5-2012

Set up time Reduction and Quality Improvement on the Shop floor using different lean and quality tools

Seetha Ram Bavuluri
Clemson University, sbavulu@clemson.edu

Follow this and additional works at: https://tigerprints.clemson.edu/all_theses
Part of the Mechanical Engineering Commons

Recommended Citation
Bavuluri, Seetha Ram, "Set up time Reduction and Quality Improvement on the Shop floor using different lean and quality tools" (2012). All Theses. 1306.
https://tigerprints.clemson.edu/all_theses/1306

This Thesis is brought to you for free and open access by the Theses at TigerPrints. It has been accepted for inclusion in All Theses by an authorized administrator of TigerPrints. For more information, please contact kokeefe@clemson.edu.
SET UP TIME REDUCTION AND QUALITY IMPROVEMENT ON THE SHOP FLOOR USING DIFFERENT LEAN AND QUALITY TOOLS

A Thesis
Presented to
The Graduate School of
Clemson University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science
Mechanical Engineering

by
Seetha Ram Bavuluri
May 2012

Accepted by:
Dr. Laine M. Mears, Committee Chair
Dr. Gang Li
Dr. Greg Mocko
The purpose of this thesis document is to describe a method developed for reducing setup time in machining processes and simultaneously improve the quality of production after setup. Bosch Rexroth at Fountain Inn is a semi-automated plant and is still in its initial stages of standardizing the setup process. Setup time at different machining centers includes: machining time, inspection time, loading and unloading times and deburring. The focus of the described method is in reducing setup times related to inspection time and loading and unloading times. To achieve success in these problems the following new tools were developed: first piece inspection charts, design inspection fixture and design of new handling tools. This work involved interaction with operators, collection of data, and analyzing and developing new plans based on the analysis. Tools like Failure Modes Effects Analysis (FMEA), 5S and Single-Minute Exchange of Die (SMED) techniques helped in making and implementing these changes on the production line. Implementation of first piece inspection charts and inspection reduced inspection time by almost 50%. Design of handling tools helped in reducing stress on the operator and also in reducing loading and unloading time by 40%. Also quality was improved through a related project. This subproject’s aim is to reduce shaft alignment problems as reported by the customer. To achieve this goal I designed a fully automatic shaft alignment tool, which helps operator in installing the shaft into the pump without any difficulty. This shaft alignment tool is installed on the line and eliminated the shaft alignment problems completely. Also the quality improvement techniques and set up time reduction techniques used at BOSCH are discussed in this document.
DEDICATION

To my parents, advisor, friends and all my well wishers for all the love and support they had given to me throughout my life.
ACKNOWLEDGMENTS

I would like to express my deepest gratitude to Dr Laine Mears for his continual support and guidance, without whom this thesis would not have been possible. It would be an honor to utilize this opportunity to Dr Gang Li and Dr Yong Huang for being on the committee.

It is my honor to thank Mr. Wolfgang Buck at Bosch Rexroth for the assistance and insightful knowledge he has provided me during my time as an intern.

Last but not the least I would also like to thank my friends and colleagues for their help and motivation during my time at Clemson University.
TABLE OF CONTENTS

TITLE PAGE ....................................................................................................................... i

ABSTRACT ......................................................................................................................... i

DEDICATION ...................................................................................................................... ii

ACKNOWLEDGMENTS ...................................................................................................... iii

LIST OF TABLES ............................................................................................................... vi

LIST OF FIGURES ........................................................................................................... vii

CHAPTER Page

INTRODUCTION .................................................................................................................. 1

SETUP TIME REDUCTION ............................................................................................... 3

2.1 SETUP TIME REDUCTION ......................................................................................... 3
2.2 FAILURE MODES AND EFFECT ANALYSIS (FMEA) ................................................ 12

PROJECTS ON SETUP TIME REDUCTION AT BOSCH .............................................. 18

3.1 INTRODUCTION ......................................................................................................... 18
3.1.1 PROJECT1: MODIFICATION OF FIRST PIECE INSPECTION CHARTS ... 20
3.2 PROJECT2: DESIGN OF INSPECTION FIXTURE .................................................. 25
3.3 RESULTS ................................................................................................................... 30
3.4 PROJECT 3: DESIGN OF HANDLING TOOLS .......................................................... 31
3.5 STRESS ANALYSIS ................................................................................................. 36
3.6 RESULTS .................................................................................................................. 38
3.7 PROJECT 4: DESIGN OF MANUFACTURING FIXTURES FOR PUMP HOUSINGS ...................... 39
3.7.2 PRELIMINARY DESIGNS .................................................................................... 41

QUALITY IMPROVEMENT ............................................................................................ 47

4.1 INTRODUCTION ......................................................................................................... 47
4.2 SIX SIGMA ............................................................................................................... 47
4.3 KAIZEN ..................................................................................................................... 49
4.4 BOSCH PRODUCTION SYSTEM .............................................................................. 53
PROJECTS ON QUALITY IMPROVEMENT ................................................................. 58

5.1 PROJECT 1: SHAFT ALIGNMENT TOOL ......................................................... 58
5.2 RESULTS ........................................................................................................ 62
5.3 PROJECT 2: TURRET CHANGE CART ......................................................... 62
5.4 CONCLUSION ................................................................................................. 66

CONCLUSION ........................................................................................................... 67

6.1 CONTRIBUTION ............................................................................................... 67
6.2 LESSONS LEARNED AND FUTURE WORK .................................................. 69

APPENDICES ......................................................................................................... 71

Appendix A ............................................................................................................. 71
Appendix B ............................................................................................................. 74
Appendix C ............................................................................................................. 75

REFERENCES ........................................................................................................ 79
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1: Load and Restraint Information</td>
<td>36</td>
</tr>
<tr>
<td>Table 3.2: Study Property</td>
<td>36</td>
</tr>
<tr>
<td>Table 3.3: Solver Information</td>
<td>37</td>
</tr>
<tr>
<td>Table 3.4: Results - Stress Analysis</td>
<td>37</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1[1]: Stages in SMED Implementation</td>
<td>5</td>
</tr>
<tr>
<td>Figure 2.2: SMED time analysis chart</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2.3: 5S Board</td>
<td>10</td>
</tr>
<tr>
<td>Figure 2.4 5S Implementation</td>
<td>11</td>
</tr>
<tr>
<td>Figure 2.5 [8]: FMEA Classification</td>
<td>13</td>
</tr>
<tr>
<td>Figure 2.6: Various stages in the FMEA Process [10]</td>
<td>15</td>
</tr>
<tr>
<td>Figure 2.7: A sample FMEA Chart</td>
<td>16</td>
</tr>
<tr>
<td>Figure 3.1: Port Block # 902020322</td>
<td>19</td>
</tr>
<tr>
<td>Figure 3.2: Initial set up time for Port Block#902020322</td>
<td>20</td>
</tr>
<tr>
<td>Figure 3.3: Initial first piece inspection chart</td>
<td>22</td>
</tr>
<tr>
<td>Figure 3.4: Modified first piece Inspection chart</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3.5: Modified first piece inspection chart 2</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.6: Comparison of Inspection Times</td>
<td>25</td>
</tr>
<tr>
<td>Figure 3.7: Port Block # 2134455</td>
<td>27</td>
</tr>
<tr>
<td>Figure 3.8: Initial Inspection Fixture</td>
<td>29</td>
</tr>
<tr>
<td>Figure 3.9: Modified Inspection Fixture</td>
<td>30</td>
</tr>
<tr>
<td>Figure 3.10: Loaded Casting on the Machining Fix</td>
<td>33</td>
</tr>
<tr>
<td>Figure 3.11: Initial handling tool design</td>
<td>34</td>
</tr>
<tr>
<td>Figure 3.12: Final Handling Tool Design</td>
<td>35</td>
</tr>
</tbody>
</table>
Figure 3.13: Results - Stress Analysis ................................................................. 37
Figure 3.14: Results - Factor of Safety ............................................................... 37
Figure 3.15: Pump Housings ............................................................................. 39
Figure 3.16: Machining Center ......................................................................... 40
Figure 3.17: Design 1 ....................................................................................... 42
Figure 3.18: Design 2 ....................................................................................... 42
Figure 3.19: Design 3 ....................................................................................... 43
Figure 3.20: Final Design Perspective View ....................................................... 45
Figure 3.21: Final Design .................................................................................. 45
Figure 4.1: Six Sigma Process ......................................................................... 49
Figure 4.2: Kaizen Process .............................................................................. 50
Figure 4.3: Kaizen system at BOSCH Group .................................................... 52
Figure 4.4 Layout of Blank Card ....................................................................... 53
Figure 4.5: BOSCH Production System ............................................................ 54
Figure 5.1: Initial Design of Shaft Alignment System ....................................... 59
Figure 5.2: Final Design of Shaft Alignment System ........................................ 61
Figure 5.1: “Traditional” Cart Depiction ............................................................ 65
Figure A-1: Handle ......................................................................................... 71
Figure A-2: Holder1 ......................................................................................... 72
Figure A-3: Holder2 ......................................................................................... 72
Figure A-4: Final assembly of Handling tool .................................................... 73
Figure B-1: Machining Fixture Final Assembly ................................................ 74
Figure C-1: Modification of first piece inspection sheet ......................................................... 75

Figure C-2: Handling tool............................................................................................................. 76
CHAPTER ONE

INTRODUCTION

The Bosch Rexroth facility at Fountain Inn manufactures axial and radial pumps, which are related to mobile hydraulics and industrial hydraulics. Set up time at Fountain Inn includes loading the castings on to the fixture, machining the fixtures, unloading the fixtures, deburring and inspection checks. The goal of this work is to reduce set up time, beginning with developing a method to measure the set up time. This began with use of tools such as Single-Minute Exchange of Die (SMED) analysis, cycle time sheets and review and interaction with the operators. Reducing set up time also reduces the cost involved in manufacturing the product, as time equals money in real manufacturing environment. I worked on reducing set up times at different machining centers which involved reducing setup time during inspection process by modification of first piece inspection charts, Design of automated machining fixtures which can loaded and unloaded easily, design of handling tools to lift heavy castings on the shop floor. These measures to reduce the set up time were taken using tools like SMED, 5S and Failure Mode Effects Analysis (FMEA). I succeeded in reducing set up time to a considerable extent on the projects I worked upon. Also I worked on quality-related issues on the assembly line. These quality-related projects include design and installation of shaft alignment tool on the assembly line to eliminate the shaft misalignment problems in pumps. As a part of the quality team I got involved in tasks using Kanban, Six Sigma and kaizen processes, through which I gained a good knowledge of lean tools used in real time manufacturing. Also I gained knowledge of the Bosch Production System (BPS),
which is a specific company-developed production system. All the setup time reduction techniques and examples of set up time reduction projects are described in the following sections of the document. Chapter 2 describes the essential functions of set up time reduction and the motivating need for it. It also describes the tools and techniques used in reducing set up time like 5S and FMEA. Chapter three includes the case examples of setup time reduction at Bosch. Chapter four discusses about the quality tools and techniques like Six Sigma, Kaizen, and BOSCH Production System. Chapter five includes the case examples of the quality improvement projects done at BOSCH. Chapter six concludes with findings, lessons learned, and a map for future directions of study in this area.
CHAPTER TWO
SETUP TIME REDUCTION

2.1 SETUP TIME REDUCTION

Setup time is defined as the time taken from the last good piece of the previous run to the first good piece of next run [1]. Setup time activities are non-value adding activities to the product value. Hence improving these setup activities i.e., reducing time taken by each of these activities helps in reducing capital costs thereby increasing the profit to the company. Setup time reduction can be achieved through many concepts and techniques, prominently SMED (Single Minute Exchange of Die) and the 5S organizational approach.

2.1.1 SMED (Single Minute Exchange of Die)

The SMED is a theory and set of techniques, which help in equipment setup in less than ten minutes i.e., in single minute range. SMED was originally developed to improve die press and machine tool setup but later on this concept is being applied in all types of processes [1].

It may not be possible to reduce every setup time to less than ten minutes but SMED is an effective tool in reducing the changeover time effectively. Shorter setup times, in turn, lead to many benefits to the company. Companies, which follow SMED, have advantages like Flexibility in production, quicker delivery, better quality and higher productivity.
While contributing to the company SMED also offers individuals the advantages like safe changeovers and simpler setups [1-3].

2.1.1.1 Important Terms and Concepts
It is important to know about the terms involved in manufacturing industries before discussing about SMED concepts and how they can be applied in the manufacturing environment.

- **Manufacturing process** is a continuous flow in which raw materials are converted into finished product. Manufacturing processes involve processing, inspection, transport and storage [3,4].
- **Manufacturing operations** are those performed by the operator on raw materials to make a final product. This includes tasks like machining, inspection, assembly, testing and more [3,4].
- **Setup Operations** is preparation before a lot is produced. Setup operations are of two types [3,4].
- **Internal Elements** can be done only when the machine is shut down [3,4].
- **External Elements** can be done while the machine is still running [3,4].

2.1.1.2 SMED Implementation
SMED implementation involves following stages (Fig 2.1).
Figure 2.1[1]: Stages in SMED Implementation

Figure 2.1 shows the different stages in reducing set up time using SMED technique. First stage involves identification of internal and external elements. Internal elements are those activities, which done when the production is stopped. External elements are those activities, which can be performed even when the production is going on. Second stage involves separation of internal and external activities into two different groups based on their nature. After categorizing internal and external elements, third stage involves conversion of internal elements to external elements. To do this one needs to analyze all the activities and implement lean manufacturing principles to achieve the goal. After converting maximum possible internal elements into external elements, last stage deals with the stream lining of all the activities.

With the help of SMED time analysis chart it is easy to differentiate internal activities and external activities. Also we can prioritize the internal activities that can be converted to external activities based on the time taken for each activity. A sample SMED time analysis chart used at BOSCH is shown in figure 1.2.
Figure 2.2: SMED time analysis chart

Figure 2.2 shows the sample SMED chart used at the plant to determine the cycle time and an effort to reduce it. This chart has all the details of the product changeover such as part number, Start time of the changeover, equipment number and production area.

Going in to the details of the chart, it has all the activities to be performed during a changeover listed in a tabular form. Also it has provisions to record the time taken for each activity performed and also to determine whether it is an external or internal element. This gives us the data about the time taking activities, waste activities, and helps us identify the internal elements, which can be converted to external elements. Also when ideas to convert internal elements into external elements are implemented, this chart has a
provision to record the improvement in set up time. This helps greatly in analyzing cycle times and reducing it.

2.1.2 5S

5S is a systematic approach to improve cleanliness and orderliness. 5S’s are sorting, setting in order, systematic cleaning, standardizing and self-discipline. Through orderliness and cleanliness we can make all processes transparent so that we can identify an abnormality easily [5-7]. The abnormality can be for particular items or a system. An audit system is designed in BOSCH to evaluate the transparency of an area as well as the adherence to the systems that are implemented or show where there is need for a system. 5S is the basis for visual management. 5S is the beginning point of improvement in every company. In actual 5S teaches us to use the workplace in an effective manner. The 5S technique, developed in Japan, is a total quality management (TQM) tool that helps proper management of the workplace for better productivity and quality. The 5S stands for five Japanese words starting with the letter S – Seiri, Seiton, Seiso, Seiketsu, Shitsuke [16]. They stand for Set, Sort, Sanitize, Standardize and Sustain. The Seiri phase deals with eliminating the unnecessary tools, parts and materials [17]. Seiton basically talks about maintaining neatness. The workplace has to be sorted and maintained in an orderly fashion so that the documents can be easily retrieved and dispatched. The Seiso phase emphasizes the importance of cleanliness of the work environment. Individuals in the organization are responsible for maintaining a clean environment around them. The above steps are to be standardized and these steps are to be repeated so as to inculcate them in every individual and every part of the organization. This stage is known as
Seiketsu. The last stage is the Shitsuke, meaning discipline. Discipline is a set of guidelines and regulations that have to be rigorously followed by all the personnel. Discipline involves repetition and practice. Maintaining discipline will help in proper functioning of the organization and also reduces lead times while maintaining high safety standards. The 5S technique urges individuals to incorporate these principles in their daily life, not just in the workplace.

These five principles when collectively and effectively followed in a firm by all its members will lead to a better team performance, minimal wastage and high productivity [18].

2.1.2.1 Important terms and Concepts

5S’s:

- **Sorting** is the first step in differentiating things as per their work areas.
- **Setting in Order** is organizing the things and arranging them orderly in their respective work areas.
- **Systematic Cleaning** is regular cleaning and maintenance.
- **Standardizing** is making the things easy to maintain.
- **Self-discipline** is maintaining the things properly which are arranged.

When an area is 5S’d following results can be expected

- Transparent process
- Increased productivity
- Improved working environment
- Increased safety
- Associate involvement
- Increased morale and implementation
- Enhanced plant appearance

2.1.2.2 5S Implementation

5S boards used at BOSCH and its implementation is depicted in the figure 2.3 and figure 2.4. 5S system at BOSCH utilizes a cleaning board and cards systems. This system basically comprises of a board with provisions for card assigned for operators of different shift timings. These 5S cards have two different colored sides, red and green. Operators are responsible for maintaining this board. Red side of the card indicates the tasks to be performed on the designated work area. Operators from different work areas are responsible for the cards pertaining to their work area. And also the cards are placed on the board based on daily, weekly and monthly basis i.e., tasks to be done daily, weekly and monthly. Weekly and monthly cards have a due date where as daily cards do not have a due date. Operators from different work areas need to pick up the cards pertaining to their work areas, which are place on their red side. They need to complete the tasks on the red side of the card and after the task is completed, it is required to place cards on the board in their previous position but with greenside facing outside. Red cards indicate the
tasks to be done and green cards indicate that the task has been performed and is ready for assessment.

Cleaning cards

Before task is completed:
The red side of the card should be showing.

When task is completed:
Cards are to be turned so that the green side is showing.

A verification that last 12 audits have been done

Production areas need to have daily, weekly and monthly cleaning cards
Weekly and monthly cards need to have a due date (not req’d on daily)

Weekly trend chart

These cards are used to maintain orderliness on the shop floor. These cards help to maintain cleanliness on the shop floor. Also these cards indicate which areas needed to be taken care of on the first shift of production.

Figure 2.3: 5S Implementation
Red side of the card

Title of the task (example: “Floor Mats”)

Lists the steps of the task

Which department the board is located in

Green side of the card

Title of the task (example: “Floor mats”)

Specifies “Daily”, “Weekly,” or “Monthly” Kanban

Each task, in each row, is numbered, starting with “#1”

Which department the board is located

Figure 2.4 5S Implementation
2.2 FAILURE MODES AND EFFECT ANALYSIS (FMEA)

FMEA a powerful tool in design and process environments is a powerful tool and is first used in aerospace industries in 1960’s. FMEA is a resource intensive process [a]. FMEA is a powerful tool in design and manufacturing process that helps to compare, from a risk point of view, alternate machine system and process configurations. FMEA is a formalized but subjective analysis for systematic identification of possible root causes and failure modes. FMEA also estimates their relative risks [8]. Several industrial FMEA standards employ Risk Priority Numbers (RPN) to measure risk and severity of failures [9]. RPN is product of Occurrence, Severity and Detection [9]. FMEA process is used to detect the possible failure mode, analyze it and suggest suitable remedies to the problem. FMEA helped me in redesigning the process and in engineering designs. FMEA is used in modification of first inspection charts, which helped in reducing inspection time. Use of FMEA in modification of inspection charts is discussed in the chapter 3. FMEA helped me in making changes to the first piece inspection chart in reducing inspection time and also in designing a handling tool. It helped in detecting the failure modes of the changes intended in the first piece inspection chart, through which it was possible for me to make some successful changes. In designing the handling tool for the castings developing FMEA charts helped in eliminating possible risks i.e., avoiding physical injuries and tool failure

- **Occurrence** is the frequency of root cause that is likely to occur that is not in form of a period of time but rather in terms like rare or occasional [8,9].
- **Severity** is magnitude of end effect of system failure. The more the severity of consequence, the higher the value of severity will be assigned to the effect [8,9].

- **Detection** refers to the probability of detecting a root cause before a failure can occur [8,9].

FMEA is of two types.

- Design FMEA
- Process FMEA

The classification of FMEA is depicted in the figure 2.5.

![FMEA Classification Diagram](image)

Figure 2.5 [8]: FMEA Classification
Figure 2.5 explains about classification of FMEA. Basically an FMEA comprises of three elements (system, sub system and component). Design FMEA only deals with designing section where as process FMEA can be performed for both assembly and manufacturing lines.

FMEA is to be carried out on personal experience, which includes various factors to be considered. FMEA process contains the following five stages:

- **Planning Stage** in which we identify the potential risk failures, their effects and assign them severity rankings. We should also estimate the occurrence of severity rankings based on experience.

- **Performing FMEA Stage** in which we perform generic FMEA i.e., we calculate RPN. Calculation of RPN’s can be done traditionally or by using FMEA software like XFMEA.

- **Redesign Stage** in which we redesign the component or the process from the results obtained in Performing FMEA stage. This should be done carefully as mistakes in this stage may lead failure of the component or the process.

- **Review Stage** in which the FMEA report should be sent to management review and quality audits.

- **Implementation Stage** is the stage in which the designed component or the modified process is implemented [10].

The various stages in the FMEA process are shown in the figure 2.6. Also a sample chart used at BOSCH in the FMEA process is shown in the figure 2.7.
FMEA involves various stages before modifying the process or designating a part. First stage involves detection and analysis of failure modes. Second stage involves thinking which may reduce the effect of failure modes or eliminates them completely. Third stage involves implementing the approved changes made in the second stage. Fourth stage involves redesigning and installing the modified part.
Figure 2.7: A sample FMEA Chart

This figure shows the provision for failure modes, which may occur while designing stage or in a process. Also the chart discusses about the potential causes for failure modes and the effects of failure modes. It determines the severance rating, rate of occurrence
and detection. With the help of these factors we get risk priority number (RPN), which helps in redesigning a product or a process more effectively.
CHAPTER 3

PROJECTS ON SETUP TIME REDUCTION AT BOSCH

3.1 INTRODUCTION

Rexroth Corporation at Fountain Inn manufactures Axial Piston motors, External Gear motors and Radial Piston motors used in Mobile Hydraulics. These products are widely used in earth moving equipment. Rexroth customers include industry giants like Caterpillar and John Deere. Manufacturing of these motors involves casting, machining and assembly processes. Rexroth purchases the casted parts from outside vendors and machines them. Then machined parts go to assembly line for assembly to come out as a finished product. The set up time for the machining process includes

- Loading Clamping Fixtures.
- Change part, Activate 1st Operation
- Machining
- Deburring
- First Piece inspection
- CMM Check

Figure 3.2 shows the setup time for the Machining center, Deckel # 13, for production of Port Block # 902020322 (figure 3.3) initially at the start of the project, which is used in assembly of axial Piston Motor. Set up time for the Port Block # 902020322 can be inferred from the figure 3.2. From the figure it can be observed that the maximum time is...
taken for the machining process, first piece inspection and CMM check. Also time taken for loading and unloading the work piece can be observed in the figure. As the machining time cannot be reduced greatly, effort is put on reducing inspection time. If the inspection time reduced by a considerable amount, it will be a good achievement in reducing set up time too. Hence inspections sheets were modified and inspection fixtures were developed to ease the inspection process and reduce the time taken in inspecting the work piece. These efforts in reducing inspection time are discussed in detail in chapters three and four.

Figure 3.1: Port Block # 902020322
Figure 3.2: Initial set up time for Port Block#902020322

Figure 3.2 shows the initial set up time for portblock#902020322. Figure depicts the time taken for clamping of the work piece, loading and unloading time, Machining time, first piece inspection time and the time taken for CMM check. This figure clearly depicts the activities, which take more time so that we can concentrate on reducing time taken for those activities. This chart is prepared with help of MS Excel.
3.1.1 PROJECT 1: MODIFICATION OF FIRST PIECE INSPECTION CHARTS

3.1.1.1 INTRODUCTION

First Piece Inspection is an important aspect in every manufacturing industry as it determines the quality of tooling, Errors in Machining and determines the changes to be made to the process for the entire shift. As First Piece Inspection is a very important process it has designed carefully and precisely so that quality of every machined product is maintained good. At Rexroth in earlier day’s first piece inspection used to be a time taking process with long first piece inspection charts.

3.1.1.2 Previous Method

Initial First piece inspection chart had all the dimensions to be measured by gauges and CMM at one place. This led to confusion among the operators. Initial first piece inspection chart is depicted below in the figure 3.3. In this figure it can be observed that all the manual inspection checks and CMM checks are placed at the same place. When using this first piece inspection chart operator had to turn the work piece many times and also to look for the manual check columns among the CMM check columns to fill the inspection results. Hence there is a scope for improvement when these manual check columns and CMM check columns are separated. By doing so confusion in the operator is eliminated, better facilitating the task and reducing the needed time.
Figure 3.3: Initial first piece inspection chart

3.1.1.3 Modified charts

Modified Inspection Chart 1:

This time all the CMM check measurements to be made are pushed to end of the sheet thereby reducing confusion in operator while performing first piece inspection (Figure 3.4). Even after making these changes operator needed to turn the port block many times to perform the manual inspection check. Hence there is a need to modify this inspection sheet further.
Modified Inspection Chart 2: As the first piece inspection chart used initially had all the dimensions to be measured placed irregularly on the chart, it created a lot of confusion among the operators. Hence, modified Inspection chart 1 was further modified putting all the dimensions that can be measured by a single gauge at one place thereby preventing the time taken in changing gauges by the operator in measuring different dimensions (Figure 3.5).
3.1.2 RESULTS

These modified first piece inspection charts reduced inspection time to a great deal. Improvement in inspection time can be observed in the figure 3.6 shown below. Improvement of inspection time by 40% is achieved by modifying the inspection sheets.
3.2 PROJECT2: DESIGN OF INSPECTION FIXTURE

3.2.1 INTRODUCTION

Inspection fixture is device, which makes inspection process easy and fast. These are widely used in industries now days to make the inspection process accurate and easy for the operator. As companies now a days manufacture a wide range of products, these inspection fixtures are specifically made one each for products with complex shape and more dimensions to inspect. Work pieces should be easily loaded and clamped on these fixtures. The inspection fixture is used to hold the part while it is being examined. Inspection fixture makes measurements easy, fast and accurate. Inspection fixture’s main purpose is providing access to all the dimensions so that operator can reach them easily and perform the inspection easily. Inspection fixtures can make less skilled personnel to
achieve accurate results. Inspection fixtures are also used in circumstances where the production part must be constrained to fixed physical conditions during inspection. In this project an inspection fixture has been designed to make the inspection process of port bock #902020322 easy and fast.

When the modified inspection charts were implemented on the production line, operator found it stressful to turn the port block many times as the dimensions in first piece inspection chart were supposed to do it that way. So designing an inspection fixture was necessary to ease the inspection process. This inspection fixture made the operator to turn the port block only once during whole inspection process.

3.2.2 Design Considerations

The inspection fixture was intended to the hold the port block # 2134455 shown in the figure 3.7 below. Design should hold the port block firmly during inspection process.
Also the inspection fixture should provide the room to access all dimensions to be measured. The inspection fixture should be easy to manufacture and should be of low cost. This inspection fixture is mainly intended to avoid turning the port block too many times during the inspection process. Reducing the operation to port block too many times is important as this the main cause for the increase in inspection time and also the port block is heavy. Hence making an inspection fixture helps in reducing the setup time for the port block. Design considerations in designing an inspection fixture are summarized in the table 3.1.

Table 3.1- Design Considerations

<table>
<thead>
<tr>
<th>No</th>
<th>Design Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fixture table should hold a port block of dimensions of 345X250X40.</td>
</tr>
<tr>
<td>2</td>
<td>Should provide access to all the dimensions to be inspected.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3.</td>
<td>Clamps should provide enough force to hold the port block firmly.</td>
</tr>
<tr>
<td>4.</td>
<td>Should not involve more physical work for the operator in turning the port block to inspect dimensions on all sides.</td>
</tr>
<tr>
<td>5.</td>
<td>Design should be cost effective.</td>
</tr>
</tbody>
</table>

3.2.3 Final Design

Inspection fixture to be designed should not be more complex for the operator to perform functions and should not be costly to manufacture. At first the inspection fixture was designed as a fixed table. In this case operator had to reach out to all sides to perform the inspection. So in the later design the part on which port block is placed is designed as a rotating table by incorporating a bearing. This helps the operator to reach out to all parts with moving from his place. These designs are explained in the figures 3.8 and 3.9. As seen from the pictures the bearing facilitates the rotation of work piece easily. This eliminates the need to turn the work piece too many times during inspection and there by saving time. As this design does not have more complex parts and automated parts, it is cost effective. Clamps used in this design are toggle clamps, which are used to hold the work piece firmly during inspection process.
Figure 3.8: Initial Inspection Fixture
This final inspection fixture designed satisfied all the needs to be tested and operated. This design has a bearing, which satisfies the need to change between different faces of the casting easily without much effort. Clamps provide enough force to hold the workpiece firmly so that operator can easily operate the gauges and take the readings. Also the holes drilled on the fixture table facilitate easy reach of gauges, which are important.

3.3 RESULTS

This design has been submitted to the TEF department and is being approved by the manufacturing manager. Manufacturing of this inspection fixture has been assigned to an
outside contractor and will soon go on the line. Testing of this inspection fixture showed the improvement in inspection by nearly 20%. Use of inspection fixture in combination with the modified inspection chart reduced the inspection time by nearly 6 minutes and the inspection time reduced from 33 minutes to 27 minutes when the inspection fixture was tested on the production line.

3.4 PROJECT 3: DESIGN OF HANDLING TOOLS

3.4.1 INTRODUCTION

Handling tool is primarily used to handle the products, which are too heavy to be lifted by an operator. Handling tools are intended to reduce the stress on the operator and make his job easy. Handling tools are designed in the companies as per their convenience and product design. Effort should be put while designing the handling tool to make it cost effective. While designing a handling tool one should be careful in choosing the material and thickness of tool so that it does not fail during operation.

As the Products manufactured at Rexroth, Fountain Inn are related to mobile hydraulics, operators are required to handle heavy castings in production line, assembly line and testing line. This induces lot of stress on operators and also a safety problem. So considering ergonomics and safety factors handling tools were designed to reduce stress on operators.

As castings are very heavy, loading of castings on the fixtures is a stressful job for the operator and consumes more time. Therefore a handling tool was necessary to load the castings onto the fixture to reduce set up time and for reduced stress on the operator. Also
these handling tools are to be designed in such a way that operator should not find it time
taking and complicated to use. Otherwise there is risk of operator not using the handling
tool at all.

3.4.2 ERGONOMICS

Ergonomics is science of work. It deals with the working conditions and positions of the
operator. In this case where operator has to load the casting on to the fixture at an angle,
requires a lot of effort to be put in by the operator as the casting for which the handling
tool is designed is very heavy (80lbs). Position of how the casting should be loaded is
shown in the figure 2.17 below. To design a handling a tool for this operation an FMEA
was performed. The housing # 02503138 to be loaded is also shown in the figure 3.10.
3.4.3 FMEA

A design of handling tool was developed to lift the casting and place it on the fixture. The handling tool should help the operator to load the casting on to the fixture at an angle of 12 degrees to the horizontal. Also the tool should not fail while lifting the casting, as it is very risky if the handling tool fails. But in this design it is needed for the operator to hook the handling tool to casting at an angle. As this was a difficult operation the design was not approved. Initial design is shown below in the figure 3.11. Also the FMEA analysis done can be observed in the appendix –C.
But as this design was not approved later an improvised handling tool was designed in which operator need not lift the casting and hook it to the handling tool at an angle. The new design has a pushpin-type hook system, which fits into the casting. Rotation of the push hook system is limited to an angle at which the casting should be placed on the fixture. This design also eliminates moving parts in the handling tool to prevent any risk if present. This handling tool utilizes the holes present on top and bottom of the casting to provide the grip to the handling tool and to lift it. This design is illustrated in the figure 3.12.
Figure 3.12: Final Handling Tool Design
3.5 STRESS ANALYSIS

Stress analysis has been carried out on the handling tool for a safety factor of 10 and is being approved, as the analysis didn’t show any failures. Stress analysis report is as follows:

Table 3.1: Load and Restraint Information

<table>
<thead>
<tr>
<th>Fixture</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-1 &lt;Handle&gt;</td>
<td>On 3 Face(s) fixed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force-1 &lt;Handle&gt;</td>
<td>On 4 Face(s) apply normal force 500 N using uniform distribution</td>
</tr>
<tr>
<td>Force-2 &lt;Handle&gt;</td>
<td>On 5 Face(s) apply normal force 500 N using uniform distribution</td>
</tr>
</tbody>
</table>

Table 3.2: Study Property

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh Type:</td>
<td>Solid Mesh</td>
</tr>
<tr>
<td>Mesher Used:</td>
<td>Standard mesh</td>
</tr>
<tr>
<td>Automatic Transition:</td>
<td>Off</td>
</tr>
<tr>
<td>Smooth Surface:</td>
<td>On</td>
</tr>
<tr>
<td>Jacobian Check:</td>
<td>4 Points</td>
</tr>
<tr>
<td>Element Size:</td>
<td>12.554 mm</td>
</tr>
<tr>
<td>Tolerance:</td>
<td>0.62767 mm</td>
</tr>
<tr>
<td>Quality:</td>
<td>High</td>
</tr>
<tr>
<td>Number of elements:</td>
<td>8047</td>
</tr>
<tr>
<td>Number of nodes:</td>
<td>13695</td>
</tr>
<tr>
<td>Time to complete mesh (hh; mm; ss):</td>
<td>00:00:03</td>
</tr>
<tr>
<td>Computer name:</td>
<td>FNI28C542</td>
</tr>
</tbody>
</table>
Table 3.3: Solver Information

<table>
<thead>
<tr>
<th>Quality:</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solver Type:</td>
<td>FFEPlus</td>
</tr>
</tbody>
</table>

Figure 3.13: Results - Stress Analysis

Table 3.4: Results - Stress Analysis

<table>
<thead>
<tr>
<th>Material name:</th>
<th>Alloy Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description:</td>
<td></td>
</tr>
<tr>
<td>Material Source:</td>
<td></td>
</tr>
<tr>
<td>Material Model Type:</td>
<td>Linear Elastic Isotropic</td>
</tr>
<tr>
<td>Default Failure Criterion:</td>
<td>Max von Mises Stress</td>
</tr>
</tbody>
</table>

Application Data:

<table>
<thead>
<tr>
<th>Property Name</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>2.1e+011</td>
<td>N/m^2</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.28</td>
<td>NA</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>7.9e+010</td>
<td>N/m^2</td>
</tr>
<tr>
<td>Mass density</td>
<td>7700</td>
<td>Kg/m^3</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>7.2383e+008</td>
<td>N/m^2</td>
</tr>
<tr>
<td>Yield strength</td>
<td>6.2042e+008</td>
<td>N/m^2</td>
</tr>
<tr>
<td>Property</td>
<td>Value</td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>1.3e-005/Kelvin</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>50/W/(m.K)</td>
<td></td>
</tr>
<tr>
<td>Specific heat</td>
<td>460/J/(kg.K)</td>
<td></td>
</tr>
</tbody>
</table>

As the design made was to be manufactured from the components present on the shop floor, the design of the handling tool has thickness more than required. This was intended to remove extra machining costs involved in reducing thickness of the handling tool. Though the factor of safety required was 4.0, design made showed a factor of safety nearly 10.0. Also, my supervisor asked me to test the handling tool for factor of safety 10.0 as he didn’t want to take any risks with the handling tool as its failure may result in serious injuries to the operators and also in financial damage to the casting.

3.6 RESULTS

Stress analysis of the handling tool showed a factor of safety greater than 10 (figure 3.14) and hence this design of handling was approved and manufactured to be tested on the production line. Operators on the production line were satisfied with this handling tool. This also helped in reducing the set up time to a great extent. Initial handling time to lift and place four castings on the fixture was nearly 10 minutes and when the handling tool was implemented it was brought down to 6 minutes. An improvement 40% was seen in time required for handling castings.
3.7 PROJECT 4: DESIGN OF MANUFACTURING FIXTURES FOR PUMP HOUSINGS

3.7.1 INTRODUCTION

Machining fixtures are very much important in modern day world. They are used wherever a high volume production is involved. They are used to reduce set up time considerably in a fast paced manufacturing environment. Fixtures are many types based on the cost and volume of products machined. They can be manual, Semi automatic and fully automatic. Manual clamping fixtures are used where is no requirement of high volume production and automatic fixtures are used where large volumes are produced.

A new machining center, DMU50, has been installed on the production line to increase the production of pump housings. A new fixture has to be designed for this machining center to ease up the clamping and production process. The new fixture to be designed is for following pump house geometries as shown in the figure 3.15.

Figure 3.15: Pump Housings
As seen in the pictures, housings have two different bases and fixture to be designed should accommodate these different types of housings. Fixture should be designed in such a way that its height should not exceed 150mm as it may result in collision with the tool and thereby posing serious threat to the machine as well as the parts. A prototype of the machine worktable is shown in the figure 3.16 below with dimensions. Operations performed on the machining center are milling, drilling, tapping and finishing.

![Machining Center](image)

**Figure 3.16: Machining Center**

Figure 3.16 shows the 3D model of workbench of CNC machining centre for which the machining fixture is to be designed. This model gives us the limitations for height of the machining fixture. As the vertical distance between table and spindle is 550mm and the casting to be machined is 310mm in height, machining fixture to be designed should be no more than 240mm.

**Design Considerations:**

- Chuck should be able to accommodate two housings of hub diameter 127mm and 101.5 mm
• Chuck should operate first and then the clamps should start functioning.

• Provision should be made such that operator can’t load the work piece in the wrong direction.

3.7.2 PRELIMINARY DESIGNS

Many designs were developed initially for the machining fixture. Design 1 (Figure 3.17) was the first design intended for machining fixture. However, this design did not comply all the needs. This design included manual clamps for clamping and used stoppers as locators for the housing. As Manual clamps were used in this design, it would have been a lengthy process for the operator to load and unload the part to be machined. Also there is a possibility of operator loading the part in opposite direction, as there was no proper guiding system to let know the operator in which direction he should load the part.
Figure 3.17: Design 1

Figure 3.18: Design 2
A second design (Figure 3.18) developed for the machining fixture. This fixture design was more automated when compared to the first one, as hydraulic clamps and vice are used. Hydraulic vice is intended to center of the work piece and clamps to clamp the work piece. But even this design did not have the provisions to guide the operator to load the work piece in the correct direction. Also locating the square based housing was not convenient in this design. Also the fixture will become heavy with the inclusion of hydraulic vice.

![Design 3](image)

Figure 3.19: Design 3

A third design (Figure 3.19) developed for the machining fixture. This design is far better compared to first two designs. This design consists of a hydraulic collet instead of vice.
for centering purpose. Also collet acts as a gripping device. This design also consists of a guiding system to assist the operator to load the part in the correct direction. But this design consists of four hydraulic clamps for clamping purpose, which makes the tool slightly inaccessible to the drilling positions on the bottom the housing. Hence this design needed to be improved to facilitate the machining processes.

3.7.3 Final Design
Taking all factors into consideration and performing fixture lay out a final design (Figure 3.20, Figure 3.21) has been developed and is being approved by the manufacturing department. This design accommodates both types of housings. For this purpose a hydraulic chuck with long stroke has been custom ordered from HAINBUCH Corporation. This chuck has a stroke of 30mm. This fixture needs only two clamps to clamp the work piece. Chuck acts as centering device as well as clamping assist. Also there have been provisions made in the design to assist the operator to place the work piece in the correct direction. Also, it prevents operator from placing the work piece in the wrong direction. In this design manufacturing engineering team lead needed the chuck to operate first as it will center the work piece and then clamps to clamp the work piece. For this purpose a directional control valve has been incorporated in the design. This valve in its primary position allows the oil to flow only to the chuck and thus chuck functions first to center the housing. Then the valve is rotated and oil flows to the hydraulic clamps. Now functioning of hydraulic clamps is initiated and used to clamp the work piece. All the hydraulic connections are also shown in the figures below. Green
color indicates the fluid flow to the hydraulic elements and red indicates the flow from hydraulic elements. Final fixture drawing can be observed in the appendix-B

![Figure 3.20: Final Design Perspective View](image)

![Figure 3.21: Final Design](image)

3.7.4 Results

This fixture design has been evaluated for locating positions, tolerances and has been approved by the manufacturing department. Manufacturing of this fixture has been assigned to Master Work Holding an outside vendor and is supposed to go on the line
from January. This fixture intends to reduce the set up time taken while loading the part on to fixture and unloading it by nearly 70%.

3.8 CONCLUSION:

At the beginning of the projects on set up time reduction, set up time was measured to be nearly five hours for port block #902020322. With the implementation of modified inspection charts and inspection fixture inspection time was nearly improved by 50%. Design of handling tool for the pump housing reduced the loading and unloading time by 40%. Also the machining fixture for pump housings intends to reduce the set up time to a considerable extent. Improvement in inspection, handling and fixturing time can be observed in the figure 3.22

![Figure 3.22: Improvement in set up time](image)

Figure 3.22: Improvement in set up time
CHAPTER FOUR
QUALITY IMPROVEMENT

4.1 INTRODUCTION

Quality improvement techniques are very important in manufacturing environment as they lead to customer satisfaction, increased customer base and increased brand value of the company. The most prominent Quality improvement techniques in recent use are Six Sigma, Kaizen, Kanban, Toyota Production System (TPS), FMEA, TPM, Taguchi methods and more. Of these BOSCH implements Six Sigma, Kaizen, FMEA. Also BOSCH developed its own production system popularly known as Bosch Production System (BPS).

4.2 SIX SIGMA

Six Sigma is an organizational initiative used to reduce variability in processes and to increase customer satisfaction, loyalty and commitment [19, 20]. It provides an opportunity to improve the efficiency of processes and reduce the defects. Organizations which practice Six Sigma should produce no more than 3.4 defective parts per million [19]. The main goal of using Six Sigma in an organization is to achieve customer satisfaction with improvement in quality [19, 20]. This approach helps to reduce the variation in the outputs, which are critical to customer or for customer satisfaction. [19]

The method employed in Six Sigma to achieve high quality standards is called the DMAIC (Define Measure Analyze Improve Control) method [19]. The Define phase is
used to analyze the relationships between the suppliers-inputs-process-outputs-customers [19]. This phase identifies the issues or concerns important to the customers, which are called critical to quality variables [19]. The Measure phase is used to develop operational definitions for each critical to quality variables. Gauge repeatability and reproducibility is studied for each critical to quality variable [19]. This phase also determines the key measures for the suppliers, inputs and processes. The Analysis phase is used to find out the issues or problems, which influence the critical to quality variables and the root cause for these issues, are found out [20]. The Improve phase is used to solve the issues identified in the analysis phase and actions are performed to achieve the desired performance [20]. The Control phase is used to locking in the improvements by standardizing and documenting [19].

Six Sigma contains both technical and management components. The technical component focuses on defect reduction and reduction in variability whereas management component focuses on setting goals, choosing projects and assigning work to the people [20].

Initially Six Sigma was applied only to manufacturing processes. Later on the versatility of the Six Sigma is identified and today it is used in various fields such as marketing, purchasing and many more [21].
4.3 KAIZEN

Kaizen is one of the important Lean tools. Kaizen in Japanese means “continuous improvement.” When it is applied to manufacturing it becomes Continuous improvement Manufacturing (CIM). Implementation of Kaizen essentially needs active participation from the associates of the company. Kaizen mainly emphasizes eliminating seven wastes, as defined by Imai, M. (1986), which are: Transportation, Inventory, Operations, Waiting, Over processing, Overproduction, Defects.

- **Over Production**. Producing unnecessary products when they are not required.
- **Inventory**. Material stored as raw material, finished products increase the costs of handling and maintenance.
- **Transportation**. Material Handling
- **Defects**. Defects in product that increases rework costs and stop productivity.
- **Processes**. Tasks accepted as necessary
- **Operations**. All Non value adding operations
- **Waiting**. Machine idle time [13,14]
By eliminating all the above-mentioned wastes gradually we can bring continuous improvement into the company. Concept of Kaizen can be understood from the figure 4.2 below.

4.3.1 Kaizen Implementation at BOSCH

Kaizen implementation at BOSCH can be understood below from the figure 4.3. This board indicates the initial situation in the work area. This board possesses blank cards, which are accessible, each and every associate at BOSCH. Lay out of a blank card is shown in the figure 4.3. If an associate notices a scope for improvement in his work area he can fill out the blank card placed in his designated work area with his idea for improvement. At the end of every week, all the filled out cards are submitted to the
managers of respective departments. Manager of respective departments analyzes the ideas given by associates for improvement on the production floor. After rigorous thinking and discussing it with associates, manager gives his nod to implement the idea on the shop floor. This is how the kaizen process works for continuous improvement at BOSCH. However kaizen cannot be applied to each and every situation. Kaizen process does not work where there is a need for immediate change. But used effectively, Kaizen can be very useful for improvement of the process. This process led to the design of shaft alignment tool on the assembly line. As many of the operators reported the problems faced in aligning the shaft in pump housings through kaizen process at BOSCH, an initiation was taken to design a shaft alignment tool. Many inputs were given by the associates in designing the shaft alignment tool. First the shaft alignment tool was designed with a rack and pinion system, which was manual. Later the idea of incorporating an acme screw instead of rack and pinion system was given by an associate and it proved to be very helpful in designing the rack and pinion system. Thus Kaizen system proved to be very helpful in designing the shaft alignment system for the assembly line. Lay out of Kaizen board and its implementation is shown in the figure 4.3. Also the lay out of blank card, which is used in kaizen process, is shown in the figure 4.4
Figure 4.3: Kaizen system at BOSCH Group
Figure 4.4 Layout of Blank Card

Figure 4.3 and 4.4 explain us the implementation of kaizen system at the plant. Figure 4.3 shows us the layout of the board on which continuous improvement cards are placed. Each department and production area has their respective slots on which the cards are placed. Every associate has access to these cards. They can write down their ideas on the cards to improve the process and place them in the slots provided for their respective departments. These ideas are discussed in the meetings of their departments and if they find them good enough to implement on the production line, they will be implemented. Figure 4.4 shows the layout of card, which can be filled by the associate. This card has...
enough space to write down their ideas and also have a provision to mark the area for which the improvement is intended.

4.4 BOSCH PRODUCTION SYSTEM

BPS is a unique production system implemented by BOSCH Group in all its locations over the world in 150 countries. There are eight components of BPS, which are shown in the figure 4.5 below.

Figure 4.5: BOSCH Production System
*Process Orientation* mainly concentrates on activities, which create value to the customer. Process orientation mainly focuses on activities irrespective of departments to achieve its aim, to create value to the customer.

*Pull System* works on customer’s demand. This process basically co-ordinates different processes in different departments so that the part produced by a department is in line and required by another department to complete the finished product. Kanban and JIT strategies are part of pull system.

*Perfect quality* strives to maintain quality in the products produced by all the departments using lean and six sigma tools.

*Flexibility* in the process is the ease to change the product line rapidly and easily. It simply means the flexibility to switch between different products easily.

*Standardization* is improving and continuing the processes developed to achieve perfect quality. This involves training all the associates for the new process changes and implementing them.

*Transparent Process* makes the process easily accessible to all the associates. Associates can clearly see and understand the changes in the process.

*Waste elimination and CIP* implies the efforts taken to eliminate the seven wastes described by BOSCH Production System (BPS) (Figure 7.6) to achieve continuous improvement in the process.

*Associate involvement and Empowerment* is basically the kaizen process, which involves all of its associates to make successful changes to the process and improve the process.
BPS mainly emphasizes on reduction of wastes and perfect quality. There are seven forms of waste as per BOSCH Production System as depicted in the figure 4.6. Waste is defined as anything customer does not see as value added activity.

The figure above illustrates the seven forms of waste of resources such as material, time and labor. Overproduction leads to supply exceeding the demand, thereby reducing the value of the part. Also the cost of procuring material, processing, inventory and labor charges increase for parts that are not currently needed. Correction and rework on manufactured parts causes wastage of parts and increase in processing cost. Packaging and shipping of parts directly influence the transportation cost. Inventory is a place for storing the finished goods. Storing manufactured parts for long periods of time highly
affects the inventory costs. Over processing on a part leads to unnecessary costs on part and also increases the time to manufacture a part. The workstations must be optimally placed so that the time taken to move one part from place to another will be reduced. This also reduces the transportation cost incurred within the plant. The plant layout and processing of jobs must be well planned so that there is least waiting time. It is advisable to manufacture the part in the least time as it lowers all the labor charges, wages associated with it.
CHAPTER FIVE
PROJECTS ON QUALITY IMPROVEMENT

5.1 PROJECT 1: SHAFT ALIGNMENT TOOL

Bosch Rexroth manufactures Hydraulic pumps for wide variety of customers like Caterpillar, John Deere, Bobcat, Reineer and more. Manufacturing Unit at Fountain Inn has individual assembly lines dedicated to each of their customers. Recently the company management received complaints from one of its customers regarding shaft alignment, which is leading to pump failure. This issue provided the need to develop a shaft alignment tool, which makes the process error free.

5.1.1 Previous method

Previously operators used to install the shaft manually i.e., by inserting the shaft with hand and hitting it with hammer. This method resulted in pump failures. Almost 20% of the pump failures were due to improperly aligned shafts. Thus a project on developing a shaft alignment tool started.

5.1.2 Preliminary Design

Shaft alignment system should consist of the following

- An automatic guiding system which inserts shaft into the housing.
- A device to hold the shaft firmly during installation.
- System should be fully automatic so that operator need not do any physical work for the installation of the shaft
Initial design for the shaft alignment system consisted of the following elements.

- Rack and Pinion System for lowering of shaft into the housing.
- Pneumatic gripper to grip the shaft on air supply and release on cut off of air supply.
- Spring pin to ensure proper alignment of housing.

The initial design is depicted in the figure 5.1

Figure 5.1: Initial Design of Shaft Alignment System
But this system of rack and pinion is operated manually and the customer did not want this shaft alignment system to be manual. Hence an improvised system is designed and installed on the assembly line.

5.1.3 Final Design

As the preliminary design is not satisfying to the customer, a new design was developed as per the customer’s requirement. These requirements are stated below:

- Shaft alignment system should be automatic
- Shaft alignment should be guided and should not provide any scope for misalignment
- System should not be complicate and should be easy for operator to operate.
- Shaft should be installed in a rotary motion as this method eliminates any damage to the shaft while installation.

To accommodate the above-mentioned requirements following changes has been made:

- Acme screw has been introduced into the design instead of rack and pinion system to facilitate the rotation of shaft while alignment process.
- Bushings are provided to guide the acme screw to eliminate any chance of misalignment.
- Acme screw is operated by an electric motor, which makes the operation automatic.
- Pneumatic gripper is not replaced, as its purpose is only to hold the shaft.
This design can be observed in the figure 5.2 below.

Figure 5.2: Final Design of Shaft Alignment System
5.2 RESULTS

After the shaft alignment tool has been installed on the assembly line, pump failures due to alignment problem has gone down to 0% i.e., no pump failures due to misalignment of shaft has been reported. This saved the cost in reworking the pumps. Initially out of 1000 pumps produced 23 pumps were reported with shaft alignment problems and costs incurred in reworking those pumps are estimated to be $570 per pump. This made the total rework costs $13110 previously. Now this cost has been brought down to a null amount.

5.3 PROJECT 2: TURRET CHANGE CART

Areas of application and the need for the turret change cart are described below. 500’s are Deckel Maho’s 500 series CNC machining centers and 300’s are 300 series machining centers.

Areas of Application:

- 500’s: Yes, due to placement of workbench – 10’ to workbench
- T/C’s: closer proximity of workbenches, lower priority – ~ 8’ to workbench
- 300’s: closer proximity of workbenches, lowest priority – ~ 5-8’ to workbench

5 Whys: (Justification for 500’s)

- Why do we need a turret change cart?
  - Because operators walk a lot during turret changing for tools and inserts.
    - This cart would bring tools and needed components right to the machine.
- Why do the operators walk a lot during current turret changing activities?
Because the workbenches are set 10 feet from the turret and all supplies are in the workbench.

- Why are the workbenches 10 feet from turret?
  - They were placed at the end of the machine, which is 10 feet from the turret.

- Why is the workbenches set-up at the end of the machine?
  - To facilitate movement within the cell, between controllers and unload stations.
  - To facilitate deburr/gage/unload work process.
  - To permit enough space for major maintenance on critical components.

5.3.1 General Functionality

- Assist in Turret Change (500)
- Temporary workspace as needed
- Scrap part movement (several pieces 3 or 4)
- Assist in Machine Set-up (500, & 300) (amount of equipment will hinder mobility)
- Assist in Magazine changes (totally multi-functional? w/ machine tool block, etc.)

*Recommendation:* Consider mainly Turret change with temporary workspace (and ability to move a few items via cart if necessary).
5.3.2 Design Considerations

General Design Requirements:

- Easy access to all items by operator
- Simple, portable, durable and ergonomic design
- Labeling system for all compartments / items (easily visible if items missing)
- Some adaptability if work methods changes such that cart could adapt (flexibility)

Recommendation: Consider “raise”-able, locking, stacking, design or traditional cart design

Cart Should Hold:

- New insert packages (~ 12 slots labeled by TDM # and Drawer # on divider to know if something is missing)
- Container for used inserts
- Container of extra screws
- Torque wrenches of each size (in foam cutouts to know if something is missing)
- Metric Allen wrenches
- Collet wrenches
- Have a space for appropriate gages
- Hold a rag (& maybe several extras)
- Have a temporary work space
- WD40 and contact cleaner
• Additional items: Other tools to set-up changes: hammer, socket wrenches, etc.

*Feedback from 500’s Operator:* Cart could be for turret changes, set-up and magazine changes. Thus, would need space for machine tool block, additional inserts and tools for magazine changes.

*Feedback from 300’s Operator:* Turret change cart not that helpful as SOME workbenches are close enough that a cart just for turret changes is not considered necessary. However, a setup cart is what is desired (which could also hold additional machine tools). However, inserts could be located on the cart if desired as well.

5.3.3 Potential Cart Design

![Diagram of a cart]

- **Temporary work space when lid down; keeps tools “clean”**: Lid is spring-loaded to keep itself up
- **Gage space**
- **Additional Storage:**
  - Other tools
  - Extra rags
  - Cleaners (WD40, contact cleaner)
  - Dykem

Inserts: labeled on dividers tabs by TDM # and Drawer #

~10 number of insert positions and 2 spaces for used insert collection, box of extra screws

Figure 5.1: “Traditional” Cart Depiction
5.4 CONCLUSION

Quality improvement techniques like Six Sigma, Kaizen, 5S, Poka Yoke implementation are discussed in this chapter. Also BOSCH Production System is also discussed in the chapter. Projects on quality improvement are also discussed in the chapter. It is observed that by the installation of shaft alignment tool on the assembly line saved a rework cost of nearly $13000. The project on turret change chart is aimed to standardize the production process and the aim is achieved through the turret change cart.
CHAPTER SIX
CONCLUSION

6.1 CONTRIBUTION

Detailed cycle times of different manufacturing processes were recorded, analyzed and suggestions were made to reduce set up time. Quality related issues were solved on the assembly line as per the customer’s quality requirements. Different set up time reduction techniques like SMED, 5S, FMEA is discussed and also provided with case examples. Need for set up time reduction and quality improvement is emphasized.

In this work tools and techniques, which help in reducing set up time, are discussed with case examples. Also the stages in developing a final procedure for a process are discussed with the help of PFMEA. Stress analysis is carried out on the designs to test the robustness of the design. These designs were approved by the Technical functions (TEF) department and were ordered to be installed on the shop floor. Some of the measures and designs are already implemented and have seen successful outcomes.

Modification of inspection charts for port block#902020322 succeeded in reducing inspection time by nearly 50% and the inspection fixture reduced the first piece inspection time by 20% more. Design of handling tool for pump housings succeeded in reducing stress on the operator and also in loading and unloading time by 40%. Design of
machining fixture has been approved and is intended to decrease set up time on DMU50 by a great extent. Also the quality improvement project, Shaft alignment tool succeeded in eliminating the rework costs due to alignment problems, thereby saving nearly $13000/month to the company. Turret change cart method is aimed to standardize the process on the shop floor and it succeeded in achieving its goal.

![Improvements in set up time](image)

**Figure 6.1: Improvements in set up time**

Also the tools and techniques used in this report can be used in any manufacturing environment to reduce the set up time and also for quality improvement. As the FMEA's discussed in this report can be used elsewhere to develop tools or to improve processes to reduce set up time. FMEA’s are the basic tools which helps us in detecting failure modes while designing a tool that can reduce set up time or if we intend to improve the process by making changes to the existing one. FMEA’s are used in this report to develop handling tool, shaft alignment tool, machining fixture and also to make changes in the first piece inspection chart to reduce the setup time. These methods can be replicated in
any manufacturing environment to develop the tools as per the products they manufacture. Also the SMED charts used can be replicated and used anywhere else in manufacturing environments. They help in collecting data about cycle times, help identify internal and external elements and also helps us in analysing cycle times. These SMED charts are very helpful in locating the prime internal elements and help us to convert them to external elements. Also the Kaizen technique mentioned in this report helps us to collect ideas from different associates and analyse them to improve set up times. This is also a tool which can be easily replicated in any other manufacturing environment. And also techniques like 5S, Kanban, Six Sigma can be used easily in any manufacturing environment. The DFM principles used in designing different tools to reduce set up time and quality improvement are helpful in designing any product and helps us to reduce most intricate shapes and manufacturing cost.

6.2 LESSONS LEARNED AND FUTURE WORK

During course of my internship I have learnt about different manufacturing techniques, Set up time reduction tools and techniques and Quality tools. Also I gained knowledge in operating Deckel MAHO CNC machining centers and their programming. Most important thing I learned from my manager during this internship is "Measure twice and cut once", which means you have to carefully study the design, process and take into consideration the requirements for the change before actually implementing the idea.
I have been offered a full time position as Manufacturing and process Engineer at BOSCH and I look forward to complete the projects assigned to me related to manufacturing and process control with success.
APPENDICES

Appendix A

Handling Tool Drawings

Figure A-1: Handle
Figure A-2: Holder1

Figure A-3: Holder2
Figure A-4: Final assembly of Handling tool

- Handle
- Weld between Pin and Holder 1
- Pin
- Holder 1
- Holder 2
- Handle with knob
Appendix B

Machining Fixture

Figure B-1: Machining Fixture Final Assembly
## Figure C-1: Modification of first piece inspection sheet

<table>
<thead>
<tr>
<th>Step</th>
<th>N</th>
<th>P</th>
<th>E</th>
<th>C</th>
<th>O</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Begin inspection process.</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inspect the product.</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Record inspection results.</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Continue inspection process.</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inspect the product.</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Record inspection results.</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Continue inspection process.</td>
</tr>
</tbody>
</table>

**Notes:**
- N: Number of inspections required.
- P: Probability of occurrence.
- E: Severity of effect.
- C: Criticality.
- O: Occurrence.
- Action: Actions to be taken if the inspection fails.

**Failure modes and effects analysis (FMEA):**

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Effect</th>
<th>Severity</th>
<th>Occurrence</th>
<th>Prevention</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Prepared by:**

**Reviewed by:**
Figure C-2: Handling tool
<table>
<thead>
<tr>
<th>N</th>
<th>Step</th>
<th>Process Failure Mode</th>
<th>Potential failure modes</th>
<th>Potential causes</th>
<th>Current process controls</th>
<th>Potential causes of failure</th>
<th>Current process controls</th>
<th>Percent failure of controls</th>
<th>Secondary failure modes</th>
<th>Percent failure of controls</th>
<th>Percentage of controls</th>
<th>Process failure mode</th>
<th>Percent failure of controls</th>
<th>Percent failure of controls</th>
<th>Percent failure of controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Design of Handling Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Product Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manufacturing Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operator Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design of Handling Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Product Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manufacturing Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operator Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design of Handling Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Product Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manufacturing Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operator Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design of Handling Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Product Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manufacturing Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operator Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design of Handling Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Product Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manufacturing Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operator Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programming Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
- N: Risk priority number is order to rank controls: Calculated by risk x severity x chance x effect
- DET: How much delay is expected to occur
- OCC: How much cost is accumulated to occur
- SEE: How much energy is spent in occurrence

Design of Handling Tool
REFERENCES


