ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Program of Mechanical Design and Manufacturing Engineering

Process capability analysis of sand casting of flange roller (A case study of Akaki basic metals industry)

A Thesis submitted in partial fulfillment of the

Requirements for the award of the degree of

Master of Science

In

Manufacturing Engineering

By

Yared Zewde Gebre

Advisor: J. Bhaskaran (PhD)

Co-Advisor: Guteta Kabeta (PhD)

September, 2018

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Approved by Board of Examines

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Candidate Declarations

I hereby declare that the work presented in this thesis entitled **“Process capability analysis of sand casting of flange roller” (A case study of Akaki basic metals industry)** in partial fulfillment of the requirements for the award of the degree of Masters of Science in Manufacturing Engineering is an authentic record of my own work carried out from **November 2017 to September 2018** under the supervision of **Dr. J. Bhaskaran** and **Dr. Guteta Kabeta,** Mechanical Design and Manufacturing Engineering Program, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Yared Zewde Gebre	________________	____________
Candidate	Signature	Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with our approval:

Dr. J. Bhaskaran	________________	____________
Advisor	Signature	Date
Dr. Guteta Kabeta	________________	____________
Co- Advisor	Signature	Date

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ABSTRACT

Process capability analysis is a technique used to identify the natural variability of the process and to check how much product is falling beyond the specifications. Akaki basic metals industry had a wide spectrum of products delivered to the customer on demand. They have variety of manufacturing process to suit the requirements for finished products but still have some issues related to quality and problem related to process in-capability in machines and methods. There is also a rejection due to poor quality, dimensional variation and geometrical tolerance of the products. The purpose of this study is to investigate the root causes of dimensional variation of the products and to improve quality by suggesting directions for improvement. The case study research was based up on the primary data collected from ABMI sand casting process. To perform capability analysis, the collected data has been checked for normality and the process has to exhibit control. For 20 subgroup of sample size 5 statistical software Minitab 17 was used to prepare control chart, frequency histogram and probability plot and for calculation of the potential and overall capability indices. The analysis indicates that though the process is centered, the process is not capable to manufacture flange roller with the customer specification limits since the values of capability indices are less than the desired value 1.33. During brainstorming session the root causes of dimensional variation are identified from method, materials, machine and man power and the Ishikawa diagram was created and corrective action has been provided for the improvement of the process.

Keywords: ***Process capability indices, specification limit, sand casting process, Statistical Process Control, Ishikawa diagram.***

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LIST OF SYMBOLS

Cp	capability index
Cpk	centering capability index
Pp	Process Performance
Ppk	Process Performance Index
σ	Process standard deviation
μ	Process mean

LIST OF ABBREVIATIONS

USL	Upper specification limit
LSL	Lower specification limit
PCI	process capability indices
QCT	Quality control tools
PPM	Parts per million
SPC	statistical process control
TQM	total quality management
CTQ	Critical to quality
ABMI	Akaki basic metals industry

CHAPTER 1: INTRODUCTION

1.1 Introduction

Manufacturing industries now a days working towards fulfilling customer requirements and increasing profit without compromising quality with minimum rejection of products. Therefore process capability study using quality control tools and the most commonly used potential and overall process capability indices Cp, Cpk, Cpm, Pp, and Ppk, had a great importance (Abhijeet B. Vante, 2015). The relationship between the actual process performance and the specified specification limits has been conducted to continuously improve process quality and productivity. It is known that the process capability indices indicates the future performance of the products and shows optimum manufacturing process and parameters combination, that many customers ask their suppliers to record the capability indices of the products (Alexis Aitken, 2010). Process capability analysis is applied to identify critical processes which are affecting the output of the foundry and help to establish a plan to manufacture products as desired specification, either by indicating directions for improvement of the process or by investigating other alternatives, whichever provides the most effective solution to the problems faced by the industry (Alexis Aitken, 2010). The purpose of a process capability study is to identify the root causes and the sources of variability, and in an effort to eliminate the cause (Adeoye Akeem, 2013). There is an increasing complexity in manufacturing industry which needs careful understanding and investigation of industrial process. Performing process capability analysis using SPC tools and Minitab software plays important role in minimizing poor quality and variability which can cause rework and rejection. The basic quality control tools such as frequency histogram, control charts, probability plots and cause and effect diagrams are used to support decision making, since statistical tools allow measurement and evaluation of the performance in a process to improve its quality (Ajit Pal Singh, 2013).

Sand cast products produced by a foundry are acceptable if their quality level and dimensional accuracy required by the customer is satisfactory. Otherwise, the casting is termed as undesired; each casting rejected contributes to the wastage and loss of value to the foundry. Therefore a sound casting involves high quality and good dimensional accuracy with perspective of customer expectation consisting of systematic blend of experience and engineering basics. Sand casting is not a precision process, and requires secondary machining processes and surface finishing processes to achieve the desired dimensions and surface quality. However, advanced sand casting process, with improved sand quality, mold rigidity, appropriate machine set up, engaging active man power, using recommended materials helps the process to produce high precision cast products with good dimensional accuracy and better surface finish that reduces the cost for post machining. This helps the process capability of sand casting to produce 'near net shape' products and improve its competitiveness. The thesis aims to reduce dimensional variability of final products and analyze a way of manufacturing products within specification limits using process capability analysis tools and Minitab software on sand casting process. Process capability analysis evaluates the process and manufactured products how well they fit specification, it is engineering management that it needs good engineering judgment to interpret and analyze the result. The results of process capability analysis could be used for new design inspection planning and evaluation technique (Belokar, 2012).

Process capability analysis which can be applied in initial design, manufacturing and manufacturing planning is used to identify the natural variability of the process and to check how much product is falling beyond the specifications (Bralla, 1999). In order to improve the manufacturing process and to reduce defects in Akaki basic metals industry (ABMI) process capability analysis is done by collecting relevant data, preparing valuable methodology and applying careful analysis. The critical to quality characteristics selected for the case study research are inner diameter, outer diameter, flange diameter and height of the product. The quality control tool X bar-R chart, frequency histogram, and probability plot are created using Minitab 17 to check whether the process is in statistical control and the distribution of the process considered is normal. The capability report is generated and also the cause and effect diagram and action plan suggestion is prepared for improvement of the manufacturing process. Data used in the case study is analyzed statistically using appropriate tools, techniques and software.

1.2 Problem statement

The intention of many manufacturing industries is to improve their output and productivity to achieve their target profit. But to achieve this, industry must manufacture products by eliminating variability and improving quality to attract customers. Many manufacturing industries are producing products taking orders from their customers by their specifications. But, during the industrial training it was observed that some products at ABMI are manufactured out of their tolerance limits. Even though there is no rejection percentage of the product from past data due to lack of proper data handling and process analysis technique in the foundry, the industry believed that there is increased rejection which causes rework and wastage in flange roller manufacturing process. The rejection is due to poor quality, dimensional accuracy and geometrical tolerance of the products and it is the interest of the industry to carry out the research on flange roller. Therefore, increased dimensional error and lack of proper investigation and analysis of the products is the problem associated with existing technique of ABMI. The industry quality experts are much worried and interested to have a research based solution for the mentioned problem. This motivated the researcher to carry out a case study at ABMI.

1.3 Objectives

1.3.1 Main objective of the research

The main objective of this study is to investigate the root causes of dimensional variation of the products and improving quality by suggesting directions for improvement.

1.3.2 Specific objectives of the research

- To develop a technique for process capability analysis of sand casting and predict the process for manufacturing products as per specification.
- To determine whether the existing process meets the specified specifications.
- To check the quality evaluation system of the industry by calculating the potential and overall process capability indices of the product.
- To minimize rework of the products by minimizing undesired castings rejected as scrap.

1.4 Scope of the study

The casting process in the industry can be various types. This thesis however, focuses on only sand casting process; furthermore, the causes of problems are identified from sand casting process, blast furnace and grinding process, thus no other secondary machining process is included. It is experimental work in the process industry as a case study research. The case study results provided the insights about the casting process in terms of process variation and target deviation with in the specification interval of the process.

The potential and overall capability indices are a statistical way of describing how well a product is manufactured compared to defined target values and specification limits. In this thesis process capability analysis was performed and the capability indices are calculated and presented with a brief analysis using Minitab 17.

1.5 limitations of the study

Many of the workers were busy with their own routine; it was difficult to find time to discuss with the functional managers and the brainstorming team. Moreover the capability analysis should be studied using continuous data, but it was difficult to collect data because furnace stops suddenly and that makes the researcher to collect data again.

1.6 Significance of the Study

Process capability analysis was performed on sand casting process; where there is no much research was done on foundry using quality control tools and Minitab software. Minitab 17 was not only used to create charts and diagrams but also to calculate capability indices instead of hand calculation. The process capability study in this thesis suggested the way to manufacture products within specification limits, minimizing variability and wastage during manufacturing process. Industrial experiment is costly that needs lengthy experiments and the data can be used to extend the research for other research which needs the same kinds of data. More ever the causes of the poor quality and variability in a case study industry is identified during brainstorming session and the corrective action was provided for the sand casting process by eliminating common causes of variation.

1.7 Thesis structure

This case study thesis is organized in six chapters and the outline is described as follows.

Chapter 1 entitled as "Introduction" gives a brief introduction, problem statement, objectives, the scope and significance of the present work briefly.

Chapter 2 entitled as "Literature Review" mainly presents literatures supporting this thesis including an overview of the research work done on the process capability analysis, quality control tools, the process capability indices.

Chapter 3 is entitled as "Methodology". In this chapter research strategy has been discussed briefly. The chapter also discusses the company visited, software used for analysis, sources of data and data collection, measuring instruments, sampling technique

Chapter 4 entitled as "Case Study" the case study on this thesis includes process and product description, identifying critical to quality characteristics and the description of foundry process.

Chapter 5 entitled as "Results and discussion" data validation using statistical software Minitab 17. The chapter also includes discussion and interpretation of results.

Chapter 6 entitled as "conclusion and recommendation" the chapter includes conclusion, recommendation and scope of future research is discussed briefly.

CHAPTER 2: LITERATURE REVIEW

2.1 Previous research works regarding statistical process control

A considerable research work in the area of process control and improvement through variation minimization has been carried out. A brief Review of some selected references on this topic is presented here.

(Abhijeet B. Vante, 2015) Discussed the research carried out in the foundry to control the increased rejection. The dimensional variations in casting wall thickness are analyzed as major defect contributing in rejection. Quality control tools such as Pareto analysis, cause and effect diagram, why-why analysis, are used for analysis of casting defects. Remedies to minimize the rejection are suggested and implemented. Various chaplets are tried and tested as remedies. The previously used 3 disc round chaplet is replaced by rectangular v-make chaplet. Pouring temperatures and chaplet size are optimized to lower the rejection percentage. Rejection percentage for dimensional variation at water jacket is decreased from 7 to 2.13. Reduced rejection indicates better control resulting in quality improvement of 3 cylinder metric block.

Adeoye Akeem.O (2013) investigate whether the specification limit of the company is properly centred and examined the process capability to state if the process is capable or not. To study the process capability analysis the parameter chosen is weight of the drug in gram manufactured in five different machines, from the analysis it is concluded that, there is difference in the weight of drug produced due to variation in machine. The process capability indices calculated also indicates that the process is not capable and off centered. The paper is good in calculating capability indices, but it accounts only one parameter weight to study the manufacturing process. No root causes analysis, corrective suggestion and analysis made on this paper.

Dr Bharat Chede (2016) presents an approach for successful implementation of SPC using cause and effect diagram, control charts and. For 20 subgroup of sample size 5, data was collected at various stage of manufacturing process for diameter of shaft. Analysis has been done using X-bar R-chart, cause and effect diagram and capability indices. As mentioned the process is not capable to manufacture shaft as per specification. Analysis of the process and fishbone diagram revealed that root cause as incorrect setting of mean dimension. By setting the mean and incorporating suitable changes the process was made capable of producing the part as per desired specification.

Dr. Kabaday(2015) studied the performance of medical bottles manufacturing process using different capability indices, there is specification limit of diameter, weight and thickness but the experiment is done only for diameter of bottle. Every hour a random sample of 5 bottles taken and measurement is done for diameter three times a day. For 20 subgroup of sample size five Xbar R-chart, histogram, probability plot and Minitab software used for the analysis. Based on the calculated indices the process is capable, but no ways are established for continuous monitoring and corrective suggestion made in the analysis on this paper.

(Rangel Peraza, 2014) investigated the way to reduce the variability of the canned tomato paste filling process from processing food industry that has problems with the net weight of their product. Process capability analysis is performed and the results indicates that 35.52% of the observations were out of the specifications during the months in study, which generates a real capability of the process (Cpk) of 0.124, and it indicates that the process does not have enough ability to fulfill the required specifications by the firm. The potential causes of the can excess fillings are identified and the statistical analysis demonstrated that filling velocity and process temperature are the most important variation causes in the tomato paste filling process.

Yerriswamy Wooluru(2014) investigated on way of reducing rejection, scrap and rework of gear performing process capability analysis for 20 subgroup of sample size of 5. To validate the critical assumptions Xbar R-chart, histogram and normal probability plot developed using Minitab software. Also run chart constructed for checking assumption of randomness and interpreted but due to the shift of process mean there is rejection encountered. Finally process capability evaluated by shifting process mean to specification mean by collecting data again. Hypothesis is done for all indices and the process become capable of meeting specification limits. But there is no identified optimum machining process and there is no suggestion for improvement for future.

Sileshi Kitata Edossa(2016) conducted research work to reduce defect rate of final products at ammunition cartridge. For 3 months in the factory Pareto chart constructed to identify common defects and since ET-tools and height out of standard contribute much percentage (%) of overall defects they are selected for the case study and cause and effect diagram constructed for the defects. By calculating control limits such as action limits and warning limits and constructing P-chart it is been found the process is not in statistical control and not capable hence root cause identified and eliminated from the process. After removing root causes control chart developed analysis made again percentage defective capability percent calculated improved. The journal is good in combining and constructing capability process but there is no software used for the analysis calculation of performance and overall capability indices.

S.C. Mondal(2010) invastigated the input materials composition and hardness for casting of worm wheel performance capability anlysis. The process capability indices developed and interpreted well in the analysis of centrifugal casting process as a case study data collected for manufacturing of worm rim quality characteristic along with specification limits and process parameters identified in the study. Amongst the quality variables, hardness is the key variable which to a larger extent determines the performance of the worm wheel in industry uses. But the analysis had done only for input materials composition and hardness. Process capability indices not calculated for products and no software used for analysis. No root causes analysis, corrective suggestion for improvement made on this paper.

More research was targeted in implementation of statistical process control in manufacturing industries other than sand casting process for process improvement, but less work has been reported in capability analysis of foundry process with variable data for minimization of dimensional variability. Some papers are more focused on calculating of process capability indices and checking whether the process is capable or not, the potential causes of defects are not investigated. Therefore the research on process capability analysis of multistage manufacturing process including blast furnace, sand casting process and grinding process using qulity control tools such as: frequency histogram, control charts, probability plots, Ishikawa diagram and Minitab software provided insightful results.

2.2 A history of capability study

The first real attempt to master variation in a scientific way and the control chart often referred to as a Shewhart control chart was proposed by (Shewhart, 1939) in the early 1920's. He presented both a strategy for how to deal with variations, as well as a tool to use in the improvement process. (Shewhart, 1939) Looked at variability as being either within limits set by chance (normal deviation), or outside those limits. This gave the strategy to identify all assignable causes of variation and then eliminating them and gives the possibility to predict the behavior of the process within the near future. The control charts are based on a combination of probability and practical experience. (J.M.Juran, 1999) Presented the first capability index in 1974. He had identified a need in industry to be able to compare the actual process deviation to defined specification limits on products.

2.3 Importance of knowing the capability of the process

Process capability measurements allow us to summarize process capability in terms of meaningful percentages and metrics. To predict the extent to which the process will be able to hold tolerance or customer requirements. Based on the law of probability, you can compute how often the process will meet the specification or the expectation of your customer. (K.Rezai, 2009) Believe that bringing the process under statistical control requires fundamental changes even redesigning and implementing a new process that eliminates the sources of variability now at work. It helps you choose from among competing processes, the most appropriate one for meeting customers' expectation. Knowing the capability of your processes, you can specify better the quality performance requirements for new machines, parts and processes.

2.4 Parameters for successful implementation of SPC

(Gajendra Patidar, 2015) Described ingredients for successful implementation of SPC tools in the manufacturing industries. In order to effectively apply SPC in any organization, it is fundamental to understand the essential ingredients that will make the application of SPC successful. These ingredients are:

Management Issues: total management support and commitment, necessary resources for training and education and follow up of training from time to time, actions on the system or processes whenever needed.

Engineering Skills: understanding the key benefits from the introduction and application of SPC, stability, capability, process prioritization, understanding what key characteristics or process parameters to measure and how to measure them, etc.

Statistical Skills: statistical stability, calculation of control limits, interpretation of control limits, selection of control charts, determination of sample size & subgroup size etc.

Teamwork Skills: companywide understanding of SPC and its benefits, cooperation from all levels of the organization, brainstorm what needs to measure in a process and so on. SPC implementation includes: a well-structured and documented SPC plan; a comprehensive SPC training program for engineers, managers, and production employees; a team approach; and senior management involvement and reviews.

2.5 Process Capability Indices

Process capability indices (PCIs) are developed to measure the process capability numerically. It is a quantitative measure that compares the behavior of process to the specifications. (Sambrani, 2016) Calculated process potential and process performance indices a suitable tool to manage the manufacturing process and improve the quality of products and suggested the way to improve quality. When there is a need to understand the ability of a process to produce products as per manufacturer specification and perform against customer's demands, process capability analysis using process capability indices is best choice. Because the process capability indices such as: Cp, Cpk (Cpl, Cpu), Cpm, Pp, Ppk, Ppl and Ppu give exact numerical result about the process and product. (Metin Uçurum, 2016) Studied construction of a system design to observe whether the conditions of an alloy production line are within the specification and control limits by calculating the capability indices. This indicated that applying capability indices on a foundry floor in order to control the process parameters and improve quality of the cast products plays a vital role. Process Capability analysis was initially has done by plotting process data, and the basic quality control tools such as histograms, control charts or probability plots etc. and comparing these visually with the upper and lower specification limits, but know process capability indices are calculated using Minitab 17 and the values tells us whether the process capable or not. If the process capability indices are outside the specified limits, there is a high risk of producing poor products with dimensional error and wastage of products as a scrap (Dr. Kabaday Nihan, 2015). Sometimes customers ask their suppliers to record the process capability indices for all special products characteristics on a regular basis. The capability indices help to decide how well the process has performed. For stable or predictable processes, it is assumed that these indices also indicate expected future performance.

(Heena Sharma, 2017)Discussed manufacturing industries making assessment of process capability analysis based on different indicators which can be described in terms of process yield; process expected loss and capability indices of particular process characteristics. Among these indicators, process capability indices have gained substantial attention both in academic community and several types of manufacturing industries since 1980s (Montgomery, 2009).

(Gabriele Arcidiacono, 2017)Recommends using the process capability indices calculated based on the estimate of the overall variation, which is the variation of the entire data in the study only when the analyzed process is under statistical control and stable. According to the Minitab help screen, the overall capability of the process tells how the process is actually performing relative to the specification limits. The most common capability indices and their meanings are shown on table 2.1.

Table 2.1 capability indices definition (Adeoye Akeem, 2013), (Yerriswamy Wooluru, 2014)

Index	equation	Usage
Cp	$Cp = \frac{USL-LSL}{6\sigma}$	It estimates that the process is capable of producing if the process mean were to be centered between the specification limits. Assumes process output is approximately normally distributed.
Cpl	$Cpl = \frac{\mu - LSL}{3\sigma}$	It estimates process capability for specifications that consist of a lower limit only. Assumes process output is approximately normally distributed.
Cpu	$Cpu = \frac{USL - \mu}{3\sigma}$	It estimates process capability for specifications that consist of an upper limit only. Assumes process output is approximately normally distributed.
Cpk	Cpk = $\min[\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}]$	It estimates whether the process is capable of producing or not, considering that the process is centered between the specifications

		limits.
Cpm	$Cpm = \frac{Cp}{\sqrt{1} + (\frac{\mu - T}{\sigma}).^2}$	It estimates process capability around a target T; it is always greater than zero. It assumes process output is approximately normally distributed. Cpm is also known as the Taguchi capability index.
Cpmk	$Cpmk = \frac{Cpk}{\sqrt{1} + (\frac{\mu - T}{\sigma}).^2}$	It estimates process capability around a target T and accounts for an off-center process mean. Assumes process output is approximately normally distributed.

The process capability indices Cp and Cpk which are the main indices to judge the process can be calculated as follows (K. Rezaie, 2015).

$$Cp = \frac{USL - LSL}{6\sigma} \qquad \text{Cpk} = \min\left[\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right] \qquad (2.1)$$

Similar to capability indices, performance indices Pp and Ppk used to judge the process can be calculated as follows (K. Rezaie, 2015).

$$Pp = \frac{USL - LSL}{6s} \qquad \text{Ppk} = \min\left[\frac{USL - \mu}{3s}, \frac{\mu - LSL}{3s}\right] \qquad (2.2)$$

Where, [LSL, USL] is the specification interval, T is the target value, μ is the actual process mean, s is σ within which represents average of sub group standard deviation and σ is σ overall, the standard deviation represents variation of all data.

2.6 Process Capability

Process capability study is a scientific and a systematic procedure that uses basic process control tools to detect and eliminate the unnatural causes of variation until a state of statistical control is reached. (Santosh S, 2017)Presented, numerical values for process capability indices for various process parameters calculated for high pressure die casting process. By analyzing those indices and using thumb rules, it was concluded that the process parameters such as feed temperature, velocity, pressure and thickness are within control of specified limit. It is also the ability of the combination of people, machine, methods, material, and measurements to produce a product that will consistently meet the design requirements or customer expectation (J.M.Juran, 1999). It is the long-term performance level of the process after it has been brought under statistical control. In other words, process capability is the range over which the natural variation of the process occurs as determined by the system of common causes. Process capability indices (PCI) measure the degree to which your process produces output that meets the customer's specification. Table 2.2, 2.3 and 2.4 shows the rule of thumb on statistical process control and based on the rule of thumb a process was judged.

Table 2.2 the overall capability index and their meaning (Belokar, 2012)

Capability index	Estimation of the process	Class or process category
Cpk$\neq Cp$	Process is inadequate, new process parameters must be chosen	6
Cpk = Cp	Process is placed exactly at the Centre of the specification limits.	5
CP< 1	Process is not adequate	4
$1< Cpk <$ 1.33	Process is adequate	3
Cp$k > 1.33$	Process is satisfactory enough.	2
Cp$k > 1.66$	Process is very satisfactory	1

Table 2.3 the potential capability index and their meaning

Results	Interpretation
Pp and Ppk > 1.67	The process definitely meets customer requirements.
1.33 > Ppk > 1.67	The process probably meets customer requirements.
Ppk < 1.33	The process is substandard for meeting customer requirements.

Table 2.4 Cpm values and their interpretation (Rangel Peraza, 2014)

Index	Interpretation
Cpm < 1	The process does not meet the specifications, whether it is by centralization problems, or variability excess
Cpm > 1	The process meets the specifications and the average is found within the third central part of the specification band
Cpm > 1.33	The process meets the specifications and the average is found within the fifth central part of the specification band.

Generally, (Dr.Kapadia, 2015) forwarded minimum of four possible outcomes can arise when the natural process variability is compared with the design specifications or customer expectations. For the calculated potential and overall capability indices some thumb rules obtained for checking process capability are as follows:

Case 1: Cpk and Ppk > 1.33, a fairly capable process

Cpk values of 1.33 or greater are considered to be industry benchmarks. This means that the process is contained within four standard deviations of the process specifications and this process should produce less than 64 non-conforming PPM. The process produces conforming products as long as it remains in statistical control. The process owner can claim that the customer should experience least difficulty and greater reliability with this product. This should translate into higher profits. This process is contained within four standard deviations of the process specifications. Figure 2.1 indicates that voice of the process is less than specification (or customer expectations). Cpk values of 1.33 or greater are considered to be industry benchmarks. This means that the process is contained within four standard deviations of the process specifications.

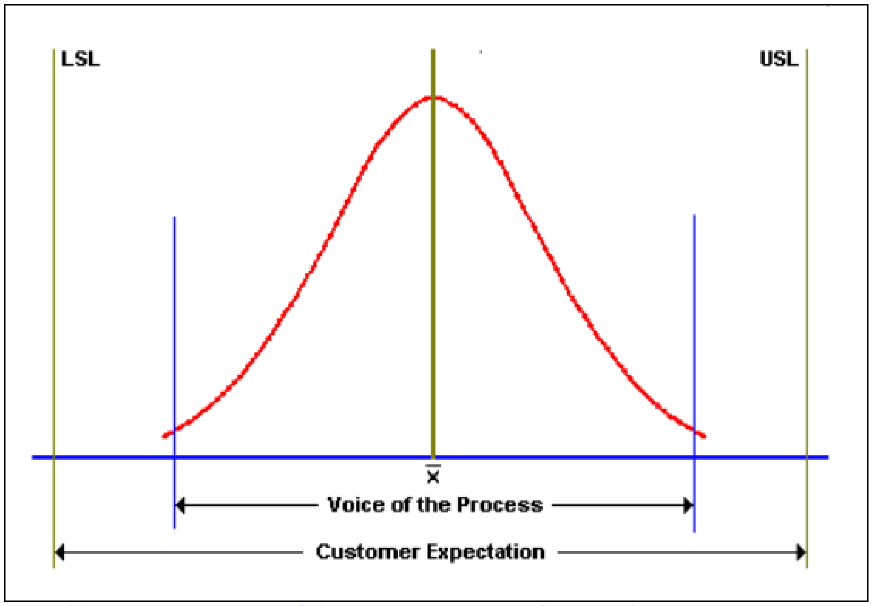

Figure 2.1 fairly capable process (Dr.Kapadia, 2015)

Case 2: 1 < Cpk and Ppk < 1.33, barely capable process

This process will produce greater than 64 PPM but less than 2700 non-conforming PPM. This process has a spread just about equal to specification width. It should be noted that if the process mean moves to the left or the right, a significant portion of product will start falling outside one of the specification limits. This process must be closely monitored. This process is contained within three to four standard deviations of the process specifications. Figure 2.2 indicates that voice of the process is equal to the customer expectations. This process is contained within three to four standard deviations of the process specifications.

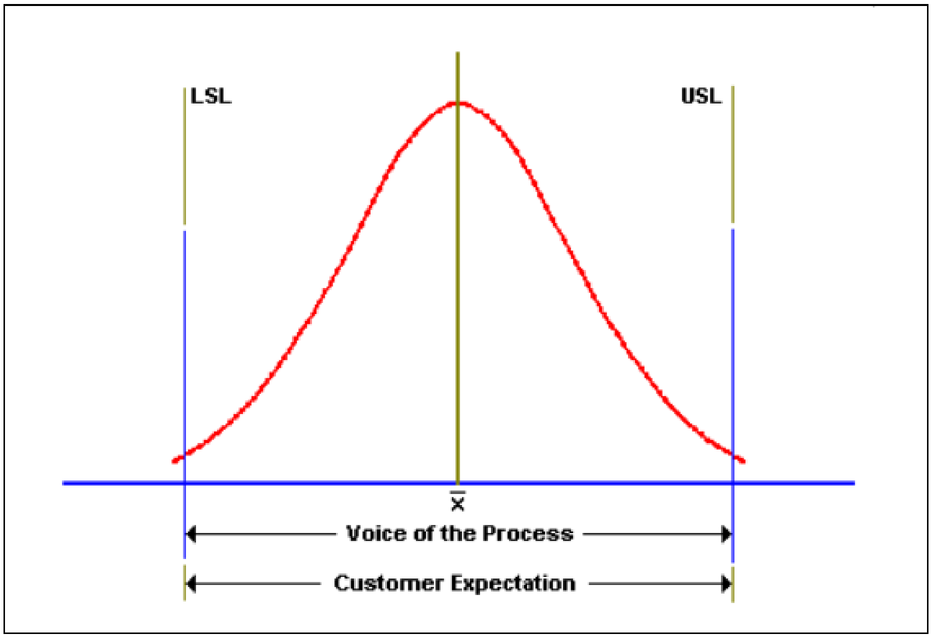

Figure 2.2 barely capable process (Dr.Kapadia, 2015)

Case 3: Cpk and Ppk < 1, not capable process

This process will produce more than 2700 nonconforming PPM. It is impossible for the current process to meet specifications even when it is in statistical control. If the specifications are realistic, an effort must be immediately made to improve the process (i.e. reduce variation) to the point where it is capable of producing consistently within specifications. Figure 2.3 indicates that the voice of the process is greater than customer expectations. It is impossible for the current process to meet specifications even when it is in statistical control. If the specifications are realistic, an effort must be immediately made to improve the process (i.e. reduce variation) to the point where it is capable of producing consistently within specifications.

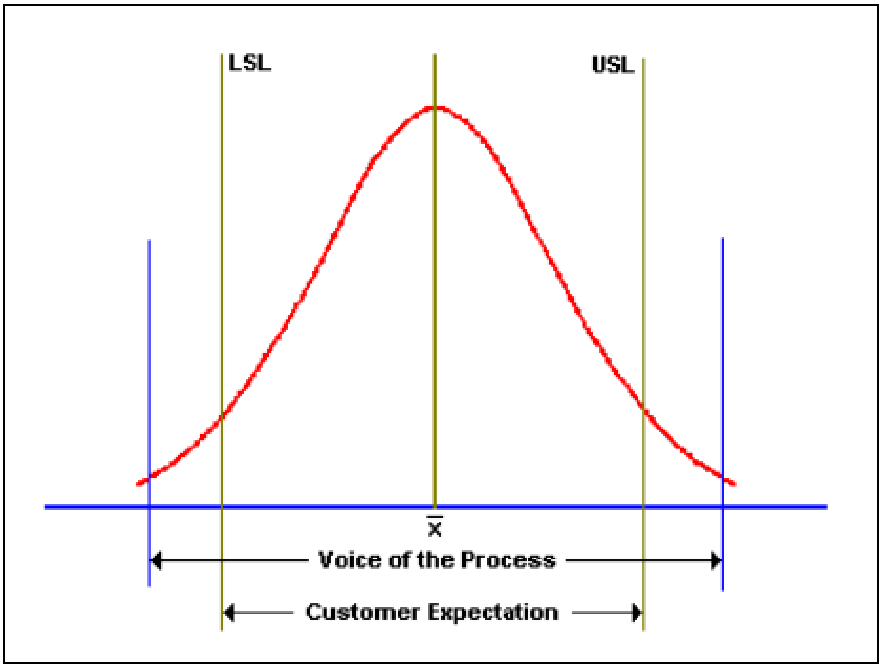

Figure 2.3 not capable process (Dr.Kapadia, 2015)

Case 4: Cpk and Ppk < 1, not capable process

This process will also produce more than 2700 nonconforming PPM. The variability and specification width is assumed to be the same as in case 3, but the process average is off-center. In such cases, adjustment is required to move the process mean back to target. If no action is taken, a substantial portion of the output will fall outside the specification limit even though the process might be in statistical control.

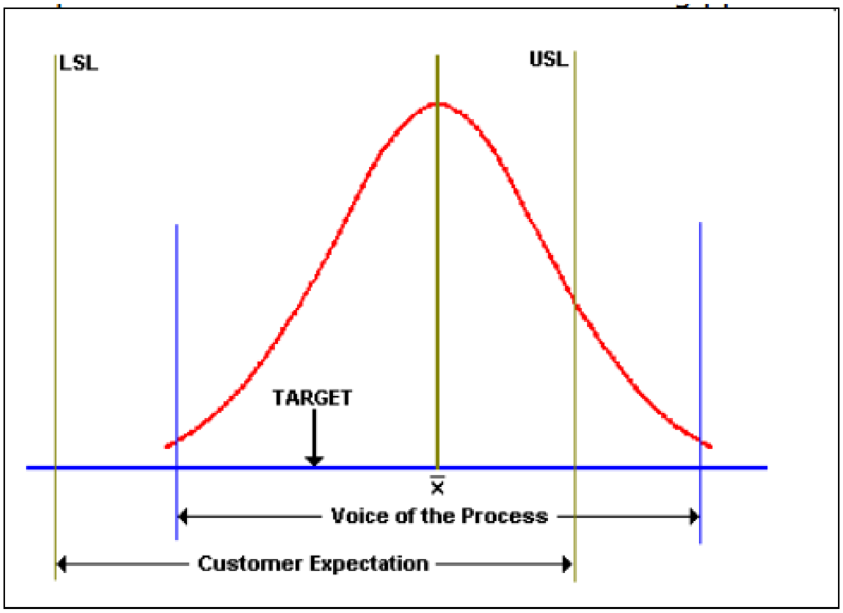

Figure 2.4 not capable process

2.7 Zones in Control Charts

(Libest B, 2012)Stated the standard rules to examine points based on zones on charts. The area between each control limit and the centerline is divided into thirds. The third closest to the centerline is referred to as zone A, the next third is zone B, and the third closest to the control limits is zone C. Note that there are two of each of the Zones, one upper and one lower. zone A is also referred to as the "3-sigma zone", zone B is the "2-sigma zone", and zone C is the "1 sigma zone". These sigma zone terms are appropriate only when 3-sigma is used for the control limits. Standard control limits are located 3 sigma away from the average or centerline of the chart. The centerline is also called the control line. These are called 3 sigma limits or 3 sigma zones. The distance from the centerline to the control limits can be divided into 3 equal parts of one sigma each. (Libest B, 2012)States that in normal data dispersion, we can expect the following percentages of data to be included within the sigma:

- 1 sigma – 68.3%
- 2 sigma – 95.5%
- 3 sigma – 99.7%

We can expect 99.7% of the process out comes to be within the 3-sigma control limits.

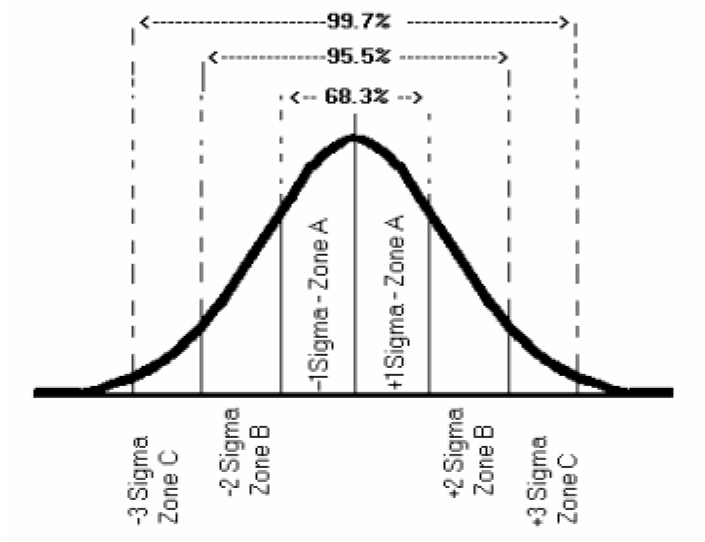

Figure 2. 5 sigma zones (Libest B, 2012)

Where, Sigma is the Greek letter for s and is used in this context to denote the spread of data.

2.8 Control Limits

Control limits which can be calculated statistically from the data are referred to as the lower control Limit (LCL) and the upper control limit (UCL) on a control chart. These are set at 3-sigma by default since this is the most commonly used limit. Control limits define the zone where the observed data for a stable and consistent process occurs virtually all of the time (99.7%). Any fluctuations within these limits come from common causes inherent to the system, such as choice of equipment, scheduled maintenance or the precision of the operation that results from the design. These normal fluctuations are attributed to statistical variability. An outcome beyond the control limits results from a special cause. Special causes are events external to the ordinary operation of a production or service. Special causes indicate that there have been one or more fundamental changes to the process and the process is out of control. Special causes need to be investigated and eliminated before a control chart can be used as a quality-monitoring tool.

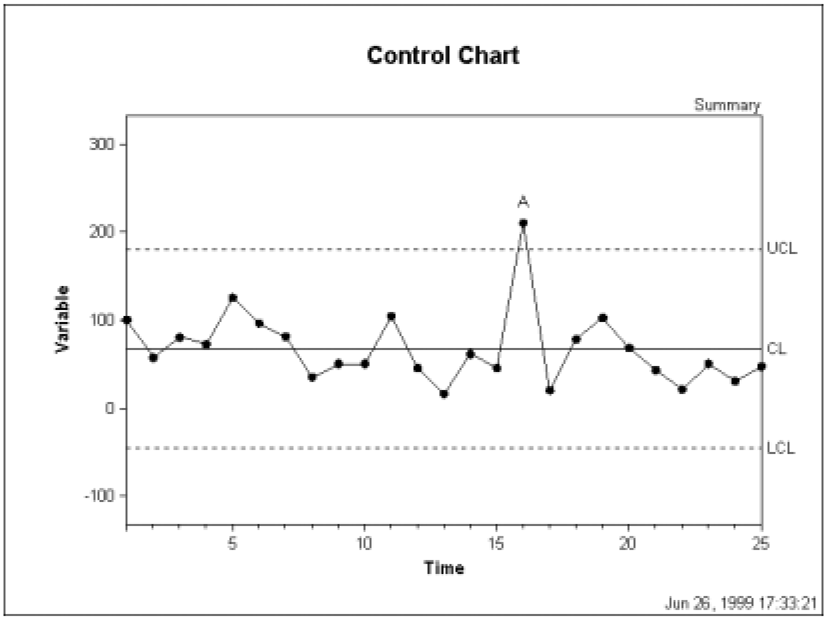

Figure 2. 6 control limits on control chart

2.9 Basic tools for statistical process control

(Saravanan A, 2013)Applied control chart approach to the data collected from glass bottles manufacturing industry for the variable under study height of the specific type of bottle. In the analysis using control charts and Minitab software it was reported that the process is in control and the assignable cause does not affect the process. If a product is to meet customer requirements, generally it should be produced by a process that is stable or repeatable. More precisely, the process must be capable of operating with little variability around the target or nominal dimensions of the product's quality characteristics (Alam, 2014). Therefore, SPC tools help process capable of operating with little variability around the target or nominal dimensions of the product's quality characteristics (Montgomery, 2009). Quality control tools such as check sheet, histogram, control chart, Pareto chart, defect concentration diagram, scatter diagram, cause and effect diagram or fishbone diagram are the seven quality control tools and also known as total quality management (TQM) tools used in statistical process control. (Heena Sharma, 2017) applied quality control tools such as histogram, control chart and cause and effect diagram in production process to reducing the rejection and rework by identifying where highest rejection occur and the quality of final products have been controlled in order to reduce the wastage and also there have been observed improvement by using the quality control tools. The quality control tools used for this case study are: check sheet, histogram, probability plot, control chart and cause and effect diagram.

2.10 Manufacturing process capability analysis

Manufacturing process capability study can be done in short-term when relatively less number of parts are measured, as well as in long term by using process capability indices. In a short term study, the recommended observations are 50 and the interest is in evaluating inherent process variation; many factors such as tools, operators, environment etc. do not change appreciably during study. In long term process capability study minimum of 100 up to 125 observations are recommended and it allows effects of many factors in the process such as operators, raw material, tools etc. (Simion, 2017). Statistical process control has been successfully implemented in both service and manufacturing industries. Table 2.5 shows the various industries implemented so forth and the benefits derived from SPC implementation.

A product is usually manufactured in more than one step and often is also defined by more than one critical characteristic. The analyst therefore has to choose from more than one manufacturing process. Process capability analysis is a scientific and systematic procedure that uses statistical quality control tools and different software to eliminate the unnatural causes of variation until the statistical control is reached. In this case study research analysis is done for flange roller manufactured in ABMI, which consists of multistage manufacturing process. The main tasks in the foundry include pattern making in pattern shop, mechanized mold preparation, blast furnace, sand casting and grinding process.

Table 2.5 benefit derived from SPC implementation (Gajendra Patidar, 2015)

Company name	Benefit derived from SPC implementation
Apurvi industry	Productivity has been increased and reduce rework
Soap industry	Reducing the variability in soap and control the process.
Garments Manufacturing Industry	Identify process capability and eliminate 100% inspection
Florida Power & Light	$4,300,000 savings through Process Improvement; attained the Deming Award.
Lifespan Pharmaceutical Limited	Controlling the process and reducing waste.
Globe Metallurgical	Client complaints dropped 91%;greater than 50% increase in market share in 1988; attained the Malcolm Baldrige Award.
Seafood Processing industry	Increasing the productivity from 70 to 80%, reducing bottle neck.
Mattatuck Manufacturing	80%reduction in client complaints 99% reduction in client rejections; 7% reduction of in-house scrap; 52% reduction in defects found at final inspection
Motorola	Attained six-sigma capability (3.4 defects per million); captured pager market; attained Malcolm Baldrige Award

2.11 Quality control

(Yadav m, 2016)investigated the root causes for variability by Performing process capability analysis using quality control tools like control charts and cause and effect diagram and the root causes were coolant overused, tool and tool life which in turn producing variations in the diameter. Because of the negative consequences of poor quality, organizations try to prevent and correct problems through various approaches to quality control. Broadly speaking, quality control refers to an organization's efforts to prevent or correct defects in its goods or services or to improve them in some way (Alam, 2014). Quality is inversely proportional to variability; this implies that if the variability in the important characteristics of the product decreases the quality of the product increases (Montgomery, 2009). It is seen that there is variation of dimensions in flange roller manufactured by sand casting in the process industry due to different reasons. So to reduce variability, increasing the quality of product by improving the production process is the intention of this case study research. Since, quality improvement of industrial products and process requires collection and analysis of data to solve quality related manufacturing problems, the collecting and validating of data is performed to calculate the process capability indices and also the causes of variation are identified during brainstorming session and cause and effect diagram is developed for identified quality problems.

2.12 Process behavior and variability

It is generally accepted that as variation is reduced, quality is improved but it is impossible to have zero variability (Libest B, 2012). Therefore sometimes not only target value there is specification to consider that are acceptable limits about target. These acceptable limits are often referred to as the upper and lower specification limits or the upper and lower tolerance limits. If the process respects specification and is under statistical control it can be foreseen that specification will not change in the future. If a process respects specification but is not under statistical control, specification could change in the future (Spano, 2012). From the continuous manufacturing process the samples are taken at regular interval. From this a decision can be made whether a process can be managed or not. Where by obtaining a managed process is the prerequisite for a goal oriented process improvement (Konzer, 2005). A process can be considered managed if it has consistent behavior and expected amount of variation.

(Taguchi, 1993) Taguchi has discussed the traditional view illustrated in figure 2.7 is not correct for two reasons:

1. From the customer's view, there is often practically no difference between a product just inside specifications and a product just outside. Conversely, there is a far greater difference in the quality of a product that is the target and the quality of one that is near a limit.
2. As customers get more demanding, there is pressure to reduce variability. However, figure 1 does not reflect this logic.

Taguchi suggests that a more correct picture of the loss is shown in figure 2.8 Notice that in this graph the cost is represented by a smooth curve.

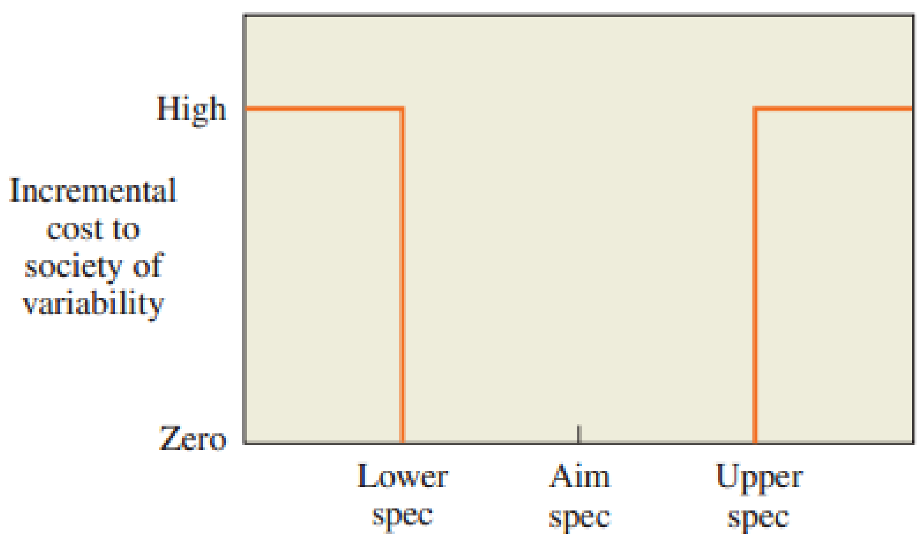

Figure 2.7 a traditional view of the cost of variability

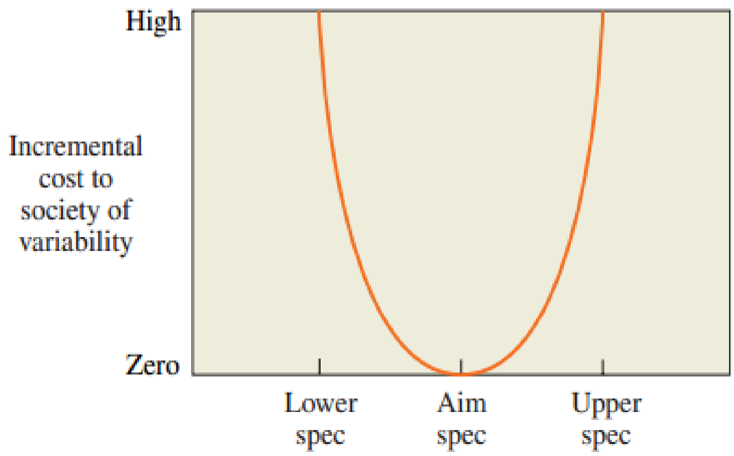

Figure 2.8 Taguchi view of the cost of variability

2.13 Types of Variation in production process of the product

(Shewhart, 1939) first developed Statistical Process Control to measure quality and variability during a manufacturing process. According to this methodology, every process can contain two types of variation known as common cause variation and special cause variation. Common cause variation is variation from an ordinary cause that is naturally present in any process in nature, is innate in the process, and it is expected to be present; variation from special causes is the variation which comes from the fact that an extraordinary event has occurred.
A control chart is useful because it can be used to distinguish between assignable and common causes of variation in the process (Ajit Pal Singh, 2013). The case study research used SPC tools and identified the causes of variation and suggestion was proposed. If common cause is the only type of variation that exists in the process then the process is said to be 'in control' and stable. It is also predictable within set limits i.e. the probability of any future outcome falling within the limits can be stated approximately. Unexpected events or unplanned situations can result in 'special cause variation', if special cause variation exists within the process then the process is described as being 'out of control' and unstable (Rebecca Kaye, 2017). Common cause variation is the normal expected variation in a process that is: Due to the process itself and they are produced by interactions of variables within that process. Common cause variations also present in all processes and they are predictable. But, special cause variation is due to specific and assignable causes that not inherent in the process and they are not predictable.

CHAPTER 3: METHODOLOGY

3.1 Research strategy

The research strategy is useful for collection and analysis of data. There are five research strategies when collecting and analyzing data, experiment survey, archival analysis, history and a case study. Identifying appropriate research strategy to solve the stated problem at the outset of a research project guides the researcher about which research design to employ and which actions to take throughout the study. In this research, the case study is the most appropriate strategy to the answer the research purpose, as the research focuses on real industrial processes in process industry. The research process in this case study research is based up on the primary data collected from ABMI sand casting process. From the start of the research project, product selection, selection of critical to quality characteristics of the product, data collection and analysis performed using control charts, histogram probability plot, Ishikawa diagram and Minitab 17.

3.2 Company visit

The research process in this thesis is started with visiting manufacturing industries and identifying major problems in the process, product and quality. ABMI, Hibret manufacturing, Ethiopian iron and steel factory, BGI Ethiopia and Ameze plastic factory are the industries asked whether they are interested on conducting the research on the process capability study. But, relatively the extent of problem in ABMI is worse; the industry is selected for this research as a case study.

3.3 Data collection and analysis

To address the stated problems the research in this thesis is mainly focused on real industrial data by developing proper methods and techniques. The data for the analysis was collected by regularly measuring the dimensions of the selected product. In order to make sure the process is in statistical control and the distribution of the process is considered normal using control charts and histograms the data is arranged in 20 subgroup of sample size 5 for each critical characteristics of the selected product. After having relevant data there are other activities which are done using the analysis techniques and specified software.

- Calculating required statistics such as mean, range and standard deviation.

- Validate the critical assumptions using control charts, histograms and probability plots.
- Determination of process capability indices.
- Comparison of these values with the established standards.
- To trace out the root causes and suggest remedies for each and every defect identified plotting and making analysis using the software.
- Providing corrective suggestion

3.3.1 Sources of Data

The sources of data to study process capability analysis in the industry include primary and secondary data sources.

Primary data sources:

- Taking actual measurements from manufacturing process at regular intervals or after production
- Results of experiments
- Discussion with the authorized person in the industry

Secondary data sources:

Secondary data sources for this case research are statistical and engineering books, different journal papers, conference papers, reports, articles in periodical and internet sources and they are duly acknowledged.

3.4 Sampling technique

In industrial experiment before collecting data defining sampling procedure and method is very important. The result of measurement should be sampled in such a way that we obtain the fair representation of the process over the chosen time frame. In order to be able to record all possible influences acting under standard production conditions, (Konzer, 2005)suggested the following conditions should be considered during sampling.

- The random samples are taken from ongoing production process under standard production conditions i.e. five samples are taken from every shift per day.
- During random sample, the parts with considered characteristics are taken as much as possible in direct sequence.

- For each and every critical quality characteristics the data are grouped in minimum of four samples in 20 groups or five sample size and twenty subgroups.

3.5 Measuring instruments

It is necessary that before we decide which measurement device will be used for measure product characteristics; we should asses it to make sure that the measurement device proper and suitable to capture the variation (Tulus Puji, 2018). Therefore the measuring instruments used in this thesis are provided from ABMI quality control department and the instruments are calibrated thus, the industry was using instruments to measure dimensions and profile of their products. Measurement in any manufacturing process requires precisely measuring instrument in order to get relatively accurate results. Thus measurement is a way of expressing the result from manufacturing process and measured value describing characteristics of an object, not the object itself. Therefore in this thesis critical dimensions of flange roller are measured to perform process capability analysis. The measuring instruments used during investigation are varnier caliper and meter, the CTQ are measured carefully cooperating with process industry quality department.

3.5.1 Measurement accuracy and errors

An accurate measurement needs a combination of the performance of the measurement tool, measuring person and environment where it is used. To achieve a reliable measured value, measurement errors need to be minimized and uncertainty has to be estimated. The data in this thesis are obtained by carefully measuring the dimensions of flange roller twice for each CTQ characteristics and taking their average after calibrating the measurement tools. Because, calibration helps to estimate uncertainty and to secure reliability of measurement method. Thus much attention has been given during measurement to minimize measuring errors and to maximize accuracy.

3.6 Software used

For successful completion of this research statistical software Minitab 17 was used for calculation and analysis of data. The commercial software Minitab was used to validate critical assumptions that the process is in statistical control and the distribution of the process considered is normal using control charts, histograms and normal probability plot from real industrial data.

The process capability indices and performance indices were calculated by using Minitab 17 unlike hand calculation which might cause errors. To create fishbone diagram the statistical software QI macros 2018 was integrated with Microsoft excel. The software known as QI macros 2018 was selected because it is easy and clearly shows the cause and effect of the problem.

3.7 The flow chart

After a process has been identified for improvement and given high priority, it should then be broken down into specific steps and put on paper in a flow chart because this procedure can uncover some of the reasons a process is not working correctly (Marilyn K. Hart, 2007). An approach to process quality contains a flow chart that acts as a guide to identify and monitor process variable. Figure 3.1 shows the flow chart of the study. As stated product selected is flange roller manufactured in the foundry which shows higher variability comparatively. Variable data has been collected for the identified CTQ characteristics diameters and height of the product. When validating critical assumptions, if the process is in control and stable, it is possible to determine capability indices otherwise the causes should be eliminated first. After determining capability indices if the process is capable, system for continuous monitoring of the process should be established. If the process is not capable, root causes should be identified and corrective suggestion should be provided.

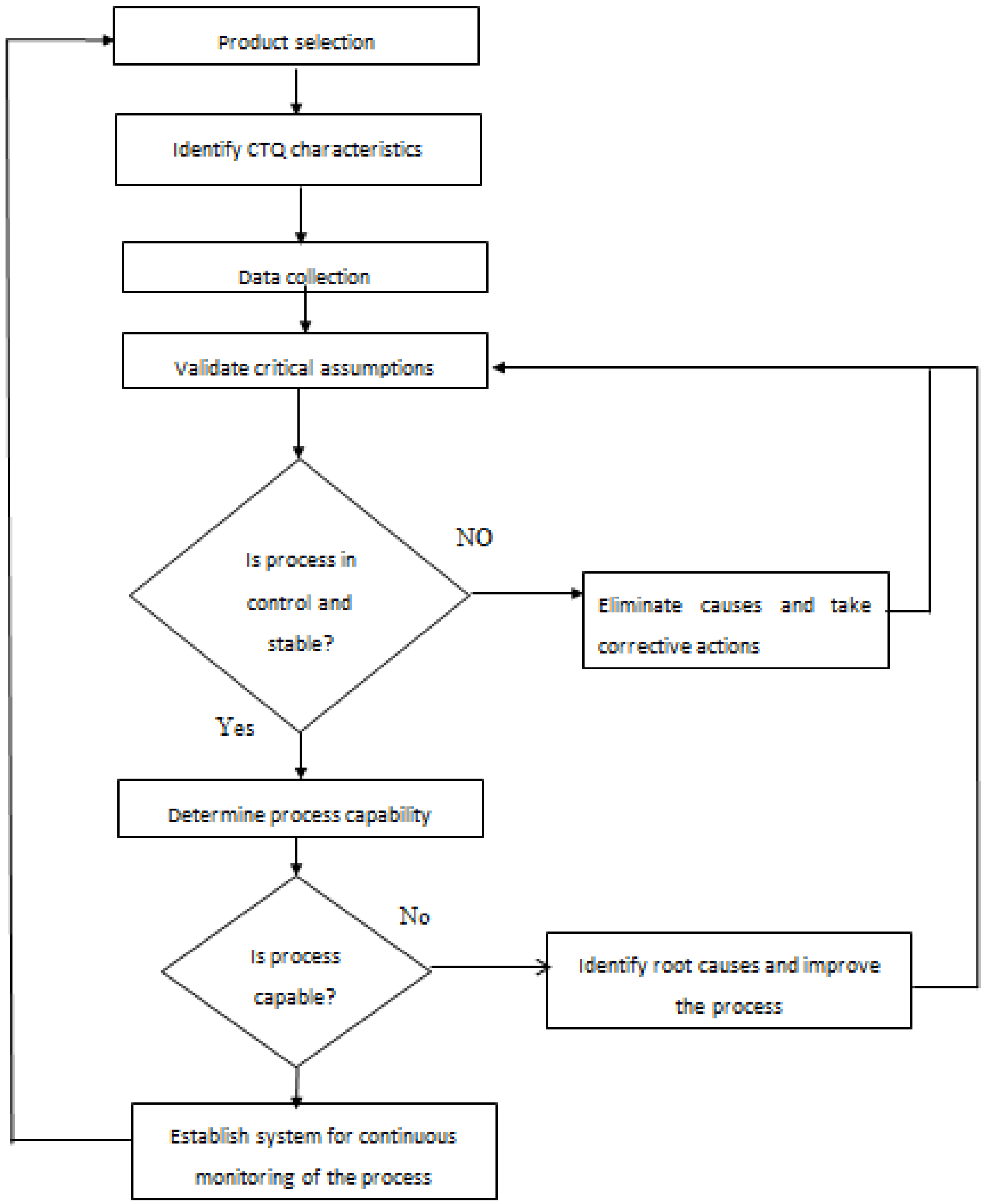

Figure 3.1 the flow chart

CHAPTER 4: A CASE STUDY

4.1 Data Evaluation and Case Study

In this thesis, an experimental case study is carried out in a metal products manufacturing industry known as ABMI. The thesis is based up on primary data from the sand casting process and the product selection and critical to quality characteristics of the products are identified. For the case study research flange roller was selected with the interest of industry quality experts to performing process capability analysis. The production performance of the process is evaluated by collecting real industrial data and implementing quality control tools and Minitab 17 software.

4.2 Product selection

In this thesis after choosing industry, product selection was done by carefully comparing the problems levels from the available products with the quality department workers in the industry. The data was taken from flange roller manufactured in ABMI foundry. Flange roller was selected from the available products such as wear socket, trash plate, gear blank, cane knife billet, flange roller etc. with the interest of industry quality experts because they found that the extent of variability is higher in flange roller. Figure 4.1 shows the flange roller selected for the case study.

Figure 4.1 the flange roller

4.3 An approach to identifying, measuring and analyzing key variables

The identification and measurement of key variables are important element of quality improvement. Therefore the ideas of statistical process control technique are employed which are widely used in industry (Alexis Aitken, 2010). User needs product quality and process quality is the requirements of this case study at ABMI. The product, process and CTQ characteristics selection is done by carefully investigating the process industry and identifying major problems regularly contacting industry workers and quality department.

4.3.1 Product description

The product for this case study research was one sided flange roller and the dimensional measurement was recorded for inner diameter, outer diameter, flange diameter and height of the product. Table 4.2 shows the specification of the flange roller with lower specification, target and upper specification limits provided by the customer for inner diameter, outer diameters, flange diameter and height of the product. It was desired that the products are manufactured with the provided specification limits.

Table 4.1 Product description

Part name: flange roller	Operation: sand casting
Instrument used: Varnier caliper and meter	Material: cast iron
All dimensions are in mm	Number of observations: 100 for each

4.3.2 Process description

ABMI has their own foundry for casting of products for customers and for their machine shops. Sand casting is the basic process which is responsible for the great growth of industries. The thesis focuses on foundry process because there is no much attention is given to study process capability analysis of sand casting, and also Any metals or parts for machining or for business comes from casting process, thus foundry is supporting and feeding any manufacturing process. The industry foundry basically engages on secondary production of melting materials for sand casting i.e. scraps processing rather than smelting or extraction of material from its major ore. The overall process in the foundry includes mold and pattern preparation, scrap melting at furnaces, pouring, sand casting and grinding process to remove extra metal parts from the product.

4.3.3 Identifying critical to quality characteristics

Identifying critical to quality characteristics is the first important thing for capability study, but when identifying CTQ characteristics the parts or parameters that cause problem should be identified. Understanding of the product characteristics that are important to customers is essential also. The capability analysis is done for flange rollers inside diameter D1, outside diameter D2, diameter D3, flange diameter D4 and Height H. The data is handled with the specifications provided by the manufacturer that is taken from customer specification.

4.4 Validation of data for process capability analysis

Control charts are quality engineering tool, used separately or within SPC to measure and Control process variation and detection of special causes of variation (Tatjana V. ŠIBALIJA, 2009). Before process capability analysis is performed the collected data has to be checked for normality and the process has to exhibit control. There are two critical assumptions to consider when performing process capability analysis with the collected data (Tulus Puji, 2018).

1. The process is in statistical control
2. The distribution of the process considered is normal.

If these assumptions are not met, the resulting statistics may be highly unreliable. To validate the data control chart, histogram and probability plots are used in this research.

4.4.1 Types of control used

If a process is not in statistical control we are unable to reliably use our estimate for spread and location. In order to assess whether or not a process is in statistical control, control charts are used. There are two categories of control charts, those that display attribute data and those that display variable data.

Attribute data: attribute data control charts displays data that results counting a number of occurrences or items in a single category of similar items. These count data may be expressed as pass/fail, yes/no or presence/absence of defect.

Variable data: variable data control chart displays values resulting from the measurement of continuous variable. Examples of variable data are length, diameter, temperature, weight, height etc. Therefore the collected data in this research is under variable data.

There are several types of control charts (Philip L Ross 1998).

i) C – Chart: this chart uses constant sample size of attribute data, where the average sample size is greater than five. It is used to chart the number of defects. C stands for nonconformities.

ii) U – Chart: is the control chart used to chart the number of defects using attribute data. It is used for varying sample size and U stands for the number of non-conforming.

iii) np – chart: used for attribute data of with sample size constant and only np chart is used to chart the number of defective in a group.

iv) P – Chart: p chart is used for the attribute data of sample size varying and the data is usually ≥ 50. The chart is used to chart the fraction of defective in a group.

v) X – MR chart: to create I – MR chart variable data is used and it is possible to use this chart if the subgroup size is 1.

vi) X – Bar and R charts: the criteria to use X bar and R charts to create control charts is the data should be variable data and the sub group size is ≤ 9.

vii) X bar - S chart: X bar - S chart is a control chart used for variable data of subgroup size >9.

Choosing the correct chart for a given a situation is the first step in capability analysis. There are actually just a few charts to choose from, and determining the appropriate one requires following some fairly simple rules based on the underlying data. These rules are described in figure 4.2 and 4.3.

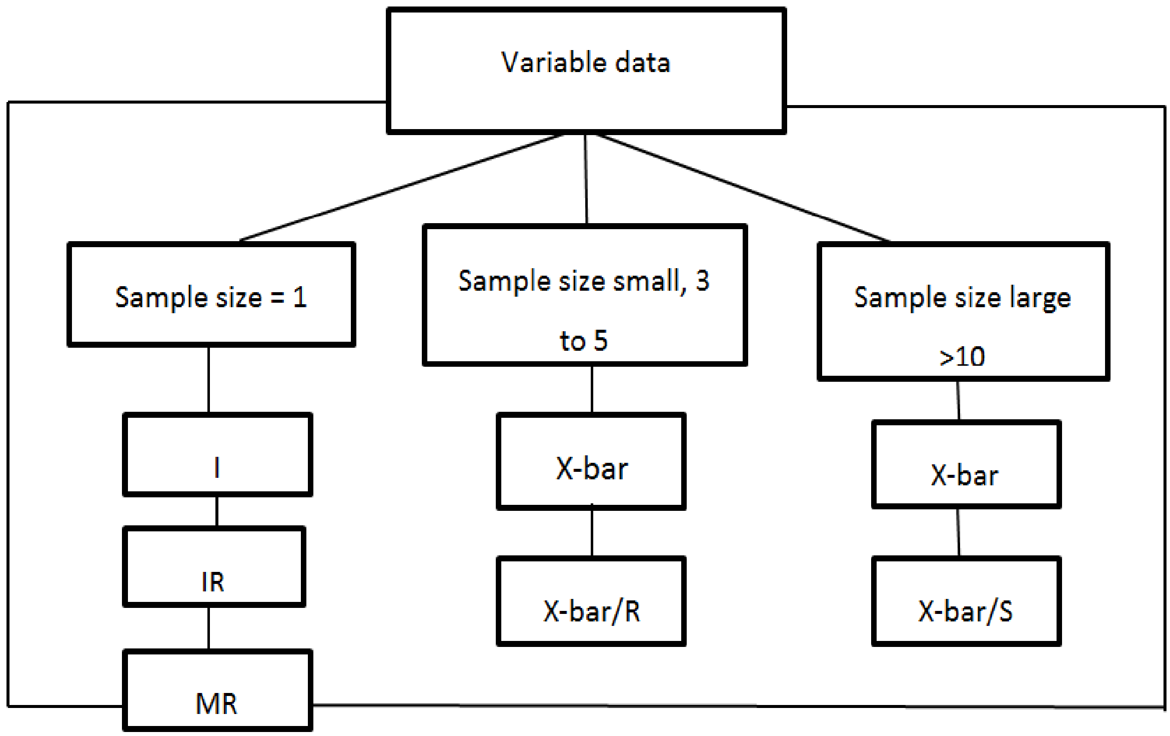

Figure 4.2 control chart decision tree for variable data

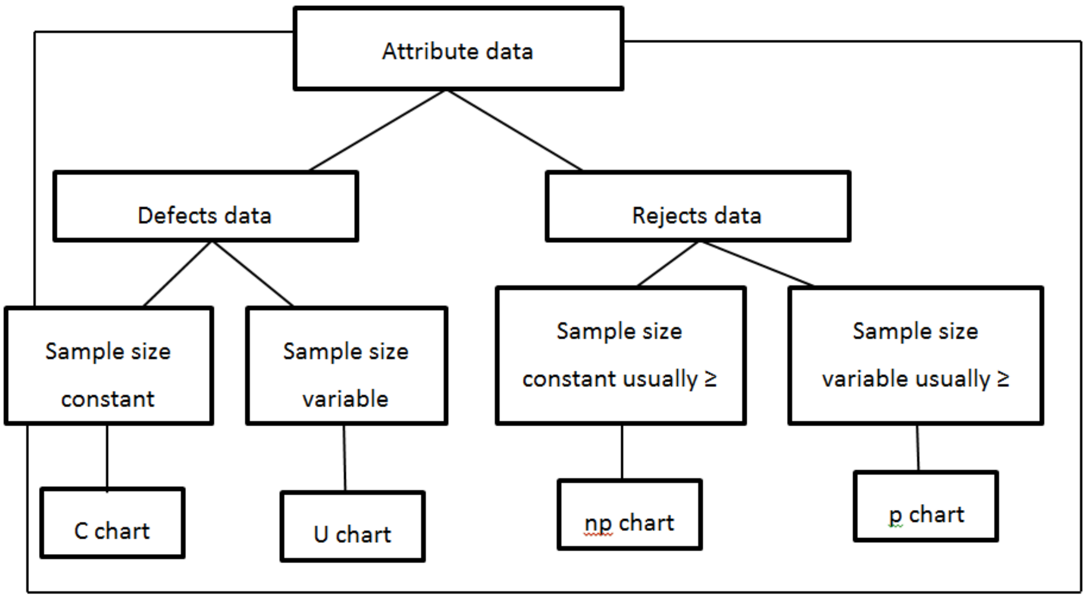

Figure 4.3 control chart decision tree for attribute data

To choose the control chart the type of data available should be identified, after that it is possible to decide the control chart. The case study data collected from the industry is variable data with subgroup of 20 and sample size of 5. Therefore the data obtained is suitable to use x bar and R chart for this study to track the process level and variation. X bar-R chart are displayed together to determine whether the process is stable. Examine R chart first to correctly interpret the X bar chart. Upper control limit and lower control limit are calculated considering both process spread and center. The control limits in X bar chart are inaccurate if the R chart is out of control.

4.4.2 Histogram

A histogram is a snapshot of the variation of a product or the results of a process. It often forms the bell-shaped curve which is characteristic of a normal process (Marilyn K. Hart, 2007). In histogram, many data are categorized in a specific format in order that the problem can be understood and analyzed more simply. It is obvious that data grouping and graphic display will help us significantly to decide logically and effectively. Histogram provides an image for data, by which three following attributes can be understood and observed more simply (Ali Mostafa, 2012):

a) Form of data frequency distribution

b) Location with central tendency for distribution

c) Dispersion by distribution development.

(Ali Mostafa, 2012)States that usually, in the best situation, histogram has a bell curve form which is symmetrical and the most of data has been aggregated around the center.

A histogram is used to validate normality assumption and it displays a frequency distribution of occurrence of various measurements, central tendency or mean of data, and its variation or spread (Marilyn K. Hart, 2007). The frequency histogram is created in this research using the collected data to check normality of the data. The created histogram depicts whether the process is normal, centered on nominal and spread is with in specification or not.

4.4.3 Probability plot

A very important application of normal probability plotting is in verification of assumptions when using statistical inference procedures that require the normality assumption (Montgomery, 2009). The probability plot is created in this thesis using Minitab 17 to graph cumulative relative frequencies of the collected data on a normal probability scale. For the collected data normality assumption is approved if it forms a line that is fairly straight the p value is greater than the significance value alpha. This can be an important assumption in much statistical analysis.

4.5 Brainstorming Session

Brainstorming is a technique used to elicit a large number of ideas from a team using its collective power (Sileshi Kitata, 2016). For brainstorming session the members are selected from the quality department and the foundry workers and brainstorming procedure and rules were taught to the team members as to establish the cause and effect diagram. The five team members discussed on the following points and tried to identify the root causes of variation.

- What is quality and variation?
- How to rate the quality and variation?
- What are the major problems in the production of flange roller?
- What are root causes for the variation?

4.5.1 Ishikawa Cause and effect diagram

Once a defect, error, or problem has been identified and isolated for further study, we must begin to analyze potential causes of this undesirable effect (Montgomery, 2009). Cause and effect diagram is a quality control tool used to analyze potential causes of problems in a product or process. The diagram organizes and displays the relationship between different causes for the effect being examined (Marilyn K. Hart, 2007). The steps in developing cause and effect diagram are (Montgomery, 2009).

1. Define the problem or effect to be analyzed.
2. Form the team to perform the analysis. Often the team will uncover potential causes through brainstorming.
3. Draw the effect box and the center line.
4. Specify the major potential cause categories and join them as boxes connected to the center line.
5. Identify the possible causes and classify them into the categories in step 4. Create new categories, if necessary.
6. Rank order that causes to identify those that seem most likely to impact the problem.
7. Take corrective action.

After defining the problems the cause and effect diagram is created using the specified steps. Meeting conducted with members of some of foundry workers and quality departments during brainstorming session to identify potential causes for variation and quality problems. Beforehand, an empty cause and effect (fishbone) diagram is printed to help organize the notes during the meeting. The example below in figure 4.4 illustrates how to generate a cause and effect diagram with empty branches. The main causes are noted in main branches and if any other sub causes are present an additional sub branch is drawn in main branches. But the fishbone diagram for this thesis is created using integrating the statistical software QI macros with Microsoft excel.

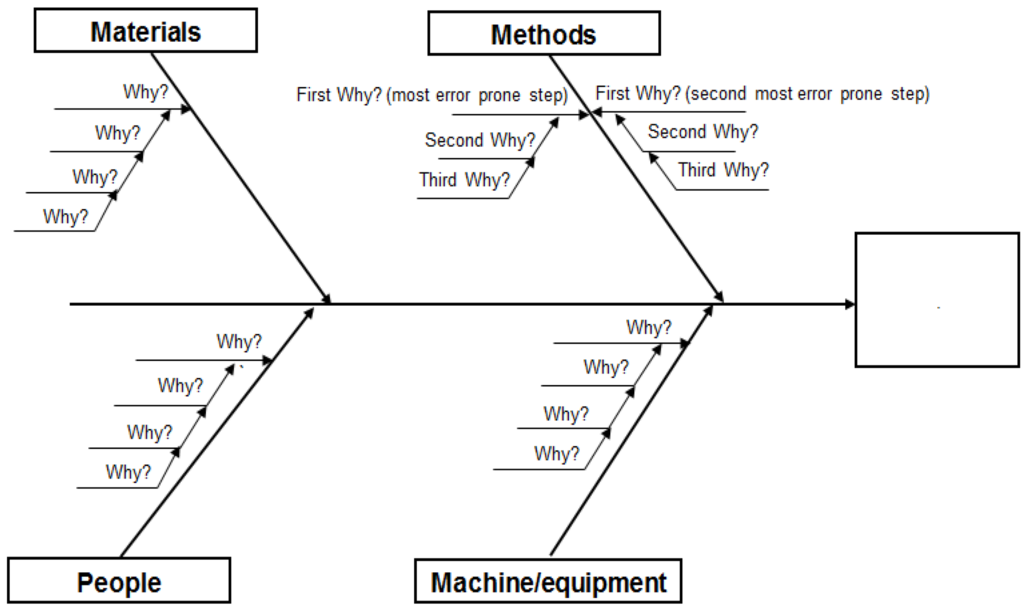

Figure 4.4 empty cause and effect drawing diagram

4.6 Process industry and manufacturing process

ABMI is one of the known industries in Ethiopia was selected from the available choice of industries as stated in problem statement. In order to perform process capability analysis in the industry first the manufacturing process must be identified. So as the capability in this paper is studied in continues process, from starting to finishing process. The process capability study performed on blast furnace and steel casting processes. The fishbone diagram was created for foundry processes to improve the process for manufacturing of the product. Thus furnace, casting process and grinding processes which studied in this thesis are the selected processes for this case study.

4.6.1 The Blast Furnace Process

The blast furnace in ABMI is a type of induction furnace used for smelting of metals and scraps in to liquid form at high temperature without using fuel. Cupolas, open hearths, air furnace, electric arc furnaces, induction furnaces and Crucible furnaces are the most common types of furnaces for melting of metals. The furnace found in ABMI foundry is induction furnace which operates using electric power. Induction furnaces have become the most widely used furnaces for melting iron and, increasingly, for non-ferrous alloys. These furnaces have excellent metallurgical control and are relatively pollution free (Quens land, 1999). The furnace builds from refractory. Refractory are materials that can withstand high temperature and resist the action of slag. This material should not show any sign of fusion below 1580c̊ because they are used to serve as receptacles for molten metal. There are three induction furnaces in ABMI with the capacity of 3.3 ton each, there is standard melting temperature of metals in the foundry for example cast iron melts at 1500°C and Steel at 1750°C and the material for flange roller is cast iron and therefore, the melting operation is at a temperature of 1500°C. Induction furnaces require much cleaner scrap than cupola furnaces and somewhat cleaner scrap than electric arc furnaces (Quens land, 1999).

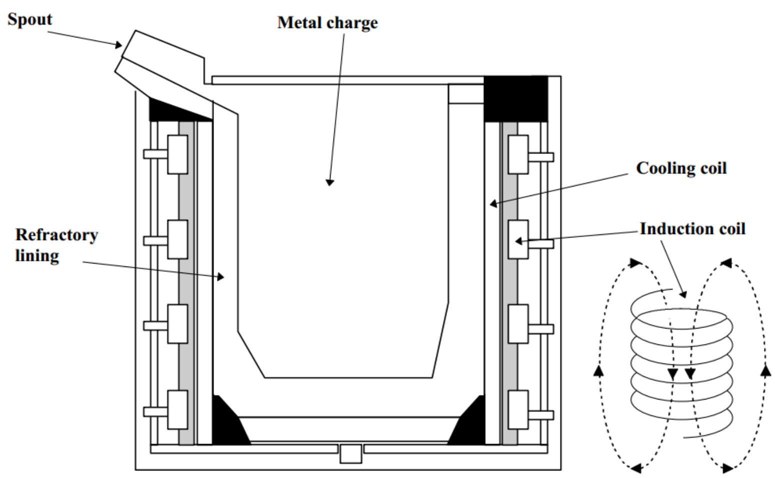

Figure 4.5 an electric induction furnace

4.6.2 Sand casting

The case study industry foundry is mainly working on sand casting with specified technique and equipment. To cast a product in a sand casting process; mold around the pattern is made, then the mold is opened and pattern is removed, close the mold and fill cavity left in the sand with molten metal. When the molten metal solidifies shake out the mold to have the desired product that is exact duplicate of the pattern (C.W.Ammen, 1997). The product manufactured in sand casting process is accepted only if the quality is improved and variation required by the customer specification is found satisfactory. Otherwise the contribution to the wastage and loss of value to the foundry is increased. The sand casting process in the foundry is working on the following systems.

1, Pattern making

2, core making

3, mold making

4, melting and pouring

5, cleaning

1. Pattern making

Pattern is the principal tool during the casting process. The quality of the casting produced largely depends up on the material of the pattern, design and construction. A pattern in Akaki basic metals industry is used to create the mold shape and is the actual shape of the metal part that needs to be created; actually the product selected for this thesis is flange roller and a core box is used for creation of cores which form the interior geometries of casting. Pattern making requires the skill of reading two dimensional drawing and creating 3D part and metallurgical concepts like shrinkage rates and solidification for different materials. ABMI foundry is using the patterns by modifying the existing patterns and preparing them for molding, sometimes if it is necessary new patterns and cores are prepared. The types of patterns produced are:

- ✓ Loose piece pattern
- ✓ Split pattern
- ✓ Single piece pattern
- ✓ Gated pattern
- ✓ Match plat pattern
- ✓ Skeleton pattern

2. Core making

Cores are usually made of sand and then placed inside the mold cavity to form the interior surface of casting. Thus the void between the core and the mold cavity forms the actual shape of castings. The core in the process industry is made of sand. Cores provide casting process with the ability to make the most intricate shapes, eliminate a lot of machining, produces shapes which would be impossible to machine, strengthen or improve mold surface and can be used as part of gating system.

3. Mold making

Sand is the principal molding material in the foundry shop where it is used for all type of castings. The molds created are with two halves and the sand is filled in each of two halves of the mold. The sand is packed around the pattern which is replica of external shape of casting. Generally mold making process includes positioning of the pattern, packing the sand and removing the pattern after the desired shape is obtained. The flange roller is produced using mechanized system and the machine rams and takes pattern by itself. But, sometimes the machine stacks. Molding process in a foundry is classified as:

- Manually (Hand molding)
- Mechanized molding

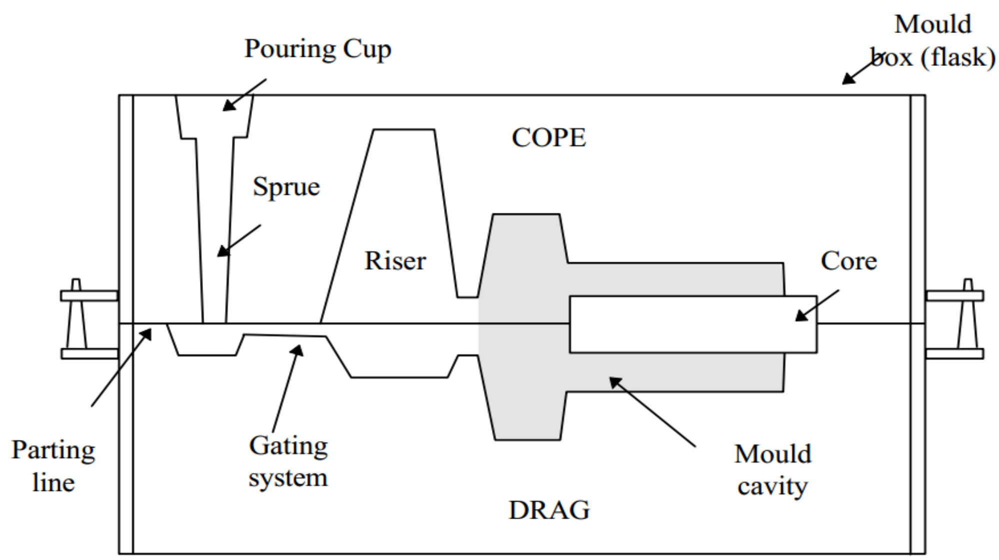

Figure 4.6 Cross-section of a typical two parts sand mold

4. Melting and pouring

The melting of metals is the process for preparation of metal for casting and its conversion from solid to liquid state in a furnace. The case study industry is using induction furnaces from melting of ferrous and nonferrous metals and once the metal has been melt at high temperature proper steps of pouring are necessary to ladle from its container in the furnace and poured in to the mold.

5 Cleaning

Cleaning is basically removal of all materials that are not part of finished castings and the cleaning operations in the foundry include:

i) Trimming to remove any superfluous metal

ii) Cleaning for improved appearance or finishing

iii) Removal of gates and risers – rough cleaning

iv) Surface cleaning, exterior and interior casting

v) Inspection.

The Sand casting process which is the most common technique used in ABMI foundry for casting of flange roller is shown in figure 4.7.

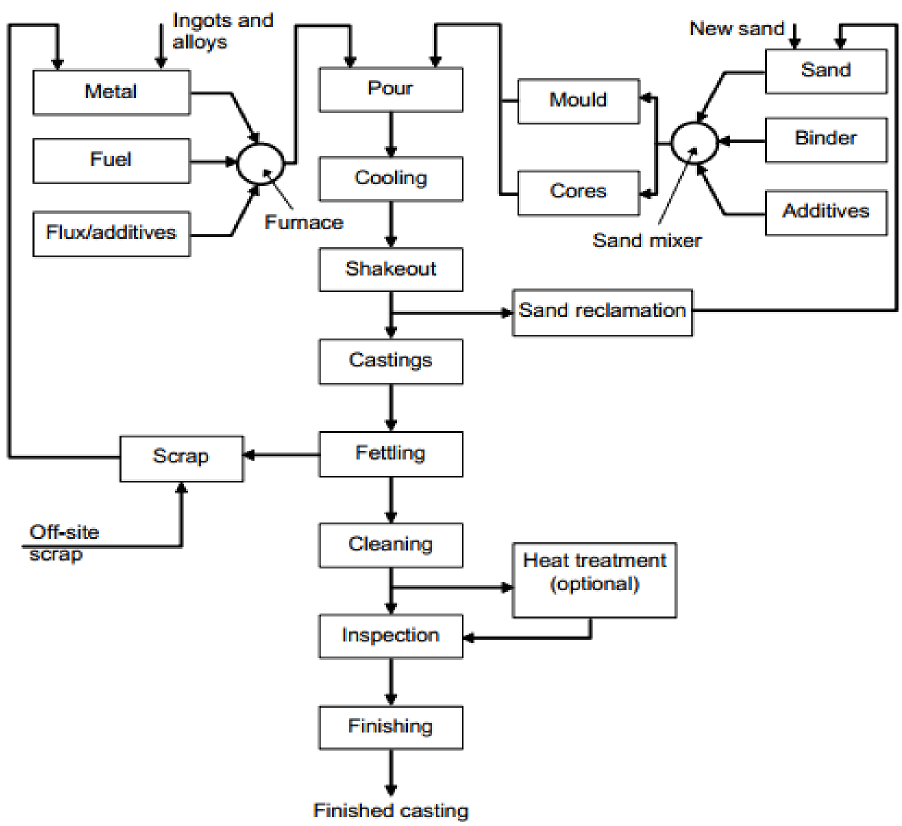

Figure 4.7 the flow chart for sand casting process

4.6.3 Grinding process

Grinding is a machining process for removing of metal but comparatively in small volume. In grinding, the material is removed by means of rotating abrasive wheels. Conventional sand casting is not a precision process, and requires post machining processes and surface finishing processes to achieve the required dimensions and surface quality. However if there is improved sand quality and mold rigidity it is possible to produce high precision cast products which reduces post machining time and cost. The grinding machine is used to remove external metal parts from flange roller and to give better surface finish. Generally grinding in foundry is used for the following purpose:

- To remove a very small amount of metal from the work piece to bring its dimensions within very close tolerances after all the rough finishing and heat treatment operation have been carried out.
- To obtain better finishing on the surface

4.7 Sand quality

The sand used for sand molding is critical and can determine the quality and outcome of the product. The sand must exhibit the following characteristics:

Flowability: The ability to pack tightly around the pattern.

Plastic deformation: Have the ability to deform slightly without cracking so that the pattern can be withdrawn.

Green strength: Have the ability to support its own weight when stripped from the pattern, and also withstand pressure of molten metal when the mold is cast.

Permeability: This allows the gases and steam to escape from the mold during casting.

All of these requirements are dependent on the amount of active clay present and on the water content of the mixture. The sand for ABMI is obtained from marabite, amhara region. The washing and cleaning was done and to bind the sand, small amount of resin was added in to old sand and high amount of resin was added in to new sand. The reason is there was already added resin in the first use and the new sand is resin free. In addition to resin catalyst was added to dry the sand.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Stability and normality tests for D1

There are two critical assumptions to consider when performing process capability analysis, the output data must follow a normal distribution and the process must be in statistical control or stable (Simion, 2017). Minitab 17 was used to create X bar R chart, histogram and probability plot to ensure the control status and normality. Table 5.1 shows the collected data from flange roller manufacturing process for inner diameter D1 with the calculated row statistics such as mean, range and standard deviation.

Table 5.1 Measured data for inner diameter D1

No.	X1	X2	X3	X4	X5	mean	Range	Stdev
1	58.7	58.8	56.1	58.0	59.0	58.12	2.9	1.19038
2	57.6	59.0	57.8	56.9	58.1	57.88	2.1	0.76616
3	57.0	57.3	57.1	58.1	55.7	57.04	2.4	0.86487
4	56.1	57.1	56.7	56.0	57.0	56.58	1.1	0.50695
5	59.0	56.9	57.0	58.0	57.0	57.58	2.1	0.91214
6	56.8	56.0	58.2	57.2	56.8	57.00	2.2	0.80000
7	58.0	56.9	56.7	58.0	57.1	57.34	1.3	0.61887
8	57.3	59.0	56.5	57.0	57.0	57.36	2.5	0.96073
9	57.5	58.0	57.0	57.0	57.2	57.34	1.0	0.42190
10	57.0	58.0	59.0	56.5	58.0	57.70	2.5	0.97468
11	57.6	57.0	58.5	57.2	57.5	57.56	1.5	0.57706
12	59.0	56.4	57.1	58.0	58.8	57.86	2.6	1.10815
13	56.5	57.5	57.0	58.0	59.0	57.60	2.5	0.96177
14	58.5	58.2	57.5	57.0	57.5	57.74	1.5	0.60249
15	56.5	58.0	59.0	57.3	58.4	57.84	2.5	0.97108
16	58.9	59.0	57.8	58.6	57.3	58.32	1.7	0.73959
17	57.1	57.9	57.5	57.5	58.0	57.60	0.9	0.36056
18	59.0	58.3	57.9	57.5	58.2	58.18	1.5	0.55408
19	56.2	57.8	57.5	59.0	56.5	57.40	2.8	1.11580
20	57.5	57.0	58.5	59.0	57.7	57.94	2.0	0.80187

Note. X1, X2, X3, X4 and X5 in table 5.1, 5.2, 5.3, 5.4 and 5.5 are number of observations representing samples for each subgroup.

5.1.1 X bar-R chart for D1

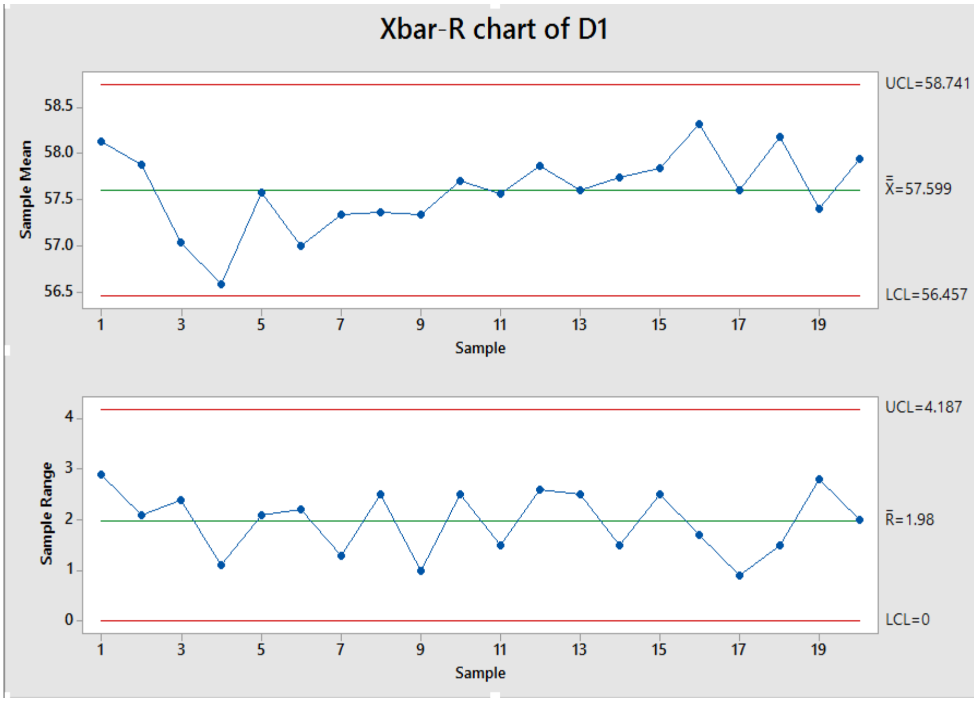

Figure 5.1 X bar-R chart of inner diameter of the product

As seen in Figure 5.1 there is no out of control points in X bar-R chart, since the R chart is in control condition, the control limits in X bar chart are acceptable. All the points fall within the control limits, so the chart shows that the process is in control condition. This indicates that there are only common causes of variation and the process is ready to be improved.

5.1.2 Frequency histogram for D1

After the critical assumption of process stability has been approved, the data is checked for normality assumption using histogram and probability plots.

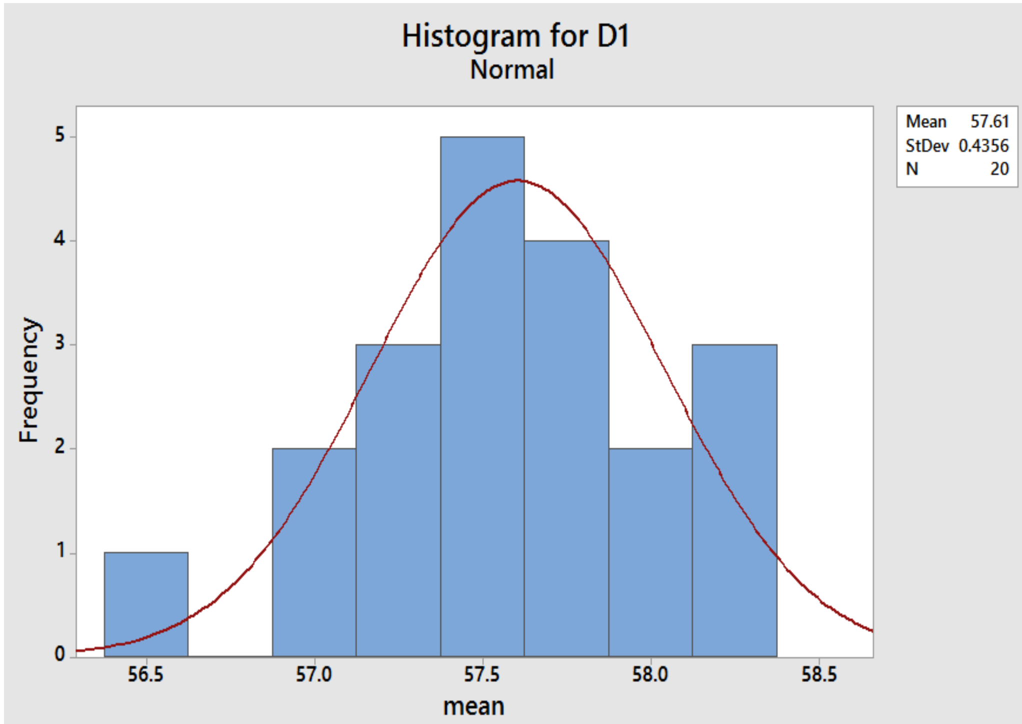

Figure 5.2 Histogram for inner diameter of the product

The frequency histogram of flange roller inner diameter in figure 5.2 is derived from statistical software Minitab 17. The histogram with mean of 57.61 seems to be approximately symmetric about to means which indicates that the data is normally distributed that the capability indices can be calculated.

5.1.3 Probability plot for D1

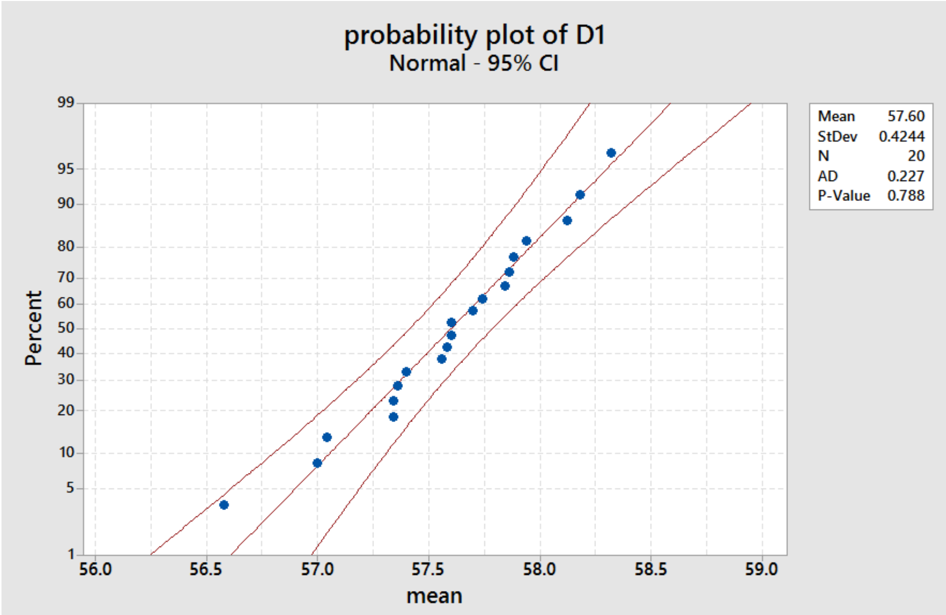

Figure 5.3 probability plot of inner diameter of the product

The test result from normal probability plot indicates that the process mean: 57.60, standard deviation: 0.4244, Anderson-Darling test statistic value: 0.227 and p-value: 0.788. It is assumed that the data is distributed normally since p-value is greater than the significance level (α=0.05).

5.2 Stability and normality tests for D2

The data for outer diameter was checked for normality and stability of the process, running in Minitab 17. Table 5.2 shows the collected data from flange roller manufacturing process for outer diameter D2 with the calculated mean, range and standard deviation.

Table 5.2 measured data for outer diameter, D2

No.	X1	X2	X3	X4	X5	mean	Range	StDev
1	125.5	125.0	122.2	125.1	125.0	124.56	3.3	1.33529
2	124.5	124.9	125.6	124.5	125.0	124.90	1.1	0.45277
3	124.6	125.0	124.2	125.0	124.0	124.56	1.0	0.45607
4	124.0	123.0	123.0	124.0	124.9	123.78	1.9	0.80125
5	124.0	124.3	124.0	125.0	124.5	124.36	1.0	0.41593
6	125.0	123.2	125.0	122.9	124.0	124.02	2.1	0.98082
7	123.5	124.9	124.0	125.9	124.5	124.56	2.4	0.91542
8	123.3	124.0	124.9	124.0	126.0	124.44	2.7	1.04067
9	124.5	123.2	125.0	124.0	123.6	124.06	1.8	0.71274
10	125.0	124.5	123.3	124.8	123.3	124.18	1.7	0.82280
11	123.0	124.0	124.8	122.5	123.0	123.46	2.3	0.92628
12	124.0	124.9	125.0	124.7	123.9	124.50	1.1	0.51478
13	124.0	123.5	123.2	123.9	125.0	123.92	1.8	0.68337
14	125.0	124.0	124.8	124.5	123.0	124.26	2.0	0.79875
15	124.8	125.0	124.5	123.5	123.8	124.32	1.5	0.64576
16	125.0	124.2	123.7	124.5	124.8	124.44	1.3	0.51284
17	123.6	124.2	124.6	125.1	123.3	124.16	1.8	0.73007
18	124.2	123.8	123.2	125.2	124.0	124.08	2.0	0.72938
19	124.5	123.8	123.1	124.5	125.5	124.28	2.4	0.89554
20	124.2	123.4	124.9	123.3	123.7	123.90	1.6	0.65955

5.2.1 X bar-R chart for D1

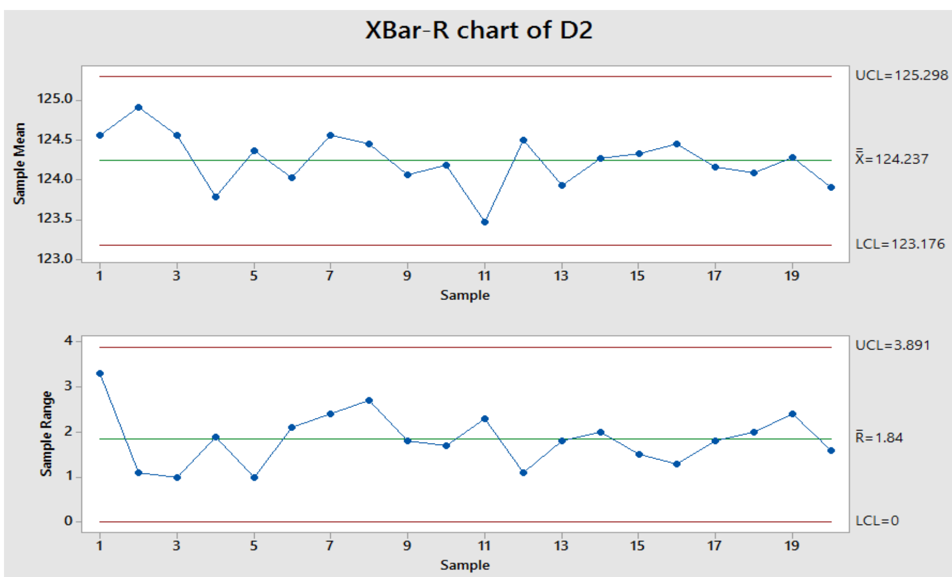

Figure 5.4 X bar-R chart of D2

In Figure 5.4 for the diameter D2, X-bar and R chart was created using statistical software Minitab 17 to monitor whether the process is in control condition or not. The results of the X-bar and R charts for the data are shows that the data for D2 is stable, since there is no out of control points in the chart. There is no assignable causes of variation and the process can be improved.

5.2.2 Frequency histogram for D2

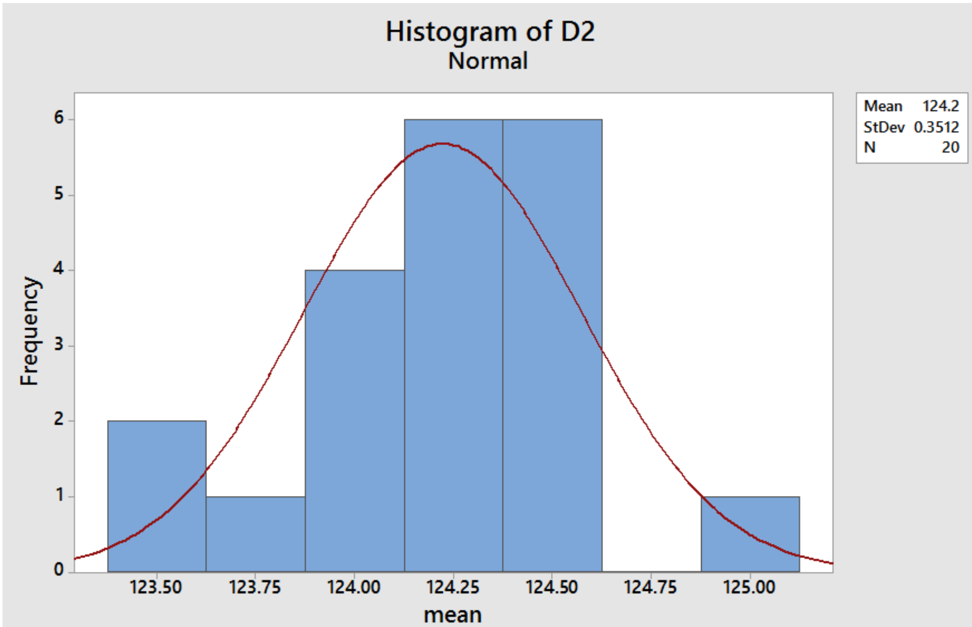

Figure 5.5 Frequency histogram of D2

The center of the histogram was estimated by calculating the average of the 100 readings. The frequency histogram with process mean of 124.2 and standard deviation of 0.3512 in figure 5.5 seems normally distributed; since the frequency histograms is properly centered and narrow enough to easily fit within the specification limits.

5.2.3 Probability plot for D1

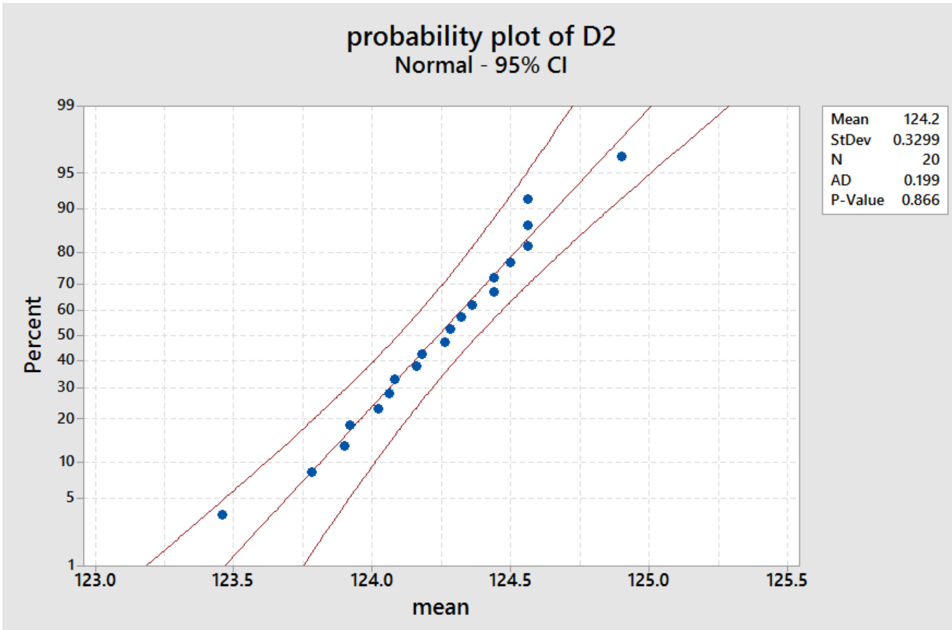

Figure 5.6 Probability plot of D2

The probability plot created using Minitab 17 for the input data of D2 in figure 5.6 with process mean: 124.2, standard deviation: 0.3299, Anderson-Darling test statistic value: 0.199 and p-value: 0.866. It is assumed that the data is distributed normally since p-value is greater than the significance level (α=0.05).

5.3 Stability and normality tests for D3

X bar-R chart, frequency histogram and probability plot were created to test stability and normality of the process. Table 5.3 shows the collected data from flange roller manufacturing process for outer diameter D3 with the calculated row statistics such as mean, range and standard deviation.

Table 5.3 Measured data for D3 with its mean and Range

No.	X1	X2	X3	X4	X5	mean	Range	StDev
1	152.0	152.4	152.5	151.5	152.0	152.08	1.0	0.39623
2	153.9	153.0	153.4	152.9	152.3	153.10	1.6	0.59582
3	152.5	152.9	152.9	152.7	153.9	152.98	1.4	0.54037
4	151.8	152.9	153.0	153.1	153.1	152.78	1.3	0.55408
5	154.0	153.0	151.2	153.0	153.1	152.86	2.8	1.01882
6	153.4	153.0	152.0	153.4	153.2	153.00	1.4	0.58310
7	152.0	153.1	152.0	151.5	154.0	152.52	2.5	1.01341
8	155.0	152.0	152.5	152.0	154.9	153.28	3.0	1.53851
9	152.5	154.0	153.2	153.8	152.3	153.16	1.7	0.75697
10	151.2	152.4	153.2	153.7	152.9	152.68	2.5	0.95237
11	153.0	152.6	153.3	154.3	151.5	152.94	2.8	1.02127
12	152.6	153.8	154.5	153.6	154.2	153.74	1.9	0.72664
13	151.8	151.2	153.1	154.2	152.0	152.46	3.0	1.19080
14	152.0	153.4	154.0	154.8	152.5	153.34	2.8	1.12606
15	151.4	151.8	153.2	154.6	153.6	152.92	3.2	1.31605
16	152.9	153.5	154.0	153.4	152.6	153.28	1.4	0.54498
17	153.6	151.1	152.3	153.4	153.8	152.84	2.7	1.13270
18	153.1	152.4	152.9	151.8	153.3	152.70	1.5	0.60415
19	153.5	154.0	152.9	152.2	154.2	153.36	2.0	0.82037
20	153.7	152.8	152.1	154.0	154.0	153.32	1.9	0.84083

5.3.1 X bar-R chart for D3

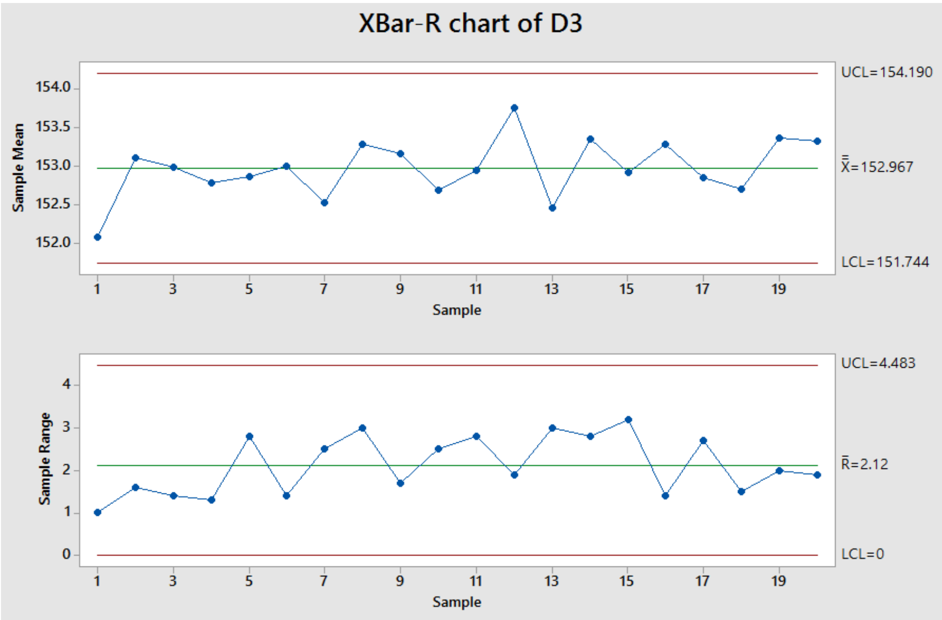

Figure 5.7 X bar-R chart of D3

To examine the stability of the process X bar-R chart was created using Minitab 17, the R chart is with in control limits and there is no out of control points in X bar chart. Therefore the process is in control and ready to be improved.

5.3.2 Frequency histogram for D3

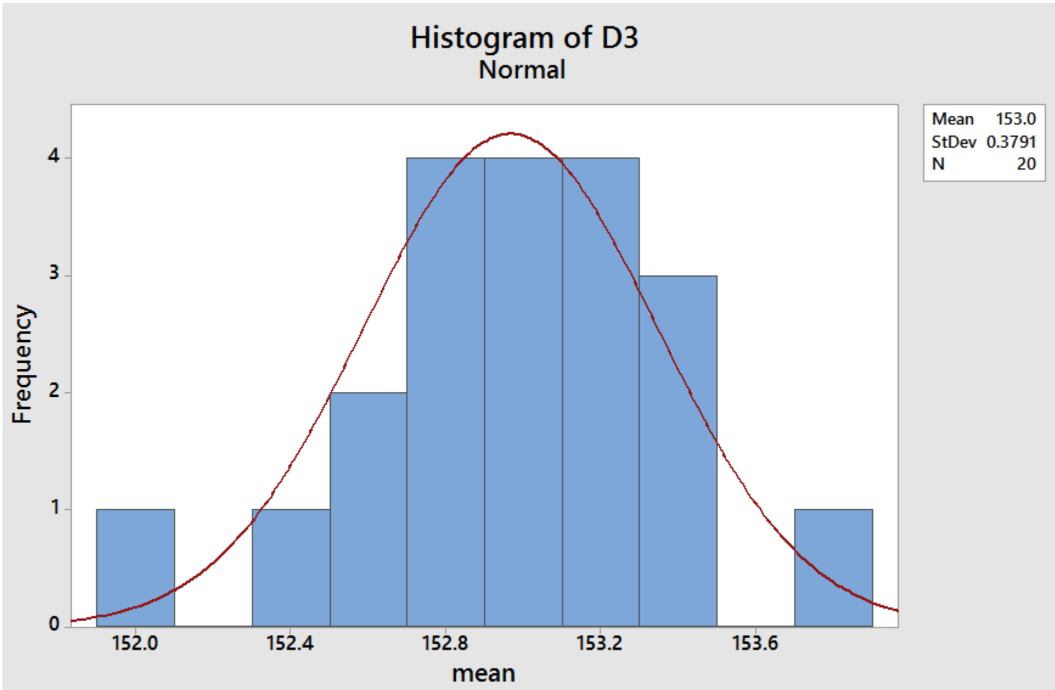

Figure 5.8 frequency histogram of D3

The frequency histogram for measured data of D3 in figure 5.8 shows a bell shaped appearance that is referred to as the normal curve. Therefore the histogram is properly centered and narrow enough to easily fit within the specification limits, thus the histogram is normally distributed.

5.3.3 Probability plot for D1

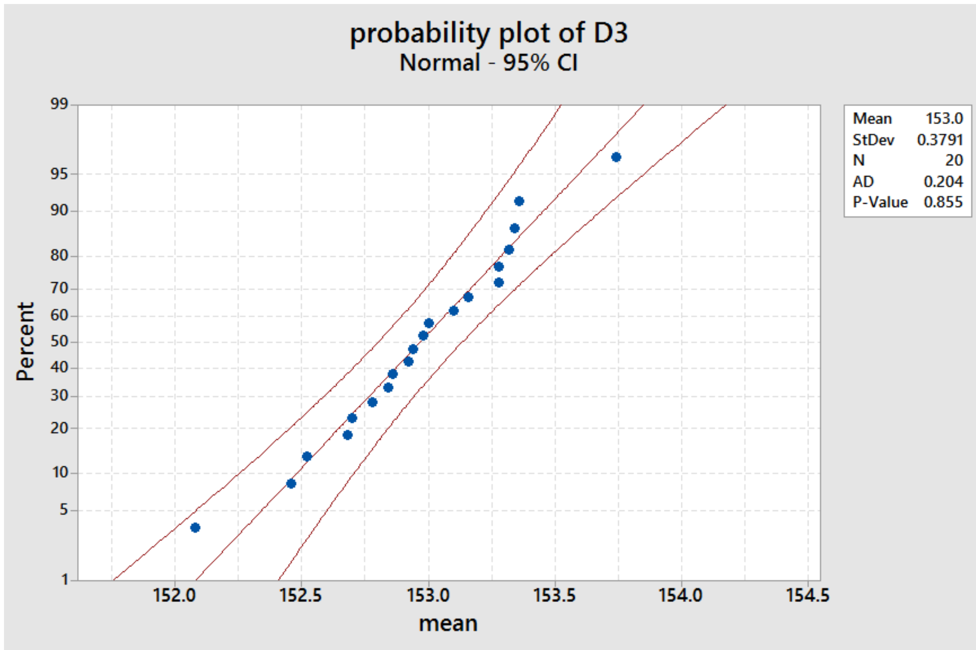

Figure 5.9 Probability plot of D3

The graph in figure 5.9 shows probability plot with process mean: 153.0, standard deviation: 0.3791, Anderson-Darling test statistic value: 0.204 and p-value: 0.855. It is assumed that the data is distributed normally since p-value 0.855 is greater than the significance level (α=0.05).

5.4 Stability and normality tests for D4

The stability and normality tests were performed using the collected data, and interpretation was done for X bar-R chart, histogram and probability plot in figure 4.11, 4.12 and 4.13 respectively. Table 5.4 shows the collected data from flange roller manufacturing process for flange diameter D4 with the calculated row statistics such as mean, range and standard deviation.

Table 5.4 Measured data for D4 with its mean and Range

No.	X1	X2	X3	X4	X5	mean	Range	StDev
1	184.5	184.8	185.1	183.9	185.0	184.66	1.2	0.48270
2	185.6	184.4	185.8	183.8	182.9	184.50	2.9	1.22066
3	186.0	186.0	184.5	184.6	183.9	185.00	2.1	0.95131
4	183.8	183.7	185.0	185.0	183.5	184.20	1.5	0.73824
5	183.0	183.2	183.6	184.0	183.5	183.46	1.0	0.38471
6	184.0	183.5	184.0	185.0	183.0	183.90	2.0	0.74162
7	184.5	184.0	184.0	184.0	183.0	183.90	1.5	0.54772
8	183.0	184.0	183.0	185.0	184.5	183.90	2.0	0.89443
9	184.0	184.8	183.5	183.9	185.0	184.24	1.5	0.63482
10	183.0	183.8	183.4	184.2	184.5	183.78	1.5	0.60166
11	183.9	184.5	185.5	183.2	183.0	184.02	2.5	1.01833
12	184.5	183.9	183.0	185.2	184.3	184.18	2.2	0.81056
13	184.9	185.5	185.0	183.4	183.9	184.54	2.1	0.86197
14	184.3	185.1	184.5	183.2	183.7	184.16	1.9	0.73348
15	184.6	185.0	184.7	184.0	183.7	184.40	1.3	0.53385
16	184.6	185.3	184.8	183.2	184.3	184.44	2.1	0.78294
17	184.0	184.5	183.6	184.2	184.8	184.22	1.2	0.46043
18	183.6	183.1	184.2	184.6	183.9	183.88	1.5	0.57184
19	183.5	184.0	184.5	183.7	183.2	183.78	1.3	0.49699
20	184.9	185.0	184.5	184.5	184.3	184.64	0.7	0.29665

5.4.1 X bar-R chart for D4

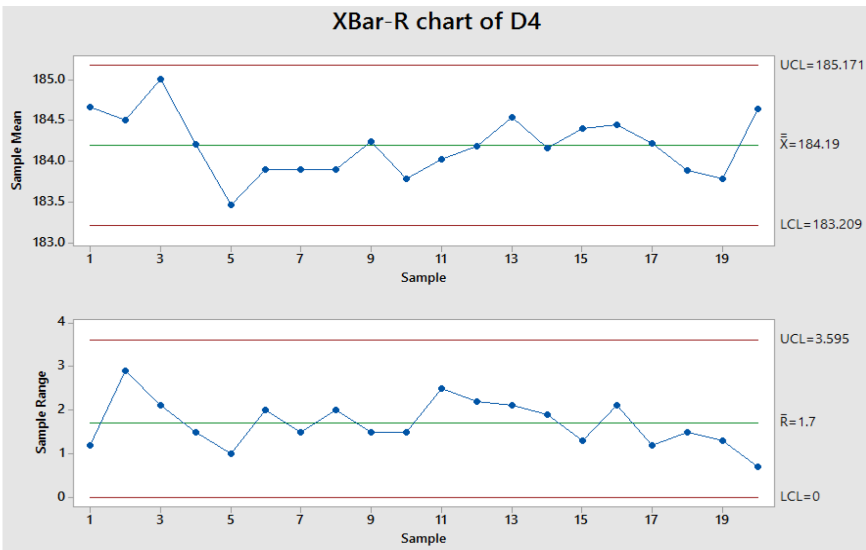

Figure 5.10 X bar-R chart of D4

From the X bar - R chart in figure 5.10 it was seen that the distribution is stable over the period of study since the range chart shows in control condition and also there is no out of control points in X bar chart. The process can be predicted and ready to be improved.

5.4.2 Frequency histogram for D4

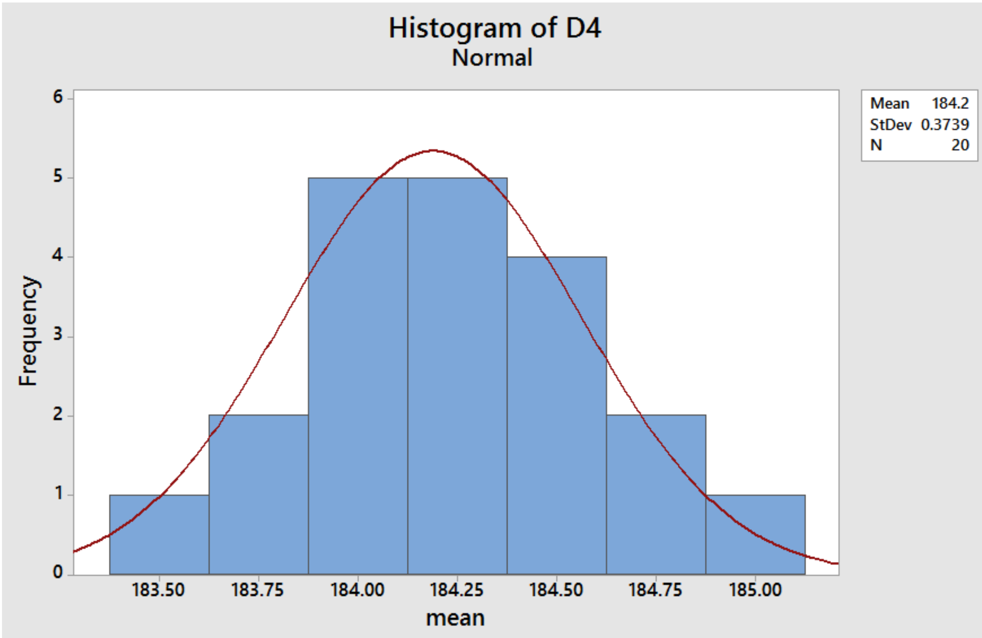

Figure 5.11 Frequency histogram of D4

The width of the histogram is estimated by calculating either the range or standard deviation. The standard deviation which represents the typical distance a unit is from the average calculated for 100 observations was 0.3739. The histogram in figure 5.11 for measured data of flange diameter D4 for process capability analysis seem to be approximately symmetric about to means, which indicates that the data is normally distributed.

5.4.3 Probability plot for D4

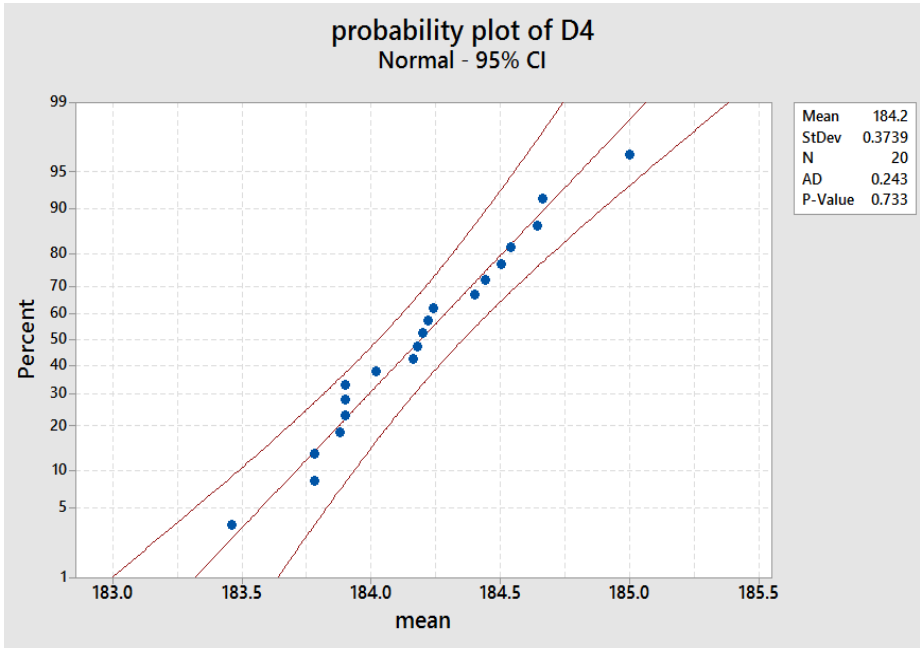

Figure 5.12 Probability plot of D4

The probability plot in figure 5.12 with process mean: 184.2, standard deviation: 0.3739, Anderson Darling test statistic value: 0.243 and p-value: 0.733 depicts that the data is distributed normally since p value is greater than the significance level (α=0.05).

5.5 Stability and normality tests for height

To perform capability analysis for the height of the product stability and normality was checked with the real industry. Table 5.5 shows the collected data from flange roller manufacturing process for height with the calculated row statistics such as mean, range and standard deviation.

Table 5.5 Measured data for height with its mean and Range

No.	X1	X2	X3	X4	X5	mean	Range	StDev
1	71.5	71.0	72.0	71.3	69.8	71.12	2.2	0.82280
2	72.1	72.9	71.8	72.5	72.0	72.26	1.1	0.43932
3	74.5	74.0	71.3	72.1	73.4	73.06	3.2	1.33154
4	72.5	74.0	71.0	72.0	72.3	72.36	3.0	1.08305
5	74.0	71.0	71.0	72.0	71.1	71.82	3.0	1.28919
6	72.0	71.9	73.5	71.0	72.4	72.16	2.5	0.90719
7	69.0	73.0	72.0	71.1	71.9	71.40	4.0	1.50167
8	73.0	72.2	72.0	72.8	72.5	72.50	1.0	0.41231
9	71.0	74.3	72.3	71.0	74.5	72.62	3.5	1.71085
10	71.8	72.6	73.1	72.0	72.1	72.32	1.3	0.52631
11	72.0	73.0	73.8	74.3	71.5	72.92	2.8	1.17771
12	72.3	71.5	71.5	71.3	73.2	71.96	1.9	0.79246
13	73.0	73.9	74.3	74.0	73.7	73.78	1.3	0.48683
14	72.4	72.5	73.4	72.0	74.4	72.94	2.4	0.96333
15	72.3	71.8	68.9	73.2	74.1	72.06	5.2	1.97307
16	73.8	72.1	71.8	73.2	73.0	72.78	2.0	0.81976
17	71.7	72.4	73.2	73.6	70.1	72.20	3.5	1.38384
18	72.5	73.7	73.0	72.2	73.0	72.88	1.5	0.57184
19	72.0	71.0	71.8	72.4	73.0	72.04	2.0	0.74027
20	71.9	72.5	74.1	73.5	69.6	72.32	4.5	1.74413

5.5.1 X bar-R chart for height

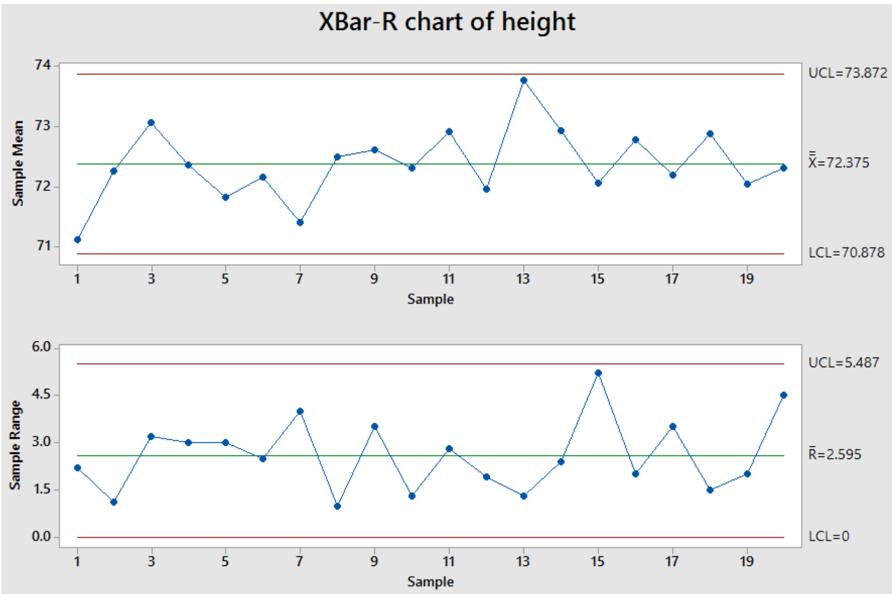

Figure 5.13 X bar-R chart of height

X bar-R chart is created in figure 5.13 using the measured data for height of the product to monitor process mean and variation. The R chart in the above figure shows that the process variation is in control; therefore the control limits in X bar chart are accurate the process is in statistical control.

5.5.2 Frequency histogram for height

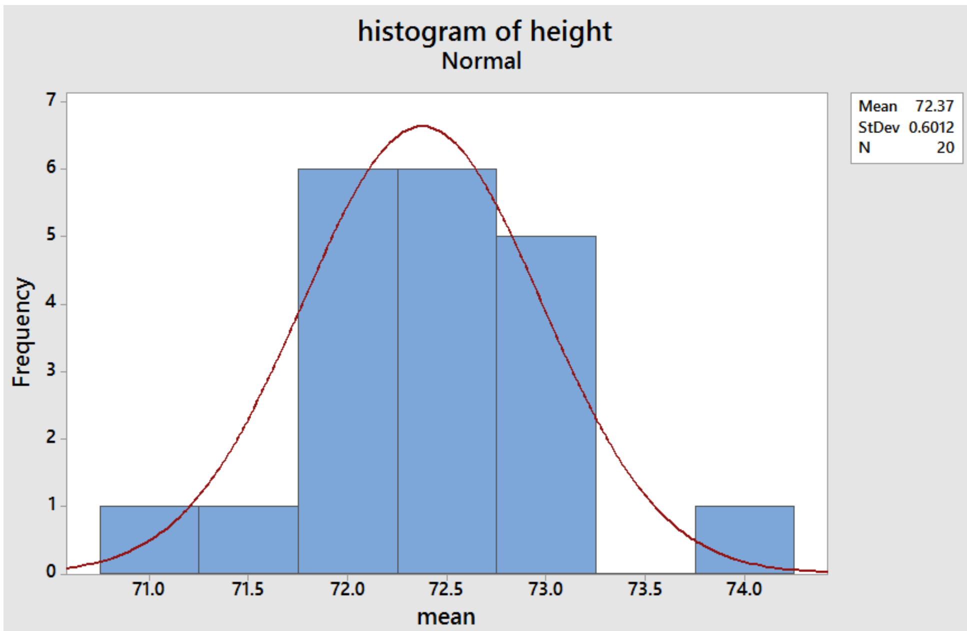

Figure 5.14 Frequency histogram of height

The frequency histogram in figure 5.14 with mean 72.37 and standard deviation 0.6012 for the height of a product seems to be symmetric about to means which indicates that the data is normally distributed.

5.5.3 Probability plot for height

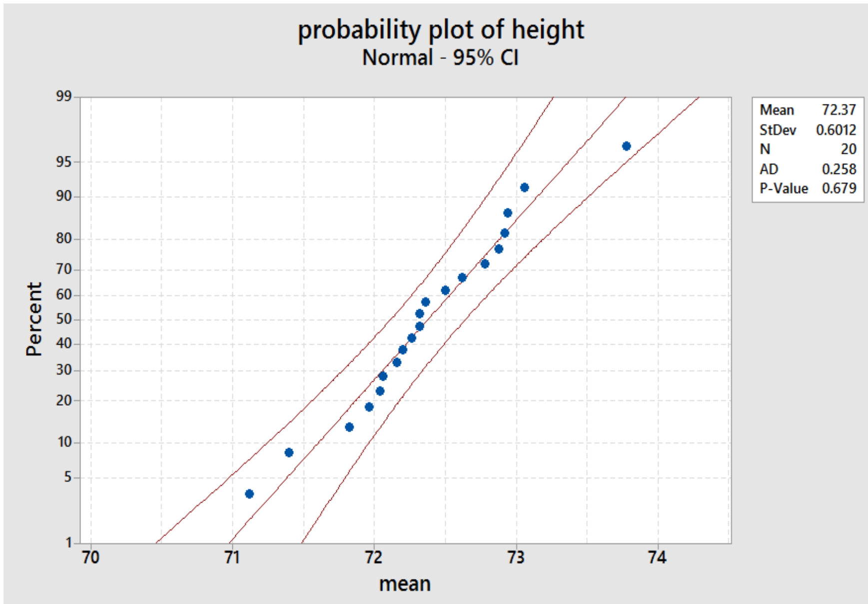

Figure 5.15 Probability plot of height

The graph in figure 5.15 is the probability plot for the data of height of the product with process mean: 72.37, standard deviation: 0.6012, Anderson-Darling test statistic value: 0.258 and p-value: 0.679. One of the critical assumption that output data must follow a normal distribution is accepted for the data of height of the product because the p-value is greater than the significance level (α=0.05).

5.6 Process capability report and interpretation

The critical assumptions to validate the data are ensured for the selected critical to quality characteristics; therefore it is possible to evaluate the process capability analysis of flange roller production.

5.6.1 Process capability report for D1

The process capability report for the inner diameter of flange roller manufacturing process is derived from Minitab 17 is given in figure below.

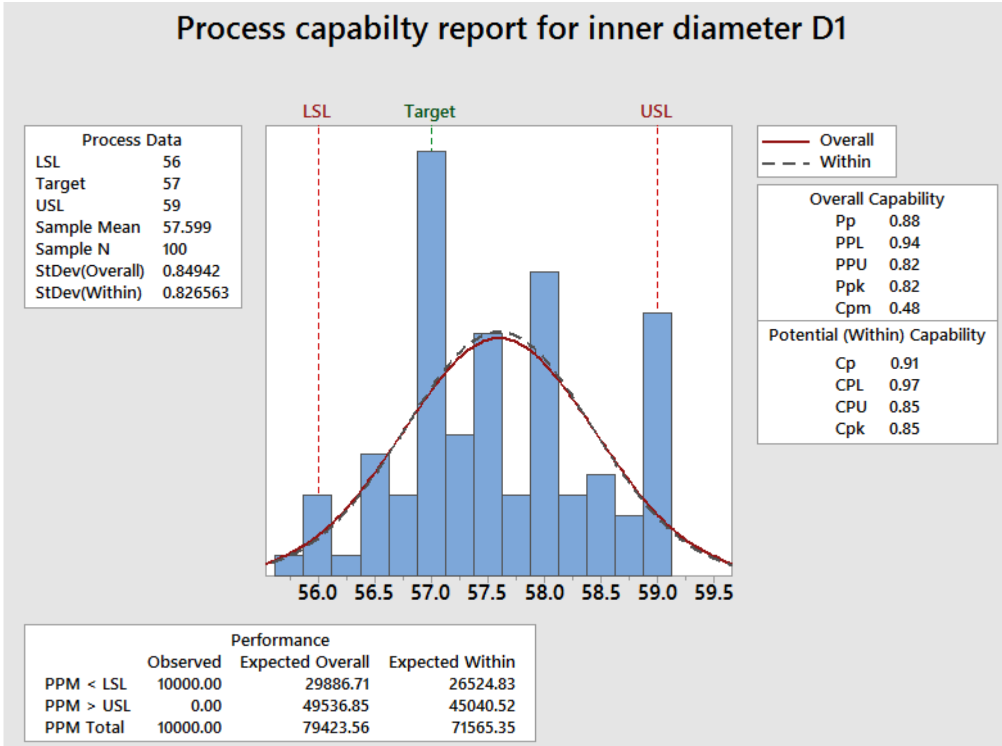

Figure 5.16 process capability report for D1

The result in figure 5.16 which was derived from statistical software Minitab 17 shows that the process is almost in center but the process is not capable for D1 since Pp = 0.88, Ppk = 0.82, Cp= 0.91 and Cpk = 0.85 are less than 1.33 based up on the rule of thumb on table 2.2 and 2.3.

5.6.2 Process capability report for D2

The process capability report was created for D2 in the figure 5.17. The report includes the process data, overall and potential capability indices and performance.

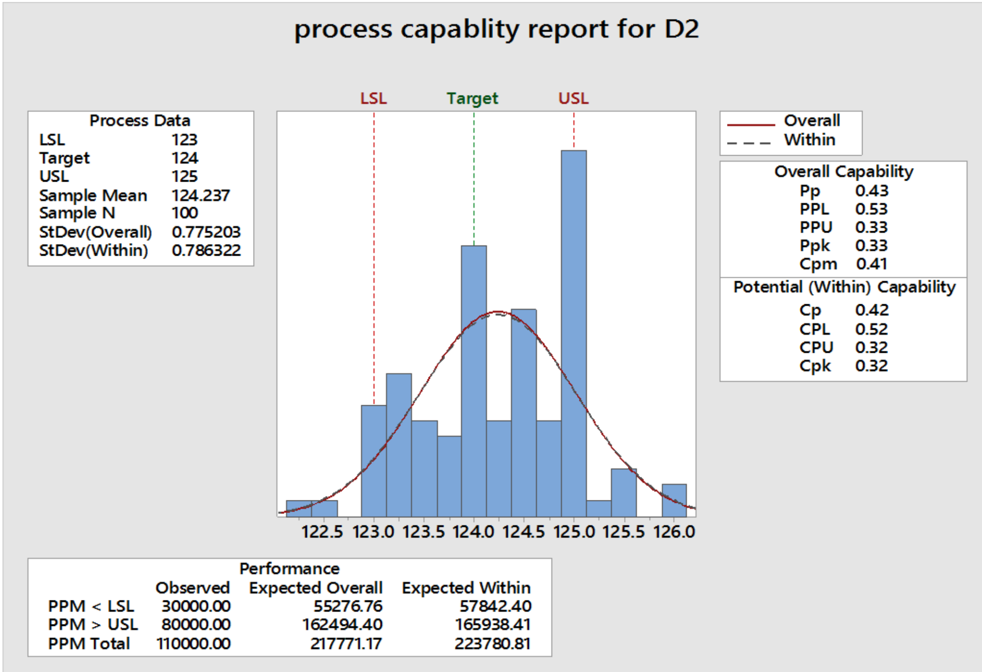

Figure 5.17 process capability report for D2

The results for the diameter D2 in figure 5.17 indicate that the process is not capable to produce the products with the required specifications, since the values of the main capability indices Cpk and Ppk are less than 1.33 which is the benchmark value of industry.

5.6.3 Process capability report for D3

Figure 5.18 is the normal process capability report for the outer diameter D3 of the product created using Minitab 17.

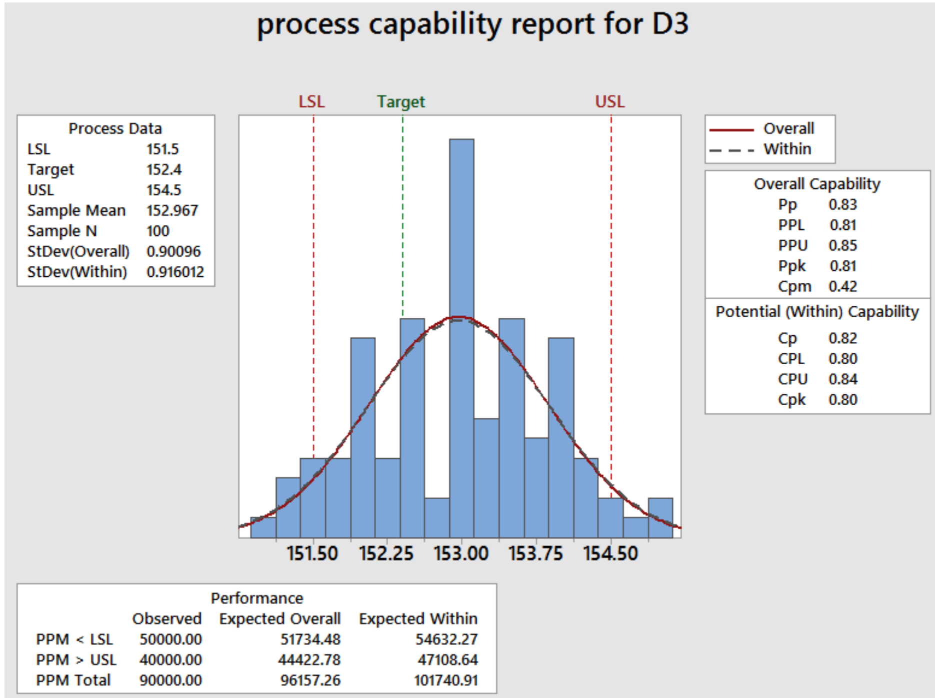

Figure 5.18 process capability report for D3

To evaluate the potential capability of the flange roller casting process based on both process location and spread consider Cp, Cpk and Pp, Ppk values in figure 5.18. Since Cp, Cpk and Pp, Ppk are approximately equal, it is considered that the process is centered between the specification limits. But Cpk = 0.80 and Ppk = 0.81 for the production process indicates that the potential capability of the process does not meet the requirements because values are less than 1.33.

5.6.4 Process capability report for D4

The potential and overall capability indices are developed for the flange diameter using the specified specification limits from Minitab 17 in the figure 5.19.

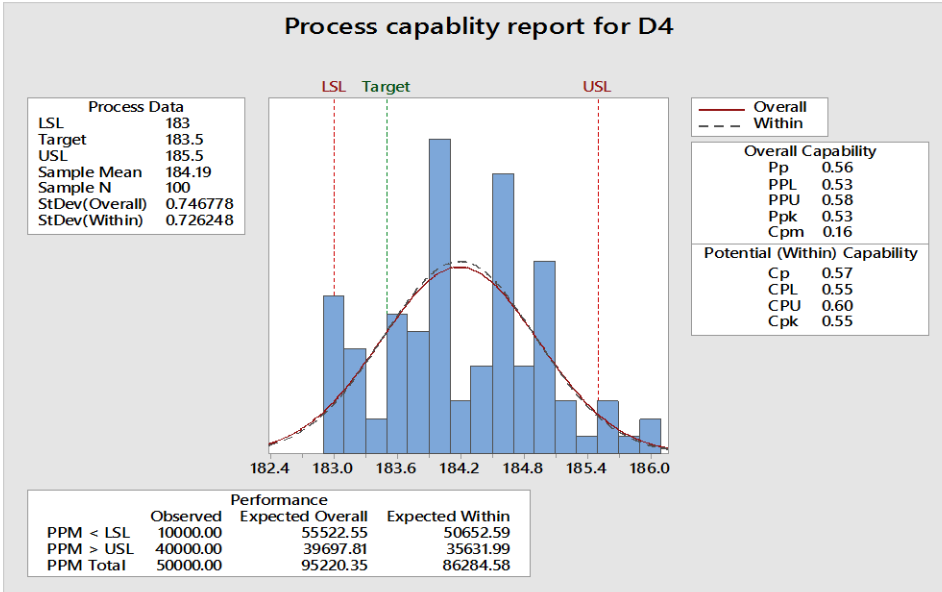

Figure 5.19 process capablity report for D4

Figure 5.19 shows that the potential capability indices Cp and Cpk and overall capability indices Pp and Ppk are approximately equal. Therefore, the process is centered between the specification limits. However Cpk value 0.55 is less than 1.33 and also Ppk value 0.53 is less than the benchmark value. Therefore the process is not adequate and it needs ways to improve the process.

5.6.5 Process capability report for height

Figure 5.20 shows the process capability report for the height of the product with process data. Potential capability indices and overall capability indices created using statistical software Minitab 17.

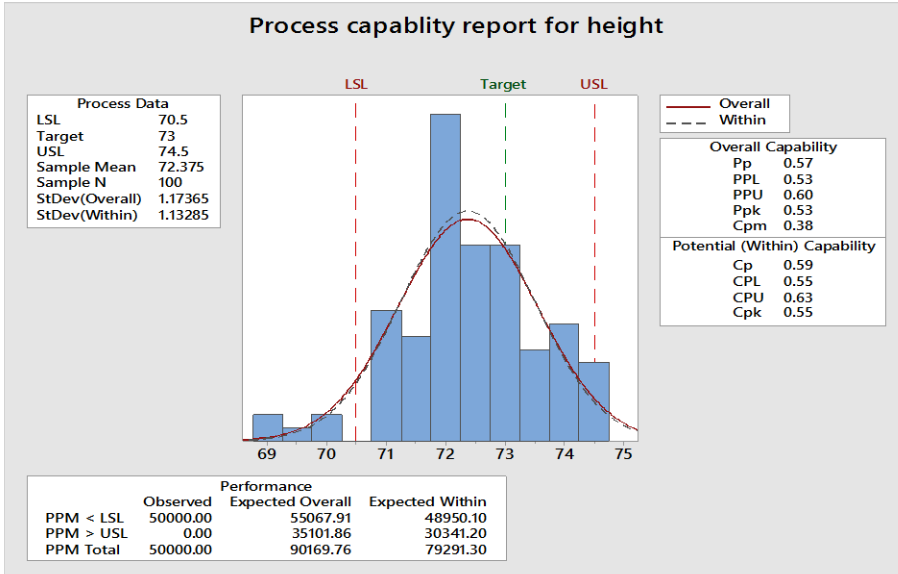

Figure 5.20 Process capability report for height

For these process data Cpk = 0.55 and Ppk = 0.53 which indicates the potential and overall capability of the process does not meet requirements, because Cpk and Ppk are less than 1.33. But the process is centered, so Cp (0.59) equal to Cpk and Pk is also approximately equal to Ppk (0.53).

5.7 Performance in terms of PPM

Another capability index is Parts per Million (PPM). This index indicates the ratio between the number of pieces exceeding the specification limits and a million produced units. PPM can be estimated based on empirical data i.e. the number of exceeding elements over one million. The data to the left bottom side for the capability report of D1, D2, D3, D4 and height indicates the observed performance, expected overall and expected between performances generated from Minitab 17 with the collected data, the inference is as below.

Table 5.6 the observed performance in terms of PPM

	D1	D2	D3	D4	H
PPM < LSL	10000	30000	50000	10000	50000
PPM > USL	0	80000	40000	40000	0
PPM total	10000	110000	90000	50000	50000

Table 5.7 the expected overall performance in terms of PPM

	D1	D2	D3	D4	H
PPM < LSL	29886	55276	51734	55522	55067
PPM > USL	49536	162494	44422	39697	35101
PPM total	79423	217771	96157	95220	90169

Table 5.8 the expected within performance in terms of PPM

	D1	D2	D3	D4	H
PPM < LSL	26524	57842	54632	50652	46950
PPM > USL	45040	165938	47108	35631	30341
PPM total	71565	223780	10740	86284	79291

Note:

The value of PPM < LSL means that value of parts per million are expected to have measurements less than the LSL.

The value of PPM > USL means that value of parts per million are expected to have measurements greater than the USL.

- In observed performance all the measurements are not located within the specification limits, hence the values of PPM total out of specification for D1, D2, D3, D4 and h are: 10000, 11000, 90000, 50000 and 50000 respectively.
- The actual process performance which is calculated by using the overall sample variance is basically represented by the expected overall performance. The total PPM out of specification limits which are the total of PPM < LSL and PPM > USL of D1, D2, D3, D4 and h are: 79423, 217771, 96157, 95220 and 90169 respectively.
- The expected "within" performance values quantitatively represent the potential process performance if the process did not have the shifts and drifts between subgroups. The expected values are calculated using the within subgroup variation. The total PPM out of specification limits for D1, D2, D3, D4 and h are: 71565, 223780, 10740, 86284 and 79291 respectively. Therefore, for all critical to quality characteristics it is clear that how much product is falling beyond specification.

5.8 Brainstorming session and findings of the root causes of variation

In a brainstorming session a team tried to identify and graphically display all the possible causes of the problem. During brainstorming session, the possible causes of variation of diameters and height of the product are identified and they are indicated in root and cause diagram (fishbone diagram). Ishikawa or fishbone diagram was formulated which is shown in figure 5.21.

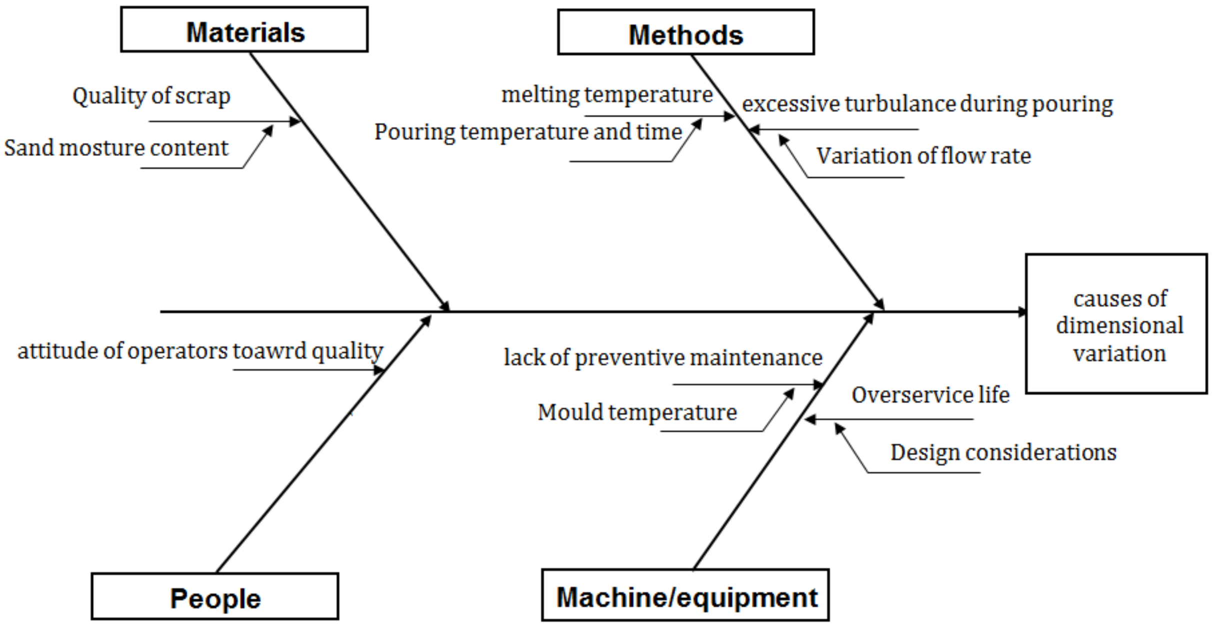

Figure 5.21 Ishikawa (Fishbone) Diagram

5.9 Corrective action

During the brainstorming session the potential causes contributing for variability were identified and they mainly include: melting and pouring temperature, sand moisture content, scrap content, turbulence, design of equipment, variation of flow rate, over service life of equipment and so on. The following points were discussed with the industrial experts and finally concluded to implement corrective actions in order to minimize variation and maximize the overall and potential capability indices for the production process of product.

5.9.1 Design considerations and suggestions

Improper methods of Pattern making, moulding and casting procedure, potentially leads to dimensional faults. Dimensional variation can be considerably reduced by implementing the design considerations such as: pattern, riser and core location, mould, and proper sprue design. The following important design considerations are needed to be considered while designing equipment for sand cast products since they have been identified as the causes of problems.

5.9.1.1 Pattern:

The pattern in a case study industry to produce flange roller is made up of wood and the shrinkage allowance given was 0.80% which was not sufficient. This excess dimension provided is known as pattern shrinkage allowance. The dimension of the cast product gets reduced as compared with the mould cavity. But, the amount of shrinkage occur depends upon the type of metal. Table 5.9 shows shrinkage allowance of various metals commonly cast in sand mould. Therefore, the recommended value for shrinkage allowance is from 0.83% to 1.3% for gray cast iron. Even using shrinkage allowance of 1.1% is better for flange roller production process. Since, it is optimum value and the dimensions are higher than the required, increasing shrinkage allowance minimizes variation.

Table 5.9 Shrinkage allowance for metals used in sand moulds (Bralla, 1999)

Metal	Allowance (%)
Gray cast iron	0.83-1.3
Ductile cast iron	0.83-1.0
Aluminum alloys	1.3
Yellow brass	1.3-1.6
Gunmetal bronze	1.0-1.6
Phosphor bronze	1.0-1.6
Aluminum bronze	2.1

5.9.1.2 Optimize gating system

(Kermel, 2016) Suggested optimizing gating and riser system reduces the amount of metal poured into the mold without deteriorating product quality, resulting in lower energy requirements for melting and increased dimensional accuracy. When designing the gating system in the foundry, the following general gating system design rules should be considered.

a. A gating system should fill the mold cavity completely before freezing.

b. A turbulence metal flow tends to form dross in the mold. Avoid sudden or right angle changes in flow direction.

c. A proper thermal gradient should be maintained so that the casting is cooled without any shrinkage cavities or distortions.

5.9.1.3 Optimized Riser, sprue and core design

Risers help to feed liquid metal into the last portion of the casting. The proper placement of the risers on castings changes the way in which both the casting and riser solidify such that the riser is the last to solidify. When the risers are designed correctly, a casting can be compensated from all types of shrinkages encountered during solidification. For top risers, riser height should be at least equal to the riser diameter and the recommended minimum height of riser is 102 mm and the maximum is 178 mm. Sprue helps in getting the melt down to the lowest level of the mold while introducing a minimum of defects despite the high velocity of the stream. Sprue should be designed as narrow as possible so that the metal has minimal opportunity to break and entrain its surface during the fall. To reduce air entrapment and oxide formation, sprues should be tapered so as following a model the taper that the falling stream adopts naturally as a result of its acceleration due to gravity. Often use of cores are unavoidable and are used to make holes. In such case, the core diameter should have at least equal to the surrounding wall thickness and preferable twice the wall thickness or more. If possible, side bosses and undercuts should be avoided. In case internal cores are used, addition of venting holes is required for removing the gases that are generated while the core comes in contact with the molten metal. The core and pattern in the case study industry is old enough and it is not in original dimension which introduces dimensional error.

5.9.2 Improving quality in recycled scraps

The case study industry was using scrap of different forms that are dirty and wet. The dirty or contaminated scrap tends to deposit a slag layer on the furnace refractory. This occurs at or just below, the liquid metal level the crucible and increases the amount of power that is drawn to the furnace. Wet or oily metal must not be charged, unless drying or pre-heating facilities are available. Table 5.10 shows the effect of inadequate raw material control on cast iron castings quality

Table 5.10 the effect of inadequate raw material control on iron castings quality (Watford, 2000)

Raw material	Examples of lack of control	Immediate effect	Effect on casting quality
Cast iron scrap	• Return scrap and bought scrap not segregated by grade • Some pieces of scrap too large • Non-ferrous parts containing lead, the aluminum etc., not removed from:bought scrap • Excess of vitreous enameled scrap in each charge	• Charge compositions not correct • Bridging and uneven melting • Contamination of the metal with: aluminum, lead, boron, antimony.	• Metal not to specification • Variable metal temperature and composition • Chill and increased hardness

Therefore, it has been suggested that the industry is to use clean scrap metal to avoid sand and rust before charging. And also it is an prerequisite that only dry material is loaded into a hot induction furnace (Kermel, 2016). Adding oily and moisture scrap metal will lead to severe explosions. Therefore, it is recommended that either operate the furnace in continuous batch mode, where any humidity is removed in the start-up process, or to preheat the metal charge.

5.9.3 Moisture content in molding sand

Moisture on molding sand should be determined before preparing mould. Maintaining the proper moisture levels when producing sand molds helps to achieve the required quality. To determine the percent of moisture content on sand, equation 5.1 with weight of aggregate and dry weight of aggregate of the sand can be used. The industry was not using any mechanisms to determine the moisture content and therefore it is suggested to use equation 5.1 or any other mechanisms to determine the moisture content and control it. (Aondona, 2011) Suggested that moisture content for natural sand should not go beyond 8% because, when the moisture content is increased more than the optimum range shrinkage cavities grow.

$$\text{Sand moisture content (\%)} = \frac{X-Y}{Y} X\ 100 \qquad (5.1)$$

Where, X is weight of aggregate and Y is dry weight of aggregate.

5.9.4 Pouring temperature and time

Pouring temperature, the initial temperature of molten metal used for the casting as it is poured in to the mold is higher than the solidification temperature of the metal. (Datau s., 2012) Stated that when the pouring temperature is lower than its optimum value, the mould cavity will not be filled because the gate or riser will solidify too rapidly and this will intercept directional solidification. Therefore the pouring temperature had to be higher by about 10 – 20 ºC than the initial melting temperature (Yury S, 2013). The industry was using the pouring temperature of 1450°C which is lower than the recommended optimum temperature. Because when the molten metal is poured in to the mold cavity with lower pouring temperature, the molten metal may solidify before reaching to the mold cavity. Therefore it is suggested to use the pouring temperature of 1470°C because the pouring temperature and distance to carry molten metal to the mold for improving the sound cast. Short pouring times decreases the exposure of molding sands to moving metal and minimize the time available for re oxidation. The average pouring time (seconds) for most castings is equal to the square root of the weight which is shown in equation 5.2.

$$PT = (Wt)^{0.5} \tag{5.2}$$

Where, PT is pouring time and Wt is weight of the product.

The weight of flange roller is 7kg. Therefore pouring time calculated using equation 5.2 is 2.645 seconds for pouring of a single flange roller.

5.9.5 Temperature of a mould

The quality of cast products is significantly affected by the temperature of the mould. When the mould is cold, joints are formed in the casting and the surface quality of casting is insufficient. When the mould is very hot, the alloys are bonded to the mould and the amount of bubbles and pores grows. Therefore the temperature of the mould should be maintained constantly at approximately 1/3 of the temperature of the cast metal (Yury S, 2013). Therefore the temperature of the mould should be maintained at a temperature of 1/3 of the cast metal. This can be achieved by placing the assembled moulds in a furnace and preheating to temperatures of 1/3 of the cast metal or by the thermoregulation of the mould. It is also suggested to avoid inadequate venting of mould by reducing excessive ramming and increase vent by means of vent wire.

5.9.6 Turbulence

Turbulence is inconsistent and irregular variations in the speed and direction of flow throughout the liquid metal as it travels through the casting. Excessive turbulence is the identified cause of variability in the foundry. Pouring rate, a volumetric rate in which the liquid metal is introduced in to the mold contributes a lot for turbulence. In the production process of flange roller, pouring rate needs to be carefully controlled during the molten metal pouring operation. If the pouring rate is too fast, then turbulence can be resulted. If it is too slow, the metal may begin to solidify before filling the mold. Therefore it is suggested to use a constant pouring time of 2.645 seconds for pouring of a single flange roller calculated by using equation 5.2 to minimize variation of flow rate and turbulence.

5.9.7 Melting temperature and time

The material for flange roller manufacturing was cast iron. Cast iron is continuously melted in three induction furnaces available with the capacity of 3 ton each. The standard melting temperature for melting of cast iron in a furnace is up to 1510°C. But, in the industry due to induction furnace problem the melting temperature deviates from the standard melting point, it was lower than the desired or sometimes very higher than the limit. Lower rate heating furnace took long time to melt the metal and excessive time will cause all refractory materials to soften and melt, and will increase the rate of lining attack significantly. High power medium frequency coreless furnaces having very high superheating capabilities, possibly in excess of 50°C per minute; therefore, adequate control or supervision is necessary to avoid overheating. Table 5.11 shows melting temperature for some metals. The melting time for flange roller casting process can be calculated using equation 5.3 where, power consumption of cast iron is in a range of 500 to 570kw/ton as shown in table 5.12 and the input power available for furnace is 600kw.

$$\text{Melting time} = \frac{A}{B} \times 1\text{hr.} \qquad (5.3)$$

Where, A is power consumption of the metal and B is the input power available of furnace

Therefore, taking the average power consumption of 535 and the input power available of 600kw, the melting time calculated was 0.891 hour per ton.

Table 5.11 Melting temperature for some metals

Metal	Melting temperature (°C)
Aluminum	600
Copper	1084
Cast iron	1450 - 1510
Stainless steel	1510
Nickel	1453

Table 5.12 Power consumption of different metals

No.	Scrap type	Power Consumption (kWh/ton)
1.	Steel	620-640
2.	Cast iron	500-570
3.	Light Aluminum	600-630
4.	Solid Aluminum	500-550
5.	Mild/ Stainless Steel	600-660

5.9.8 Over service life and Maintenance

When an equipment and machine total life in use is for long duration of time or when equipment is used over time, the normal wear and tear will reduce the reliability of the equipment and increases maintenance expense. The equipment in a case study industry which was used for a long time and contributing for variation are: induction furnace, pattern and grinding machine. The foundry basically has three induction furnaces with the capacity of 3.3 ton each. The industry also uses by modifying old method for casting and also the grinding machine was used for a long time without dressing frequency and it stacks many times. The furnace in the industry stops suddenly many times and due to this the production process has been stopped since the furnace is main system providing molten metal for casting. The industry must develop scheduled planned maintenance which can maximize machine performance by keeping machine running safely for as long as possible without having unplanned outages. Therefore it has been suggested that proper scheduled maintenance tasks(weekly and Monthly) to initiated based up on equipment running hours, casting process and number of items produced.

5.9.9 Training for man power

Providing regular training, industry can more easily identify the problems and skill gaps within the existing workforce. By identifying these gaps early, it is possible to train the staff in these required areas so they can fulfill the role effectively. Therefore it has been suggested to provide additional training to workers on statistical process and quality control. And also the industry must have skilled man power for maintenance because, the furnace stops working many times and it took two months and more to maintain the furnace.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

From the performed process capability analysis, the following conclusions can be formulated:

- For the capability analysis the tested data for normality indicates that the process considered is normal and in control condition, consisting common causes of variation in a process which can be improved.
- From the analysis potential and overall capability indices are calculated using Minitab 17 and the value of Cp and Cpk for the inner diameter D1 is 0.91 and 0.85; for the diameter D2 is 0.42 and 0.32; for the outer diameter D3 is 0.82 and 0.80; for the flange diameter D4 is 0.57 and 0.55 and for the height is 0.57 and 0.55 respectively.
- The value of overall capability indices Pp and Ppk for the inner diameter is 0.88 and 0.82; for the diameter D2 is 0.43 and 0.33; for the outer diameter D3 is 0.83 and 0.81; for the flange diameter D4 is 0.56 and 0.53 and for the height is 0.56 and 0.53 respectively.
- The analysis reveals that even though the process is centered, the process is not capable to manufacture flange roller with the customer specification limits Since the value of Cp, Cpk , Pp and Ppk of D1, D2, D3, D4 and height obtained is less than the desired value.
- In observed performance the values of PPM total out of specification for D1, D2, D3, D4 and h are: 10000, 11000, 90000, 50000 and 50000 respectively. In expected performance the total PPM out of specification limits of D1, D2, D3, D4 and h are: 79423, 217771, 96157, 95220 and 90169 respectively. In expected "within" performance the total PPM out of specification limits for D1, D2, D3, D4 and h are: 71565, 223780, 10740, 86284 and 79291 respectively.
- The root causes identified during brainstorming session are mostly due equipment, method and materials. It was suggested to implement provided corrective actions in order to minimize variation and maximize the overall and potential capability indices for the production process of product.

6.2 Recommendation

- ➢ The root causes for the dimensional variation of flange roller can be reduced by implementing changes in manufacturing process, supplying quality raw materials and improving material inspection.
- ➢ The industry must apply planned maintenance especially for induction furnace and automatic ramming machine.
- ➢ It is suggested to use SPC tools and process capability indices as it could improve process performance and quality of the products.

6.3 Scope for future research

To assess the quality of overall production process, multivariate process capability indices analysis can be to handle the corresponding quality related problems. The process capability analysis with the same technique and procedure can be applied to surface roughness, weight of product machine and human capability. Also the SPC technique and results presented in this thesis could be tested in other industrial processes and products like, machining process, chemical industry, bottle manufacturing, textile industry and automobile industry

References

1. Abhijeet B. Vante, G. (2015). Quality Improvement for Dimensional Variations in sand Casting Using Quality Control Tools. International Journal of Innovative Research in Science,Engineering and Technology, 6917-6926.
2. Adeoye Akeem, A. S. (2013). Process Capability Analysis as a Means of Decision Making in manufacturing company. International Journal of Advanced Research in Computer Science & Technology (IJARCST), 1(1), 15-18.
3. Ajit Pal Singh, Y. M. (2013). Quality improving using statistical quality control tools in glass bottles manufacturing company. International Journal for Quality Research 7(1), 107-126.
4. Alam, G. A. (2014). Improving Quality and Productivity in Manufacturing Processby using Quality Control Chart and Statistical Process Control including Sampling and Six Sigma. Global Journal of Research in Engineering, 14(3), 1-20.
5. Alexis Aitken, J. H. (2010). Handbook on improving quality by analysis of process variables. Europian commision eurostat.
6. Ali Mostafa, A. S. (2012). The use of Statistical Process Control Technique in theCeramic Tile Manufacturing: a Case Study. International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868, 2(5), 14-19.
7. Andrew A. Erameh, Nurudeen A. Raji, Rasheed O. Durojaye,Abiodun A. Yussouff. (2016). Process Capability Analysis of a Centre Lathe turning process. journal of engineering, 79-85.
8. Belokar, P. K. (2012). Improving the process capability of boring operation by the application of statistical techniques. International journal of scientific and Engineering research, 1-6.
9. Bralla, J. G. (1999). Design for Manufacturability Handbook. New york: McGraw Hill.
10. C.W.Ammen. (1997). The complete hand book of sand casting. Blue ridge summit.
11. Datau s., E. I. (2012). The effects of sand casting process parameters on mechanical properties of Al alloy casting. International Journal of Metallurgical & Materials Science and Engineering (IJMMSE), 2(3), 32-41.

12. Dr Bharat Chede,Prof Aparna Chede,Dr Ajay Mishra. (2016). Statistical Process Control a Rejection Control Tool “A Case Study”. International Journal of Research and Engineering , 7-9.
13. Dr. Kabaday Nihan. (2015). Process Performance Analysis in the Production Process of Medical Bottles. international journal of bussiness and management, 159-167.
14. Dr.Kapadia, M. (2015, September 4). Symphoney technologies. Retrieved November 6, 2017, from Symphoney technologies: http://www.symphonytech.com
15. Gabriele Arcidiacono, S. N. (2017). A Review of the Fundamentals on Process Capability, Process Performance,and Process Sigma, and an Introduction to Process Sigma Split. International Journal of Applied Engineering Research, 12(14), 4556-4570.
16. Gajendra Patidar,Dr. Devendra Singh. (2015). implementation of statistical control in small scale industry- A review. International Journal of Emerging Technologies and Engineering, 120-124.
17. Heena Sharma, D. N. (2017). Implementation of Quality Control Tools and Techniques inManufacturing Industry for Process Improvement. International Research Journal of Engineering and Technology (IRJET), 4(5), 1581-1587.
18. J.M.Juran, A. G. (1999). Quality control handbook (5th ed.). New york: Mc.Grew Hill.
19. K.Rezai, B. M. (2009). Application of process capability and performance indices. international journal of applied science, 2(5), 1186-1191.
20. Katerina Kermel, R. D. (2016). Energy Efficiency and Cost Saving Opportunities for Metal Casting. USA: Energy star.
21. Kermel, K. (2016). Energy Efficiency and Cost Saving Opportunities for Metal Casting. USA: Energy sta.
22. Konzer, v. (2005, february). Process Capability Investigation for Measurable Characteristics. volkswagen AG, pp. 1-64.
23. Libest B, s. M. (2012, october 3). Process capability and statistical quality control. study lib, pp. 300-314.
24. Marilyn K. Hart, P. &. (2007). introduction to statistical process control techniques. Corvallis, Oregon: Statit Software, Inc.
25. Marilyn K. Hart, Robert F. Hart (PHD). (2007). Introduction to statistical process control technique. Corvallis, Oregon: Statit Software.

26. Metin Uçurum, M. Ç. (2016). Implementation of Statistical Process Control (SPC) Techniques as Quality Control in Cast Iron Part Production. International Journal of Engineering Precious Research and Application, 1(3), 14-24.
27. Montgomery, D. C. (2009). Introduction to Statistical Quality Control, Sixth Edition. USA: John wiley and sons, inc.
28. Patidar, G. (2015). Implementation of statistical process control in a small scale industry. International Journal of Emerging Technologies and Engineering (IJETE), 2(7), 120-124.
29. Quens land. (1999, november). overview of foundry processes. Cleaner Production Manual for the Queensland Foundry Industry, pp. 1-38.
30. Rahul Raut, M. P. (2016). optimization of process capability in an automobile industry: A case study. International Research Journal of Engineering and Technology (IRJET), 289-295.
31. Rangel Peraza, D. M. (2014). Statistical quality control and process capability analysis for the variability reduction of tomatoe paste filling process. Industrial Engineering & Management, 3(4), 1-7.
32. Rebecca Kaye. (2017, november 6). national service scotland. Retrieved june 12, 2018, from a national service scotland website: http://www.indicators.scot.nhs.uk
33. S C Mondal ,J Maiti, P K Ray. (2010). Process Capability Analysis of Centrifugal Casting Process . International Conference on Industrial Engineering and Operations Management .
34. Sambrani, D. V. (2016). Process Capability–A Managers Tool for 6 Sigma Quality advantage. Global Journal of Management and Business Research: G, 16 Version 1.0(3), 29-30.
35. Santosh S, C. A. (2017). Process Capability Analysis of High Pressure Die Casting Process for Cap Manufacturing. International Journal for Research in Applied Science & EngineeringTechnology (IJRASET), 5(8), 2088-2094.
36. Saravanan A, D. P. (2013). implementation of quality control charts in bottle manufacturing industry. International Journal of Engineering Science and Technology (IJEST), 2(5), 335-340.
37. Shewhart, W. A. (1939). Statistical method from the viewpoint of quality control (1st ed.). Washington, D.C.: The Graduate School, the Department of Agriculture.

38. Sileshi Kitata, A. P. (2016). reducing the defect rate of final products through spc tools: A case study on ammunition cartridge factory. International Journal of Mechanical Engineering andTechnology (IJMET), 296–308.
39. Simion, C. (2017). Capability studies, helpful tools in process quality improvement . MATEC Web of Conferences 121, (pp. 1-11).
40. Spano, A. (2012, march). Process Capability Analysis. knowledge from data, pp. 1-68.
41. Taguchi, G. (1993). Taguchi on robust technology development bringing quality upstream (2nd ed.). New york: ASME.
42. Tatjana V. ŠIBALIJA, V. D. (2009). SPC AND PROCESS CAPABILITY ANALYSIS– CASE STUDY. International Journal ’’Total Quality Management & Excellence, 37(12), 56-67.
43. Tulus Puji, H. (2018). A case study to know the acceptance measurement system and process capability using Statistical Process Control in Manufacturing Industry. International Journal of Business & Management Science, 54-69.
44. Watford, G. (2000). Efficient melting in coreless induction furnace. London: Good practice guide.
45. Yadav m, M. K. (2016). Analyzing the process capability for auto manual transmission base plate manufacturing. International Journal of Managing Value and Supply Chains (IJMVSC), 7(3), 79-86.
46. Yerriswamy Wooluru, S. D. (2014). the process capability analysis a tool or process performance measure and metrices - A case study. International Journal for Quality Research, 2(6), 399-416.
47. Yury S, N. R. (2013). Metal casting Principles & Techniques (1st edition.). New york: American foundry society.
48. Aondona, J. J. (2011). Effects of Moisture Content on the Foundry Properties of Natural Sand. *Journal of Practices and Technologies*, *5*(19), 85-96.