operator and Inspector for the fitness to do work. In this activity, behavioral based interviews focus on a person’s specific past performances and experiences. Questions will predominately surround past work experiences that can illustrate the candidate’s competence. For these types of interviews, the STAR system (Situation/Task, Action and Result) may be useful for answering questions. These four titles serve as a framework for describing work experiences. When relating the facts of an experience, remember that interviewers are often looking for someone who's Optimistic, Creative, a Leader and a Team player [2] [3].

8.7.5 Patrol Inspection and Dock Inspection Report: Check the Patrol Inspection and Dock Inspection Reports: Both the reports cross checked with the senior inspector and found as per predefined norms. No any deviation found in the reports regarding dimensional quality. It was mentioned in the report that the non-confirmed products were sent to rework.

8.7.6 First Article Inspection Report (FAIR): The First Article Inspection Reports of last months were checked. All reports found that production process met the predefined requirements. First Piece Approval (FPA) was taken as per the inspection plans.

8.8 FMEA - Failure Mode and Effects Analysis

It is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. The first step is to prepare a 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 the respective factor on non-conformance).

- This action identified the reason for rejection in the present case. The majority of rejections taken place due to an oval of the big end bore. The report of oval pieces prepared for the torque applied to assemble the rods with a cap. It is found that the rejected pieces had higher torque at the time of second assembly operation. Due to higher torque, the possibility of an oval in big end bore increases and hence, rejection has taken place.

A p-FMEA (Product Failure Mode and Effect Analysis) sheet for three machining processes and two intermediate assembly processes is shown in Fig. 8.3.

From the causes enumerated in the cause and effect diagram, the failure modes and effects analysis was performed.

The risk priority numbers which were above 50 (as per the management decision) were considered to be the criteria for implementing the corrective action.

It can be noticed that the highest risk priority number (RPN) is for Assembly operation. Variation in torque value at the time of assembly of rod and cap results in bore diameter variation and oval of the bore after dis-assembly. Hence, to mitigate these causes, a necessary action plan was devised.

8.9 Data collection

Data collection of the key process characteristic was performed for 60 consecutive machined components. Data to be collected and tabulated per week (one iteration per week). After each iteration, readings are taken and recorded as represented in respective iteration tables. (Table 8.3, 8.4, 8.5, 8.6). The process monitoring chart is prepared to show process variation. The average value of bore diameter of the group of four components is plotted on the x-axis and respective group numbers on the y-axis.

Process Failure Modes and Effects Analysis sheet										
Operation No.	Process Name	Potential Failure	Potential effect	Severity	Potential Cause	Occurrence	Current Controls	Detection	Risk Priority Number
15	Assembly 1	Torque wrench setting	Torque value less/more	9	Ovality of bore varies after disassembly	8	In process Inspection Report	3	51
		Lack of Inspection	Torque value less/more	9	Ovality of bore varies after disassembly	9		3	54
19	Assembly 2	Torque value in Assembly	Torque value less/more	7	Honning pattern not maintained in Big End bore	9	Visual inspection and bore guage	2	32
		Lack of Inspection	Torque value less/more	7		8		2	30
16	Big End Pre and Final Boring	Ovality of bore after final boring	Taperness of bore	6	Misalignment of Axis in final boring	7	Tool set up control in check list	3	39
		Machine Incapability	Bore diameter variation	5	measuring instruments to be checked	7	Gauge R & R study report	2	24
		Big End Pre boring oversize	Bore diameter variation	6	worn out fixture setup	8	fixture calibration procedure report	3	42
		Big End Pre boring undersize	rework to be done	5	dimensional inaccuracies of forging	8	In process Inspection Report	3	39
2	Rod Face Grinding	Rod face width variation	incorrect location of the component in fixtures of next operations	6	dimensional inaccuracies of forging	4	Forging Inspection Report	4	40
		Machine Worktable Flatness Irregularities	Rod face taper	7	improper zero setting and referencing of the grinding wheel position	6	fixture calibration procedure document	3	39
		Tool wear	Dimensional variation	5	improper zero setting and referencing of the grinding wheel position	7	tool setup control in the check list	3	36
		Machine Incapability	Component rejection	6	improper zero setting and referencing of the grinding wheel position	5	Machine Capability Report	3	33
		Lack of Inspection	Component rejection	5	Dial gauge not calibrated	6	In process Inspection Report	2	22
21	Big End Honing	Big end honing oversize	Improper Fixture Setup Process	4	First Piece Approval process not standardized	5	First Piece Approval Report (FPA)	3	27
		Big end honing undersize	incorrect location of the component in fixtures of next operations	4	First Piece Approval process not standardized	5	First Piece Approval Report (FPA)	2	18
		Unskilled Operator	honing pattern disturbed	3	Inprocess Inspection frequency change	4	Visual inspection & IIR	1	7
		Inexperienced Operator	honing pattern disturbed	4	Inprocess Inspection frequency change	4	Visual inspection & IIR	2	16
		Hardness Of Material	Bore diameter variation	3	Inprocess Inspection frequency change	5	Material Test Report	2	16

FIGURE 8.3 : Process FMEA Sheet

8.10 Analysis

The analysis phase comprises performing the calculations for the C_p and C_{pk} values across each iteration. This was followed by one-way ANOVA method of investigation to test for the differences between the four iterations of the data sets.

8.10.1 First Iteration

The readings of the first week of 60 components are tabulated in Table 8.3. The readings are taken after the final honing operation. The computation report indicates lower values of process capability indices.

8.10.2 Second Iteration

In this iteration, gauge repeatability and reproducibility was performed and data were collected as represented in Table 8.4. It is seen that there is a marginal improvement in process capability indices. This marginal improvement is a positive sign for performed Gauge R & R.

8.10.3 Third Iteration

This iteration was performed after checking rod face width parameter. The components selected with the lower range of variation in two parameters i.e. rod face width and taper. The axial alignment in big end boring operation also checked and corrected as per predefined range. The readings are taken and represented in Table 8.5. Again it shows a slight improvement in C_p and C_{pk}. The process is still not capable as the values are lower. Hence iteration is performed after other corrective action.

8.10.4 Fourth Iteration

In this iteration, data is collected after correction in torque value in both assemblies. It is observed that the value of torque in the second assembly was not with the range. The torque wrench for the second assembly was altered and frequency of calibration was reduced from once in a shift to twice in a shift. The readings were taken and values of process capability indices represented in Table 8.6 shows considerable improvement.

Table 8.3 : Process Capability Report First Iteration

Sub-Group	Readings of Big Bore Diameter				x_{avg}	Range	Results	
	1	2	3	4				
1	60.842	60.840	60.839	60.834	60.839	0.008	X_{avg}	60.8382
2	60.838	60.839	60.838	60.833	60.837	0.006	R_{avg}	0.0035
3	60.834	60.833	60.838	60.835	60.835	0.005		
4	60.839	60.839	60.840	60.837	60.839	0.003	USL	60.8460
5	60.837	60.837	60.838	60.839	60.838	0.002	LSL	60.8330
6	60.840	60.838	60.838	60.839	60.839	0.002		
7	60.839	60.840	60.842	60.839	60.840	0.003	σ	0.00168
8	60.838	60.835	60.834	60.833	60.835	0.005		
9	60.835	60.841	60.839	60.838	60.838	0.006	**C_p**	**1.2875**
10	60.842	60.841	60.839	60.840	60.841	0.003	**C_{pk}**	**1.5483**
11	60.839	60.839	60.837	60.839	60.839	0.002		**1.0267**
12	60.838	60.837	60.838	60.837	60.838	0.001		
13	60.842	60.839	60.842	60.839	60.841	0.003	A_2	0.73
14	60.839	60.839	60.838	60.837	60.838	0.002	D_4	2.28
15	60.838	60.839	60.838	60.838	60.838	0.001		

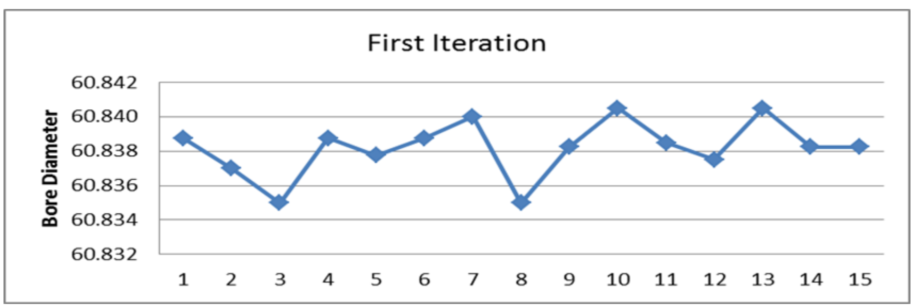


FIGURE 8.4 : First Iteration

Table 8.4: Process Capability Study Report Second Iteration

Sub-Group	Readings of Big Bore Diameter				x_{avg}	Range	Results	
	1	2	3	4				
1	60.838	60.842	60.841	60.843	60.841	0.005	X_{avg}	60.8386
2	60.840	60.839	60.838	60.833	60.838	0.007	R_{avg}	0.0033
3	60.841	60.838	60.838	60.839	60.839	0.003		
4	60.838	60.839	60.840	60.837	60.839	0.003	USL	60.8460
5	60.838	60.839	60.838	60.840	60.839	0.002	LSL	60.8330
6	60.834	60.838	60.838	60.839	60.837	0.005		
7	60.838	60.837	60.838	60.839	60.838	0.002	Σ	0.00159
8	60.838	60.835	60.834	60.833	60.835	0.005		
9	60.839	60.841	60.839	60.838	60.839	0.003	**C_p**	**1.3663**
10	60.839	60.841	60.839	60.840	60.840	0.002	**C_{pk}**	**1.5660**
11	60.842	60.839	60.837	60.839	60.839	0.005		**1.1666**
12	60.838	60.838	60.838	60.837	60.838	0.001		
13	60.842	60.840	60.842	60.839	60.841	0.003	A_2	0.73
14	60.837	60.839	60.838	60.839	60.838	0.002	D_4	2.28
15	60.838	60.839	60.838	60.838	60.838	0.001		

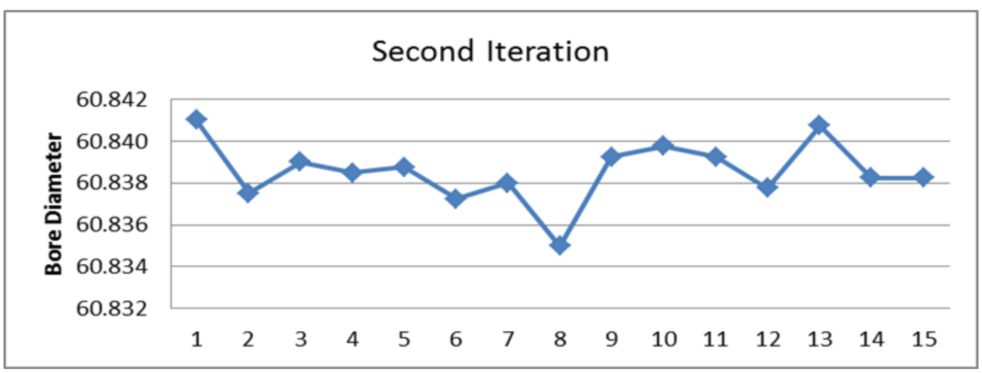


FIGURE 8.5 : Second Iteration

TABLE 8.5: Process Capability Study Report Third Iteration

Sub-Group	Readings of Big Bore Diameter				x_{avg}	Range	Results	
	1	2	3	4				
1	60.834	60.838	60.838	60.839	60.837	0.005	X_{avg}	60.8386
2	60.839	60.840	60.839	60.837	60.839	0.003	R_{avg}	0.0031
3	60.842	60.841	60.842	60.843	60.842	0.002		
4	60.838	60.838	60.839	60.833	60.837	0.006	USL	60.8460
5	60.837	60.838	60.837	60.839	60.838	0.002	LSL	60.8330
6	60.838	60.834	60.835	60.833	60.835	0.005		
7	60.837	60.838	60.839	60.840	60.839	0.003	Σ	0.00152
8	60.840	60.838	60.838	60.839	60.839	0.002		
9	60.835	60.839	60.841	60.838	60.838	0.006	$\mathbf{C_p}$	**1.4245**
10	60.842	60.839	60.841	60.840	60.841	0.003	$\mathbf{C_{pk}}$	**1.6180**
11	60.840	60.842	60.840	60.839	60.840	0.003		**1.2309**
12	60.839	60.838	60.839	60.839	60.839	0.001		
13	60.840	60.842	60.840	60.839	60.840	0.003	A_2	0.73
14	60.839	60.837	60.839	60.839	60.839	0.002	D_4	2.28
15	60.838	60.838	60.838	60.837	60.838	0.001		

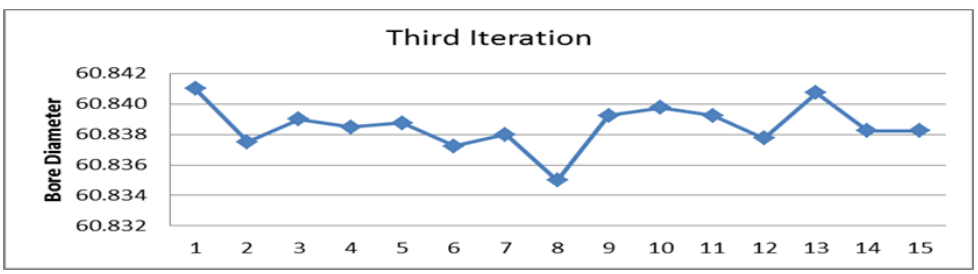


FIGURE 8.6 : Third Iteration

TABLE 8.6 : Process Capability Report Fourth Iteration

Sub-Group	Readings of Big Bore Diameter				x_{avg}	Range	Results	
	1	2	3	4				
1	60.838	60.838	60.838	60.842	60.839	0.004	X_{avg}	60.8384
2	60.837	60.838	60.839	60.838	60.838	0.002	R_{avg}	0.0029
3	60.838	60.838	60.838	60.842	60.839	0.004		
4	60.839	60.839	60.838	60.837	60.838	0.002	USL	60.8460
5	60.837	60.837	60.838	60.838	60.838	0.001	LSL	60.8330
6	60.838	60.838	60.838	60.838	60.838	0.000		
7	60.838	60.838	60.837	60.840	60.838	0.003	σ	0.00142
8	60.834	60.838	60.840	60.839	60.838	0.006		
9	60.838	60.839	60.839	60.838	60.839	0.001	**C_p**	**1.5216**
10	60.838	60.839	60.837	60.838	60.838	0.002	**C_{pk}**	**1.7908**
11	60.840	60.842	60.843	60.838	60.841	0.005		**1.2524**
12	60.839	60.838	60.833	60.834	60.836	0.006		
13	60.840	60.842	60.839	60.838	60.840	0.004	A_2	0.73
14	60.840	60.837	60.839	60.839	60.839	0.003	D_4	2.28
15	60.838	60.838	60.838	60.837	60.838	0.001		

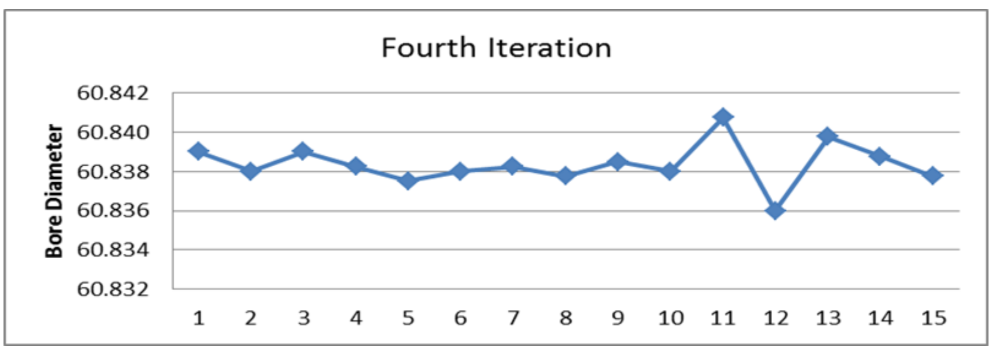


FIGURE 8.7 : Fourth Iteration

8.11 Process capability study report compilation

This phase is related to select those product performance characteristics which must be improved to achieve the goal. In the present case, few aspects need to have attention as far as quality is concerned. The causes and reasons matrix is drawn and results are entered and the improvement actions that are to be taken are listed. The values of process capability indices are stated to indicate the impact of implemented actions.

TABLE 8.7 : Compiled Process Capability Study Reports

Cause	Reason	Actions to be implemented	Process Capability Indices	
			C_p	C_{pk}
More rework after final honing operation	Operator tendency to work on lower side	Instructed operator to do honing to mean value of bore diameter.	1.2875	1.5483 1.0267
Bore diameter variation	Bore Gauge variation in reading	Gauge R & R study to be conducted.	1.3663	1.5660 1.1666
Rod face width variation	Fixture setup not done properly	The fixture to be set properly.	1.4245	1.6180 1.2309
Torque value of nut and bolt assembly varies	Torque wrench not checked regularly	Torque wrench checking frequency decided.	1.5216	1.7902 1.2524

8.12 Implemented action plan

The value of torque at the time of the second assembly of connecting rod should be maintained in the pre-defined range. The use of precise torque wrench is proposed to have better accuracy in an assembly operation. It is also proposed to do the calibration of the torque wrench regularly. Further, it is also decided to check a sample of a batch for torque at the time of the second assembly of rod and cap. This reduced the possibility of rejection in big end bore diameter variation up to a considerable extent. This phase assures that the implemented action will sustain and it is incorporated into the system.

8.13 Conclusion

Assembly of the connecting rod during manufacturing operations needs to be performed in the pre-defined range. When rod and cap are assembled, the value of torque applied to bolts makes the great impact over the dimensional quality of connecting rod. The quality of subsequent operations of connecting rod depends on the tightness of the rod and cap. The higher value of torque results in ovality of big end bore. The lower value of torque may cause vibration and parting line misalignment and ultimately bend and twist of the connecting rod.

The objective of introducing the Six Sigma – DMAIC methodology to the concern by applying it to the most chronic problem faced by the company was successfully achieved. The implementation of it resulted in understanding the problem from all aspects, qualitatively as well as quantitatively, and laying out the improvements through effective analysis of the roots of the problem.

CHAPTER – 9

Computation of Performance Excellence, Conclusion and Future Scope

9.1 Performance Excellence

Excellence means a talent or quality which is good and so surpasses ordinary standards. Excellence is a quality that people really appreciate because it's so difficult to discover. It is also used as a standard of performance. The meaning of excellence is to improve the existing one. Performance excellence means to improve the existing situation.

According to NIST, Performance excellence refers to an integrated approach to organizational performance management that result in, delivery of ever-improving value to customers and stakeholders, contributing to organizational sustainability, Improvement of overall organizational effectiveness and capabilities and oorganizational and personal learning [60].

It is difficult to statistically justify actual impact of any alteration or modification made on the shop floor. Many factors should be considered before and after modification employed. The method to compute performance excellence includes some statistical parameters like rework quantity, rejection quantity, inventory, customer complaints, scrape quantity and production quantity. The reduction in these parameters illustrates the implementation of performance excellence in connecting rod manufacturing industries.

9.2 Data analysis

Statistical Process Control report prepared for critical parameters of connecting rod represent the improvement in terms of quality. The Tables 9.1 to 9.7 represent the improvement in performance of connecting rod manufacturing processes.

The graph represents the improvement in values of process capability indices. The higher value of these indices represents more stability of the process.

TABLE 9.1 : Big End Bore Diameter

PART NAME:			**Con Rod**			INSTRUMENT USED:		Air Guage				
PART NO.:						LEAST COUNT:		0.001 mm				
CUSTOMER NAME:			M/s. Simpson			M/C NO.:		07-08iXi				
OPERATION NAME:			Honning			MACHINE NAME:		Manisa				
PARAMETER:			Big End Diameter			OPERATOR NAME:		Birju Patel				
SUB-	READINGS											
GROUP	1	2	3	4	$\bar{X}$	R	RESULTS					
1	60.842	60.840	60.839	60.838	60.840	0.004	$\bar{\bar{X}}$	60.8388	CONTROL LIMITS:		INTERPRETATION	
2	60.838	60.839	60.838	60.839	60.839	0.001	$\bar{R}$	0.0022	UCLX	60.8404	**Cp<1.00**	
3	60.839	60.837	60.838	60.839	60.838	0.002	UTL	60.8460	LCLX	60.8372	1. Process is not capable	
4	60.839	60.839	60.840	60.837	60.839	0.003	LTL	60.8330	UCLR	0.0050	- try to shift the job to	
5	60.837	60.837	60.838	60.839	60.838	0.002	σ	0.00107	LCLR	0.0000	another process with	
6	60.840	60.838	60.838	60.839	60.839	0.002	**Cp**	**2.0288**	A2	D4	adequate capability	
7	60.839	60.840	60.842	60.839	60.840	0.003	Cpk	2.2369	0.73	2.28	-try to improve capability	
8	60.838	60.839	60.838	60.838	60.838	0.001		1.8207			**Cp=1.00**	
9	60.838	60.841	60.839	60.838	60.839	0.003					1. Process is just capable	
10	60.842	60.841	60.839	60.840	60.841	0.003	Comments (If any):				**Cp>1.00**	
11	60.839	60.839	60.837	60.839	60.839	0.002					1. Process is quite capable	
12	60.838	60.837	60.838	60.837	60.838	0.001					**Cp>1.67**	
13	60.842	60.839	60.842	60.839	60.841	0.003					1. Process is capable	
14	60.839	60.839	60.838	60.837	60.838	0.002					**Cpk<1.67**	
15	60.838	60.839	60.838	60.838	60.838	0.001					1. Machine setting required	
	JAN	**FEB**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Cp	**1.71**	**1.91**	**2.15**	**1.91**	**2.00**	**2.03**						
Cpk	**1.51**	**1.65**	**1.90**	**1.71**	**1.90**	**1.82**						

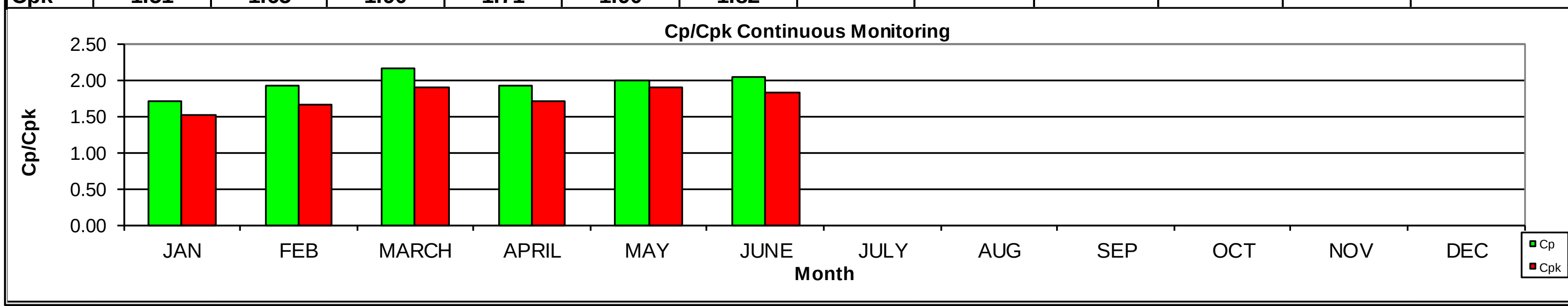


TABLE 9.2 : Small End Boring (Parent bore-without bush)

PART NAME:	**Con Rod**	INSTRUMENT USED:	Air Guage
CUSTOMER NAME:		LEAST COUNT:	0.001 mm
CUSTOMER NAME:	M/s. Simpson	M/C NO.:	G2709ix
OPERATION NAME:	Boring	MACHINE NAME:	Gehring
PARAMETER:	Bore Diameter	OPERATOR NAME:	Kalu Mal

SUB-GROUP	READINGS 1	2	3	4	$\bar{X}$	R	RESULTS				
1	34.945	34.937	34.941	34.940	34.941	0.008	$\bar{\bar{X}}$	34.9395	CONTROL LIMITS:		INTERPRETATION
2	34.937	34.945	34.935	34.938	34.939	0.010	$\bar{R}$	0.0061	UCLX	34.9439	**Cp<1.00**
3	34.940	34.937	34.937	34.945	34.940	0.008	UTL	34.9560	LCLX	34.9350	1. Process is not capable
4	34.937	34.941	34.940	34.937	34.939	0.004	LTL	34.9200	UCLR	0.0140	- try to shift the job to
5	34.937	34.937	34.938	34.941	34.938	0.004	σ	0.00298	LCLR	0.0000	another process with
6	34.937	34.937	34.945	34.940	34.940	0.008	**Cp**	**2.0152**	A2	D4	adequate capability
7	34.935	34.937	34.937	34.941	34.938	0.006	**Cpk**	**1.8510**	0.73	2.28	-try to improve capability
8	34.937	34.935	34.940	34.940	34.938	0.005		**2.1794**			**Cp=1.00**
9	34.940	34.937	34.937	34.940	34.939	0.003					1. Process is just capable
10	34.938	34.940	34.937	34.937	34.938	0.003	Comments (If any):				**Cp>1.00**
11	34.945	34.938	34.937	34.945	34.938	0.008					1. Process is quite capable
12	34.937	34.940	34.935	34.937	34.941	0.005					**Cp>1.67**
13	34.941	34.935	34.937	34.941	34.942	0.006					1. Process is capable
14	34.945	34.940	34.937	34.937	34.945	0.008					**Cpk<1.67**
15	34.937	34.941	34.935	34.935	34.938	0.006					1. Machine setting required

	JAN	**FEB**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Cp	**1.87**	**1.97**	**2.03**	**2.18**	**2.00**	**2.01**						
Cpk	**1.70**	**1.82**	**1.86**	**2.00**	**1.80**	**1.85**						

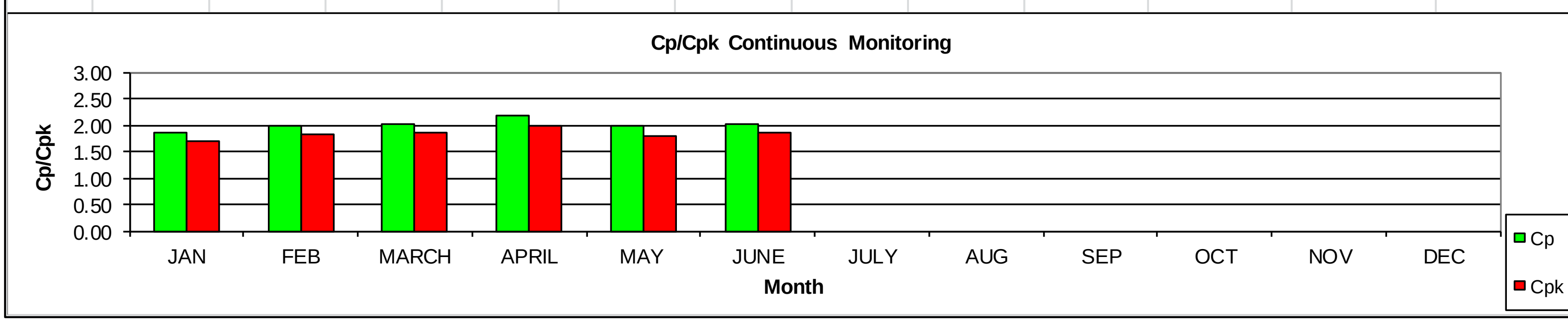


TABLE 9.3 : Bolt Hole Drilling

PART NAME:	**Con Rod**					INSTRUMENT USED:		Air Guage				
PART NO.:						LEAST COUNT:		0.001 mm				
CUSTOMER NAME	M/s. Simpson					M/C NO.:		BHxddi				
OPERATION NAME	Bolt Hole Drilling					MACHINE NAME:		Aurum Multy Spindle Drilling Machine				
PARAMETER:	Bolt Hole Diameter					OPERATOR NAME:		Manoj pai				
SUB-	READINGS											
GROUP	1	2	3	4	$\bar{X}$	R	RESULTS					
1	11.138	11.135	11.130	11.142	11.136	0.012	$\bar{\bar{X}}$	11.1327	CONTROL LIMITS:		INTERPRETATION	
2	11.131	11.134	11.131	11.130	11.132	0.004	$\bar{R}$	0.0067	UCLX	11.1376	**Cp<1.00**	
3	11.130	11.130	11.135	11.131	11.132	0.005	UTL	11.1500	LCLX	11.1278	1. Process is not capable	
4	11.131	11.131	11.138	11.135	11.134	0.007	LTL	11.1000	UCLR	0.0154	-try to shift the job to	
5	11.138	11.126	11.135	11.131	11.133	0.012	σ	0.00327	LCLR	0.0000	another process with	
6	11.131	11.135	11.134	11.138	11.135	0.007	**Cp**	**2.5495**	A2	D4	adequate capability	
7	11.131	11.135	11.138	11.142	11.137	0.011	Cpk	1.7626	0.73	2.28	-try to improve capability	
8	11.126	11.131	11.131	11.131	11.130	0.005		3.3365			**Cp=1.00**	
9	11.142	11.130	11.130	11.135	11.134	0.012					1. Process is just capable	
10	11.130	11.131	11.131	11.131	11.131	0.001	Comments (If any):				**Cp>1.00**	
11	11.131	11.131	11.138	11.130	11.133	0.008					1. Process is quite capable	
12	11.135	11.135	11.131	11.131	11.133	0.004					**Cp>1.67**	
13	11.131	11.134	11.131	11.126	11.131	0.008					1. Process is capable	
14	11.134	11.131	11.131	11.135	11.133	0.004					**Cpk<1.67**	
15	11.131	11.130	11.131	11.131	11.131	0.001					1. Machine setting required	
	JAN	**FEB**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Cp	**2.14**	**2.36**	**2.52**	**2.57**	**2.40**	**2.54**						
Cpk	**1.51**	**1.66**	**1.75**	**1.80**	**1.90**	**1.76**						

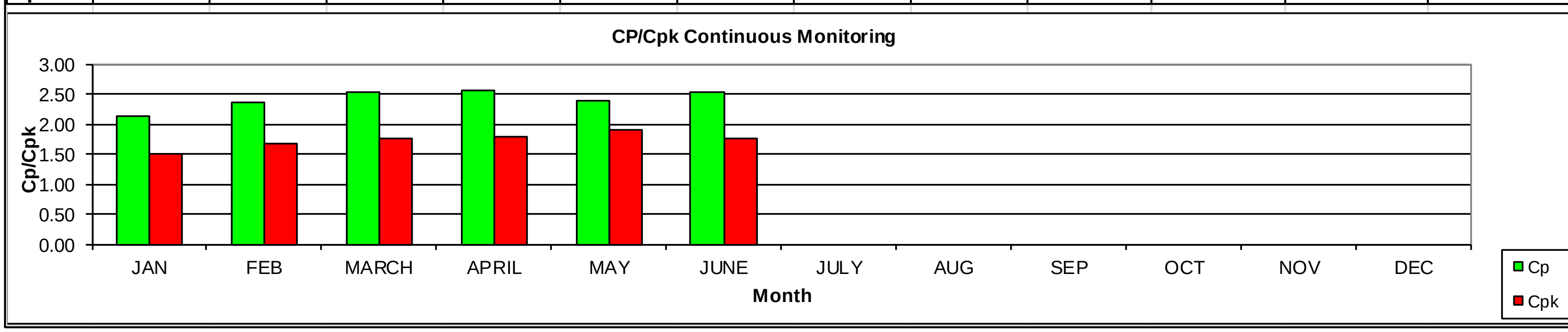


TABLE 9.4 : Center Distance

PART NAME:	Con Rod	INSTRUMENT USED:	Task Special Purpose Guage
PART NO.:		LEAST COUNT:	0.001 mm
CUSTOMER NAME:	M/s. Simpson	M/C NO.:	17-08-00
OPERATION NAME:	Small End Bush Boring	MACHINE NAME:	Profitech
PARAMETER:	**Center Distance**	OPERATOR NAME:	Rajan Pal

SUB-GROUP	READINGS 1	2	3	4	$\bar{X}$	R	RESULTS				
1	223.840	223.847	223.841	223.838	223.842	0.009	$\bar{\bar{X}}$	223.8414	CONTROL LIMITS:		INTERPRETATION
2	223.839	223.845	223.839	223.847	223.843	0.008	$\bar{R}$	0.0087	UCLX	223.8478	**Cp<1.00**
3	223.838	223.838	223.847	223.841	223.841	0.009	UTL	223.8630	LCLX	223.8351	1. Process is not capable
4	223.847	223.847	223.836	223.839	223.842	0.011	LTL	223.8120	UCLR	0.0199	-try to shift the job to
5	223.840	223.847	223.845	223.847	223.845	0.007	σ	0.00424	LCLR	0.0000	another process with
6	223.847	223.845	223.838	223.838	223.842	0.009	**Cp**	**2.0050**	A2	D4	adequate capability
7	223.841	223.838	223.840	223.845	223.841	0.007	**Cpk**	**1.6957**	0.73	2.28	-try to improve capability
8	223.841	223.847	223.839	223.838	223.841	0.009		**2.3142**			**Cp=1.00**
9	223.839	223.839	223.838	223.844	223.840	0.006					1. Process is just capable
10	223.847	223.847	223.847	223.838	223.845	0.009	Comments (If any):				**Cp>1.00**
11	223.836	223.836	223.840	223.842	223.839	0.006					1. Process is quite capable
12	223.845	223.845	223.847	223.839	223.844	0.008					**Cp>1.67**
13	223.838	223.838	223.841	223.837	223.839	0.004					1. Process is capable
14	223.838	223.838	223.830	223.847	223.838	0.017					**Cpk<1.67**
15	223.847	223.836	223.847	223.835	223.841	0.012					1. Machine setting required

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Cp	**1.99**	**1.96**	**2.05**	**1.90**	**2.01**	**2.11**						
Cpk	**1.60**	**1.62**	**1.65**	**1.63**	**1.72**	**1.78**						

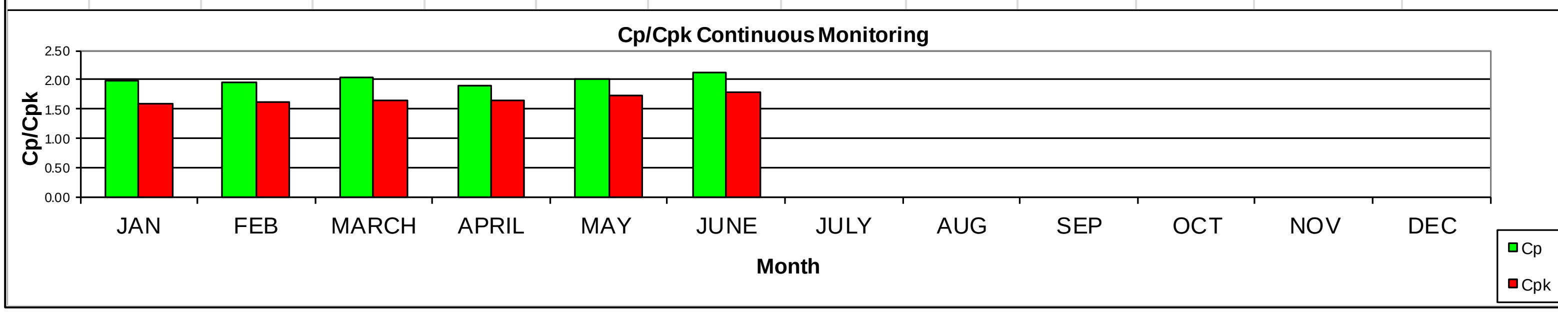


TABLE 9.5 : Bend (Axial Mis-alignment)

PART NAME:			**Con Rod**			INSTRUMENT USED:	V Block, Pins, Height Gauge					
PART NO.:						LEAST COUNT:	0.001 mm					
CUSTOMER NAME:			M/s. Simpson			M/C NO.:	xn99d					
OPERATION NAME:			Small End Bush Boring			MACHINE NAME:	Profitech					
PARAMETER:			**Bend**			OPERATOR NAME:	Nayan Sahu					
SUB-	READINGS											
GROUP	1	2	3	4	$\bar{X}$	R	RESULTS					
1	0.003	-0.001	0.004	0.003	0.002	0.005	$\bar{\bar{X}}$	0.0008	CONTROL LIMITS:		INTERPRETATION	
2	-0.004	-0.003	-0.003	-0.003	-0.003	0.001	$\bar{R}$	0.0037	UCLX	0.0035	**Cp<1.00**	
3	0.003	0.002	0.003	0.004	0.003	0.002	UTL	0.0100	LCLX	-0.0020	1. Process is not capable	
4	-0.001	0.001	-0.003	-0.004	-0.002	0.005	LTL	0.0000	UCLR	0.0085	-try to shift the job to	
5	0.004	0.005	0.002	0.001	0.003	0.004	σ	0.00181	LCLR	0.0000	another process with	
6	0.004	0.003	0.005	0.003	0.004	0.002	**Cp**	**0.9196**	A2	D4	adequate capability	
7	-0.004	0.003	0.003	0.002	0.001	0.007	**Cpk**	**1.6983**	0.73	2.28	-try to improve capability	
8	-0.004	-0.003	-0.004	-0.003	-0.004	0.001		**1.6700**			**Cp=1.00**	
9	0.003	0.005	0.003	0.004	0.004	0.002					1. Process is just capable	
10	0.002	0.003	0.004	0.003	0.003	0.002	Comments (If any):				**Cp>1.00**	
11	-0.004	-0.001	-0.004	-0.006	-0.004	0.005					1. Process is quite capable	
12	-0.001	0.003	0.001	0.001	0.001	0.004					**Cp>1.67**	
13	0.003	0.003	-0.001	0.005	0.003	0.006					1. Process is capable	
14	-0.001	0.002	0.003	0.002	0.002	0.004					**Cpk<1.67**	
15	-0.003	0.002	-0.004	0.001	-0.001	0.006					1. Machine setting required	
	JAN	**FEB**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Cp	**1.70**	**1.70**	**1.68**	**1.70**	**1.71**	**1.73**						
Cpk	1.600	1.630	1.650	1.660	1.690	1.670						

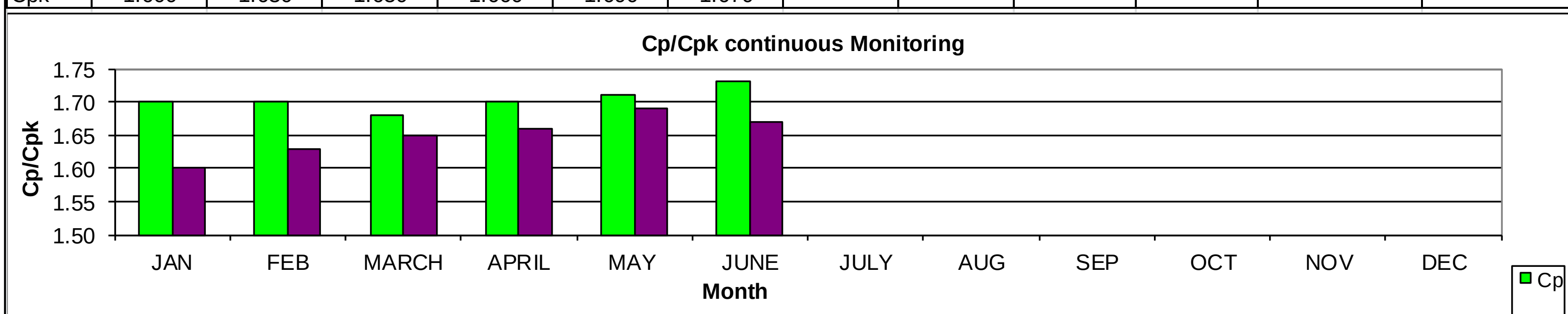


TABLE 9.6 : Small End Diameter (After Bush Boring)

PART NAME:			**Con Rod**			INSTRUMENT USED:		Air Guage				
PART NO.:						LEAST COUNT:		0.001 mm				
CUSTOMER NAME:			M/s. Simpson			M/C NO.:		17-08-00				
OPERATION NAME:			Small End Bush Boring			MACHINE NAME:		Profitech				
PARAMETER:			Bush Diameter			OPERATOR NAME:		Nayan Sahu				
SUB-	READINGS											
GROUP	1	2	3	4	$\bar{X}$	R	RESULTS					
1	31.773	31.772	31.773	31.776	31.774	0.004	$\bar{\bar{X}}$	31.7765	CONTROL LIMITS:		INTERPRETATION	
2	31.774	31.773	31.776	31.773	31.774	0.003	$\bar{R}$	0.0045	UCLX	31.7798	**Cp<1.00**	
3	31.773	31.774	31.779	31.774	31.780	0.006	UTL	31.7880	LCLX	31.7733	1. Process is not capable	
4	31.774	31.771	31.773	31.772	31.773	0.003	LTL	31.7630	UCLR	0.0102	-try to shift the job to	
5	31.779	31.771	31.773	31.773	31.780	0.008	σ	0.00217	LCLR	0.0000	another process with	
6	31.776	31.775	31.776	31.776	31.776	0.001	**Cp**	**1.9216**	A2	D4	adequate capability	
7	31.779	31.779	31.776	31.775	31.780	0.004	Cpk	1.7653	0.73	2.28	-try to improve capability	
8	31.779	31.773	31.773	31.773	31.775	0.006		2.0779			**Cp=1.00**	
9	31.773	31.779	31.773	31.773	31.775	0.006					1. Process is just capable	
10	31.776	31.773	31.774	31.772	31.780	0.004	Comments (If any):				**Cp>1.00**	
11	31.779	31.771	31.773	31.773	31.774	0.008					1. Process is quite capable	
12	31.773	31.776	31.776	31.772	31.780	0.004					**Cp>1.67**	
13	31.776	31.775	31.779	31.771	31.775	0.008					1. Process is capable	
14	31.776	31.776	31.776	31.776	31.780	0.000					**Cpk<1.67**	
15	31.773	31.774	31.773	31.775	31.774	0.002					1. Machine setting required	
	JAN	**FEB**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Cp	**1.78**	**1.92**	**1.95**	**2.01**	**1.78**	**1.92**						
Cpk	**1.61**	**1.71**	**1.75**	**1.79**	**1.70**	**1.76**						

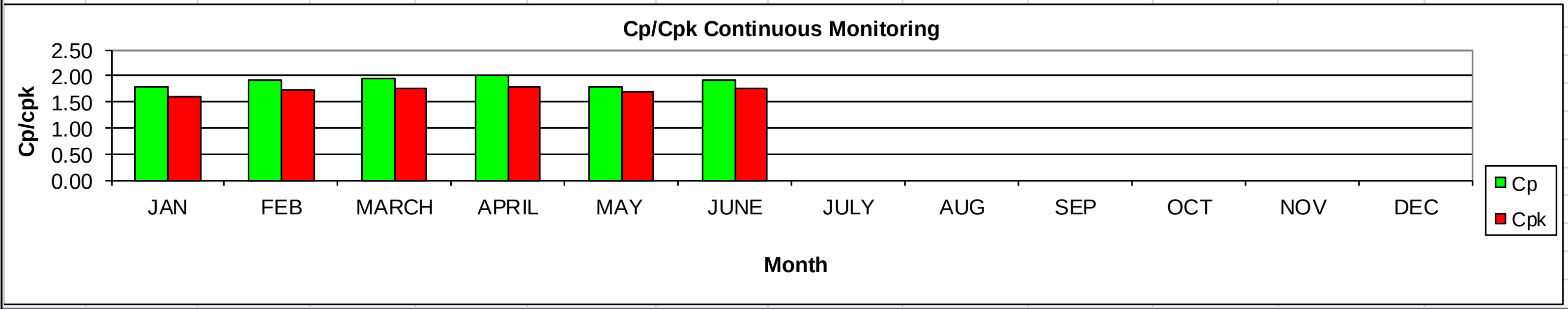
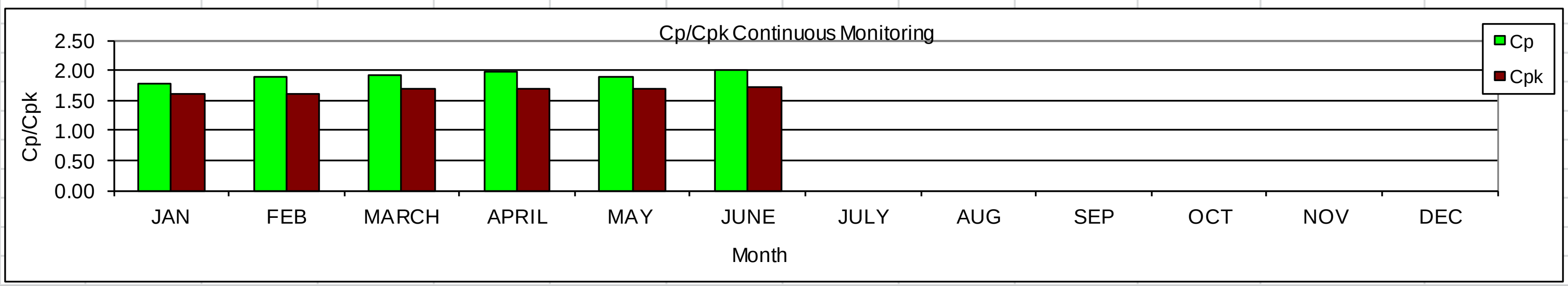


TABLE 9.7 : Twist (Axial Mis-alignment)

PART NAME:	Con Rod	INSTRUMENT USED:	V Block, Pins, Height Gauge
PART NO.:		LEAST COUNT:	0.001 mm
CUSTOMER NAME:	M/s. Simpson	M/C NO.:	bkXn
OPERATION NAME:	Small End Bush Boring	MACHINE NAME:	Profitech
PARAMETER:	**Twist**	OPERATOR NAME:	Nayan Sahu

SUB-	READINGS						RESULTS				
GROUP	1	2	3	4	$\bar{X}$	R					
1	-0.002	-0.003	0.001	0.001	-0.001	0.004	$\bar{\bar{X}}$	0.0013	CONTROL LIMITS:		INTERPRETATION
2	-0.003	-0.002	-0.002	-0.002	-0.002	0.001	$\bar{R}$	0.0023	UCLX	0.0030	**Cp<1.00**
3	0.003	0.002	0.004	0.003	0.003	0.002	UTL	0.0100	LCLX	-0.0004	1. Process is not capable
4	0.002	0.005	0.003	0.003	0.003	0.003	LTL	0.0000	UCLR	0.0053	- try to shift the job to
5	0.002	0.003	0.002	0.002	0.002	0.001	σ	0.00113	LCLR	0.0000	another process with
6	-0.001	-0.002	0.002	0.002	0.000	0.004	**Cp**	**1.7000**	A2	D4	adequate capability
7	0.002	0.003	0.003	0.002	0.003	0.001	**Cpk**	**1.6700**	0.73	2.28	-try to improve capability
8	0.005	0.002	0.003	0.003	0.003	0.003		**1.6900**			**Cp=1.00**
9	-0.003	-0.002	-0.002	-0.002	-0.002	0.001					1. Process is just capable
10	0.002	0.005	0.002	0.002	0.003	0.003	Comments (If any):				**Cp>1.00**
11	0.005	0.005	0.005	0.005	0.005	0.000					1. Process is quite capable
12	0.001	0.003	0.002	0.003	0.002	0.002					**Cp>1.67**
13	-0.003	0.001	-0.004	0.002	-0.001	0.006					1. Process is capable
14	0.002	0.002	0.002	0.002	0.002	0.000					**Cpk<1.67**
15	-0.003	0.000	-0.002	0.001	-0.001	0.004					1. Machine setting required

	JAN	**FEB**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Cp	**1.77**	**1.90**	**1.92**	**1.98**	**1.89**	**1.99**						
Cpk	*1.6*	1.6	1.7	1.7	1.7	1.7						



It can be concluded from Tables 9.1 to 9.7 that the processes are under statistical control, as the values of process capability indices are higher. It can also be concluded that there is an improvement in the values of process capability indices in each case.

The data represented in Table 9.8 shows the rework quantity year wise and parameter wise. Table 9.9 shows the rejection quantity year wise. The graph is shown in Fig. 9.1 and Fig. 9.2 represents the reduction in rework and rejection quantity year wise. The quantity of production is shown in Fig. 9.3.

The reduction in rework and rejection ultimately results in the reduction in customer complaints and hence customer satisfaction. The ultimate aim of present work is to enhance the customer satisfaction by employing various quality improvement techniques.

TABLE 9.8 : Rework Quantity year wise

Sr. No.	Parameters	Actual Production Quantity Q (year wise)							
		2012-13		2013-2014		2014-15		2015-16	
		Q = 65184		Q = 71349		Q = 75723		Q = 79803	
		Rework pcs	%	Rework pcs	%	Rework pcs	%	Rework pcs	%
1	Big End bore diameter	890	1.37	1105	1.55	987	1.30	1011	1.27
2	Small End bore diameter	824	1.26	998	1.40	787	1.04	976	1.22
3	Center Distance (C.D.)	909	1.39	802	1.12	839	1.11	56	0.07
4	Bend	891	1.37	782	1.10	445	0.59	40	0.05
5	Twist	793	1.22	292	0.41	432	0.57	28	0.04
6	End Float more/less	34	0.05	43	0.06	23	0.03	42	0.05
7	Big end bore width	45	0.07	54	0.08	43	0.06	45	0.06
8	Rib diameter variation	193	0.30	64	0.09	22	0.03	64	0.08
9	Honing pattern in big end bore	765	1.17	654	0.92	43	0.06	23	0.03
10	Big End Bore Oval	821	1.26	665	0.93	342	0.45	65	0.08
11	Surface Finish in Big End Bore	678	1.04	564	0.79	42	0.06	43	0.05
12	Surface Finish in Small End Bore	192	0.29	43	0.06	556	0.73	28	0.04
13	Big End bore Taper	345	0.53	543	0.76	65	0.09	78	0.10
14	Small End bore Taper	392	0.60	453	0.63	433	0.57	54	0.07
15	Oil Hole Diameter in Small End	232	0.36	122	0.17	344	0.45	65	0.08
16	Cap Face Taper	324	0.50	329	0.46	343	0.45	34	0.04
17	Cap Face Surface Finish	45	0.07	53	0.07	2	0.00	5	0.01
18	Rod Face Taper	49	0.08	45	0.06	34	0.04	8	0.01

Cont…

TABLE 9.8 : Rework Quantity year wise

Sr. No.	Rejection Parameters	Actual Production Quantity Q (year wise)							
		2012-13		2013-2014		2014-15		2015-16	
		Q = 65184		Q = 71349		Q = 75723		Q = 79803	
		Rework pcs	%	Rework pcs	%	Rework pcs	%	Rework pcs	%
19	Rod Face Surface Finish	34	0.05	98	0.14	34	0.04	76	0.10
20	Squareness of Small End face w. r. t. Big End Bore	78	0.12	45	0.06	56	0.07	75	0.09
21	Big End Chamfer Diameter	29	0.04	85	0.12	6	0.01	78	0.10
22	Big End Chamfer angle	273	0.42	86	0.12	65	0.09	79	0.10
23	Parting face Finish Rod+Cap	54	0.08	451	0.63	56	0.07	54	0.07
24	Cap rib dimension	46	0.07	676	0.95	36	0.05	5	0.01
25	Rod spot face dimension	340	0.52	43	0.06	78	0.10	56	0.07
26	Rod Spot face surface finish	89	0.14	54	0.08	67	0.09	65	0.08
27	Bolt Hole Center Distance	53	0.08	45	0.06	5	0.01	4	0.01
28	Bolt Hole Diameter	98	0.15	75	0.11	34	0.04	29	0.04
29	Notch Length Rod & Cap	45	0.07	65	0.09	4	0.01	3	0.00
30	Notch Depth Rod & Cap	36	0.06	43	0.06	34	0.04	5	0.01
31	Notch Width Rod & Cap	32	0.05	67	0.09	52	0.07	2	0.00
32	Magnetism	25	0.04	34	0.05	43	0.06	30	0.04
33	Visual Inspection	0	0.00	0	0.00	0	0.00	0	0.00
34	Packing	0	0.00	0	0.00	0	0.00	0	0.00
35	Others	60	0.09	56	0.08	76	0.10	50	0.06
	Total Rework	**9714**	**14.90**	**9534**	**13.36**	**6428**	**8.49**	**3276**	**4.11**

TABLE 9.9 : Rejection Quantity year wise

Sr. No.	Rejection Parameters	Actual Production Quantity Q (year wise)							
		2012-13		2013-2014		2014-15		2015-16	
		Q = 65184		Q = 71349		Q = 75723		Q = 79803	
		Rejection pcs	%	Rejection pcs	%	Rejection pcs	%	Rejection pcs	%
1	Big End bore diameter	95	0.15	87	0.12	78	0.10	65	0.08
2	Small End bore diameter	101	0.15	98	0.14	65	0.09	57	0.07
3	Center Distance (C.D.)	36	0.06	53	0.07	52	0.07	45	0.06
4	Bend	323	0.50	36	0.05	34	0.04	30	0.04
5	Twist	234	0.36	45	0.06	65	0.09	59	0.07
6	End Float more/less	753	1.16	44	0.06	23	0.03	20	0.03
7	Big end bore width	36	0.06	54	0.08	12	0.02	65	0.08
8	Rib diameter variation	64	0.10	34	0.05	43	0.06	3	0.00
9	Honing pattern in big end bore	56	0.09	56	0.08	23	0.03	3	0.00
10	Big End Bore Oval	22	0.03	243	0.34	67	0.09	45	0.06
11	Surface Finish in Big End Bore	21	0.03	65	0.09	87	0.11	53	0.07
12	Surface Finish in Small End Bore	4	0.01	57	0.08	56	0.07	39	0.05
13	Big End bore Taper	65	0.10	56	0.08	36	0.05	22	0.03
14	Small End bore Taper	6	0.01	43	0.06	75	0.10	47	0.06
15	Oil Hole Diameter in Small End	0	0.00	67	0.09	87	0.11	43	0.05
16	Cap Face Taper	0	0.00	87	0.12	45	0.06	43	0.05
17	Cap Face Surface Finish	9	0.01	97	0.14	96	0.13	89	0.11
18	Rod Face Taper	0	0.00	54	0.08	23	0.03	19	0.02

Cont…

TABLE 9.9 : Rejection Quantity year wise

Sr. No.	Rejection Parameters	Actual Production Quantity Q (year wise)							
		2012-13		2013-2014		2014-15		2015-16	
		Q = 65184		Q = 71349		Q = 75723		Q = 79803	
		Rejection pcs	%	Rejection pcs	%	Rejection pcs	%	Rejection pcs	%
19	Rod Face Surface Finish	3	0.00	23	0.03	54	0.07	36	0.05
20	Squareness of Small End face w.r.t. Big End Bore	4	0.01	9	0.01	3	0.00	3	0.00
21	Big End Chamfer Diameter	5	0.01	8	0.01	7	0.01	4	0.01
22	Big End Chamfer angle	3	0.00	7	0.01	4	0.01	5	0.01
23	Parting face Finish Rod+Cap	2	0.00	8	0.01	3	0.00	2	0.00
24	Cap rib dimension	6	0.01	9	0.01	5	0.01	1	0.00
25	Rod spot face dimension	7	0.01	5	0.01	6	0.01	2	0.00
26	Rod Spot face surface finish	5	0.01	4	0.01	7	0.01	4	0.01
27	Bolt Hole Center Distance	4	0.01	3	0.00	2	0.00	6	0.01
28	Bolt Hole Diameter	5	0.01	5	0.01	8	0.01	6	0.01
29	Notch Length Rod & Cap	3	0.00	0	0.00	2	0.00	3	0.00
30	Notch Depth Rod & Cap	7	0.01	0	0.00	1	0.00	0	0.00
31	Notch Width Rod & Cap	8	0.01	2	0.00	2	0.00	0	0.00
32	Magnetism	0	0.00	0	0.00	0	0.00	0	0.00
33	Visual Inspection	0	0.00	0	0.00	0	0.00	0	0.00
34	Packing	0	0.00	0	0.00	0	0.00	0	0.00
35	Others	9	0.01	28	0.04	40	0.05	5	0.01
	Total Rejection	**1896**	**2.91**	**1387**	**1.94**	**1111**	**1.47**	**824**	**1.03**

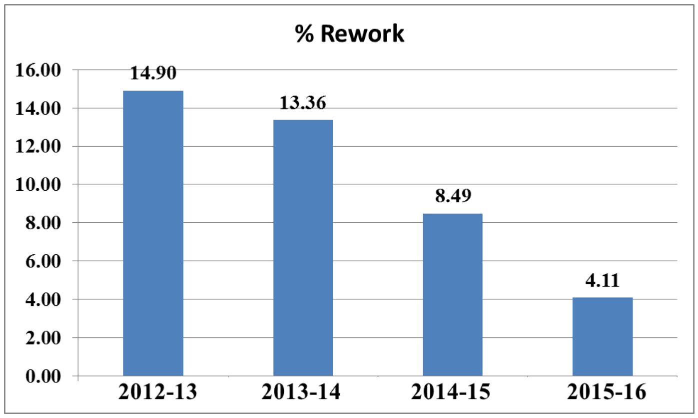


FIGURE 9.1 : Rework % year wise

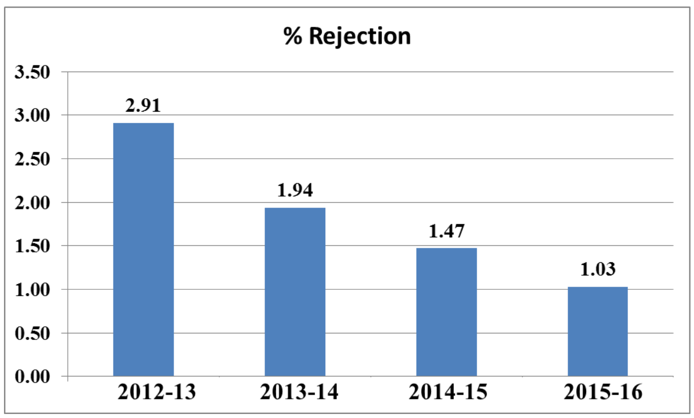


FIGURE 9.2 : Rejection % year wise

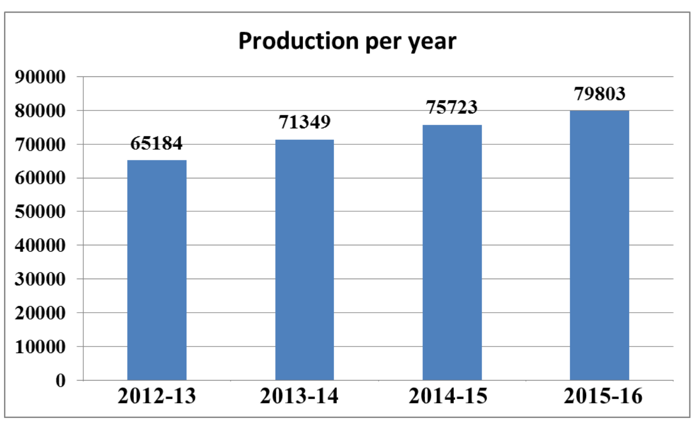


FIGURE 9.3 : Production per year

TABLE 9.10 : Parameter wise Total Rework

(From 1st April, 2012 to 31st March, 2016)

Sr.	Parameter	Rework Qnty.	%
1	Big End bore diameter	3993	1.37
2	Small End bore diameter	3585	1.23
3	Center Distance (C.D.)	2606	0.89
4	Bend	2158	0.74
5	Big End Bore Oval	1893	0.65
6	Twist	1545	0.53
7	Honing pattern in big end bore	1485	0.51
8	Small End bore Taper	1332	0.46
9	Surface Finish in Big End Bore	1327	0.45
10	Big End bore Taper	1031	0.35
11	Cap Face Taper	1030	0.35
12	Surface Finish in Small End Bore	819	0.28
13	Oil Hole Diameter in Small End	763	0.26
14	Cap rib dimension	763	0.26
15	Parting face Finish Rod+Cap	615	0.21
16	Rod spot face dimension	517	0.18
17	Big End Chamfer angle	503	0.17
18	Rib diameter variation	343	0.12

Sr.	Parameter	Rework Qnty.	%
19	Rod Spot face surface finish	275	0.09
20	Squareness of Small End face w.r.t. Big End Bore	254	0.09
21	Rod Face Surface Finish	242	0.08
22	Others	242	0.08
23	Bolt Hole Diameter	236	0.08
24	Big End Chamfer Diameter	198	0.07
25	Big end bore width	187	0.06
26	Notch Width Rod & Cap	153	0.05
27	End Float more/less	142	0.05
28	Rod Face Taper	136	0.05
29	Magnetism	132	0.05
30	Notch Depth Rod & Cap	118	0.04
31	Notch Length Rod & Cap	117	0.04
32	Bolt Hole Center Distance	107	0.04
33	Cap Face Surface Finish	105	0.04
34	Visual Inspection	0	0.00
35	Packing	0	0.00
	Total	**28952**	**9.91**

TABLE 9.11 : Parameter wise Total Rejection

(From 1st April 2012 to 31st March 2016)

Sr.	Parameter	Rejection Qnty.	%	Sr.	Parameter	Rejection Qnty.	%
1	End Float more/less	840	0.29	19	Rod Face Taper	96	0.03
2	Bend	423	0.14	20	Others	82	0.03
3	Twist	403	0.14	21	Big End Chamfer Diameter	24	0.01
4	Big End Bore Oval	377	0.13	22	Bolt Hole Diameter	24	0.01
5	Big End bore diameter	325	0.11	23	Cap rib dimension	21	0.01
6	Small End bore diameter	321	0.11	24	Rod spot face dimension	20	0.01
7	Cap Face Surface Finish	291	0.10	25	Rod Spot face surface finish	20	0.01
8	Surface Finish in Big End Bore	226	0.08	26	Squareness of Small End face w. r. t. Big End Bore	19	0.01
9	Oil Hole Diameter in Small End	197	0.07	27	Big End Chamfer angle	19	0.01
10	Center Distance (C.D.)	186	0.06	28	Parting face Finish Rod+Cap	15	0.01
11	Big End bore Taper	179	0.06	29	Bolt Hole Center Distance	15	0.01
12	Cap Face Taper	175	0.06	30	Notch Width Rod & Cap	12	0.00
13	Small End bore Taper	171	0.06	31	Notch Length Rod & Cap	8	0.00
14	Big end bore width	167	0.06	32	Notch Depth Rod & Cap	8	0.00
15	Surface Finish in Small End Bore	156	0.05	33	Magnetism	0	0.00
16	Rib diameter variation	144	0.05	34	Visual Inspection	0	0.00
17	Honing pattern in big end bore	138	0.05	35	Packing	0	0.00
18	Rod Face Surface Finish	116	0.04		**Total**	**5218**	**1.79**

9.3 Objectives Achieved

The key contributions of the thesis can be summarized by following.

1. The improvement potentials are identified in manufacturing processes of the connecting rod.
2. The improvement in Customer satisfaction attained by reducing the reduction in rework and rejection every year.
3. Various shop floor issues related to Connecting Rod manufacturing operations are solved using various problem-solving techniques.
4. Performance Excellence is achieved as the percentage of rejection and rework reduces continuously as shown in Fig. 9.1 and 9.2 even there is the rise in production shown in Fig. 9.3.

9.4 Conclusion

In Present work, various problems related to quality are solved using TMS (Tailor-Made solution). The generalization of such TMS becomes little beat challenging as it may not give a better result for the same kind of other problem. The generalized approach discussed in present work would be highly significant for the people involved in connecting rod manufacturing to enhance their existing performance.

The present work highlights the employability of various quality improvement aspects like Cause and Effect diagram, Brainstorming, Failure Mode and Effects Analysis, Kaizen, Six Sigma, etc. The corrective actions proposed with the help of these aspects are implemented in a structured way within the constraints. Hence, Performance Excellence in connecting rod manufacturing industries is implemented.

The first case covered Overall Equipment Effectiveness (OEE) in connecting rod manufacturing processes is prepared. The OEE sheet enables companies to attain a rapid assessment of their operations performance. It highlights the gray area of the shop floor. The OEE sheet discussed is a dominant tool to evaluate 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 adequate input to identify improvement objectives and review the ongoing operations strategy.

The second case is conducted for bush boring operation. After a bush boring operation, in Small End of connecting rod, pillar drill is used to eliminate dent marks and burrs, as a replacement for manual de-burring operation. It reduces manual work with better concentricity of small end and improves the quality of product up to a considerable extent. Assembly of gudgeon pin in the small end of connecting rod becomes easier as compared to the previous method due to chamfered end.

The third case covered the discussion and solution of a technical problem identified from customer complaint redressal form . The study examined one of the shop floors long-lasting quality issues to maintain the End Float in a connecting rod during the manufacturing process. The corrective actions for the problem are discussed and implemented which improves the customer satisfaction and reduces the rejection quantity. The fixture of one of the manufacturing operations is to be redesigned and altered.

The fourth case covered the statistical control of customer defined critical parameter i.e. axial alignment (bend and twist) of connecting rod. The connecting rod is one of the most important elements of the internal combustion engine. As it is subjected to alternative stresses, tensile and compressive, it is designed for compressive stress as it is higher at the time of power stroke. The $\bar{x}$ and R chart is prepared for continuous monitoring of the process. This chart also indicates the trend of the process with the help of which the chance of rejection can be interpreted.

The fifth case discussed the effect of temperature variation at the time of manufacturing of the connecting rod. Temperature variation 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 the 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 masterpiece of the similar material and calibrate the gauge at regular interval. Failure Mode and Effects analysis are conducted to identify the rejection potential.

9.5 Future Scope

Based on the outcomes obtained from the present work, though the existing problems dealing with connecting rod manufacturing are solved more efficiently, still the scope exists to reduce rework and rejection as mentioned in Table 9.8 and Table 9.9. The percentage of rework and rejection continuously reduces as represented in Fig. 9.1 and Fig. 9.2. These performance measurement parameters can be further reduced to a negligible amount.

The Preventive Actions (PA) can be prepared for other manufacturing operations wherever the rejection potential exists. The solutions implemented in present cases can be employed in other manufacturing industries for solutions of running issues. There is also a scope to improve Layout of the shop floor to reduce unnecessary movement of the materials.

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List of Publications

Journal Publication

1. 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).*

2. Sonigra S.S., Qureshi M.N., Lohia A.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).

3. Sonigra S.S., Qureshi, M. N. (2012). Solving the problem of End Float with the Application of Six Sigma Tools : A Case Study. *The IUP Journal of Mechanical Engineering, IUP India, Vol. V, No.2, (pp.7-20).*

Conference Publication

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Computation of Overall Equipment Effectiveness in Connecting Rod Manufacturing Operations

S S Sonigra* and M N Qureshi **

This paper presents the method to compute Overall Equipment Effectiveness (OEE) in connecting rod manufacturing operations. The OEE sheet also 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 leading 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 in one example considered froma reputed connecting rod manufacturing company, and some insights are extracted and mentioned regarding the sheet's applicability for different types of manufacturing processes.

Keywords: Performance measurement, Effectiveness, Quality, Manufacturing process

Introduction

The **Overall equipment effectiveness** (OEE) is a hierarchy of metrics developed by Seiichi Nakajima in the 1960s to evaluate how effectively a manufacturing operation is employed and utilized. It is based on the Harrington Emerson way of thinking regarding labor efficiency.An OEE System is a powerful tool which is best used to light up our understanding of the production process and identify opportunities to initiate improvements. The results are stated in a generic form which allows comparison between manufacturing operations in different units or manufacturing units in different industries. It is not an absolute measure but it reflects the comparative performance with each other. It is used to identify scope and direction for process performance improvement.OEE was not designed to make comparisons from machine-to-machine, plant-to-plant, or company-to-company, but it has evolved to these common levels of misuse.

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If the cycle time is reduced, the OEE will increase, as more products are produced in lesser time but it is always not true. The reduction in cycle time may have adverse effect on the quality of product. If the adverse effect over quality is more than the improved effect due to time saving, OEE leads towards reduction. There may be more interrelationships between many other factors. The reduction in cycle time may have influence over rejection or rework quantity. The tool wear, initial cost, machine wear and many other factors may alter if more products are produced in lesser time. Hence all impacts to be combined compute OEE to be a common platform for all the operations evaluation.

Another example is if one manufacturing operation produces better quality at the cost of time, there may be alteration in OEE. It depends upon the impact of change in quality and change in time over the process. The improvement in quality is higher as compared to increase in time lead towards higher OEE, but improvement in quality is lower as compared to increase in time lead towards reduction in OEE value.

1. Literature Review

Overall Equipment Effectiveness is a matter of prime interest for researchers for management of asset performance. Managing the asset performance is critical for the long term economic and business viability. To integrate a whole organization, where free flow and transparency of information is possible; and each process is linked to integrate to achieve the company's business goals is a real challenge. Jose Arturo et al. [1] conducted a relationship analysis between Overall Equipment Effectiveness (OEE) and Process Capability (PC) measures. PC uses the capability indices (CI) to help in determining the suitability of a process to meet the required quality standards. Although statistically value of process capability indices C_p and C_{pk} equal to 1.0 indicates a capable process. The generally accepted minimum value in manufacturing industry of these indices is 1.33. The results of the investigation challenge the traditional and prevailing knowledge of considering this value as the best PC target in terms of OEE. This provides a useful perspective and guide to understand the interaction of different elements of performance and help managers to take better decisions about how to run and improve their processes more efficiently and effectively.

Paul et. al. [2] introduced a measure of Six Sigma process capability using extant data from the OEE framework. Similarly, indicators of plant reliability, maintainability and asset management effectiveness were calculated taking extant data from the OEE frame work. The ability to compare internal performance against external competition and vice versa is argued as being a critical attribute of any performance measurement system.Bulent et al.[3]expressed that OEE is used to track and trace improvements or decline in equipment effectiveness over a period of time.

Fleischer *et al*[4] noted that the competitiveness of manufacturing companies depends on the availability and productivity of their production facilities. Huang *et al*[5] also states that due to intense global competition, companies are striving to improve and optimize their productivity in order to remain competitive. This would be possible if the production losses are identified and eliminated so that the manufacturers can bring their products to the market at a minimum cost. This situation has led to a need for a rigorously defined performance measurement system that is able to take into account different important elements of productivity in a manufacturing process.

The industrial application of OEE, as it is today, varies from one industry to another. Though the basis of measuring effectiveness is derived from the original OEE concept, manufacturers have customized OEE to fit their particular industrial requirements. Furthermore, the term OEE has been modified in literature to differentiate other terms with regard to the concept of application. This has led to widen the concept of OEE to many measures. This includes total equipment effectiveness performance (TEEP), production equipment effectiveness (PEE), overall plant effectiveness (OPE), overall throughput effectiveness (OTE), overall asset effectiveness (OAE) and overall factory effectiveness (OFE).

Pintelon et al. [6] discussed major six big losses from a palletizing plant in a brewery which affects OEE.Bamber et al. [7]have shown that the most successful method of employing OEE is to use cross-functional teams aimed at improving the competitiveness of business.Muchiri and Pintelon[8] discussed two industrial examples of OEE application and analyzed the differences between theory and practice. A framework proposed for classifying and measuring production losses for overall production effectiveness, which harmonizes the differences between theory and practice and makes possible the presentation of overall production/asset effectiveness that can be customized with the manufacturers needs to improve productivity.

When machines operate jointly in a manufacturing line, OEE alone is not sufficient to improve the performance of the system as a whole. Bragliaet al [9] have presented a new metric OEEML (overall equipment effectiveness of a manufacturing line) for such manufacturing lines and an integrated approach to assess the performance of a line. OEEML highlights the progressive degradation of the ideal cycle time, explaining it in terms of bottleneck, inefficiency, and quality rate and synchronization-transportation problems.Anvari et al [10] illustrated a new method, OEEMB (overall equipment effectiveness market-based) for the precise calculation of equipment effectiveness for full process cycle in order to respond to the steel market, as it is a capital-intensive industry.

2. OEE Objectives

- To identify a single asset (machine or equipment) and/or single stream process related lossesfor the purpose of improving total asset performance and reliability.
- To provides the basis for setting improvement priorities and beginning root cause analysis.
- To develop and improve collaboration between asset operations, maintenance, purchasing, and equipment engineering to jointly identify and eliminate (or reduce) themajor causes of poor performance.
- To identify hidden or untapped capacity in a manufacturing process and lead to balanced flow.

- To identify and categorize major losses or reasons for poor performance.
- To track and trend the improvement, or decline, in equipment effectiveness over a period of time.

3. OEE Implementation

Overall equipment effectiveness (OEE) is related measurements that report the overall utilization of facilities, time and material for manufacturing operations. It directly indicates the gap between actual and ideal performance. It quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run. OEE analysis starts with Plant Operating Time which is the amount of time the facility is available and open for equipment operation. Planned Production Time excludes Planned Shut downTime from Plant Operating Time. Planned Shut down time includes all events that should not be included in efficiency analysis because there is no intention for running production. The events like scheduled maintenance, breaks and planned period where nothing is to be produced are considered in planned shut down time.

The OEE measure is defined as the ability to run equipment at the designed speed with zero defects. In order to maximize OEE, the major losses should be reduced. The literature review on OEE evolution reveals a lot of differences in formulation of equipment effectiveness. The main difference lies in the types of production losses that are captured by the measurement tool. Though the original OEE tool identifies six major losses in a production set up, other types of losses have been found to have a significant contribution to the overall production loss.

OEE breaks the performance of a manufacturing unit into three separate components. The components are Availability, Performance and Quality. These components are measurable and points to an aspect of the process that can be targeted for improvement. OEE can also be applied to any individual work center or production unit or plant level. It also allows knowing very specific analysis like shift, particular part number or any of several other parameters. The ideal value of OEE would be 100%, but achieving value up to 80 % is quite remarkable.

4. OEE factors

Three measurable components for the calculation of OEE are as follows.

1. Availability = (Operating Time) / (Planned production)

It represents the percentage of scheduled time that the operation is available to operate. It also takes into account the fraction of Down Time Loss. It covers equipment failures, unavailability due to accidental reasons and change over time and material shortages. Changeover time is a form of down time which may not be possible to eliminate but can be reduced up to considerable extent. Availability is a pure measurement of Uptime that is designed to exclude the effects of Quality, Performance and Scheduled Downtime Events.

2. Performance= (Ideal Cycle Time)/(Operating Time)

It represents the speed at which the Work Center runs as a percentage of its designed speed. It takes into account Speed Loss, which includes any factors that cause the process to operate at less than the maximum possible speed, when running. It covers operator efficiency, variation in feeds, substandard materials and machine tool wear. Ideal Cycle time is the minimum cycle time that the process can be expected to achieve in optimal circumstances. It is also called as Theoretical Cycle Time or Design Cycle Time. Performance is a pure measurement of speed that is designed to exclude the effects of Quality and Availability.

3. Quality =(Total Production – Defectives) / (Total Pieces produced)

It represents the good units produced as a percentage of total units produced.It takes into account Quality Loss, which accounts for produced pieces that do not meet quality standards, including pieces that require rework. Quality is a pure measurement of Process Yield that is designed to exclude the effects of Availability and Performance.

OEE = Availability x Performance x Quality

Hence OEE considers all three factors. These three measures indicate the degree of conformation to output requirements. OEE gives one magic number which is a measure of effectiveness. It includes three numbers which are all useful individually as the situations vary from day to day. It also helps to visualize performance in simple terms.This is in agreement with the definition in literature that OEE measures the degree to which the equipment is doing what it is supposed to do base on availability, performance and quality rate.OEE percentages are useful when tracking and trending the performance effectiveness (reliability) of a single piece of equipment or single-stream process over a period of time.

Determining how management intends to use the OEE score is very important consideration in the planning process for implementing an OEE System. If score is used as a mean to penalize or reward, the staff may be encouraged to manipulate the data, which will dilute the impact of potential benefits from OEE. It is therefore necessary to focus one's attention beyond the performance of individual equipment toward performance of the whole factory. Oechsner et al [10] expressed that the ultimate objective of any factory is to have a highly efficient integrated system and not brilliant individual equipment.

5. Computation

Following details are prepared for a product to compute OEE to enlighten the working environment of shop floor activities.

<u>Product : Connecting Rod</u>

1	Shift Length	10	Hours =	600	Minutes		
2	Short Breaks	2	Breaks @	30	Minutes Each =	60	Minutes Total
3	Meal Break	1	Breaks @	60	Minutes Each =	60	Minutes Total

4 Planned Production Time = Shift Length – Break= 480 Minutes

5 Operating Time =Planned Production Time - Down Time

6 Good pcs = Total pcs – Rejected pcs

A Availability = (Operating Time/Planned Production Time) x 100%

B Performance = (Actual Produced/Ideal Production)x100 %

C Quality = (Good pcs / Total pcs produced) x 100 %

Operation No.	Operations	Down Time	Operating Time	Availability (%)	Time per pc. Sec.	Ideal Rate pcs/hr	Total Pcs produced/hr.	Performance (%)	Rejection/Rework	Good Pcs	Quality (%)	**OEE (%)**
10	Cap Facing	75	435	85.29	40	82	60	73.33	5	55	91.67	57.34
20	Rod Face	80	430	84.31	45	73	55	75.63	4	51	92.73	59.13
30	Small End	56	454	89.02	45	73	52	71.50	5	47	90.38	57.53
40	Small End	65	445	87.25	70	47	35	74.86	4	31	88.57	57.85
50	Rod Rib Turning	70	440	86.27	67	49	39	79.84	5	34	87.18	60.05
60	Rough Joint	75	435	85.29	70	47	38	81.28	3	35	92.11	63.85
70	Final Joint Face	70	440	86.27	95	34	27	78.38	4	23	85.19	57.60
80	Cap Groove	75	435	85.29	82	40	33	82.68	4	29	87.88	61.98
90	Spot Face [R+C]	80	430	84.31	61	54	44	82.01	5	39	88.64	61.29
100	Bolt Hole Rough Drilling	78	432	84.71	38	86	71	82.44	7	64	90.14	62.95
110	Bolt Hole Final Drilling	80	430	84.31	35	94	81	86.63	9	72	88.89	64.92
	Quotation											
	Assembly-1											
120	B.E.Pre boring	85	425	83.33	70	47	40	85.56	6	34	85.00	60.60
130	B.E.Final boring	80	430	84.31	40	82	70	85.56	6	64	91.43	65.95
140	B.E.Chamfer	85	425	83.33	40	82	71	86.78	8	63	88.73	64.17
	Dismental											
150	Notch	75	435	85.29	22	149	121	81.34	11	110	90.91	63.07
	Assembly-2											
160	B.E.Rough	80	430	84.31	42	78	69	88.55	8	61	88.41	66.00
170	B.E.Final	90	420	82.35	33	99	79	79.66	8	71	89.87	58.96
180	Bush Pressing	75	435	85.29	51	64	55	85.71	14	41	74.55	54.50
180B	Bush Boring	75	435	85.29	51	64	55	85.71	14	41	74.55	54.50

Table 1 Computation of OEE for each Operation

6. Analysis

The data sheet prepared indicates the gray area of the shop floor. There is need to emphasize 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 the deep study of bush pressing and bush boring operation which includes many parameters.The fish bone diagram prepared for this operation as shown in figure.Following actions taken and appropriate corrections implemented to have better quality at this stage.

- Alignment (straightness) of the fixture checked and found correct.
- The spindle axial alignment checked and corrected with necessary action.
- Tool wear measured for a lot size and suggested to alter the tool change frequency as the previous one was inadequate.
- Measuring instrument checked with master calibration unit and found correct.
- Operator interviewed for his fitness to the work and asked for necessary improvement.

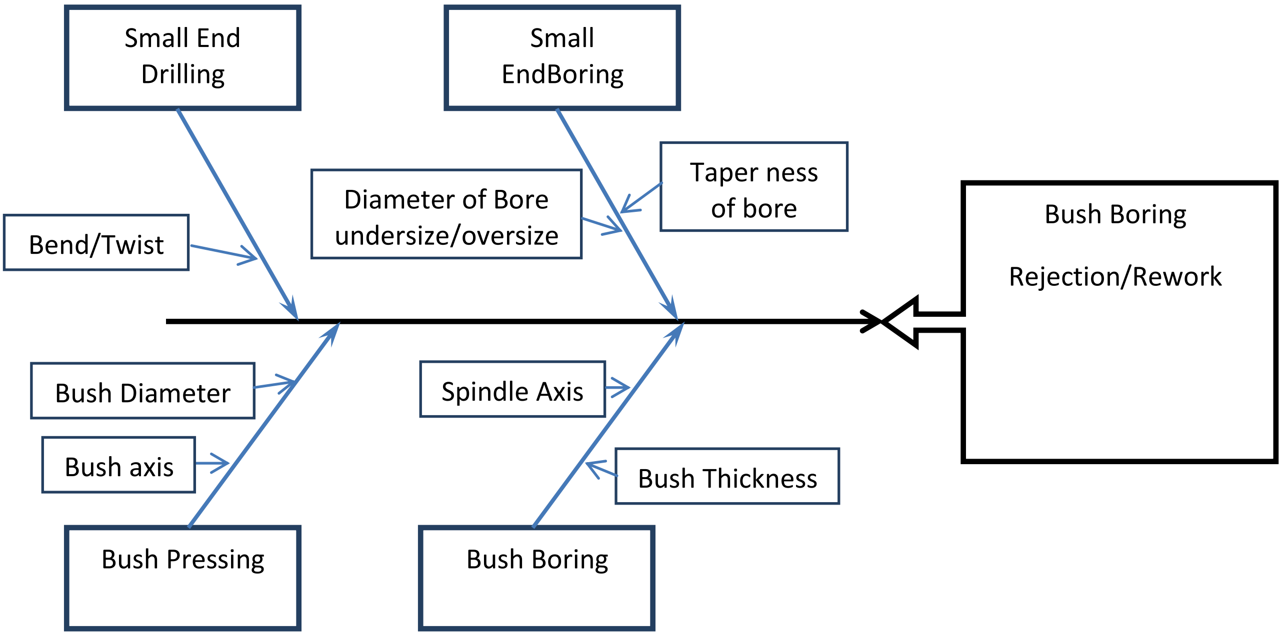
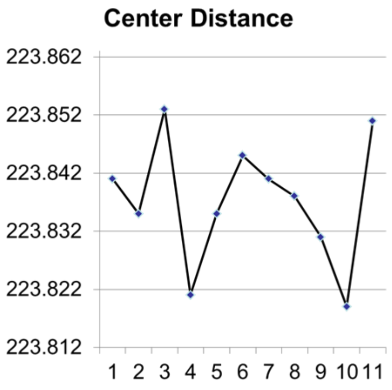


Figure 1 : Fishbone diagram showing rejection potentials

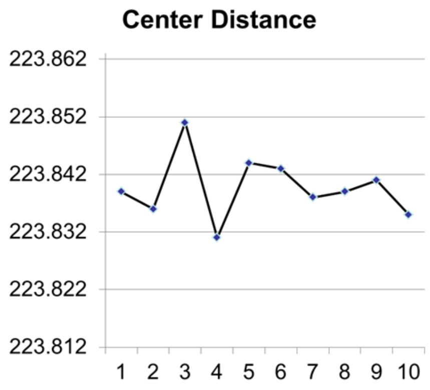
7. Result

The impacts of implemented actions are represented in the graph. There is reduction in variation in the center distance parameter (*Graph 1 & 2*). There is reduction in rework (*Graph 3*), rejection (*Graph 4*) and customer complaints (*Graph 5*) for this parameter.



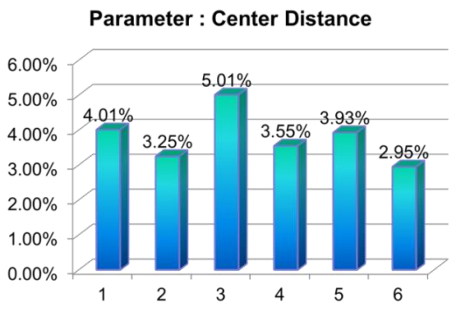
Graph 1. Variation before implementation

(More variation)

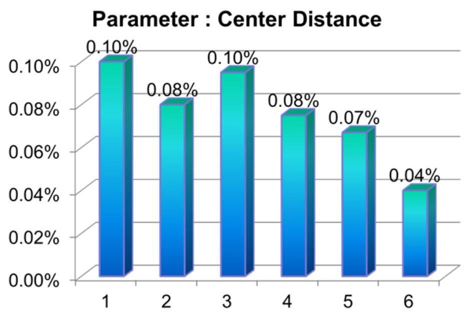


Graph 2. Variation after implementation

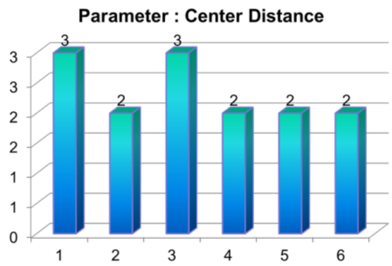
(Less variation)



Graph 3. % Rework (Month wise)



Graph 4. % Rejection (Month wise)



Graph 5. % Customer Complaint(Month wise)

8. Limitations for using OEE system

- The percentage calculation of OEE is statistically cannot be said valid. A calculated OEE percentage assumes that all equipment-related losses are equally significant and any improvement in value of OEE is a positive improvement for whole plant. This may not be true for all the cases. For example, the calculated OEE percentage does not consider that two percent improvement in quality may have a bigger impact on the business than does a two percent improvement in availability.

- Calculated OEE is not valid for benchmarking or comparing various processes, assets or equipment. It is a relative measure of a specific single asset effectiveness associated to itself over a period of time. However, OEE can be used to compare identical equipment in identical situations producing identical output.
- The calculated OEE cannot be used as a corporate level measure. It is just an estimated measure of selected equipment effectiveness only.
- Also, it does notmeasure maintenance effectiveness because most of the loss factors are not under the direct control of the maintainers.

9. Conclusion

OEE System identifies problem area and accurately the symptoms of each problem. However, the real opportunity lies in the ability to determine the root causes for each loss, and to then implement effective corrective actions to eliminate them. OEE Systems can also be used to gather additional data, create and report against improvement plans/agendas, and verify or validate the actions taken to rectify the issues identified. To achieve a successful implementation and to optimize the success of an OEE System, organizations must focus to ensure a commitment to use it as a fundamental, organization-wide tool to drive continuous improvement in an effective manner. OEE can be applied to manufacturing, petrochemical processes and environmental equipment. Overall, OEE can be visualized in single statement as, *Implementation an OEE System can be compared to switching on the light in a darkened room. Nothing has changed, but the things can be seen more clearly.*

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REVIEW OF IMPLEMENTATION OF OVERALL EXCELLENCE MODEL IN SELECT MANUFACTURING INDUSTRIES SBI

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Abstract

There has been significant research on many concepts implementation for framing quality work in organization. All aspects included in implementation having different impact on outcome. The combination of all aspects with appropriate fractions of elements results in Overall Excellence Model. The model is presented with different project types to describe the project organization, giving guidance to the application of the model. This paper includes findings of a case study showing how the model to be used to improve the performance of organization. The EFQM Excellence model is also discussed with due impact to express the exact view of Overall Excellence Model and its outcome.

Keywords: Overall Excellence, quality, performance, continuous improvement, impact factor

Review of implementation of Overall Excellence Model in Select Manufacturing Industries

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1. Introduction

Overall Excellence in the manufacturing industry includes all the aspects related to quality improvement tools. It integrates the basic elements covered in TQM, Six Sigma, Lean manufacturing, flexible manufacturing, ISO standards, QS Standards, Quality Circles, Kan ban technique, Mistake proofing, Zero Defect concept, etc.

Indian manufacturing industries felt drastic change because of Globalization. It resulted in the need to implement various quality tools. The word *Quality* became the center of attention in manufacturing processes. In order to provide customers with good products and be able to survive, manufacturing organizations are required to ensure that their processes are continuously monitored and product quality is improved. To excel in global competition, ISO certification system was implemented in many industries. Then after TQM, QS Standards, Quality Circle; etc came in various sectors for better improvement in outcome. In present scenario, there is need to implement the combination of all these tools in industries with appropriate impact. Higher impact of one tool may not be advantageous to some cases. There is need to prepare a model to combine these tools with appropriate impact.

At present, a new concept is introduced namely ***Overall Excellence*** in the manufacturing industries which results in combination of these aspect with due impact. The framework described in present work provides a practical blueprint to achieve Overall Excellence. An implementation framework is needed to build on and pull together all of the ideas and concepts.

It includes tools and techniques, people development, management system, teamwork, performance measurement, processes, self-assessment, TQM, etc.

2. Literature Survey

The first Excellence Model was Deming Prize, introduced by JUSE in 1951 (Union of Japanese Scientists and Engineers, 2010). The next was CAE Quality Award being introduced in Canada in 1984 (National Quality Institute, 2007). A numerous types of various Quality Awards were initiated by various countries. In USA in 1987, the Malcolm Baldrige National Quality Award (MBNQA) was introduced (National Institute of Standards and Technology, 2009). The Baldrige Excellence Model was implemented in many sectors (Kanter (Talwar B. , 2008; Institute, 2007; Technology, 2009) (The Deming Prize, 2010) & Page, 2011). The model of Excellence in Manufacturing, Small Business, A service company, Education, Health care and many Non Profit sectors have shown following outcomes

1. Increasing Sales, Profits and Market Share
2. Increasing Customer Satisfaction and Retention
3. Improving Employee Measures
4. Reducing Defects and Non conformances
5. Ensuring On-Time Delivery
6. Increasing Productivity and Return on Assets

For implementation of this model following DOs and DON'Ts are followed.

- Don't expect only highs along the journey. Executives must be willing to make incremental improvements every day.
- Don't reject external feedback without giving it due consideration. The hardest part about feedback is having the courage to accept it.
- Do make the decision to truly become a process honoring culture.
- Do accept that an outside set of eyes can point out your blind spots.
- Do recognize the elements critical to success: Leadership involvement and support, determination, resources (both internal and external) and willingness to accept feedback.

The development and application of a quality assurance system helps companies to organize and synchronize their operations by documenting their processes, clearing out ambiguities and clearly defining duties and responsibilities among employees and departments. There is a general confusion and uncertainty regarding the effectiveness of the standards and their long-term contribution to the companies. Two different and to a high degree conflicting views/assertions were revealed about the effectiveness of the quality assurance standards (Katerina & George, 2001).

The quality control technique was implemented in four Malaysian Organisations Bandar Baru Bangi Industrial Area to identify the factors that influence the selection of quality control techniques in these companies (Hairulliza, Ruzzakiah, & Genasan, 2011). The reasons for applying quality control techniques, the techniques used, and problems faced by them during the Implementation are discussed. The study finds that the motivating factors for these companies to apply quality control come internally from the management and parent company or externally from customer. SPC and acceptance sampling are used widely by the companies. Six sigma, DOE, Taguchi methods, and capability studies are left behind from being used in these four industries, due to lack of knowledge in the technique. The selection of quality control technique in these companies is influenced by three factors: ease of use of the technique; ability to measure product specification fulfillment; and ability to improve critical quality and productivity problem.

Even more, its greatest and most important advantage lies in the fact that the system introduces a preventive way of managing quality, focusing mainly on the prevention of errors, rather than their later detection and correction, which was the focus of the traditional 'Quality Control'. A management model is needed that helps the managers deal with large and complex project.

The effect of temperature variation is highly considerable for precise dimensional quality of the product. The experimentation and solution is proposed for the parameters where the effect of temperature is considerable for dimensional control (Sonigra & Qureshi, 2010). The capability analysis of production processes is a complicated task where there are more than one correlated quality variables. A new methodology is proposed to estimate process capability indices (PCIs) of multivariate non normal processes. (Abbasi, Taghi, & Niaki, 2010).

The procedure for conducting SPC analysis starts from selection of manufacturing operation. Statistical process control analysis of the critical parameters is required to be maintained at the pre decided frequency. The frequency for checking may be daily, weekly, monthly or may be yearly. Even it may be once in three years. The selection of the period for the frequency depends upon the criticality of the parameter and the value of process capability indices. Higher the value of process capability indices, lesser will be the frequency for SPC analysis (Sonigra & Patel, 2009).

The application of the seven quality tools in maintenance management and engineering is focused with some activities (Qureshi & Sonigra, 2010). The use of single SPC tool will not be sufficient for overall improvement of organization. Both, the full strength of these tools and their respective benefits can only be realized if they are all integrated and used with a view to eliminate causes of substandard quality in maintenance engineering. The integration of all these tools can be done as a case study to demonstrate the utility of these tools in maintenance and the need for their integration. The necessary maintenance data needed for applying these tools have also been outlined.

An implementation framework is needed to build on and pull together all of the ideas and concepts covered – the Excellence Model and self-assessment. Based on many years of research, education and advisory work in the European Centre for Business Excellence, the framework described as European Foundation for Quality Management (EFQM) was founded in 1992 for assessing organizations. It provides a practical blueprint for achieving organizational excellence. It is used to improve and measure the overall quality of an organization. It is distinguished into two areas called as Result areas and Organizational areas. The project Excellence Model was developed and how it can be applied to project is also described in literature (Westerveld, 2003).

EFQM Excellence Model has been extensively used and implemented in banking, finance, management, manufacturing, education and consultancy. Companies apply this Excellence

Model since the pursuit of business excellence through TQM is a decisive factor in allowing them to compete in today's global market (Watson, 2002). This model provides a valuable framework for addressing the key operational activities of construction organizations. It is useful because it enables a link to be made between people, organizational objectives and improvement processes, all encompassed under the umbrella of continued improvement.

3. EFQM Excellence Model

The use of EFQM Excellence Model as a framework for organizational self-assessment has spread to many companies in Europe since its introduction making it the most popular tool for self-assessment (Hakes, 1997). The companies' increased focus on continuous improvements has been pointed out as a major benefit from the self-assessment process.

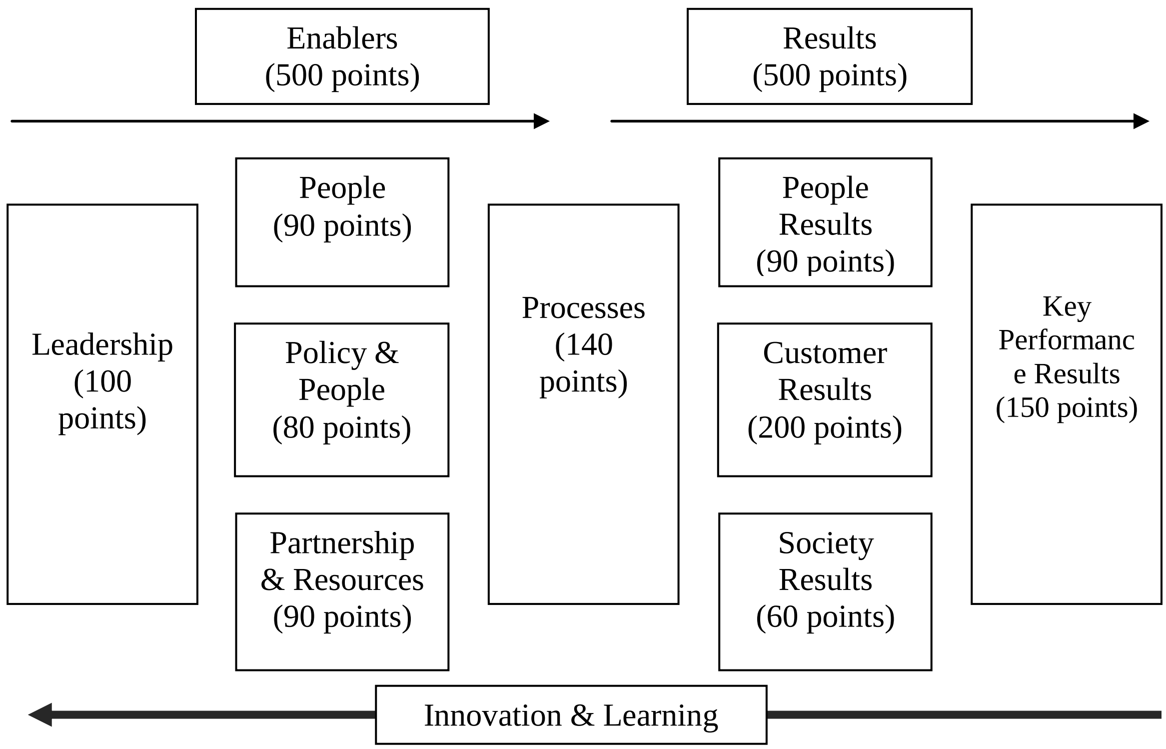

Figure 1 EFQM Model

The EFQM model consists of nine criteria (Fig. 1) and it reflects eight fundamental concepts.

1. Results orientation
2. Customer Focus
3. Leadership & Constancy of Purpose

4. Management by Processes & Facts
5. Development & Involvement
6. Continuous Learning, Innovation & Improvement
7. Partnership Development
8. Public Responsibility

The left hand side is called as “Enablers” which consists of five criteria. These Enablers are concerned with how the organization performs various activities. The remaining four criteria residing on the right side is called as “Results”. Results indicate what the organization is achieving with respect to different stake holders. The model is a self- assessment tool. The rationale behind the EFQM Excellence Model is that some causal relationship between eight fundamental concepts must be reflected in the model as a causal relationship between the enablers and the result criteria.

The changes in the 2010 version of EFQM model signify an increasing realization of the importance of society. The weighting of the criterion ‘‘Society’’ increased from 6 per cent to 10 per cent. New fundamental concepts of the EFQM model – viz. ‘‘Leading by vision, inspiration and integrity’’, ‘‘Achieving balanced results’’, ‘‘Building partnerships’’, and ‘‘Taking responsibility for a sustainable future’’ – have an increasing sustainability focus. In addition, the focus of sub-criteria is more explicitly towards human values such as practicing ethics and transparency in the Leadership criterion, and sustainability in the Strategy criterion, etc. Thus, new dimensions of excellence towards the sustainability focus are clearly emerging, and their impact on business will be visible in coming times. The recent changes in the EFQM model indicate a step forwards in enhancing the weighting of goodwill criteria.

The EFQM excellence award is announced to recognize Europe’s best performing organization whether it is private, public or non-profit. Only EFQM member can apply for this award. It is supported by one of the most rigorous assessment processes. To identify the finalists, a team of 4 –8 international experienced managers spend one week on site, or an average of 500 hours per applicant; reviewing documents, interviewing and analyzing the organization against the EFQM Excellence Model.

The through assessment and feedback from a team of 100 assessors, jury selected thirteen nominees for present year. Each nominee presented to an independent jury that decides the level of recognition for each Finalist. To win the EFQM Excellence Award, an applicant must be able to demonstrate that their performance not only exceeds that of their peers, but also that they will maintain this advantage into the future (EFQM Excellence Award, 2012). Out of the 13 nominees, the jury identified one EFQM Award Winner, an organization showing excellent approaches and results across the entire organization. The Jury decided to name the Robert Bosch Bamberg Plant, the EFQM Excellence Award Winner 2012. Moreover, another 6 organizations got an EFQM Prize in different categories. The organization which demonstrates role model behavior in one of the following eight criteria’s is announced to be prize winner for the EFQM Excellence Award:

1. Leading with Vision, Inspiration & Integrity
2. Managing Processes

3. Succeeding through People
4. Adding Value for Customers
5. Nurturing Creativity and Innovation
6. Building Partnerships
7. Taking Responsibility for a Sustainable Future

From the self-assessment process, companies experienced the increased focus on continuous improvements. The continuous improvement must be linked to an increased focus on employee involvement and employee satisfaction, as they are the most important drivers for that. Involved and satisfied employees are a primary concern for companies striving for excellence. The productivity can be improved by raising the number of suggestions for improvement per employee per year, and thus involving the employees in the companies search for continuous improvement.

It is therefore vital for any company to identify the drivers of loyalty and employee satisfaction. If an organization wishes to improve the loyalty and satisfaction of working employees, it can concentrate the improvement effort within the relevant enabler criteria from the EFQM Excellence Model and expect a positive impact on loyalty and employee satisfaction. When trying to determine the drivers of the criterion "Customer Results" it is advantageous to turn to another customer satisfaction model-the European Customer Satisfaction Index (ECSI) model as shown in figure 2 (Kristensen, Martensen, & Gronholdt, 1999).

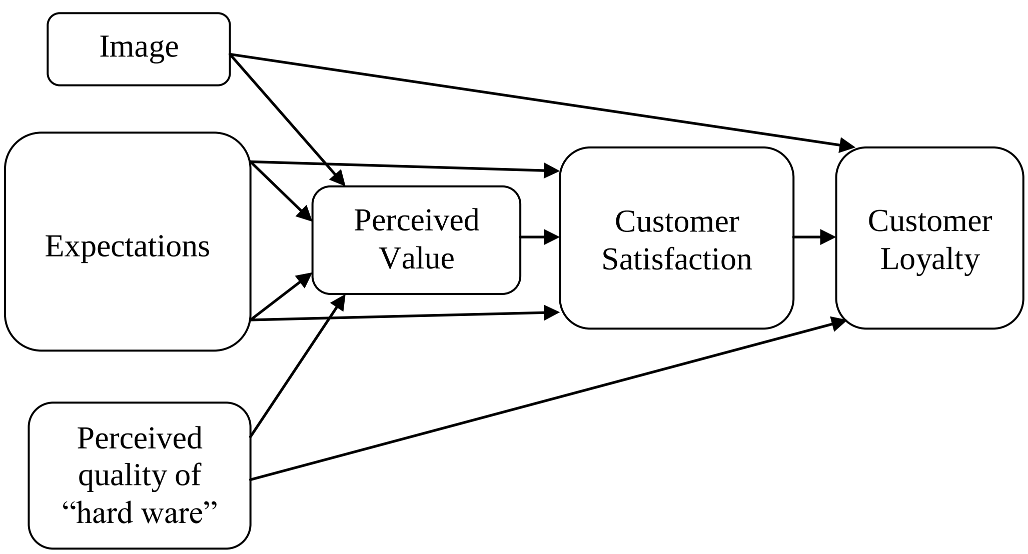

Figure 2. The ECSI Model

This model is validated in many empirical settings and stipulates that loyalty and customer satisfaction is generated by four variables: expectations, image, perceived quality of human ware and perceived quality of hard ware. The impact of image in both customer satisfaction models indicates that "Society Results" must have an impact on "Customer Results" since sub criterion under "Society Results" deals with "Society's perception of the organization".

Excellence Model frameworks have different shapes. Most Excellence Models start with the criterion ‘‘Leadership’’ and end with ‘‘Results’’. Ancient wisdom emphasizes that the ultimate goal of business is the wellbeing of society. Although the criteria of Excellence Models are similar, the criterion weighting changes due to external environment and cultural factors. The study is made with nine criteria to integrate the common learning/contradictions of twenty Excellence Models and provide the clues to achieve sustainability (Talwar, 2011).

4. The Implementation of Overall Excellence Model within the Manufacturing Company

A sample of ten companies was asked to identify any problems related to the application of the Overall Excellence model. Information was gathered from five structured interviews and a case study carried out. The results of this consultation process have been utilized in the production of a generic model designed to assist manufacturing related organizations in their implementation of the Overall Excellence Model. The success of business organizations, long-lasting and sustainable need to be explored empirically.

The Model is designed to be flexible, holistic, dynamic, simple and innovative. The fundamental advantages of Overall Excellence Model include knowledge management, performance, learning, partnership, customer focus, results orientation and increased cost effectiveness.

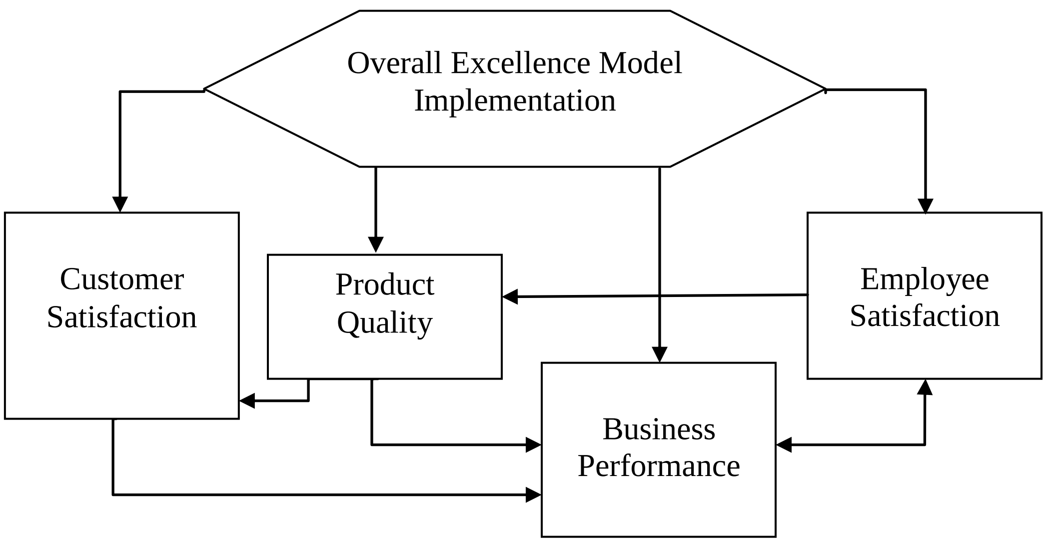

Figure 3: Theoretical Overall Excellence Model

4.1 Customer Satisfaction

In customer satisfaction research, analytic methods are needed to capture the complex relationship between overall satisfaction with a product or service and the underlying performance on the product’s or service’s attributes. Eventually, the method should allow identifying the attributes that need improvement and that most significantly enhance the business relationship with the customer (Vanhoof, Pauwels, Dombi, Brijs, & Wets, 2005).

In prevailing cut throat competition, it is very clear that a company survival depends on its ability to satisfy customer's expectations and needs. Quick response to customer complaints on a product is essential to minimize customer dissatisfaction. The information must be gathered from surveys regarding competency of product in global market. Intensive examination of finished products from the customer view point can be useful predictor of customer satisfaction. It may very well predict the future success or failure of a firm. Thus it is very important to find customer satisfaction and perception of quality. The maintenance and attainment of satisfactory levels is today fundamental determination for business growth, economic viability and health.

It can be measured by comparing product quality and service quality with those in other firms in the same industrial sector. Use of customer satisfaction information can provide a focus and direction for continuous improvement throughout the entire firm. By delighting the customer you can turn satisfied customers into loyal customers. Loyalty generates repeated purchases and increased revenues, thus leading to organizational excellence.

4.2 Employee Satisfaction

One of the key performance measures of a firm is Employee Satisfaction. It is a topic of interest to both researchers who study it and practitioners who work in firms. It is the extent to which employees like or dislike their jobs. It is an attitudinal variable and can be considered as a global feeling about the job. Employee satisfaction is needed to support continuous improvement and external customer satisfaction. Delighted employees who feel proud of their work have an outstanding performance, thus having a positive impact on business excellence.

The employee involvement and satisfaction has a positive effect on the organization's ability to continuously improve in the competitive market. The productivity can be improved by raising the number of suggestions for improvement per employee per year, and thus involving the employees in the companies search for continuous improvement.

4.3 Product Quality

A narrow definition of product is that they are tangible and physical. This is in contrast to service, which is intangible. In manufacturing processes, conformance to standards is a very critical aspect. It relates to how closely the final product matches its design specification. The quality of the final product should not merely rely on the general inspections due to the complexity of unstable factors in manufacturing process. The errors or variation caused by those factors could be accumulated gradually in the process and thus avoid serious troubles in the subsequent stages (Sonigra & Qureshi, 2012). The process performance is estimated by the quality characteristics of items produced from a process. A process capability index is used as one of the evaluation measures for process performance.

The quality of process output can be measured in various ways. The percentage of the fraction of items that does not confirm to specifications is used. In many practical situations it is convenient to measure the quality of the product or the service by the number of nonconformities per 'unit area of opportunity'. Some times the quality of sample of items is measured by the mean of the measurements or by some other measure of central tendency such as a percentile.

Many studies have been conducted to estimate the importance of quality. Some studies have tried to find a linkage between high products qualities and companies' financial performances. It demonstrate that companies that win quality awards outperform other firms on operating income measures as well as stock performance (Hendricks & Singhal, 2001).

“Total quality control", also called total quality management, is an approach that extends beyond ordinary statistical quality control techniques and quality improvement methods. It implies a complete overview and re-evaluation of the specification of a product, rather than just considering a more limited set of changeable features within an existing product. If the original specification does not reflect the correct quality requirements, quality cannot be inspected or manufactured into the product. For instance, the design of a pressure vessel should include not only the material and dimensions, but also operating, environmental, safety, reliability and maintainability requirements, and documentation of findings about these requirements.

4.4 Business Performance

The six sigma process is an excellent fit for the fabrication and machining industries. Any company that needs solutions for quality related problems should benefit from this process. Companies will be most likely to succeed if their top-level management is supportive of a continuous improvement culture. Organizations need a framework that is comprehensive, flexible and easy to adopt. Since success clearly depends on a combination of factors that are interrelated, the approach must be highlighting and holistic. Any change in one of the components will have impact on the overall system.

Several studies point out that a focus on customers, employees and business results is a must for survival in the current economic environment. Increasing globalization, rapid transportation, the information technology boom and improved communications have enhanced competitiveness and have further reduced the gap between developed and developing economies. The key concern of organizations is not just customer satisfaction, but customer retention. Though most corporate entities make profits, they are not able to retain even half of their customers.

5. Conclusion

The proposed Overall Excellence model offer companies the capability to develop and implement an effective and dynamic quality system, with a focus on continuous improvement and adaptation. The real benefits can be realized only when the companies that apply them truly understand both their capabilities and their limits. The Overall Excellence model is expected to provide a direction to obtain sustainable profits, people and planet development. It brings business organizations closer to their truly final objective of long-run satisfaction of the needs and desires of all stakeholders and the global community.

There are other issues concerning the model, after establishing the causality in the Overall Excellence model. These issues provides platform for future research. More research is possible on the simplification this model. It is not possible for any company to get excellence but the company can strive to attain the excellence. An emerging focus on environmental concerns, inclusive growth, corporate governance and ethical practices, etc., in recent times is an indication of a paradigm shift towards the growing importance of goodwill criteria (Talwar, 2008).

The structure of learning organization is built on strong foundations of management culture that implements the right management systems to establish deep knowledge through leadership and employee professional development, which ensure business survival and growth through quality focus and excellence. This should be harmonized with society benefit, embracing also environmental protection and resources management toward sustainable development (Pantazopoulos, 2012).

At present, manufacturers are facing an increasingly uncertain external environment with a cumulative effect of changes in customer requirements, global competition, and technological advancement. Manufacturers face the challenge of improving efficiency and lowering costs. QC techniques would be continuously exploited to help organizations to improve their products and process in order to be accepted by customers.

The long term effectiveness and real value of the quality assurance standards are not based on their content and requirements, but on the way that these are adopted and implemented by the companies. The key for their success lies in the companies' real commitment to quality improvement and their true motives for certification, which finally dictate the way and depth to which the standards are implemented. The firm may develop its own specific measurement system that can better measure employee satisfaction, product quality, customer satisfaction, and strategic business performance. Though several initiatives have taken place in past four decades to attain excellence, some of the software criteria have still not yet gained adequate focus. A lack of focus on human values gives rise to the risk of the use of unethical practices to maximize short-term gains. Financial scandals at large multinational corporations such as Enron and WorldCom have brought the need for ''ethical'' management into focus. Vedic philosophy and other religious texts emphasizes that one should work not for own self only, but for universal wellbeing, also.

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