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JUDUL: RELIABILITY ASSESMENT OF CNC TURNING CENTER
BASED ON INDUSTRIAL STATISTICS

SESIPENGAJIAN: 2010/2011

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RELIABILITY ASSESMENT OF CNC TURNING CENTER BASED ON
INDUSTRIAL STATISTICS

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Thesis is submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing

Faculty of Mechanical Engineering
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DECEMBER 2010

SUPERVISOR DECLARATION

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STUDENT DECLARATION

I declare that this thesis entitled “*Reliability Assesment of CNC Turning Center Based On Industrial Statistics*” is the result of my own research except as cited in the references. The thesis has not been accepted for my degree and is not concurrently candidature of any other degree.

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To my Beloved Parents

KAMARUDIN BIN MANSOR
ENGKU HANIZAH BINTI ENGKU HAMZAH

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ABSTRACT

Control charts are basic tools in industrial statistics to statistically assess performance-related parameters of a machine or process. The objective of this project is to evaluate the reliability of the CNC machine in the UMP lab using the concept of quality control, namely \bar{x} and R. In order to develop the control chart, a number of identical round bars will be generated on titanium in different environments. The measured data used for \bar{x} and R are diameter and surface roughness. For machining tests, all of the machining experiments were carried out on ROMI C420 CNC turning machine. The machining parameters are set based on literature. Diameters of the bars are measured with digital micrometer and the surface roughness by using perthometer. A total of 60 data for each bar was collected. In control chart, 20 samples of size 3 were used. The control charts were plotted manually as well as in STATISTICA. It has been found that reliability of the machine tested depends on the control limits defined and tolerable part dimensions.

ABSTRAK

Carta kawalan kualiti ialah cara asas dalam statistik industri untuk menilai prestasi mesin atau proses. Tujuan projek ini adalah untuk menilai kebolehpercayaan mesin CNC di lab UMP dengan menggunakan konsep carta kawalan kualiti, iaitu \bar{x} dan R. Dalam rangka menghasilkan carta kawalan kualiti, sejumlah bar bulat identik akan dihasilkan pada titanium dalam keadaan persekitaran yang berbeza. Data yang diukur digunakan untuk menghasilkan \bar{x} dan R adalah diameter dan kekasaran permukaan. Untuk ujian mesin, semua eksperimen dilakukan pada mesin CNC Romi C420 berputar. Parameter pemesinan dipersiapkan berdasarkan literatur. Diameter bar diukur dengan mikrometer digital dan kekasaran permukaan dengan menggunakan perthometer. Sebanyak 60 data untuk setiap bar dikumpulkan. Pada carta kawalan, 20 sampel dengan saiz 3 digunakan. Grafik kawalan diplot secara manual maupun di Statistica. Didapati bahawa kebolehpercayaan mesin diuji bergantung pada kawalan batasan yang telah ditentukan dan ukuran bahagian toleransi.

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LIST OF SYMBOLS

mm	Millimeter
μm	Micron meter
σ	Standard Deviation
\bar{X}	Mean
μ	Mean of Sample Mean
N	Number of Sample
\bar{R}	Mean of range
d	Diameter

LIST OF ABBREVIATIONS

UMP	Universiti Malaysia Pahang
FKM	Fakulti Kejuruteraan Mekanikal
CNC	Computer Numerical Control
UCL	Upper Control Limit
LCL	Lower Control Limit
AHWR	Advanced Heavy Metal Reactor
APSRA	Assesment of Passive System Reliability
FORM	First-Order Reliability Method
SORM	Second-Order Reliability Method
IS	Industrial Statistics

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Computer numerical controlled (CNC) machines play a major role in the modern machining industry, product qualities as well as productivity become important issues. Therefore, the optimum turning conditions have to be set. Throughout the entire production processes, the product needs to be monitored in order to meet the overall specifications.

In the most general terms, there are two product defects; i.e. are the deviations from target specification and excessive variability around target specifications. During the earlier stages of developing the production process, designed experiments are often used to optimize these two quality characteristics. The term reliability used in industrial statistics denotes a function describing the probability of failure as a function of time. As the marketplace for industrial goods has become more global, manufactures have realized that the quality and reliability of their products must be as high as possible for them to be competitive. To cope with other competitors, many machines have begun to give importance to the reliability of CNC machines because CNC machines are expensive and complicated.

In this project, a quality control chart will be developed using STATISTICA software for a CNC turning center to investigate the reliability of the machine. A number of identical geometry bars will be machined on cylindrical titanium in different environments. Diameter of cylindrical bar will be measured by using a micrometer and the

surface roughness will be measured by using perthometer to verify the accuracy of the machine.

1.2 PROBLEM STATEMENT

The reliability knowledge of a particular process is important to track their performance from time to time and quality control. It is generally recognized that the most cost-effective way to maintain high quality is through constant monitoring of the production process. This monitoring is often done by sampling unit production and measuring some quality characteristic. The reliability record of turning center commonly used in manufacturing process is unknown. Seems the titanium pure is expensive, so it is important to control the quality of the product to reduce defect in the manufacturing industry.

1.3 PROJECT OBJECTIVES

The objectives of this study consist of:

- (i) To develop the quality control charts for CNC turning center.
- (ii) To evaluate the reliability of CNC turning center based on industrial statistics.

1.4 SCOPE OF PROJECT

The scopes of this project are:

- (i) A number of round bars having same diameter will be generated on titanium using CNC turning center in different time frames and environmental condition.
- (ii) Surface roughness of turned bars will be measured using perthometer.
- (iii) Diameters of the bars will be measured with precision vernier caliper or micrometer.
- (iv) Quality control chart will be developed manually as well as by using STATISTICA software to asses reliability of turning center.

1.5 THESIS ORGANIZATION

Chapter 1 introduces the background of the project. The problem statement and the scopes of this study also included in this chapter. Chapter 2 presents the literature study. Chapter 3 discusses the experimental under different experimental conditions, data measurements and analysis. Chapter 4 presents the results and analysis of the obtained results. Chapter 5 presents the conclusion and recommendation of the future work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The main purpose of this literature review is to get the information from reference books, journals, technical papers and website to complete the project. For this chapter, some information from different sources will be discussed.

2.2 RELIABILITY

Reliability is the ability of a set of device or measuring instrument to consistently perform without failure under given circumstances such as environmental condition (John Davidson, 1994). The reliability of a result pertains to the representative of the result found in a specific sample for the entire population. In other words, it says how probable it is that a similar result would be found if the data collection procedure was replicated with other samples drawn from the same population. A number of specialized techniques in industrial statistics have been developed to quantify reliability. These techniques are all based on statistical analysis (B. S. Dhillon, 2004). The more critical the application of a particular product, the higher its reliability must be (Serop Kalpakjian, et al 2006).

A.K.Nayak, et al 2009, explained about the methodology known as APSRA (Assessment of Passive System Reliability) has been used to evaluated the reliability of isolation condenser system of AHWR (advanced heavy metal reactor).The system failure probability has been identified through fault-tree analysis and it's found to be

3.703e-07/yr. As per the APSRA methodology, the passive system reliability evaluation is based on the failure probability of the system to perform the design basis function.

N.Mealier, et al 2008, explained about the failure probability of a locking system. This failure probability is assessed using complementary methods: the First-Order Reliability Method (FORM) and Second-Order Reliability Method (SORM) as approximated methods, and Monte Carlo simulations as the reference method. In this work, a reliability approach is developed for analyzing the safety of locking systems. A mechanic reliability engineer method, combining both mechanical and reliable tools, is proposed to assess the failure probability P_f of those systems including uncertainties.

Haita Guo, et al 2008, explained about the wind energy industry, wind farm operators have greater interest in recording wind turbine operating data. However, field failure data may be tainted or incomplete, and therefore it needs a more general mathematical model and algorithms to solve the model. The aim of this paper is to provide a solution to this problem. A three-parameter Weibull failure rate function is discussed for wind turbines and the parameters are estimated by maximum likelihood and least squares. Two populations of German and Danish wind turbines are analyzed. The traditional Weibull failure rate function is also employed for comparison. Analysis shows that the three-parameter Weibull function can obtain more accuracy on reliability growth of wind turbines. This work will be helpful in the understanding of the reliability growth of wind energy systems as wind energy technologies evolving.

Q. Long, et al 2005, explained about further proposes a reliability optimization problem of weighted voting systems under cost constraints. Monte Carlo algorithm is given to analyze the model and evaluate the reliability. A reliability optimization problem with cost constraints is then formulated.

2.3 QUALITY CONTROL

Quality Control describes numerous methods for monitoring the quality of a production process. However, once a process is under control the question arises, "to what extent does the long-term performance of the processes comply with engineering

requirements”. The methods provided in Quality Control are on-line or in-process quality control procedures to monitor an on-going production process. Even though one could arbitrarily determine when to declare a process out of control it is common practice to apply statistical principles to do so.

One of the early pioneers in the area of statistical quality was Dr. Walter A. Shewart of the Bell Telephone Laboratories. In 1924, he developed the modern control chart, which remains one of the most widely used tools for quality control to this day. After World War II, W. Edwards Deming was instrumental in stimulating interest in quality control. The Japanese scientist Genichi Taguchi played a major role as well, developing methods of experimental design with a view toward improving quality (W. Navidi, 2008).

2.4 TURNING MACHINE

Turning center or lathe is very common process found in manufacturing industry which spins the workpiece to perform various operations such as cutting, sanding, knurling, drilling, or deformation with tools that are applied to the workpiece to create an object which has symmetry about an axis of rotation. There are a number of other lathe machine types such as bench lathes, special-purpose lathes, tracer lathes, automatic lathes, automatic lathes and computer-controlled lathes. The dimensional accuracy and surface finish obtained in turning and related operations depend on several factors such as the characteristics and condition of the machine tool, stiffness, vibration and chatter, process parameters, tool geometry and wear, the use of cutting fluids, the machine ability of the workpiece material, and operator skill. Vibration during cutting can cause poor surface finish, poor dimensional accuracy, excessive tool wear and premature failure (Serope Kalpakjian, et al 2006). The precision of CNC or NC machine is defined by its resolution. The resolution of this machine is typically 0.001 mm. This precision is dependent on the machine part which is the spindle, hydraulic and the workpiece clamping,

Yiqiang Wang, et al 2001, explained about an effective reliability method is needed to allocate system level reliability requirements into subsystem and component

levels. A comprehensive method is proposed in this paper for allocating the required system reliability level into each subsystem. Actions should be taken to improve the reliabilities of this subsystem such as turret, clamping accessory and so on.

2.5 TITANIUM

Matthew J. Donaiche explained about the titanium that was discovered in 1790 but purified until the early 1990s. Moreover, the metal did not become widely used until the second half of the twentieth century. However, titanium now has the accumulated experience of some 50 years of modern industrial practice and design application to support its use. Much of this use has come in military application in aircraft or gas turbine engine. More recent used have featured such items as golf clubs and bicycles. Titanium has found its niche in many industries, owing to its unique density, corrosion resistance and relative strength advantages over competing materials such as aluminium, steels and superalloys. Some significant facts and/or important benefits offered by titanium alloys illustrate the basis for the widespread use of titanium today. The density of titanium is only 60% of that of steel or nickel-base superalloys. The tensile strength of titanium can be comparable to that of lower-strength martensitic stainless and is better than that of austenitic or ferritic stainless. Alloys can have ultimate strength comparable to iron-base superalloys, such as A286, or cobalt-base alloys, such as L605. The commercial alloys of titanium are useful at temperatures to about 538°C to 595°C, dependent on composition. Some alloys systems may have useful strengths above this temperature. The cost of titanium, while approximately four times that of stainless steel, is comparable to that of superalloys. Titanium is exceptionally corrosion resistant. It often exceeds the resistant of stainless steel in most environments and it has outstanding corrosion resistance in the human body.

Shane Y. Hong, et al 2001, explained about titanium and its alloys are classified as difficult-to-machine materials. The main problems in machining them are the high cutting temperatures and the rapid tool wear. Most tool materials wear rapidly even at moderate cutting speeds. To minimize tool wear, current machining practice limits the cutting speed to less than 1 m/s. The machining characteristics for titanium and its alloys are summarized as followed.

Firstly, titanium and its alloys are poor thermal conductors. As a result, the heat generated when machining titanium cannot dissipate quickly; rather, most of the heat is concentrated on the cutting edge and tool face. Secondly, titanium has a strong alloying tendency or chemical reactivity with the cutting tool material at tool operation temperatures. This causes galling, welding, and smearing, along with rapid wear or cutting tool failure. Thirdly, during machining, titanium alloys exhibit thermal plastic instability which leads to unique characteristics of chip formation. The shear strains in the chip are not uniform; rather, they are localized in a narrow band that forms serrated chips. Fourth, the contact length between the chip and the tool is extremely short (less than one-third the contact length of steel with the same feedrate and depth of cut). This implies that the high cutting temperature and the high stress are simultaneously concentrated near the cutting edge (within 0.5 mm). Lastly, serrated chips create fluctuations in the cutting force; this situation is further promoted when alpha-beta alloys are machined. The vibrational force, together with the high temperature, exerts a micro-fatigue loading on the cutting tool, which is believed to be partially responsible for severe flank wear.

Titanium and its alloys represent the most challenging materials in machining. With advances in cutting tool materials, many difficult-to-machine materials can now be machined at higher metal removal rates. None of these tool materials, however, seems to be effective in machining titanium because of their chemical affinities with titanium. New development in tool coating also does not help titanium machining. Al₂O₃ coating has a lower thermal conductivity than the tungsten carbide insert, which prevents heat dissipation from extremely concentrated high stress and high temperature at the cutting point. Titanium carbide and titanium nitride coatings are not suitable for machining titanium alloys because of their chemical affinities. Thus, cryogenic machining, which is able to both lower the cutting temperature and enhance chemical stability of the workpiece and the tool, is expected to greatly increase productivity level in the machining of titanium and its alloys.

2.6 MEASUREMENT TOOL

In this project, two types of instruments which is micrometer and perthometer were used to obtain the diameter and surface roughness of the sample in order to finish the project.

2.6.1 Micrometer

Francis T. Farago, et al 1994, explained that a few decade ago micrometer were considered he ultimate in precision for length measurements. Even the measuring machines used at those times in gage laboratories operated on the principles of micrometer. More sensitive measuring instruments were developed to satisfy the accuracy for higher accuracy and they replaced the use of micrometers in many application. Most of the higher sensitivity instruments, however, are of the comparator type, which require setting masters for referencing, possess only a reduced measuring range and are, to some extent, generally stationary. These, and many other characteristics, are definite disadvantages in comparison to the portable micrometer, with its capability of measuring actual lengths by direct indication over a substantial measuring range. In addition, to these inherent advantages of the micrometer system and the relatively low price of measurements, many recent improvements in the design and manufacture of micrometer gages contribute to assuring continuing important role to this category of measuring tools in the field of length measurements.

2.6.2 Perthometer

Boubekri N explained that, instrument called Perthometer are used to measure and record surface roughness. In Perthometer, the stylus is loaded on the surface to be measured and then moved across the surface at a constant velocity to obtain surface height variation. Perthometer is characterized by a multitude of functions. After carrying out a measurement, periodic and non-periodic profiles can be identified and the cutoff set according to standards automatically, such that unintentional non-standard measurements are excluded.

Serope Kalpakjian, et al 2006 explained that the distance that the stylus travels is called the cutoff, which generally ranges from 1.75 mm to 17.5mm. The rule of thumb is that the cutoff must be large enough to include 1 to 5 roughness irregularities, as well as all surface waviness. In order to highlight the roughness, the Perthometer M1 traces are recorded on an exaggerated vertical scale that is a few order of magnitude larger than horizontal scale. The magnitude of the scale is called gain on the recording instrument. Thus the recorded profile is distorted significantly, and the surface appears to be much rougher than it actual is. The recording instrument compensates for any surface waviness. The smaller stylus diameter and the smoother surface, the closer is the path of the stylus to the actual surface profile.

2.7 STATISTICS

Jay Devore, et al 2005 explained that, statistics is widely employed in government, business, and the natural and social sciences. Statistics is the science of making effective use of numerical data relating to groups of individuals or experiments. It deals with all aspects of this, including not only the collection, analysis and interpretation of such data, but also the planning of the collection of data, in terms of the design of surveys and experiments. A statistician is someone who is particularly versed in the ways of thinking necessary for the successful application of statistical analysis. Often such people have gained this experience after starting work in any of a list of fields of application of statistics

There is also a discipline called mathematical statistics, which is concerned with the theoretical basis of the subject. Statisticians improve the quality of data with the design of experiments and survey sampling. Statistics also provides tools for prediction and forecasting using data and statistical models. Statistics is applicable to a wide variety of academic disciplines, including natural and social sciences, government, and business

2.7.1 Sample and Population

W. Navidi, 2008 explained that in statistics, a sample is a subset of a population. Typically, the population is very large, making a census or a complete enumeration of all the values in the population impractical or impossible. The sample represents a subset of manageable size. Samples are collected and statistics are calculated from the samples so that one can make inferences or extrapolations from the sample to the population. This process of collecting information from a sample is referred to as sampling. The best sampling method is random sampling and the most basics are simple random methods. Simple random methods of n is sample chosen by method in each collection of n population. The best way to avoid a biased or unrepresentative sample is to select a random sample, also known as a probability sample. A random sample is defined as a sample where the probability that any individual member from the population being selected as part of the sample is exactly the same as any other individual member of the population. Several types of random samples are simple random samples, systematic samples, stratified random samples, and cluster random samples.

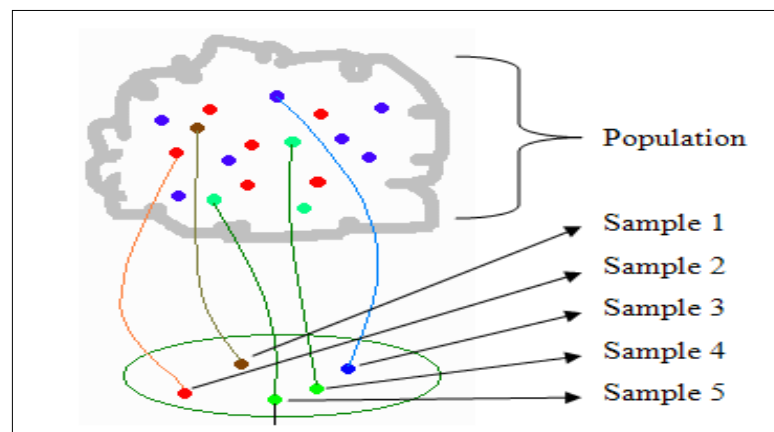


Figure 2.3: Sample and population example

Figure 2.3 show the example of sample and population. There are seventeen points in the population group and five samples was randomly choose

2.7.2 Mean and Standard Deviation

W. Navidi, 2008 explained about the mean of a data set is simply the arithmetic average of the values in the set, obtained by summing the values and dividing by the number of values. The mean is a measure of the center of the distribution. The following formula is for finding the mean \bar{x} :

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n X_i \quad (2.1)$$

And for mean of sample mean

$$\mu = \frac{1}{n} \sum_{i=1}^n \bar{x}_i \quad (2.2)$$

The standard deviation is a quantity that measures the degree of spread in a sample. It shows how much variation there is from the average (mean or expected). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data is spread out over a large range of values. The following formula is for finding the standard deviation, σ :

$$\sigma_{\bar{x}} = \sqrt{\frac{1}{N} \sum_{i=1}^N (\bar{x}_i - \mu)^2} \quad (2.3)$$

2.7.3 Histogram

W. Navidi, 2008 explained about histogram is a graphical display of tabulated frequencies, shown as bars. The purpose is to roughly assess the probability distribution of a given variable by depicting the frequencies of observations occurring in certain ranges of values. Sample of histogram is shown in Figure 2.4.

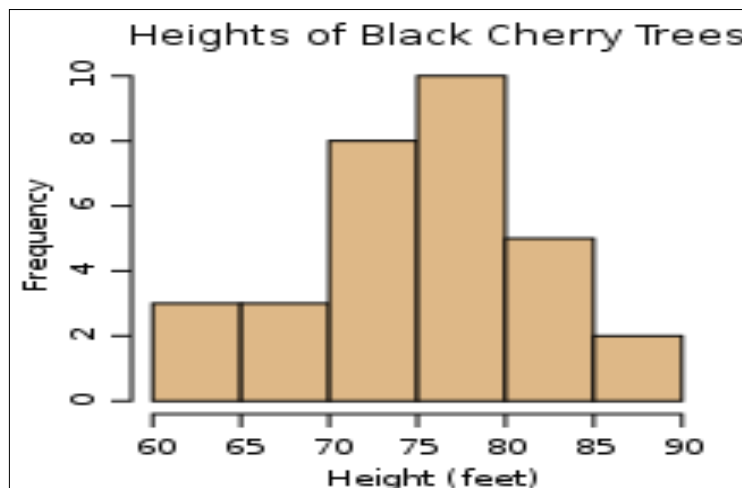


Figure 2.4: Example of histogram

Source: W. Navidi 2008

Figure 2.4 presents the example of histogram which is the unit on the horizontal axis are the units of the data. Each class interval represented by a rectangle. The height of each rectangle is the frequency of the sample in the class interval. The area of each rectangle is thus the relative frequency of the class interval. Since the relative frequencies sum to 1, the area under the entire histogram must equal to 1.

2.7.4 Probability

W. Navidi, 2008 explained about probability is a way of expressing knowledge or belief that an event will occur or has occurred. In mathematics the concept has been given an exact meaning in probability theory. It is used extensively in such areas of study as mathematics, statistics, science, and etc to draw conclusions about the chances of potential event. In order to measure probabilities, the following formula is for finding the probability.

2.7.5 Normal Distribution

William Navidi, 2008 explained about the normal distribution also called the Gaussian distribution is by far the most commonly used distribution in statistics. This

distribution provides a good model for many, although not all, continuous populations. The normal distribution is continuous rather than discrete. The mean of a normal random variable may have any value, and the variance may have any positive value. At the end of section, μ and σ^2 are the mean and variance, respectively. The probability density function of a normal variable with mean μ and variance σ^2 is given by the following formula

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \quad (2.4)$$

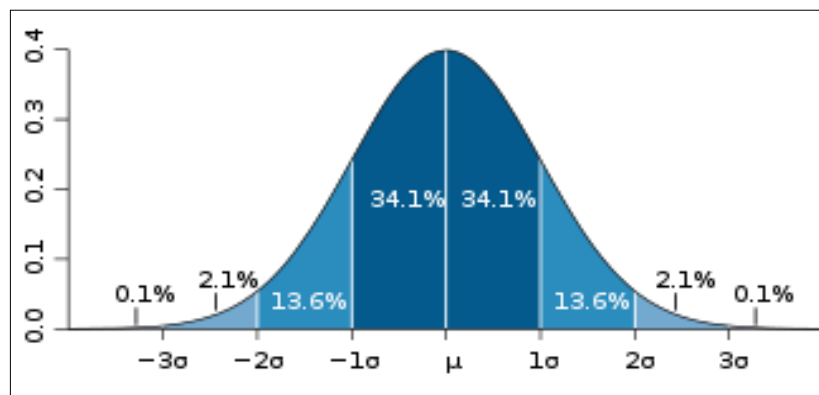


Figure 2.5: Probability function of normal random variable with mean μ and variance σ^2 .

Source: W. Navidi 2008

Figure 2.5 presents a plot of the normal probability density function with mean μ and standard deviation σ . The normal probability density function is sometimes called normal curve. It is also the case that for any normal population which is: (W.Navidi, 2008).

- 68% of the population in the interval $\mu \pm \sigma$
- 95% of the population in the interval $\mu \pm 2\sigma$
- 99.7% of the population in the interval $\mu \pm 3\sigma$

2.7.6 Confidence Interval

William Navidi, 2008 explained about confidence interval (CI) is a particular kind of interval estimate of a population parameter. It is used to indicate the reliability of an estimate. The larger the interval value, the more confident that the interval contains the parameter. Confidence interval is always qualified by a particular confidence level, usually expressed as a percentage; thus one speaks of a "95% confidence interval".

2.7.7 Quality control chart

Jay Devore, et al 2005 explained that the control chart is one of the seven basic tools of quality control. Control Chart is use to monitor a process. It graphically shows the average value and the upper and lower control limits of a process. If a trend emerges in those lines, or if samples fall outside pre-specified limits, it declares the process to be out of control. It is use when to determine whether a process is stable or not. The sample of control charts is shown in figure 2.6. William Navidi, 2008 said the following charts are commonly constructed for controlling variables. Commonly used charts are \bar{X} and R charts. The former is typically to control precision of the machine or processes while the latter to control the variation. Frequently, mean are based on number of samples drawn from population due to fair data representation. For such case,

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n X_i \quad (2.1)$$

Where X is any measured variable in the population

$$\mu = \frac{1}{n} \sum_{i=1}^n \bar{x}_i \quad (2.2)$$

$$\sigma_{\bar{x}} = \sqrt{\frac{1}{N} \sum_{i=1}^N (\bar{x}_i - \mu)^2} \quad (2.3)$$

\bar{x} = Population mean

n = Number of measurements

Control limits are then defined as:

$$\begin{aligned} \text{UCL} &= \text{upper control limit} & \text{LCL} &= \text{lower control limit} \\ &= \mu + \sigma\bar{x} & &= \mu - \sigma\bar{x} \end{aligned} \quad (2.5)$$

If based on population.

For R chart, range, R in population or sample is defined as:

$$\text{Range} = X_{\text{higher}} - X_{\text{lower}} \quad (2.6)$$

$$\bar{R} = \frac{\sum(R_1 \dots R_k)}{k} \quad (2.7)$$

Where k is a number of subgroup.

Control limits are defined as:

$$\begin{aligned} \text{UCLR} &= \text{upper control limit R} & \text{LCLR} &= \text{lower control limit R} \\ (2.8) & & & \\ &= D4 * \bar{R} & &= D3 * \bar{R} \end{aligned}$$

Where constants D4 and D3 are obtained from a statistical table as shown in table 2.1

Table 2.1: Factors for computing Central lines R charts

OBERVATIONS IN SAMPLE, n	CHART FOR RANGES					
	CENTRAL LINE	FACTORS FOR CONTROL CHART				
		<i>d2</i>	<i>d3</i>	<i>D1</i>	<i>D2</i>	<i>D4</i>
2	1.128	0.853	0	3.686	0	3.267
3	1.693	0.888	0	4.358	0	2.574
4	2.059	0.880	0	4.798	0	2.282
5	2.326	0.864	0	4.918	0	2.114

Source: Jay Devore et al 2005

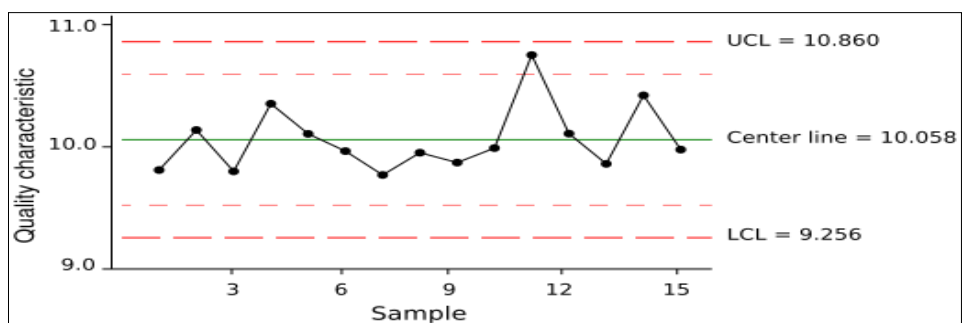


Figure 2.6: Example of Control Chart

Source: W. Navidi 2008

Figure 2.4 presents \bar{x} chart which is clearly shows that the data points are in control as there are several plotting inside the control limits. That's mean the data of measurement is in control. The upper control limit is 10.860 and the lower control limit is 9.256

M. Xie, et al 2002, explained about the use of control charting technique to monitor the failure of components. Control charts are widely used for process monitoring in the manufacturing industry. Some Shewhart control charts, especially those for the number of defects, can be used for monitoring the number of failures per fixed interval; however, they are not effective especially when the failure frequency becomes small. An investigation of its use for reliability monitoring is presented in this paper and the scheme can be easily extended to monitor inter-failure times that follow other distributions such as the Weibull distribution. Furthermore, the scheme is extended to the monitoring of time required to observe a fixed number of failures. The advantages of this scheme include the fact that the scheme does not require any subjective sample size, can be used for both high and low reliability items and can detect process improvement even in a high-reliability environment.

2.7.8 Statistical Process Control

A statistical package is a suite of computer programs that are specialized for statistical analysis. It enables people to obtain the results of standard statistical procedures and statistical significance tests, without requiring low-level numerical programming. Most statistical packages also provide facilities for data management.

There are many statistical analyses such as Minitab, SSPS, Design expert, STATISTICA and etc.

2.7.9 STATISTICA Software

STATISTICA is a comprehensive, integrated data analysis, graphics, database management, and custom application development system featuring a wide selection of basic and advanced analytic procedures for business, data mining, science, and engineering applications. STATISTICA is a carefully planned, brilliantly designed, and meticulously executed line of software solutions that follows industry-standard software rules and interfaces, language standards, accessibility standards.

2.8 CONCLUSION

This chapter is about the summary works that related to this project. The works were discussed about reliability, basic statistic, quality control and statistical analysis.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the overall methodology of the experiments. The quality control is the most critical process in the manufacturing industry. It is very important into manufacturing industries to control their product to meet the customer specification. The aim of this chapter is to discuss about the experiment under environmental condition.

3.2 METHODOLOGY FLOW CHART

The methodology flow chart is a visual representation of the sequence of the project. A completed flow chart organizes the topic and strategies done to ensure smooth working flow of project. Figure 3.1 shows the process flow of this project. As illustrated, the first step is literature study on related topic. Machining work started by using conventional lathe machine.

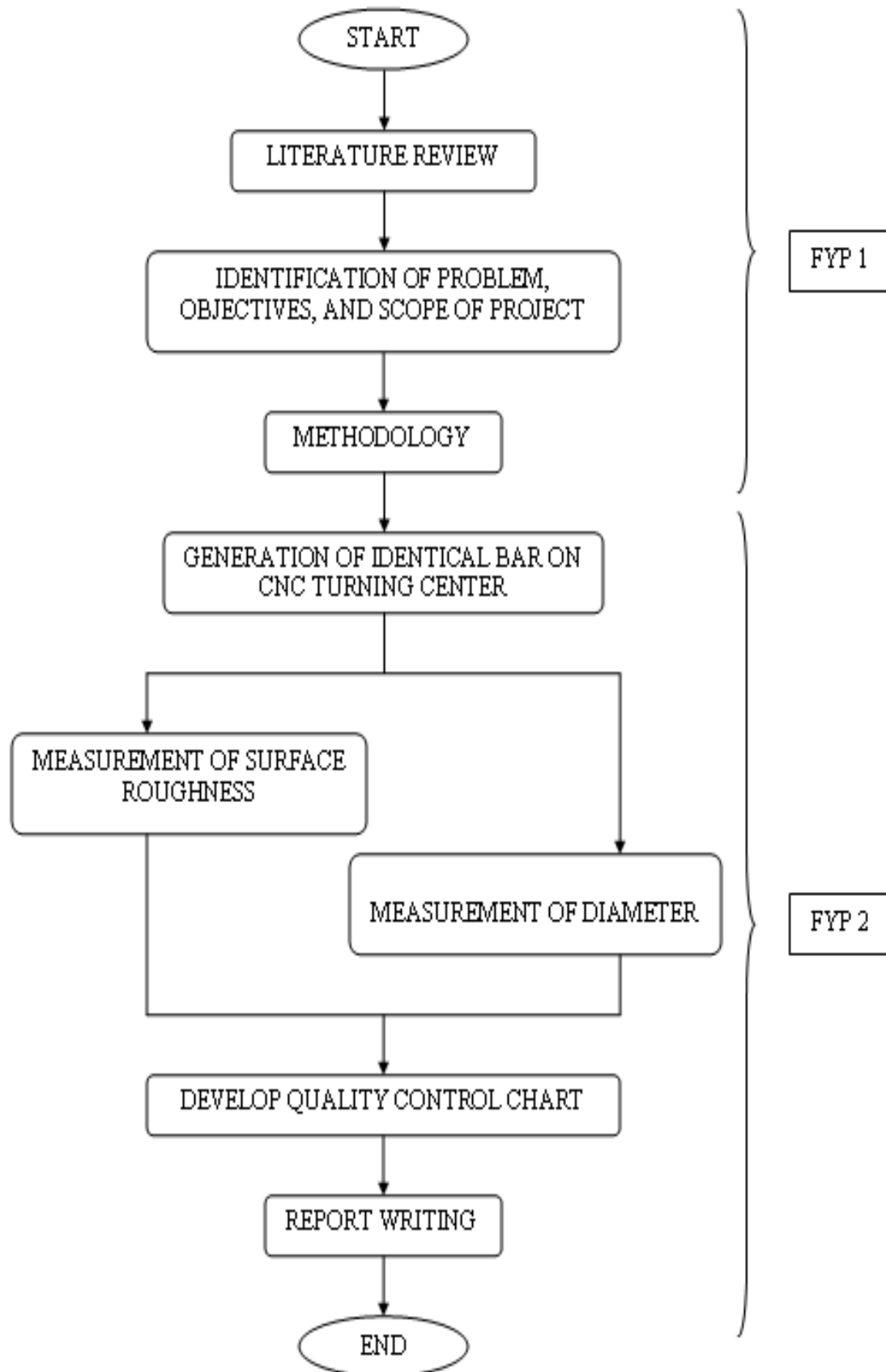


Figure 3.1: Flow Chart

3.3 GENERATION OF IDENTICAL BARS

3.3.1 Material work piece

The work piece is a pure titanium bar (grade 1). Original dimensions of specimen is 23.80 mm diameter and 100 mm long. Before the actual turning, a layer of 0.15mm was removed to eliminate any surface defect and to align the identical bar with the center of the chuck. There were 20 samples machined.



Figure 3.2: Workpiece Material

3.3.2 Cutting Tool Materials

Carbide with coated code as NC3020 from Korloy, Inc insert was used in this experiment. The insert with 55° at each side have been used in this experiment. This insert is commonly used in turning process for titanium.



Figure 3.3: Triangular Insert and Tool Holder

3.4 Machining Tests

For machining tests, all of the machining experiments were carried out by using ROMI C420 CNC turning machine. The machining parameters for conventional machining are shown in Table 3.1. The experiment is under done four different conditions which are:

- i. Machining with using fan.
- ii. Machining without using fan.
- iii. Machining at night.
- iv. Machining with increase the moisture.

Five samples were made under each condition. The conventional coolant was applied to experiments tip at the appropriate flow. For last test condition, the machine was covered with paper to isolate the machining zone surrounding air and to control the moisture. Figure 3.4 shows the machined workpieces.



Figure 3.4: Generated workpieces



Figure 3.5: First condition experiment



Figure 3.6: Second condition experiment



Figure 3.7: Third condition experiment

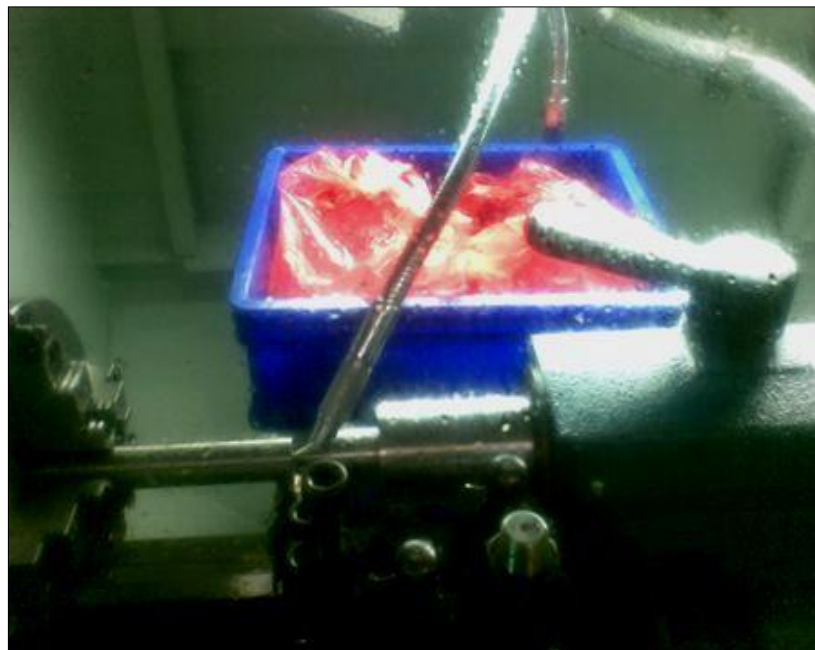


Figure 3.8: Fourth condition experiment



Figure 3.9: Close the machine

Table 3.1: Machining Parameters for all machining tests

Tool	Carbide Brazed Coated
Cutting Speed (m/min)	120
Depth of Cut (mm)	1.00
Feed Rate (mm/rev)	0.150

3.4.1 Diameter Measurement

Diameter measurement is the main measurement. Micrometers with 1 μm resolution were used to measure diameter of the turned bar. The measurements were taken three times for each sample and average to obtain the actual diameter. Figure 3.10 shows the pictures of micrometer that were use for this experiment.



Figure 3.10: Micrometer

3.4.2 Surface Roughness Measurement

The surface roughness of each sample was measured with perthometer. The measurements were taken three times and the average value was taken as the actual value. The picture of perthometer is shown in Figure 3.11.

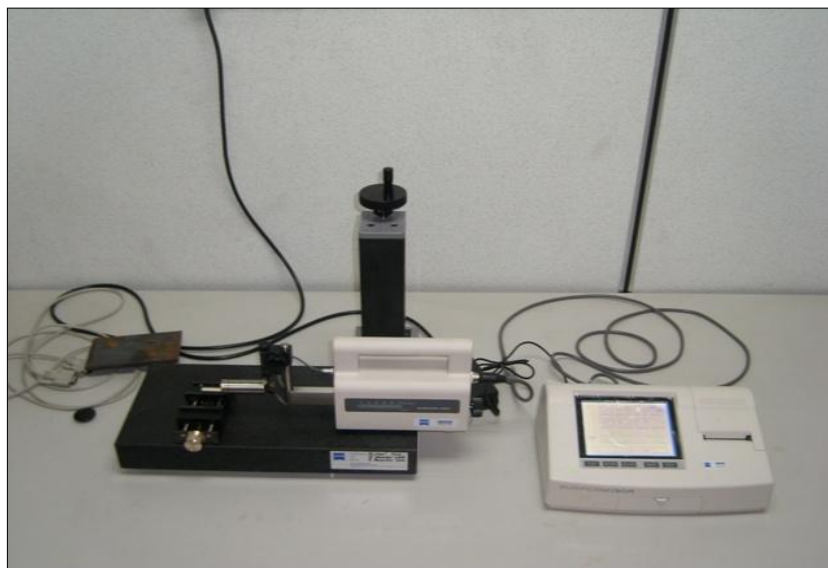


Figure 3.11: Perthometer

3.5 ANALYSIS IN STATISTICA and EXCEL

After all the machining and measurements done under the four conditions, the diameter is analyzed in STATISTICA and manually plot in excel. The data first need to be filled in this software and from that, proceed with the analysis to create the histogram, normal probability plot and quality control chart. The data that had been gathered after the analysis then needed to be interpreted. The main objective of this project is to check the reliability of the machine. The results are presented and discussed in the following chapter.

3.6 CONCLUSION

This chapter discussed about the whole experiment that are running under four different conditions with a constant parameter. The measurement of identical bar diameter and surface roughness also discussed and the software that is use to analyzed the result.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter generally discussed about the results and the analysis that have been obtained throughout the experimental research analysis on the diameter and the surface roughness from the beginning until the end of the experiment. Furthermore, this chapter will discuss about the reliability of the machine from the data that had been gathered during the experiment.

4.2 MEASUREMENT TOOL CONDITIONS

Two types of instruments, micrometer and perthometer were used to obtain the diameter and surface roughness of the sample. The instrument has been properly calibrated. It was assumed that environmental and operation conditions do not affect the measuring reading. There are 60 measurements in the population and the population was grouped into 20 samples with size of three. Five samples were obtained under same environmental conditions. Table 4.1 shows the detail of sample data and range.

4.3 ANALYSIS OF DIAMETERS

The sampled diameters shown in Table 4.1 were analyzed manually as well as in STATISTICA analysis to plot quality control chart. The following section provides manual calculation required for control charts that would be plotted in excel.

Table 4.1: Sampling of diameters

Measurements of diameter (mm)						
Experiment condition	Date	Sample no	d1	d2	d3	Sample Range (mm)
With fan	17/05/2010	1	22.651	22.65	22.653	0.003
	17/05/2010	2	22.649	22.651	22.653	0.004
	17/05/2010	3	22.647	22.646	22.648	0.002
	17/05/2010	4	22.648	22.647	22.649	0.002
	17/05/2010	5	22.652	22.656	22.654	0.004
Without fan	19/05/2010	6	22.656	22.653	22.658	0.005
	19/05/2010	7	22.653	22.651	22.654	0.003
	19/05/2010	8	22.652	22.653	22.656	0.004
	19/05/2010	9	22.651	22.654	22.652	0.003
	19/05/2010	10	22.654	22.653	22.656	0.003
Night	25/05/2010	11	22.652	22.656	22.653	0.004
	25/05/2010	12	22.652	22.655	22.652	0.003
	25/05/2010	13	22.651	22.65	22.653	0.003
	25/05/2010	14	22.652	22.652	22.652	0.000
	25/05/2010	15	22.649	22.646	22.648	0.003
Ice	27/05/2010	16	22.647	22.646	22.648	0.002
	27/05/2010	17	22.651	22.653	22.652	0.002
	27/05/2010	18	22.658	22.653	22.654	0.005
	27/05/2010	19	22.65	22.651	22.654	0.004
	27/05/2010	20	22.653	22.653	22.653	0.000

4.3.1 Mean and deviation for diameter

Firstly, mean and range of each sample were calculated. The examples of the calculation are shown below. The standard deviations were calculated based on the sample mean using the formula from statistics.

(i) Sample Mean, \bar{x} :

The mean is the average of the data point according to equation 2.1,

$$\bar{x}_1 = \frac{1}{n} \sum_{i=1}^n X_i$$

$$\begin{aligned} \bar{x}_1 &= \frac{22.651 + 22.650 + 22.653}{3} \\ &= 22.6520 \text{ mm} \end{aligned}$$

$$\begin{aligned} \bar{x}_2 &= \frac{22.649 + 22.651 + 22.653}{3} \\ &= 22.651 \text{ mm} \end{aligned}$$

Then, the mean of sample mean according to equation 2.2,

$$\mu = \frac{1}{n} \sum_{i=1}^n \bar{x}_i$$

$$\begin{aligned} \mu &= 22.6520 + 22.6510 + 22.6470 + 22.6480 + 22.6540 + 22.6557 + 22.6527 + \\ &\quad 22.6537 + 22.6523 + 22.6543 + 22.6537 + 22.6530 + 22.6513 + 22.6520 + \\ &\quad \frac{22.6477 + 22.6470 + 22.6520 + 22.6550 + 22.6517 + 22.6530}{20} \end{aligned}$$

$$\mu = 22.652 \text{ mm}$$

(ii) Standard Deviation, $\sigma_{\bar{x}}$ based on sample mean $\bar{\sigma}_{\bar{x}}$

Standard deviation is based on sample mean according to equation 2.3 were calculated as,

$$\sigma_{\bar{x}} = \sqrt{\frac{1}{N} \sum_{i=1}^N (\bar{x}_i - \mu)^2}$$

$$N = 20$$

$$\mu = 22.652$$

$$\bar{x} = 22.6520, 22.6510, 22.6470, 22.6480, 22.6540, 22.6557, 22.6527, 22.6537, \\ 22.6523, 22.6543, 22.6537, 22.6530, 22.6513, 22.6520, 22.6477, 22.6470, \\ 22.6520, 22.6550, 22.6517, 22.6530$$

$$\sigma_{\bar{x}} = 0.003$$

(iii) Sample Range, R

According to equation 2.6, ranges for each sample were calculated as,

$$\text{Sample Range} = \text{Max diameter} - \text{Min Diameter}$$

Example,

For sample 1:

$$R_1 = 22.653 \text{ mm} - 22.650 \text{ mm} \\ = 0.003 \text{ mm}$$

For sample 2:

$$R_2 = 22.653 \text{ mm} - 22.649 \text{ mm} \\ = 0.004 \text{ mm}$$

For sample 3:

$$R_3 = 22.648 \text{ mm} - 22.646 \text{ mm} \\ = 0.002 \text{ mm} \quad \text{etc.}$$

(iv) Upper Control Limit and Lower Control Limit \bar{x} chart

Then the control limits for \bar{x} chart of diameter were established based on mean of sample mean and standard deviation. Referring to equation 2.5, \bar{x} control chart was defined at one sigma (σ).

UCL = upper control limit

$$\begin{aligned} &= \mu + \sigma \\ &= 22.652 \text{ mm} + 0.003 \\ &= 22.655 \text{ mm} \end{aligned}$$

LCL = lower control limit

$$\begin{aligned} &= \mu - \sigma \\ &= 22.652 \text{ mm} - 0.003 \\ &= 22.649 \text{ mm} \end{aligned}$$

(v) Range of diameter

According to equation 2.7, the mean range of sample mean range was calculated as:

$$\begin{aligned} \bar{R} &= \frac{\sum(R1 \dots Rk)}{k} \\ \bar{R} &= \frac{0.003 + 0.004 + 0.002 + 0.002 + 0.004 + 0.005 + 0.003 + 0.004 + 0.003 + 0.003 + 0.004 + 0.003 + 0.003 + 0.000 + 0.003 + 0.002 + 0.002 + 0.005 + 0.004}{20} \\ &= 0.003 \text{ mm} \end{aligned}$$

(vi) Upper Control Limit and Lower Control Limit R chart

Control limit for R chart of diameter was defined. The value of D4 and D3 is taken from table 2.1:

UCL = upper control limit

$$\begin{aligned} &= D_4 \bar{R} \\ &= 2.575 * 0.003 \\ &= 0.0077 \text{ mm} \end{aligned}$$

LCL = lower control limit

$$\begin{aligned} &= D_3 \bar{R} \\ &= 0.000 * 0.003 \\ &= 0.000 \text{ mm} \end{aligned}$$

Finally, quality control chart \bar{x} and R based one sigma, two sigma and three sigma were constructed in Excel. In excel, the line of control limit can be drawn based on three sigma. Figure 4.1 and 4.2 illustrates the control charts with different control limits.

Then, STATISTICA software was used to plot control chart alternatively. Industrial Statistics (IS) tools available in STATISTICA provide variety of quality control charts. The user just needs to input sampling data and IS generating control charts automatically. Important information such as normal distribution can also be extracted from the software.

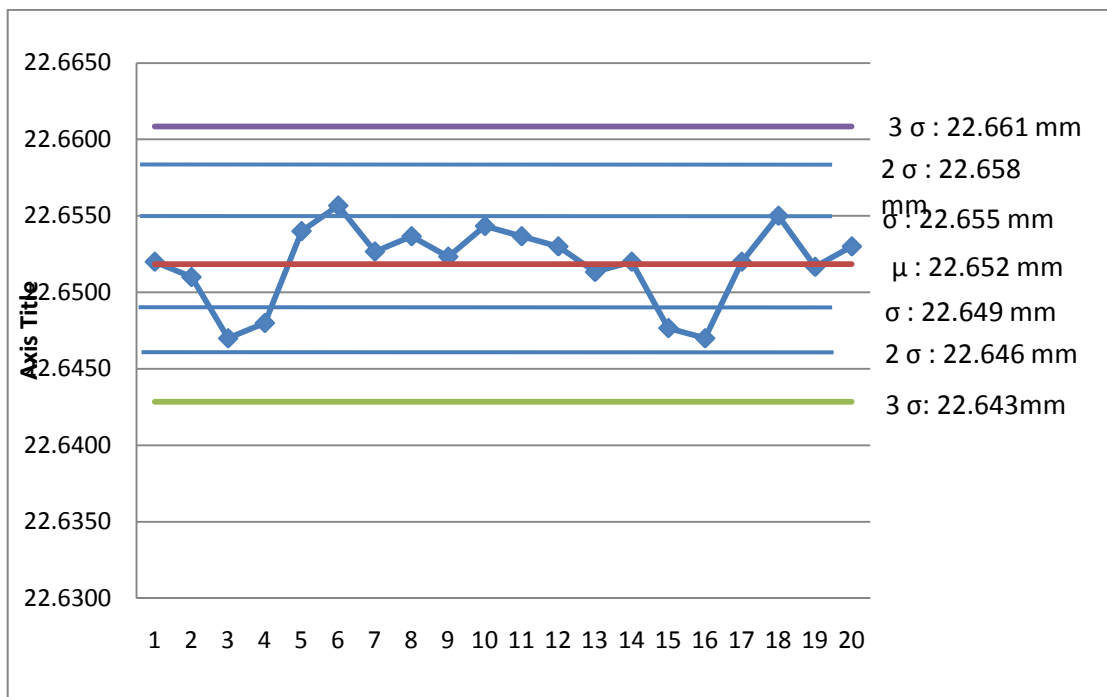


Figure 4.1: \bar{x} chart from Excel

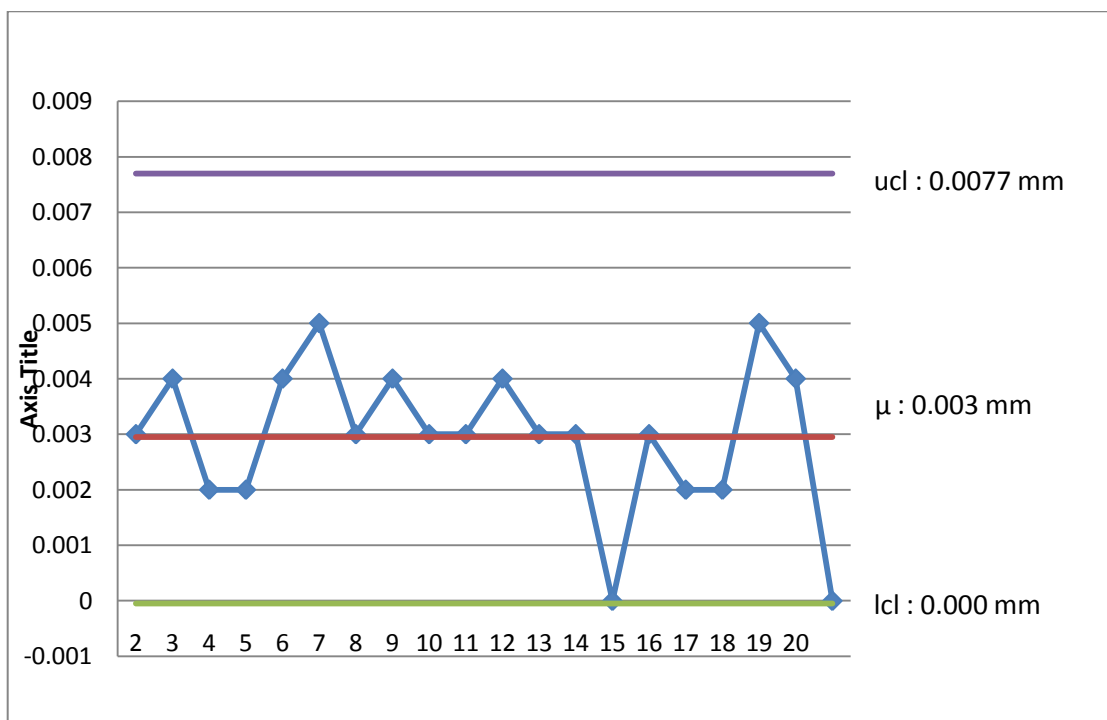


Figure 4.2: R chart from Excel

Figure 4.3 illustrated the sampling plot in STATISTICA. It shows the number of sample and sample size considered for statistical analysis. It's also show the population mean and standard deviation.

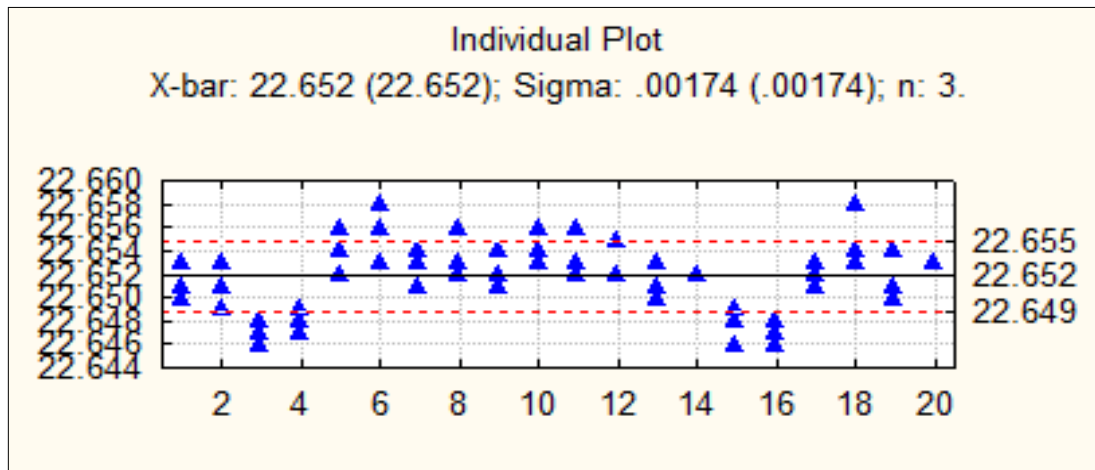


Figure 4.3: Sampling plot

Normal distribution is examined by figure 4.4. As seen to figure, almost all data points fall near to the normal line. This indicates that normal distribution is valid.

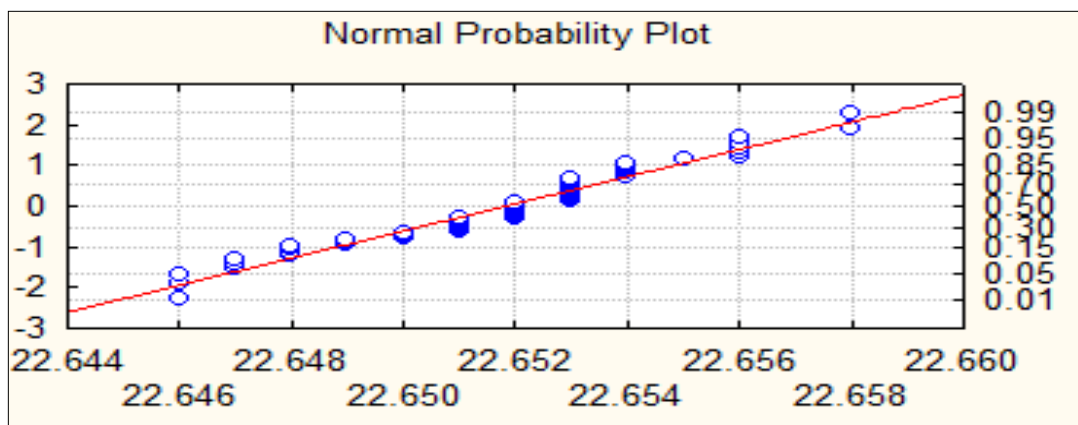


Figure 4.4: Normal Probability plot

Figure 4.5 is the histogram of the frequency against diameter and the bell curve. The highest frequency is 22.652 mm to 22.654 mm. It shows that all the data is in three sigma range.

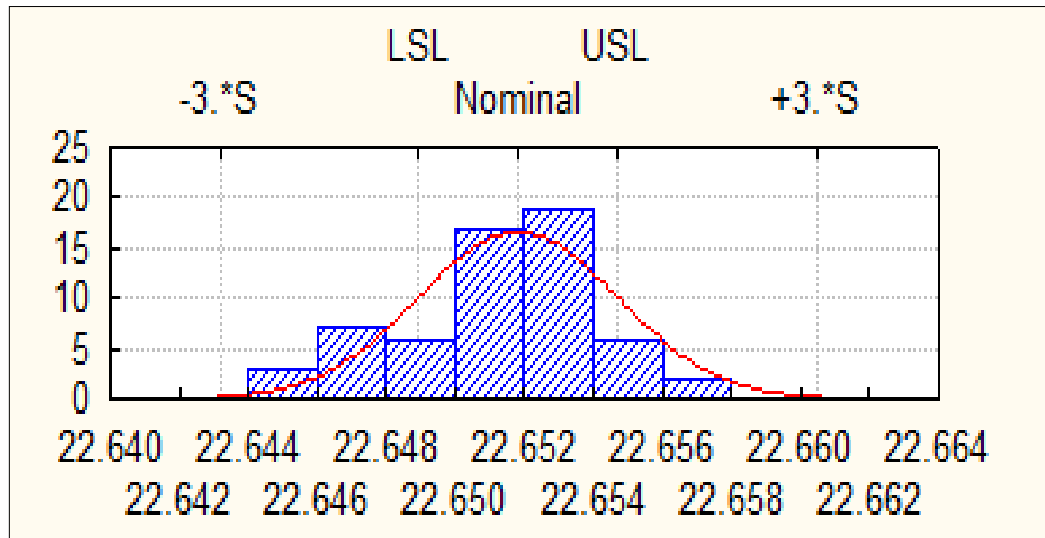


Figure 4.5: Histogram

Figure 4.6, the \bar{X} chart shows that there are six data points beyond the control limits with one sigma. The UCL is 22.655mm, LCL 22.649mm and the central line is 22.652 mm. The data is creating by using three constants sample points.

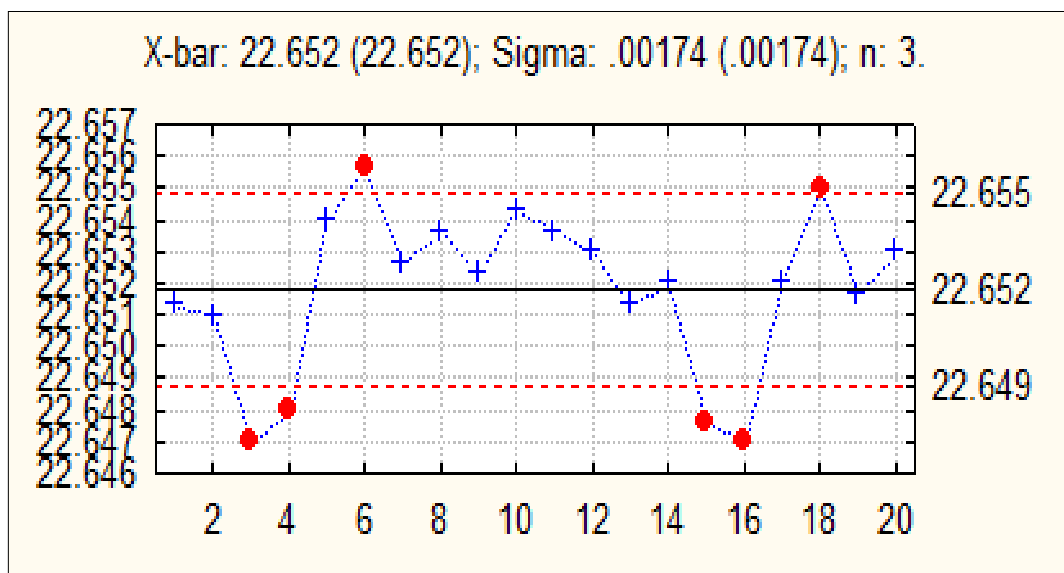


Figure 4.6: \bar{X} chart from STATISTICA

By referring to Figure 4.7, the R chart shows that all data points are in the control limits. The UCL is 0.00760mm, LCL is 0.0000 and the central line is 0.00295

mm. All data is in the range which is mean sample ranges are plotted in order to control the variability of a variable. Figure 4.3 shows all data points in the \bar{X} chart.

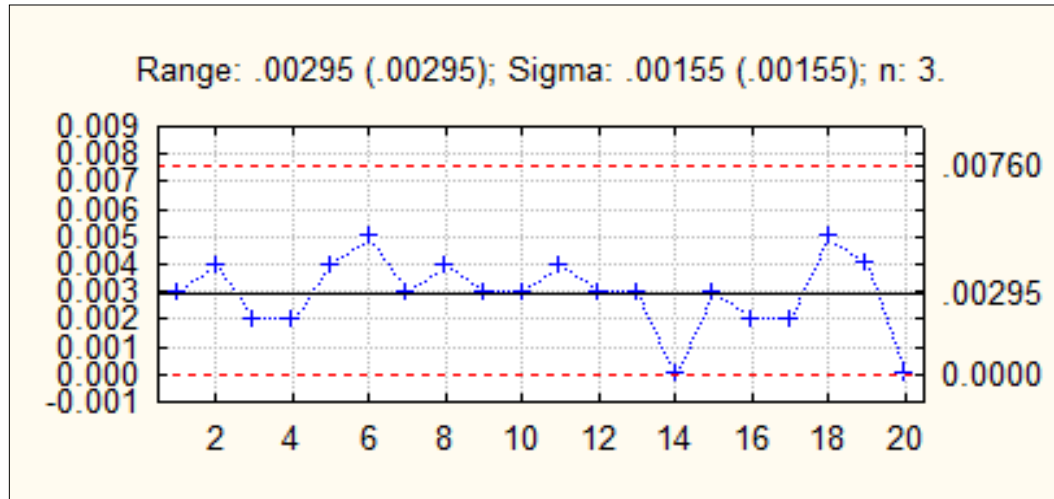


Figure 4.7: R chart STATISTICA

Similarly, sampling data of surface roughness were analyzed. For plotting control \bar{x} and R charts, the population and number of sample size are the same as that of diameter. The following section presents those results.

4.4 ANALYSIS OF SURFACE ROUGHNESS

The measuring of surface roughness was tabulated as show in Table 4.2 for STATISTICA analysis to plot quality control chart. There were 20 population, 4 sample and each sample consist of five 5 measurement, we group the sample according to experimental condition and 60 population with 3 measuring data each for each sample. Form each three samples were drawn to calculated sample and range according to experiment condition.

Table 4.2: Sampling of Surface roughness

Measurements of surface roughness, Ra (μm)						
Experimental Condition	Date	Sample no	Ra1	Ra2	Ra3	Sample Range(μm)
With Fan	17/05/2010	1	0.356	0.345	0.358	0.013
	17/05/2010	2	0.378	0.360	0.369	0.018
	17/05/2010	3	0.340	0.352	0.368	0.028
	17/05/2010	4	0.379	0.364	0.349	0.030
	17/05/2010	5	0.438	0.437	0.435	0.003
Without Fan	19/05/2010	6	0.429	0.431	0.456	0.026
	19/05/2010	7	0.370	0.377	0.382	0.012
	19/05/2010	8	0.397	0.383	0.382	0.015
	19/05/2010	9	0.322	0.340	0.328	0.018
	19/05/2010	10	0.385	0.369	0.354	0.031
Night	25/05/2010	11	0.357	0.372	0.354	0.018
	25/05/2010	12	0.335	0.372	0.348	0.037
	25/05/2010	13	0.369	0.364	0.357	0.012
	25/05/2010	14	0.372	0.354	0.347	0.025
	25/05/2010	15	0.430	0.472	0.451	0.042
Ice	27/05/2010	16	0.356	0.332	0.339	0.024
	27/05/2010	17	0.447	0.478	0.462	0.031
	27/05/2010	18	0.426	0.454	0.411	0.043
	27/05/2010	19	0.568	0.586	0.597	0.029
	27/05/2010	20	0.509	0.501	0.522	0.021

4.4.1 Mean and Deviation for surface Roughness

The similarly calculation as diameter analysis is applied to surface roughness analysis is based on the statistic formula. Firstly, mean and range of each sample were calculated. The examples of the calculation are shown below. The standard deviations were calculated based on the sample mean using some formula from statistics.

(i) Sample Mean, \bar{x} :

The mean is the average of the data point according to equation 2.1,

$$\bar{x}_1 = \frac{1}{n} \sum_{i=1}^n X_i$$

$$\begin{aligned} \bar{x}_1 &= \frac{0.356 + 0.345 + 0.358}{3} \\ &= 0.353 \mu\text{m} \end{aligned}$$

$$\begin{aligned} \bar{x}_2 &= \frac{0.378 + 0.360 + 0.369}{3} \\ &= 0.369 \mu\text{m} \end{aligned}$$

Then, the mean of sample mean according to equation 2.2,

$$\mu = \frac{1}{n} \sum_{i=1}^n \bar{x}_i$$

$$\begin{aligned} \mu &= \frac{0.3530 + 0.3690 + 0.3533 + 0.3640 + 0.4367 + 0.4387 + 0.3763 + 0.3873 + \\ &\quad 0.3300 + 0.3693 + 0.3610 + 0.3517 + 0.3633 + 0.3577 + 0.4510 + 0.3423 \\ &\quad + 0.4623 + 0.4303 + 0.5837 + 0.5040}{20} \\ \mu &= 0.39958 \mu\text{m} \end{aligned}$$

(ii) Standard Deviation, $\sigma_{\bar{x}}$ based on sample mean $\bar{\sigma}_{\bar{x}}$

Standard deviation is based on sample mean according to equation 2.3 were calculated as,

$$\sigma_{\bar{x}} = \sqrt{\frac{1}{N} \sum_{i=1}^N (\bar{x}_i - \mu)^2}$$

$$N = 20$$

$$\mu = 0.39958$$

$$\bar{x} = 0.3530, 0.3690, 0.3533, 0.3640, 0.4367, 0.4387, 0.3763, 0.3873, 0.3300, \\ 0.3693, 0.3610, 0.3517, 0.3633, 0.3577, 0.4510, 0.3423, 0.4623, 0.4303, \\ 0.5837, 0.5040$$

$$\sigma_{\bar{x}} = 0.03$$

(iii) Sample Range, R

According to equation 2.6, ranges for each sample were calculated as,

$$\text{Sample Range} = \text{Max Surface roughness} - \text{Min Surface roughness}$$

Example,

For sample 1:

$$R_1 = 0.358 \mu\text{m} - 0.345 \mu\text{m} \\ = 0.013 \mu\text{m}$$

For sample 2:

$$R_2 = 0.378 \mu\text{m} - 0.360 \mu\text{m} \\ = 0.018 \mu\text{m}$$

For sample 3:

$$R_3 = 0.368 \mu\text{m} - 0.340 \mu\text{m} \\ = 0.028 \mu\text{m} \quad \text{etc.}$$

(iv) Upper Control Limit and Lower Control Limit \bar{x} chart

Then the control limits for \bar{x} chart of surface roughness were established based on mean of sample mean and standard deviation. Referring to equation 2.5, \bar{x} control chart was defined at one sigma (σ).

$$\begin{aligned}\text{UCL} &= \text{upper control limit} \\ &= \mu + \sigma \\ &= 0.39958 \mu\text{m} + 0.03 \\ &= 0.42958 \mu\text{m}\end{aligned}$$

$$\begin{aligned}\text{LCL} &= \text{lower control limit} \\ &= \mu - \sigma \\ &= 0.39958 \mu\text{m} - 0.03 \\ &= 0.36958 \mu\text{m}\end{aligned}$$

(v) Range of surface roughness

According to equation 2.7, the mean range of sample mean range was calculated as:

$$\begin{aligned}\bar{R} &= \frac{\sum(R1 \dots Rk)}{k} \\ \bar{R} &= 0.013 + 0.018 + 0.028 + 0.030 + 0.003 + 0.026 + 0.012 + 0.015 + 0.018 + \\ &0.031 + 0.018 + 0.037 + 0.012 + 0.025 + 0.042 + 0.024 + 0.031 + 0.043 + 0.029 \\ &\quad + 0.021 \\ &\quad 20 \\ &= 0.0238 \mu\text{m}\end{aligned}$$

(vi) Upper Control Limit and Lower Control Limit R chart

Control limit for R chart of diameter was defined. The value of D4 and D3 is taken from table 2.1:

UCL = upper control limit

$$\begin{aligned} &= D_4 \bar{R} \\ &= 2.575 * 0.0238 \\ &= 0.0613 \mu\text{m} \end{aligned}$$

LCL = lower control limit

$$\begin{aligned} &= D_3 \bar{R} \\ &= 0.000 * 0.0238 \\ &= 0.000 \mu\text{m} \end{aligned}$$

Finally, quality control chart \bar{x} and R based one sigma, two sigma and three sigma were constructed in Excel. From excel, the line of control limit can be draw based on three sigma and if using STATISTICA, it only can create one sigma control limit only. Figure 4.8 and 4.9 shows respective charts. By referring to Figure 4.8, it show that two data point out of control based on three sigma.

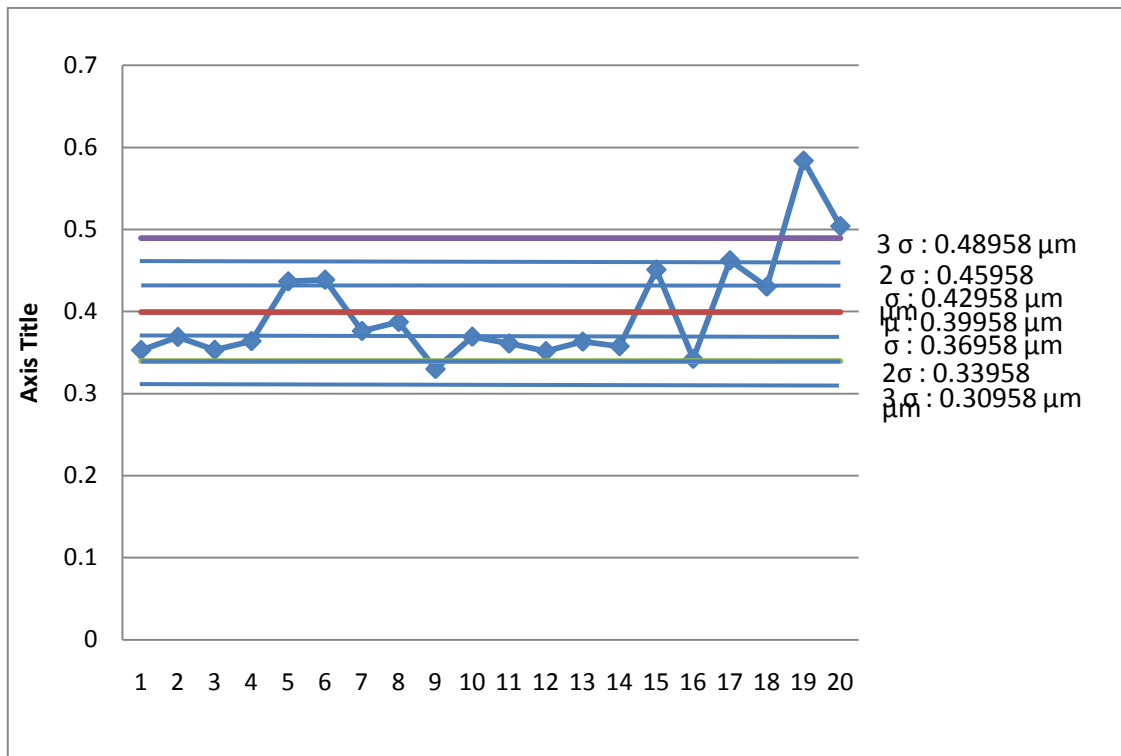


Figure 4.8: \bar{X} chart from excel.

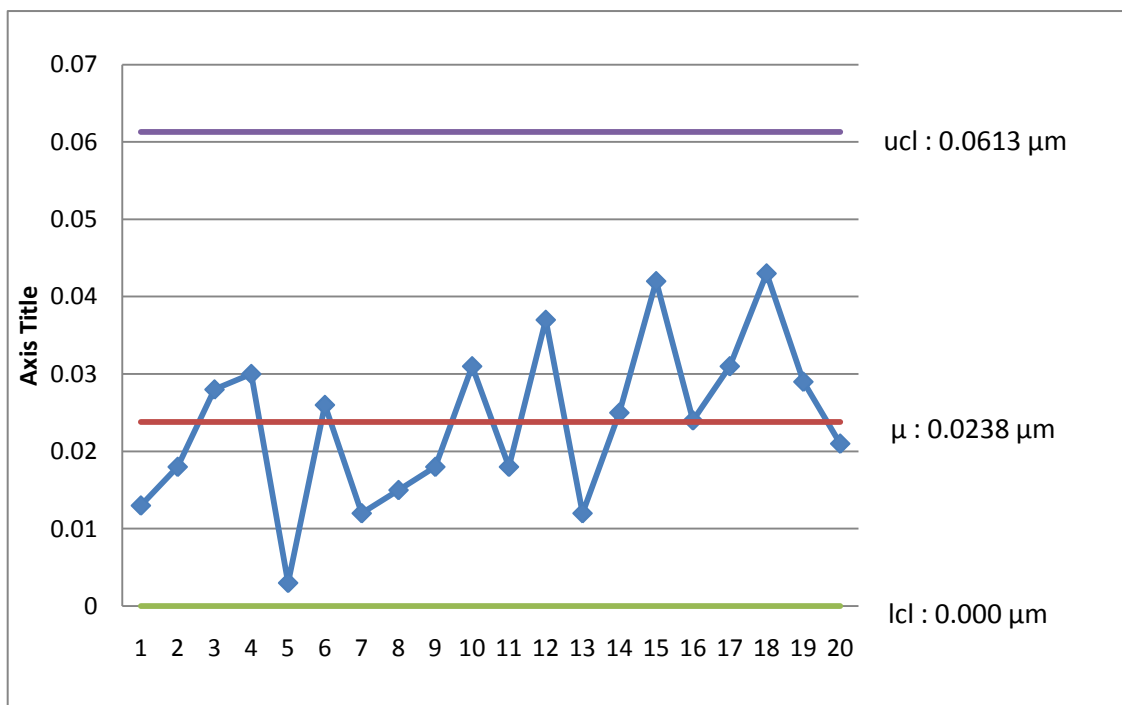


Figure 4.9: R chart from excel

Figure 4.10 illustrated the sampling plot in STATISTICA. It shows the number of sample and sample size considered for statistical analysis. It's also show the population mean and standard deviation.

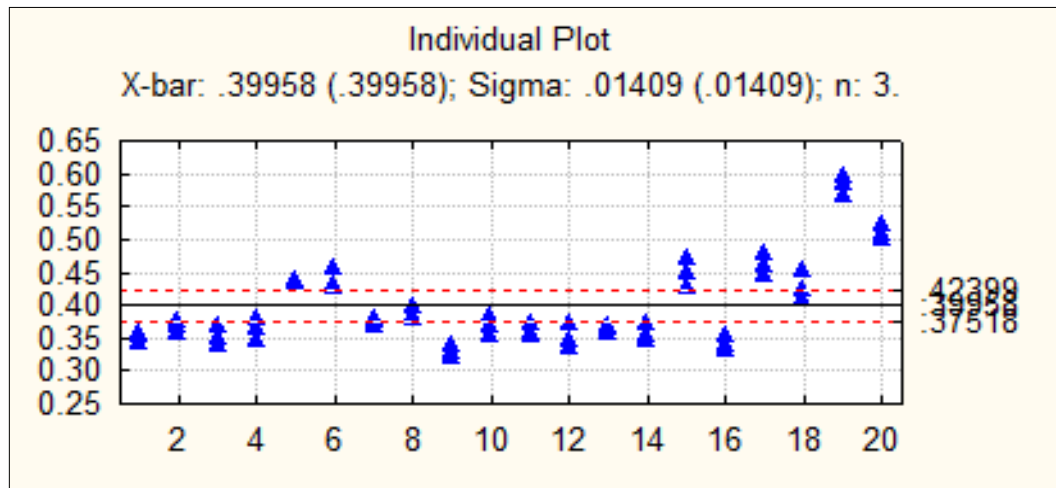


Figure 4.10: Sampling Plot

Normal distribution is examined by figure 4.11. As seen to figure, it shows the normal probability plot which is some of the data point is around the prediction line and some far from the line.

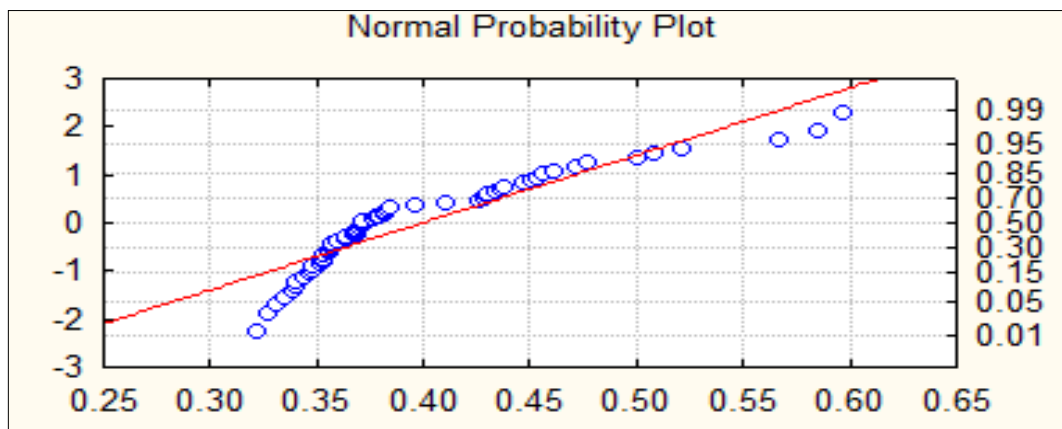


Figure 4.11: Normal Probability Plot

Figure 4.12 is the histogram of the frequency against diameter and the bell curve. The highest frequency is 0.35 μm to 0.40 μm . It shows that all the data is in three sigma range.

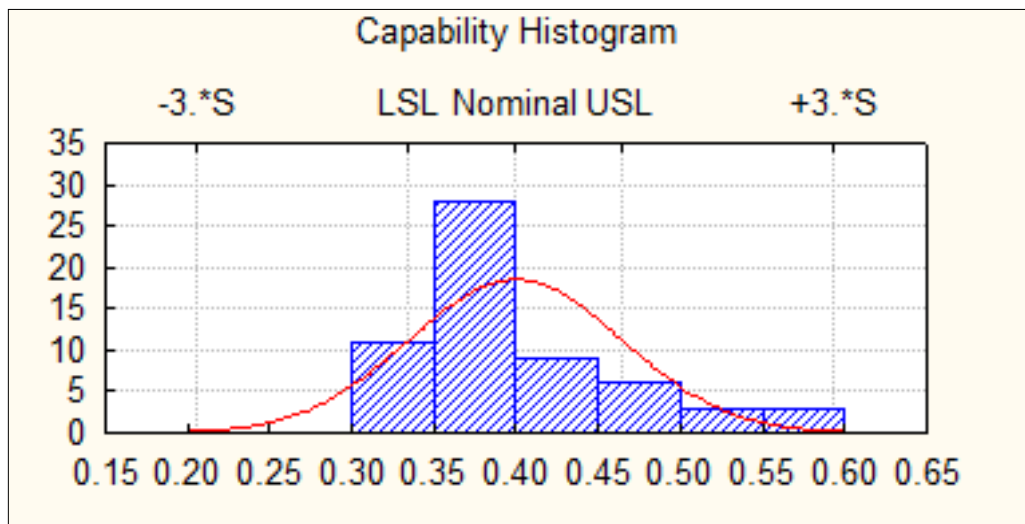


Figure 4.12: Histogram

By referring to Figure 4.13, the \bar{X} chart shows that there are 18 data points beyond the control limits. The UCL is $\text{UCL} = 0.42399\mu\text{m}$ and $\text{LCL} = 0.37518\mu\text{m}$ and the central line is $0.39958\mu\text{m}$. The data is creating by using three constants sample points.

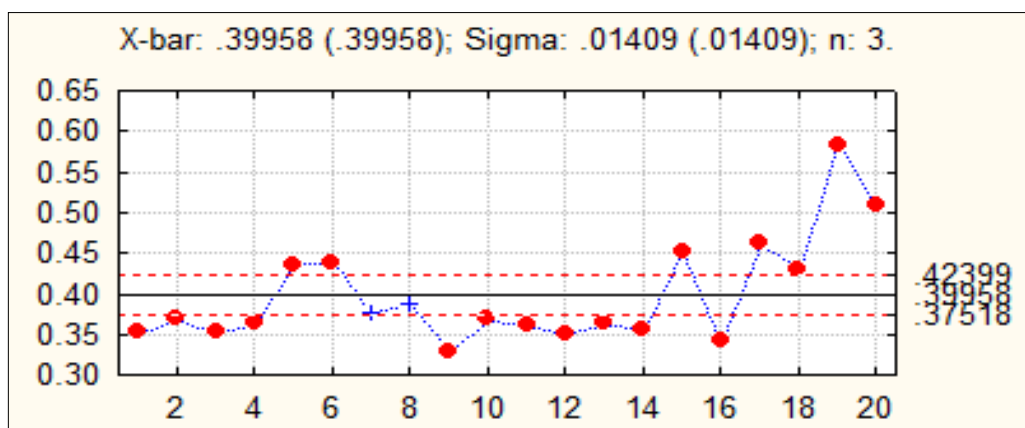


Figure 4.13: \bar{X} chart from STATISTICA

For Figure 4.14, it shows the R chart. From the following graph, it shows that all data point is the control limits range. The UCL is 0.06140 μm , LCL 0.0000 μm and the central line is 0.02385 μm .

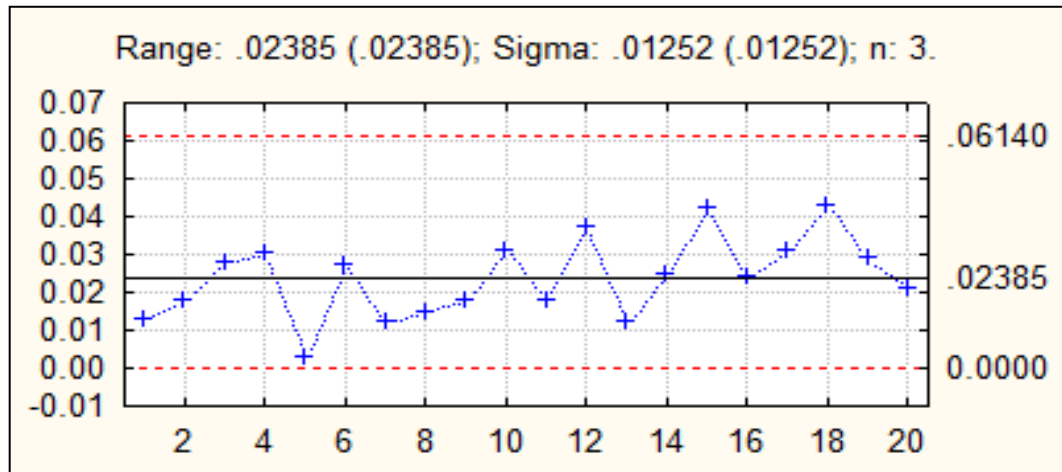


Figure 4.14: R chart from STATISTICA

4.5 OVERALL DISCUSSION

In this project, the concept of quality control chart was applied to assess reliability of turning centre in producing same diameter and surface roughness. Basically, the effective use of any control chart requires periodic revision of the control limits and centre lines. The control charts show out of control, the user may revise shifting the process average or redesigning the control limits. The charts were used here are \bar{x} and R.

The charts show that some of the data from diameter and surface roughness are out of control, even with all the precaution taken before starting and during the experiment, there is always a chance for an error to occur. From the information that had been gathered, the error that occurs is depending on several factors.

Variation in sampled diameter depending on UCL and LCL from control charts is 0.003 mm. Looking at the precision of the machine being 0.001 mm, it can be said

that machine is no longer reliable. Variation for Ra from control chart is 0.39958 μm . Typically Ra for rough turning is 0.4 μm and it can be said the result for surface roughness is not acceptable.

The main causes that affect the accuracy of the dimension and also poor surface finish are the vibration of the workpiece during the turning operation, tool wear, tool, workpiece setting and environmental condition. Although it was assumed that tool wear did not affect the results, there was significant tool wear due to machining characteristic of the titanium. The source of vibration very often came from machine rigidity and setup. Accident to the machine and daily usage of the machine are some other compounded factors. In addition, samples were produced under different environmental conditions. Control charts do show such effect on the results, especially the precision of the results.

It has been found that reliability of the turning centre depends on how control limits were defined in the control charts. In \bar{x} and R chart, for instance, if the control limit is based on IS, many points are out where as If the limit lines are extended to 2σ or 3σ , all points are within the control. In this case, the machine is not reliable to produce part diameters with a tolerance of 1 μm . If the part needs to be produced with variation in size within 1 μm , then the machine should be recalibrated for reliable performance under controlled environmental condition.

4.6 CONCLUSION

The quality control chart, normal probability plot and histogram have been presented. The summary of the finding will be present in the next chapter.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter is summarized about the conclusion of the project based on the project objective and the project scope. Recommendation also will be discussed to provides the helpful information to improve the experiment in the future. This recommendation will help other researcher to enhance the result for this experiment.

5.2 CONCLUSION

A control chart has been developed to investigate the machine reliability. Based on the experimental result, it can be concluded that this machine is not reliable if the requirement diameter of the product is within the ± 0.003 mm range which is using one sigma control limit as shown in the Figure 4.1. It show that six data point that are out of control but if the precision is within ± 0.009 mm tolerable range based on three sigma control limit, the machine can be said reliable to use, otherwise some calibration need to be carried out.

As for surface roughness, also it can be said that the machine is not reliable according to the standard acceptable Ra for rough turning is 0.004 mm since there are eighteen data out of control based on one sigma control limit and even if use three sigma the data still out of control by referring to the histogram.

Overall results show that the machine is no longer reliable according to its resolution of 0.001 mm. Current accuracy is about to be 0.003 mm. However, to obtain the consistent result, the machine needs to be recalibrated.

5.3 RECOMMENDATION

From the experiment and the analysis, there should be more addition to improvement needs to make the model developed become more reliable. Firstly, the number of the experiment and parameter range should be expanded for more valid conclusion. With the higher number of experiment, the experimental data would become more accurate approaching the predicted value. From that, the experimental data that will be used will increase the accuracy of diameter and the surface roughness that had been developed for the experiment.

Secondly, different or better insert tool should be consider into this experiment, the coated brazed carbide insert cannot be use to get a better surface result. By using the better cutting tool type such diamond tool, the characteristic of the surface roughness and also the dimensional will be more accurate. Since the material has high mechanical properties, there might be a chance that the better cutting tools can influence the result.

Thirdly, since the machine is daily use at the lab, limitation on machine utilization required to avoid the accident occurred or setting of the tool changed. And for the last recommendation is, student that runs this experiment should have a good skill and better knowledge in conduct the machine.

Furthermore, with the some additional recommendation, the investigation of the reliability turning centre can be considered to get a better conclusion.

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APPENDIX A
Gantt chart for FYP 1

SUBJECT /WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
LITERATURE REVIEW														
SET OBJECTIVES AND SCOPE OF PROJECT														
METHODOLOGY														
LEARNING CNC TURNING MACHINE														
FYP REPORT 1														
SLIDE PREPARATION														
FYP 1 PRESENTATION														

Figure 6.1: FYP 1 project planning

APPENDIX B
Gantt chart for FYP 2

SUBJECT /WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TURNING ON IDENTICAL ROUND BARS ON CNC TURNING														
MEASUREMENT OF SPECIMEN OF DIAMETER AND SURFACE FINISHED														
DATA ANALYSIS														
QUALITY CONTROL CHART DEVELOP														
FYP 2 REPORT														
SLIDE PREPARATION														
FYP 2 PRESENTATION														

Figure 6.1: FYP 2 project planning