QUALITY CONTROL IN BEARING MANUFACTURING COMPANY USING STATISTICAL PROCESS CONTROL (SPC)

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QUALITY CONTROL IN BEARING MANUFACTURING COMPANY USING STATISTICAL PROCESS CONTROL (SPC)

PANIRCHELVAN RAMANATHAN

A report submitted in partial fulfillment of
the requirements for the award of the degree of
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NOVEMBER 2009

EXAMINERS APPROVAL DOCUMENT

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We certify that the project entitled "*Quality Control in Bearing Manufacturing Company Using Statistical Process Control (SPC)*" is written by *Panirchelvan Ramanathan.* We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

....

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SUPERVISOR'S DECLARATION

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STUDENT DECLARATION

I declare that this thesis entitled *“Quality Control in Bearing Manufacturing Company Using Statistical Process Control (SPC)”* 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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DEDICATION

To my beloved parents, Ramanathan Sockalinggam, Danalhatmi Yalumalai, and not to forget to my beloved Renuka Devi Ramachandran, my respectful brother, Tevan Ramanathan and sister, Dellagawathi Ramanathan. This thesis is the token in reciprocation of your scarifies that you made to brought me up and the strong supports.

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ABSTRACT

Statistical process control(SPC) is an important tool used widely at manufacturing field to monitor the overall operation. SPC can be applied to all kind of manufacturing operations. The significant application of the SPC analysis elements to the operation will make the process more reliable and stable. For the case study, bearing manufacturing process were selected. Bearing is one of important part in mechanical devices. A complete bearing consist of outer ring, steel ball, cage, metallic shield and inner ring. The dimensions of the bearing components are must control tight to its tolerance to ensure the bearing fit to its clearance. To ensure the process is under the production control statistical process control (SPC) methods are being used. To converge the study on SPC application on the bearing manufacturing processes, a visit to SKF Bearing Industries (Malaysia) Sdn. Bhd. has been made. The case study was done on bearing product number 6206-2Z. The bearings outer ring manufacturing processes were take into consideration. Each processes of the outer ring making were observed carefully. The quality control (QC) data were obtained from SKF and further analysis on the data was done manually and by using MINITAB software. The analyzed data were compared and the root problems and errors were identified. The problems are further discussed and some recommendations were made to make the process more efficient. In the bearing industry, bearings outer ring making operation is on of the critical process. Significant differences in dimension and deviation from the parts tolerance will make the bearing produced is rejected or categories as low quality bearing. A class 1 bearing will have tight clearance. Statistical process control will monitor the processes and magnifies the small deviations of the process from the actual control limits. Thus, the manufacturing processes can be controlled directly and good bearing which meets all the specifications can be produced.

ABSTRAK

Bearing adalah satu componen penting dalam alat-alat mekanikal yang digunakan pada masa kini. Bearing terdiri daripada gelung luar, gelung dalam, bebola besi, sangkar bebola dan penutup. Semua ukuran bahagian bearing kenala tepat. Bearing yang bahagianya tidak tepat akan ukuran tidak boleh berfungsi dengan betul dan ia boleh rosak dengan cepat. Oleh yang demikian, process pembuatan setiap bahagian bearing kenalah di beri tumpuan yang tinggi. Kawalan Process Statistikal (SPC) digunakan untuk mengukur setiap detik prosess pembuatan bearing. Untuk kajian pembelajaran, satu lawatan telah dibuat ke SKF Bearing Industries (Malaysia) Sdn. Bhd. Setiap process pembuatan bearing di SKF telah diteliti. Process pembuatan gelang luar telah dipilih untuk kajian seterusnya. Aplikasi SPC dalam pembuatan gelang luar diperhatikan. Data pengawalan qualiti(QC) telah deperolehi dari SKF. Data tersebut di kaitkan dengan applikasi SPC. Pengiraan manual dan analisis melalui perisian MINITAB telah dibuat dengan mengunakan data QC tersebut. Keputusan data di bandingkan dan setiap punca masalah dikenal pasti. Setiap masalah tersebut dibincang dengan lebih meluas. Cara-cara mengatasi masalah tersebut dicadangkan pada akhir kajian. Setiap process pembuatan bearing boleh di perhatikan dengan teliti dengan bantuan SPC. Dengan itu bearing yang berkualiti boleh dihasilkan melalui kawalan SPC yang teliti.

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LIST OF SYMBOLS

$\bar{\bar{X}}$	-	Average of the subgroup average
$\bar{X}$	-	Average of subgroup
m	-	Number of subgroups
UCL	-	Upper Control Limit
LCL	-	Lower Control Limit
σ	-	Population standard deviation of the subgroup averages
$\bar{R}$	-	Average of the range
R	-	Individual range value for the sample
A_2	-	Approximation factor used to calculate control limits
σ_R	-	Population standard deviation of the subgroup ranges
D_3	-	Approximation factor used to calculate range chart control limits
D_4	-	Approximation factor used to calculate range chart control limits
PCR	-	Process capability ratio
6s	-	6-sigma
2s	-	2-sigma
T	-	Tolerance (Specification tolerance)
d_2	-	Approximation factor for calculating within subgroup standard deviation

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will discuss about the project background, the problem statement, objectives and scopes of the project.

1.2 PROJECT BACKGROUND

Statistical process control (SPC) involves using statistical techniques to measure and analyze the variation in processes. Most often used for manufacturing processes, the intent of SPC is to monitor product quality and maintain processes to fixed targets. Statistical quality control refers to using statistical techniques for measuring and improving the *quality* of processes and includes SPC in addition to other techniques, such as sampling plans, experimental design, variation reduction, process capability analysis, and process improvement plans.

The consistent, aggressive and committed use of SPC to bring all processes under control, recognize and eliminate special causes of variation, and identify the capability of all operations is a key requirement. SPC is defined as pr5evention of defects by applying statistical methods to control the process.

In this project the relevant SPC method applied to bearing outer ring production process at SKF Bearing Industries (Malaysia) Sdn. Bhd. The process analyzed using SPC method and its effectiveness is studied.

1.3 PROBLEM STATEMENT

Ball bearing consist of outer ring, steel ball, cage, metallic shield and inner ring. The manufacturing of each components of the bearing must be very much precise to control the quality of the bearing. The manufactured bearing in industry is classified according to its tolerance and vibration level by class 1,2 and 3. Class 1 bearing is the bearing with most perfect fitness where all of its components are exact with its dimension. Most of the customers request is on class 1 bearing where its more reliable and long lasting. In order to keep the production of the bearing components in control to its dimension; an accurate and effective process control method is required.

1.4 PROJECT OBJECTIVES

The objectives of this project are determined. There are two objectives have been defined to be focused on and to simplify the project as stated below:

i) To perform a quality control technique for a selected manufacturing process using statistical process control method.

ii) To propose method to improve the selected manufacturing process base on the case study.

1.5 SCOPE OF STUDY

The project objective is narrowed down by performing scopes of study. Firstly a comprehensive literature review has been conducted to determine the best quality statistical method. Secondly a case study has been conducted at SKF Bearing Industries (Malaysia) Sdn. Bhd. on 6206-2Z bearings outer ring production. Then, the processes of the case study analyzed using statistical process control method. Lastly the methods to improve the manufacturing processes further were proposed base on the analysis outcome.

CHAPTER 2

LITERATURE REVIEW

2.1 STATISTICAL PROCESS CONTROL (SPC) BACKGROUND

Statistical Process Control (SPC) is a control mechanism whereby measurements of product quality are actively obtained and charted simultaneously as industrial products are produced. Control is obtained when a statistical measurement such as means of a group of products are within certain control limits drawn on the statistical process chart. For these charts, there are certain set of rules to follow that will tell the technicians when a process may be out of control. When these conditions are observed, the technicians are expected to stop the manufacturing process so that corrective actions can be taken. (Dougles .C.Montgomery ,2003)

2.2 RATIONAL SUBGROUPS

Taking measurements of products on an assembly line can be costly or can potentially damage product quality. Naturally, companies often do not measure all products produced on an assembly line as this may prove to be counter-productive or economically not feasible. A compromise is often taken. For measurement of consistent product quality, most companies select what is termed as ‘rational subgroups’ of products. Some random sampling scheme is usually employed to secure these ‘rational subgroups’. These ‘rational subgroups’ are then laboriously checked for quality. Measurements emanating from these ‘rational subgroups’ are then charted for quality control purposes. (Dougles .C.Montgomery ,2003)

2.3 APPLYING SPC IN MANUFACTURING PROCESSES

When SPC is introduced to a process, the initial thought should be about the quality characteristics. What are they and what are their associated measurement requirements? In most situations, a statistical quality control (SQC) analysis would be done first by identifying the quality characteristics are critical to quality (CTQ) and determining how those characteristics can be controlled.

As an example, when an automobile transmission or a four-wheel-drive transfer case is made, one of the quality characteristics is the noise (or lack of it) at various speeds. The SQC analysis of the noise at specific speeds could then lead to several SPC charts of CTQ measurements in the manufacturing of the gears that would contribute to the noise factor. Below are the steps in brief of existing SPC in manufacturing process. (Dougles .C.Montgomery ,2003)

i) The initial step in SPC is diagramming and analyzing the process to decide where control charts may be best applied.

ii) Decrease any obvious variability in the target process.

iii) The third step involves statistically testing the gauges using a gauge capability study. This must be done before measurements are taken for control charting. The variation that shows up on the control charts must reflect the process variation that needs to be reduced.

iv) Make a sampling plan. Determine the size of the sample and when the samples are to be taken.

v) By using control chart, find the out-of-control situation caused by common-cause and special-cause, evaluates what happened at that specific time to cause it, and then work to prevent that cause. This procedure continues until the control chart indicates that there are no more special-cause variation problems. By this time, the process is running as well as it possibly can without process modifications and it is said to be in statistical control.

vi) The sixth step is to put operator in-charged. This step and step 5 actually occurred simultaneously because the operator should be doing the control charting and attaining statistical control with the help of the process control team.

vii) This step is to determine how capable the process is according to product specifications and customer expectations.

viii) This step is designed to improve the process. Eighty-five percent or more of the process problem are handheld at this stage, according to quality consultant W.Edwards Deming. At this stage, process changes can be analyzed on control charts either singly or in variable interaction studies for signs of process improvement. Designed experiments may also be used in the search for improvements. When improvements are found, management must follow thru and see the appropriate changes are incorporated in the process without backsliding. (S B Billatos, B S Kim)

ix) The ninth step calls for a switch to pre-control, a monitoring technique that compares a measurement with target and warning measurements, when the process is in control and capable.

x) Quality improvement is a continuous process. Two things should be done at this step; first, continue to look for ways to improve the process at hand and second, return to step 1 for the next critical measurement.

Historically, many companies did not begin using SPC until they were forced. Either they could see their competitive position diminishing or they were obliged to meet their customers requirement that contracts would not be awarded until their workforce was trained in SPC. Unfortunately, some companies just met the minimum requirement of providing basic SPC training and discovered that it’s was not good enough.

Both workers and supervisors must understand the essential of the SPC for their own good to prevent losses becoming routine. The management also must have good interpretation on SPC where when workers suggestion is made based on SPC analysis, the management should not neglect their recommendation.

2.4 ANTICIPATED BENEFITS OF IMPLEMENTATION

SPC is a powerful tool to optimize the amount of information needed for use in making management decisions (Dougles .C.Montgomery ,2003). Statistical techniques provide an understanding of the business baselines, insights for process improvements, communication of value and results of processes, and active and visible involvement. SPC provides real time analysis to establish controllable process baselines; learn, set, and dynamically improve process capabilities; and focus business on areas needing improvement. SPC moves away from opinion-based decision making. (S B Billatos, B S Kim)

These benefits of SPC cannot be obtained immediately by all organizations. SPC requires defined processes and a discipline of following them. It requires a climate in which personnel are not punished when problems are detected. It requires management commitment. (Samuel Kotz, 2002)

Statistical process control is an important tool and leads to many process improvements and positive process results, such as:

- Uniformity of output.
- Reduced rework.
- Fewer detective product.
- Increased profit.
- Lower average cost.
- Fewer errors.
- Higher quality output.
- Less scrap.
- Less machine downtime.
- Less waste in production labor hours.
- Increased job satisfaction.
- Improved competitive position.
- More jobs.

2.4.1 SPC Implementation Issues

Implementing SPC in a manufacturing process starts with defining the process its self. Consistent measurements cannot be expected from software processes that are not documented and generally followed. Then appropriate measures must be chosen. Measures need not be exhaustive. One or two measures that provide insight into the performance of a process or activity are adequate, especially if the measures are related to the process or activity goal. Measures that can be tracked inexpensively are preferable. After that, the process trends must be focused. Control charts should be constructed so as to detect process trends, not individual nonconforming events. Eventually the investigation on the chart trend must be done. Appropriate action should be taken for each causes. SPC only signals the possible existence of a problem. Without detailed investigations, as in an audit, and instituting corrective action, SPC will not provide any benefit. Finally the operating personals should provided needed training. Problems in following the above recommendations for implementing SPC can be decreased with effective training. SPC training based on examples of software processes is to be preferred.

2.5 THE BASIC TOOL FOR SPC

Usually, there are **seven commonly recognized tools** or **diagrams** for statistical process control:

1. Check sheet
2. Run chart
3. Histogram
4. Pareto chart
5. Scatter diagram/chart
6. Cause and effect or fishbone diagram
7. Control chart

Some basic examples are shown in following which we have cited from (Fred Spring, 1995) only for illustration the general characteristics.

Check Sheet: The check sheet (see Table 2.1) is used for counting and accumulating data in a general or special context.

Table 2.1: Check sheet Used for Counting and Accumulating Data

Student Name	*In Class This Week?*
Jane	√ √ √ √ √
Robert	√ √ √ √ √
Jennifer	√ √ √
Puff Daddy	

Source : Fred Spring, 1995

Run Chart: The run chart (see Figure 2.1) tracks trends over a period of time. Points are tracked in the order in which they occur. Each point represents an observation. We can often see interesting trends in the data by simply plotting data on a run chart. A danger in using run charts is that we might overreact to normal variations, but it is often useful to put our data on a run chart to get a feel for process behavior.

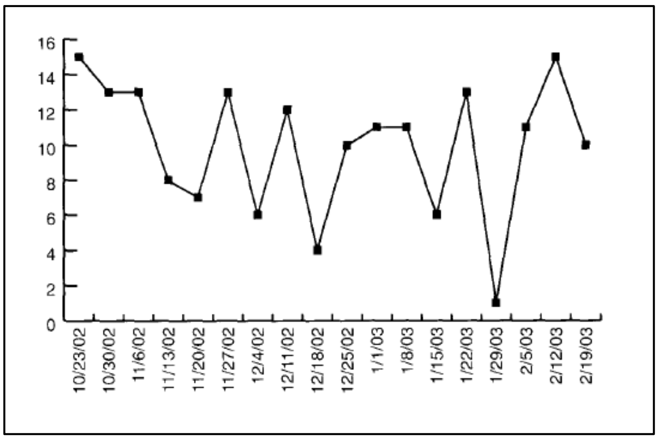

Figure 2.1: Example of a run chart

Source : Thomas, 1987

Histogram: The histogram (see Figure 2.2) is a bar chart that presents data that have been collected over a period of time, and graphically presents these data by frequency. Each bar represents the number of observations that fit within the indicated range. Histograms are useful because they can be used to see the amount of variation in a process. The data in this histogram are the same data as in the run chart in Figure 1. Using the histogram, we get a different perspective on the data. We can see how often similar values occur and get a quick idea of how the data are distributed.

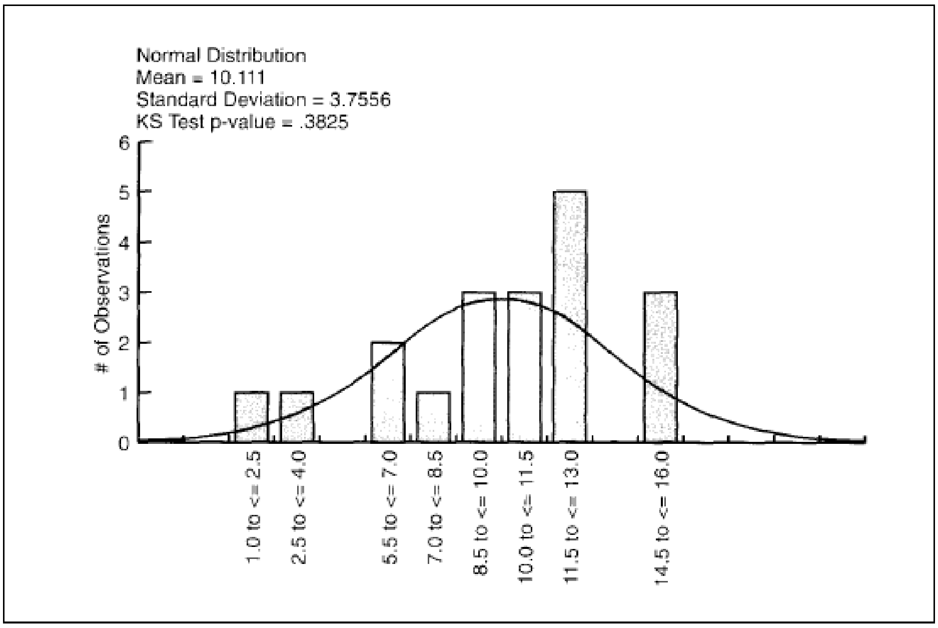

Figure 2.2: Example of a Histogram

Source : Thomas, 1987

Pareto Chart: The Pareto chart (see Figure 2.3) is a bar chart that presents data prioritized in some fashion, usually either by descending or ascending order of importance. Pareto diagrams are used to show attribute data. Attributes are qualitative data that can be counted for recording and analysis; for example, counting the number of each type of defect. Pareto charts are often used to analyze the most often occurring type of something.

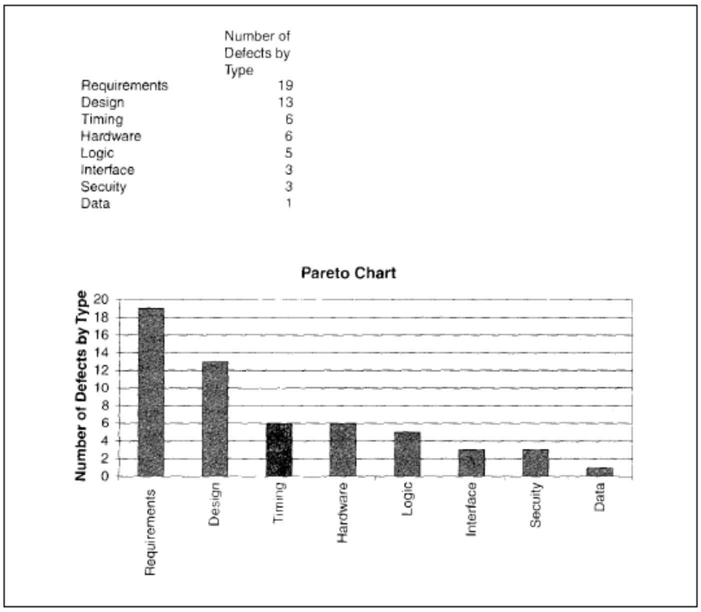

Figure 2.3: An example of a Pareto chart (Thomas, 1987)

Source : Thomas, 1987

Scatter Diagram/Chart: The scatter diagram (see Figure 2.4) is a diagram that plots data points, allowing trends to be observed between one variable and another. The scatter diagram is used to test for possible cause-and-effect relationships. A danger is that a scatter diagram does not prove the cause-and-effect relationship and can be misused. A common error in statistical analysis is seeing a relationship and concluding cause-and-effect without additional analysis.

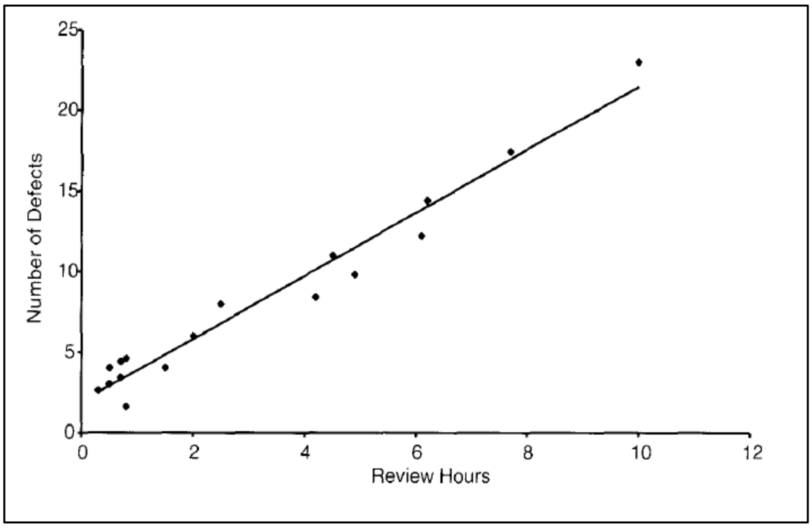

Figure 2.4: An example of a scatter diagram/chart

Source : Thomas, 1987

Cause-and-Effect/Fishbone Diagram: The cause-and-effect/fishbone diagram (see Figure 2.5) is a graphical display of problems and causes. This is a good to capture team input from a brainstorming meeting, from a set of defect data, or from a check sheet.

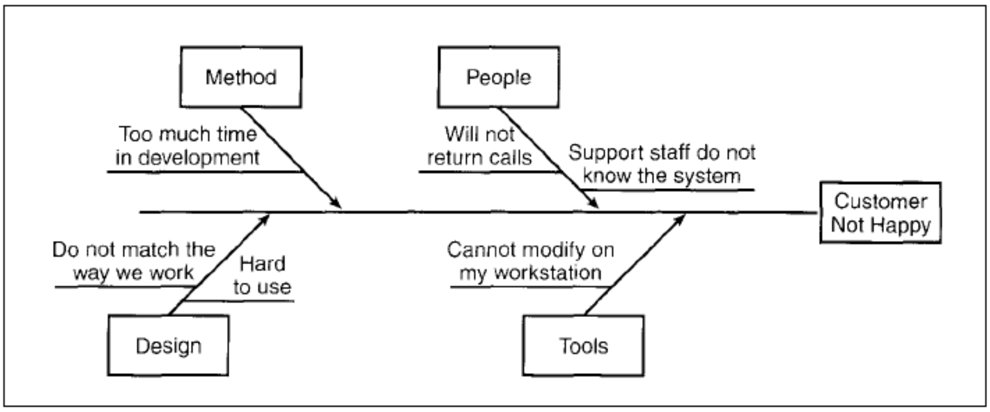

Figure 2.5: A cause and effect/fishbone diagram example

Source : Thomas, 1987

Control Chart: The control chart (see Figure 2.6) is basically a run charts with upper and lower limits that allows an organization to track process performance variation. Control charts are also called process behavior charts.

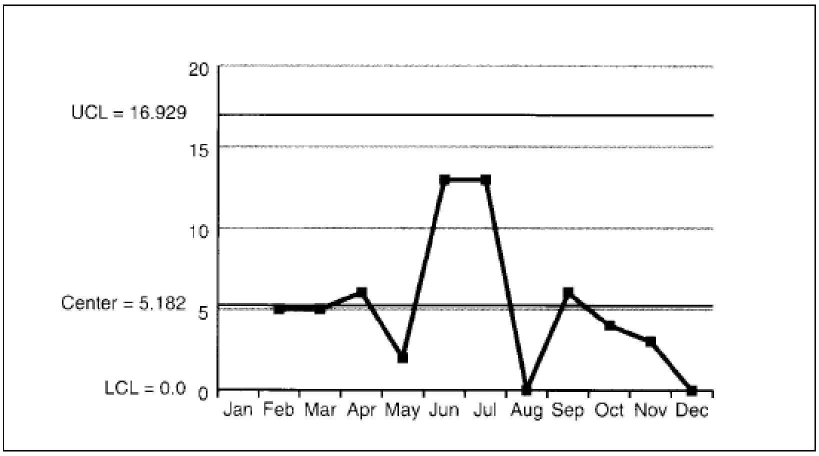

Figure 2.6: Example of a control chart

Source : Thomas, 1987

These seven graphical displays can he used together or separately to help gather data, accumulate clam, and present the data for different functions associated with SPC.

2.5.1 Example of SPC Tools Presentations in the Manufacturing Process.

Table 2.2 : SPC tools and its example of application

Tool	Example of Application
Check Sheet	To count occurrences of problems.
Run Chart	For visualize the trend of data distribution.
Histogram	To identify central tendencies and any skewing to one side or the other.
Pareto Chart	To identify the 20% of the modules which yield 80% of the issues.
Scatter Diagram	For identifying correlation and suggesting causation.
Cause and Effect Diagram	For identifying assignable causes.
Control Chart	For identifying processes that are out of control.

Source : Michael V Petrovich

2.6 VARIATION IN A MANUFACTURING PRODUCT LINE

The most important goal of understanding the principle of natural process variation is to consider the natural variance in the output before we make any changes to the process. Since SPC tends to minimize the process variations in time, as we better understand the process and have more experience with running it, we try to reduce the variation of it. The knowledge of the principle of natural variance helps us avoid making any unnecessary changes to the process, which might add variance to the process, instead of removing it. The technical goal is to reduce process variation such that the amount of unacceptable product is not more that 3 defects per million parts. (Michael V Petrovich)

Here are a few examples:

1. We manufacture tires and the tread depth needs to be 5/8 inch plus or minus 0.05 inch.
2. We approve loans and we promise a response to the customer within 24 business hours of receipt.
3. We write code and the manager expects less than 5 bugs found over the life of the product per thousand lines of code written.
4. We process invoices for healthcare services and the customers expect zero errors on their bills.

So how we can determine if the process is scattered around the target, grouped well but off the target? We can display our data in frequency distributions showing the number (percentage) of our process outputs having the indicated dimensions. (Michael V Petrovich)

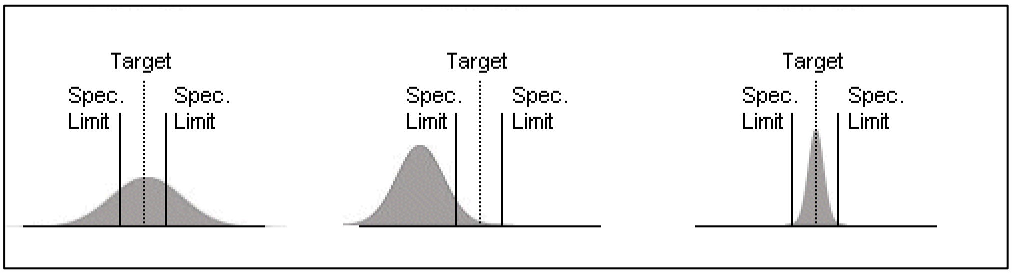

Figure 2.7 : Targeting Process Variation With The Process Capability Ratio

Source : Thomas, 1987

In Figure 2.7, the far left picture displays wide variation that is centered on the target. The middle picture shows little variation, but off target. And the far right picture displays little variation centered on the target. Shaded areas falling between the specification limits indicate process output dimensions meeting specifications; shaded areas falling either to the left of the lower specification limit or to the right of the upper specification limit indicate items falling outside specification limits. (Phillip L Ross, 1998)

2.7 PRINCIPLES OF SPC TECHNIQUES

There are a few key principles of SPC techniques. In any process or system, variation is to be expected. By use of simple statistical techniques we can define the limits of variation beyond which data points are deemed worthy of investigation. These limits are known as control limits. Variation within these limits is often called common-cause or process variation; variation outside these limits is often called special-cause or extra-process variation. Common-cause variation is that which can be expected to occur in a stable process or system - one which is ‘under control’. Special-cause variation may derive from systematic or unexpected deviation from the norm and may highlight an area or an observation which is worthy of further investigation. A useful estimate of expected ‘performance’ of a system is often the group average, and the best estimate of expected variation around the group average is ±3 standard deviations(SDs) (roughly equivalent to 99.8% confidence intervals). This degree of variation has both empirical and theoretical justification. These limits (control limits) can be readily derived and depend on the nature of the data being used to assess the process.

2.8 TYPES OF CONTROL CHARTS

Control charts are used to identify process variation over time. All processes vary. The degree of variance, and the causes of the variance, can be determined using control charting techniques. While there are many types of control charts, the ones we have seen the most often are the : (Phillip L Ross, 1998)

i) C-chart:

This chart uses a constant sample size of attribute data, where the average sample size is greater than five. It is used to chart the number of defects (such as “12” or “15” defects per thousand lines of code). c stands for the number of nonconformities within a constant sample size.

ii) U-chart:.

This chart uses a variable sample size of attribute data. This chart is used to chart the number of defects in a sample or set of samples (such as "20 out of 50" design flaws were a result of requirements errors). u stands for the number of nonconformities with varying sample sizes.

iii) np-chart:

This chart uses a constant sample size of attribute data, usually greater than or equal to 50. This chart is used to chart the number defective in a group. For example, a hardware component might be considered defective, regardless of the total number of defects in it. np stands for the number defective.

iv) p-chart*:*

This chart uses a variable sample size of attribute data, usually greater than or equal to 50. This chart is used to chart the fraction defective found in a group. p stands for the proportion defective.

v) X and ***mR charts****:*

These charts use variable data where the sample size is one.

vi) X-bar and ***R charts:***

These charts use variable data where the sample size is small. They can also be based on a large sample size greater than or equal to ten. X-bar stands for the average of the data collected. R stands for the range (distribution) of the data collected.

vii) X-bar and ***s charts****:*

These charts use variable data where the sample size is large, usually greater than or equal to ten.

For the case study purposes, **average and range (X-bar and R charts) chart** is chosen. The sample data that obtained from the visited company is suitable to use this control chart method analysis. This will be further discussed in next chapter. The features of this type of chart is discussed in the following topics.

2.9 VARIABLE CONTROL CHARTS

During the 1920's, Dr. Walter A. Shewhart proposed a general model for control charts as follows : (Wood, 1994)

2.9.1 Shewhart Control Charts for Variables

Let *w* be a sample statistic that measures some continuously varying quality characteristic of interest (e.g., thickness), and suppose that the mean of *w* is μ_w, with a standard deviation of σ_w. Then the center line, the UCL and the LCL are (Montgomery, 2005; Wood, 1994) :

$$\text{UCL} = \mu_w + k\sigma_w \quad \text{(eq 2.1)}$$

$$\text{Center Line} = \mu_w \quad \text{(eq 2.2)}$$

$$\text{LCL} = \mu_w - k\sigma_w \quad \text{(eq 2.3)}$$

Where *k* is the distance of the control limits from the center line, expressed in terms of standard deviation units. When *k* is set to 3, we speak of 3-sigma control charts. (Wood, 1994)

Historically, k = 3 has become an accepted standard in industry. (D Saravan, 2002; Constantian Anghel, 2001)

The centerline is the process mean, which in general is unknown. We replace it with a *target* or the *average* of all the data. The quantity that we plot is the sample average, $\bar{\mathbf{X}}$. The chart is called the $\bar{\mathbf{X}}$chart.

We also have to deal with the fact that σ is, in general, unknown. Here we replace σ_w with a given standard value, or we estimate it by a function of the *average standard deviation*. This is obtained by averaging the individual standard deviations that we calculated from each of *m* preliminary (or present) samples, each of size *n.* It is equally important to examine the standard deviations in ascertaining whether the process is in control. There is, unfortunately, a slight problem involved when we work with the usual estimator of σ. The following discussion will illustrate this.

2.9.2 Differences between control limits and specification limits

Control Limits are used to determine if the process is in a state of statistical control (i.e., is producing consistent output). Specification Limits are used to determine if the product will function in the intended fashion.

2.10 NUMBER OF DATA POINTS NEEDED TO SET UP A CONTROL CHART

Shewhart gave the following rule of thumb:

"It has also been observed that a person would seldom if ever be justified in concluding that a state of statistical control of a given repetitive operation or production process has been reached until he had obtained, under presumably the same essential conditions, a sequence of not less than twenty five samples of size four that are in control." (Constantian Anghel, 2001)

It is important to note that control chart properties, such as false alarm probabilities, are generally given under the assumption that the parameters, such as μ and σ, are known. When the control limits are not computed from a large amount of data, the actual properties might be quite different from what is assumed (Constantian Anghel, 2001).

2.11 SHEWHART X-BAR AND R CONTROL CHARTS

If the sample size is relatively small (say equal to or less than 10), we can use the range instead of the standard deviation of a sample to construct control charts on $\bar{X}$ and *the range, R*. The range of a sample is simply the difference between the largest and smallest observation.

There is a statistical relationship (Chin-Chuan Wu, 2004) between the mean range for data from a normal distribution and σ, the standard deviation of that distribution. This relationship depends only on the sample size, *n*. The mean of R is $d_2 \sigma$, where the value of d_2 is also a function of *n*. *An estimator of* σ is therefore R / d_2.

Armed with this background we can now develop the $\overline{X}$ and R control chart. Let R_1, R_2, ..., R_k, be the range of k samples. The average range is :

$$\bar{R} = \frac{R_1 + R_2 + ... + R_k}{k} \qquad \text{(eq 2.4)}$$

Then an estimate of σ can be computed as :

$$\hat{\sigma} = \frac{\bar{R}}{d_2} \qquad \text{(eq 2.5)}$$

2.11.1 $\overline{X}$ control charts

So, if we use $\bar{\bar{x}}$ (or a given target) as an estimator of μ and $\bar{R}/d_2$ as an estimator of σ, then the parameters of the $\overline{X}$ chart are :

$$UCL = \bar{\bar{x}} + \frac{3}{d_2\sqrt{n}}\bar{R} \qquad \text{(eq 2.6)}$$

$$\text{Center Line} = \bar{\bar{x}} \qquad \text{(eq 2.7)}$$

$$LCL = \bar{\bar{x}} - \frac{3}{d_2\sqrt{n}}\bar{R} \qquad \text{(eq 2.8)}$$

The simplest way to describe the limits is to define the factor $A_2 = 3/(d_2\sqrt{n})$ and the construction of the $\overline{X}$ becomes

$$UCL = \bar{\bar{x}} + A_2\bar{R} \qquad \text{(eq 2.9)}$$

$$\text{Center Line}\ ,\ \bar{\bar{X}} = \frac{\sum_{i=1}^{m} \bar{x}_i}{m} \qquad \text{(eq 2.10)}$$

$$LCL = \bar{\bar{x}} - A_2\bar{R} \qquad \text{(eq 2.11)}$$

The factor A_2 depends only on n, and is tabled below.

2.11.2 The R Control Chart

This chart controls the process variability since the sample range is related to the process standard deviation. *The center line of the R chart is the average range.* To compute the control limits we need an estimate of the true, but unknown standard deviation $W = R/\boldsymbol{\sigma}$. This can be found from the distribution of $W = R/\boldsymbol{\sigma}$ (assuming that the items that we measure follow a normal distribution). The standard deviation of W is d_3, and is a known function of the sample size, n. It is tabulated as statistical quality control. Therefore since $R = W\boldsymbol{\sigma}$, the standard deviation of R is $\boldsymbol{\sigma}_R = d_3\,\boldsymbol{\sigma}$. But since the true $\boldsymbol{\sigma}$ is unknown, we may estimate $\boldsymbol{\sigma}_R$ by

$$\hat{\sigma}_R = d_3 \frac{\bar{R}}{d_2} \qquad \text{(eq 2.12)}$$

As a result, the parameters of the R chart with the customary 3-sigma control limits are :

$$UCL = \bar{R} + 3\hat{\sigma}_R = \bar{R} + 3d_3 \frac{\bar{R}}{d_2} \qquad \text{(eq 2.13)}$$

$$\text{Center Line} = \bar{R} \qquad \text{(eq 2.14)}$$

$$LCL = \bar{R} - 3\hat{\sigma}_R = \bar{R} - 3d_3 \frac{\bar{R}}{d_2} \qquad \text{(eq 2.15)}$$

As was the case with the control chart parameters for the subgroup averages, defining another set of factors will ease the computations, namely:

$D_3 = 1 - 3\, d_3 / d_2$ and $D_4 = 1 + 3\, d_3 / d_2$.
These yields

$$UCL - \bar{R}D_4 \qquad \text{(eq 2.16)}$$

$$\text{Center Line} = \bar{R} \qquad \text{(eq 2.17)}$$

$$LCL = \bar{R}D_3 \qquad \text{(eq 2.18)}$$

The factors D_3 and D_4 depend only on n, and are tabled below.

Table 2.3 : Factors for Calculating Limits for $\overline{\mathbf{X}}$ and R Charts

Observations in Sample, n	Chart for Averages			Chart for Ranges						Chart for Standard Deviations				
	Factors for Control Limits			Factor for Central Line	Factors for Control Limits					Factor for Central Line	Factors for Control Limits			
	A	A_2	A_3	d_2	d_1	D_1	D_2	D_3	D_4	c_4	B_3	B_4	B_5	B_6
2	2.121	1.880	2.659	1.128	0.853	0	3.686	0	3.267	0.7979	0	3.267	0	2.606
3	1.732	1.023	1.954	1.693	0.888	0	4.358	0	2.574	0.8862	0	2.568	0	2.276
4	1.500	0.729	1.628	2.059	0.880	0	4.698	0	2.282	0.9213	0	2.266	0	2.088
5	1.342	0.577	1.427	2.326	0.864	0	4.918	0	2.114	0.9400	0	2.089	0	1.964
6	1.225	0.483	1.287	2.534	0.848	0	5.078	0	2.004	0.9515	0.030	1.970	0.029	1.874
7	1.134	0.419	1.182	2.704	0.833	0.204	5.204	0.076	1.924	0.9594	0.118	1.882	0.113	1.806
8	1.061	0.373	1.099	2.847	0.820	0.388	5.306	0.136	1.864	0.9650	0.185	1.815	0.179	1.751
9	1.000	0.337	1.032	2.970	0.808	0.547	5.393	0.184	1.816	0.9693	0.239	1.761	0.232	1.707
10	0.949	0.308	0.975	3.078	0.797	0.687	5.469	0.223	1.777	0.9727	0.284	1.716	0.276	1.669
11	0.905	0.285	0.927	3.173	0.787	0.811	5.535	0.256	1.744	0.9754	0.321	1.679	0.313	1.637
12	0.866	0.266	0.886	3.258	0.778	0.922	5.594	0.283	1.717	0.9776	0.354	1.646	0.346	1.610
13	0.832	0.249	0.850	3.336	0.770	1.025	5.647	0.307	1.693	0.9794	0.382	1.618	0.374	1.585
14	0.802	0.235	0.817	3.407	0.763	1.118	5.696	0.328	1.672	0.9810	0.406	1.594	0.399	1.563
15	0.775	0.223	0.789	3.472	0.756	1.203	5.741	0.347	1.653	0.9823	0.428	1.572	0.421	1.544
16	0.750	0.212	0.763	3.532	0.750	1.282	5.782	0.363	1.637	0.9835	0.448	1.552	0.440	1.526
17	0.728	0.203	0.739	3.588	0.744	1.356	5.820	0.378	1.622	0.9845	0.466	1.534	0.458	1.511
18	0.707	0.194	0.718	3.640	0.739	1.424	5.856	0.391	1.608	0.9854	0.482	1.518	0.475	1.496
19	0.688	0.187	0.698	3.689	0.734	1.487	5.891	0.403	1.597	0.9862	0.497	1.503	0.490	1.483
20	0.671	0.180	0.680	3.735	0.729	1.549	5.921	0.415	1.585	0.9869	0.510	1.490	0.504	1.470

Source : Wood, 1994

In general, the range approach is quite satisfactory for sample sizes up to around 10. For larger sample sizes, using subgroup standard deviations is preferable. For small sample sizes, the relative efficiency of using the range approach as opposed to using standard deviations is shown in the following table.

Table 2.4: Efficiency of R versus S

n	Relative Efficiency
2	1.000
3	0.992
4	0.975
5	0.955
6	0.930
10	0.850

Source : Wood, 1994

A typical sample size is 4 or 5, so not much is lost by using the range for such sample sizes.

2.12 RECALCULATION OF THE CONTROL LIMITS

Since a control chart "compares" the current performance of the process characteristic to the past performance of this characteristic, changing the control limits frequently would negate any usefulness.

So, only change the control limits if did have a valid, compelling reason for doing so. Some examples of reasons:

- When we have at least 30 more data points to add to the chart and there have been no known changes to the process.
    - ➢ We will get a better estimate of the variability.
- If a major process change occurs and affects the way of our process runs.
- If a known, preventable act changes the way the tool or process would behave (power goes out, consumable is corrupted or bad quality, etc.) (Thomas, 1987)

2.13 ANALYSIS OF OUT-OF-CONTROL

2.13.1 WECO (Western Electric Company Rules) rules for signaling "Out of Control".

General rules for detecting out of control or non-random situations (Thomas, 1987)

Any Point Above +3 Sigma

--- +3 σ LIMIT

2 Out of the Last 3 Points Above +2 Sigma

--- +2 σ LIMIT

4 Out of the Last 5 Points Above +1 Sigma

--- +1 σ LIMIT

8 Consecutive Points on This Side of Control Line

=================================== **CENTER LINE**

8 Consecutive Points on This Side of Control Line

--- -1 σ LIMIT

4 Out of the Last 5 Points Below - 1 Sigma

--- -2 σ LIMIT

2 Out of the Last 3 Points Below -2 Sigma

--- -3 σ LIMIT

Any Point Below -3 Sigma

Trend Rules : 6 in a row trending up or down. 14 in a row alternating up and down.

1. WECO rules based on probabilities

The WECO rules are based on probability. We know that, for a normal distribution, the probability of encountering a point outside ± 3σ is 0.3%. This is a rare event. Therefore, if we observe a point outside the control limits, we conclude the process has shifted and is unstable. Similarly, we can identify other events that are equally rare and use them as flags for instability. The probability of observing two points out of three in a row between 2σ and 3σ and the probability of observing four points out of five in a row between 1σ and 2σ are also about 0.3%. (Chin-Chuan Wu, 2004)

2. WECO Rules Increase False Alarms

Note: While the WECO rules increase a Shewhart chart's sensitivity to trends or drifts in the mean, there is a severe downside to adding the WECO rules to an ordinary Shewhart control chart that the user should understand. When following the standard Shewhart "out of control" rule (i.e., signal if and only if we see a point beyond the plus or minus 3 sigma control limits) we will have "false alarms" every 371 points on the average. Adding the WECO rules increases the frequency of false alarms to about once in every 91.75 points, on the average. We has to decide whether this price is worth paying (some add the WECO rules, but take them "less seriously" in terms of the effort put into troubleshooting activities when out of control signals occur). (Thomas, 1987)

2.13.2 Time To Detection or Average Run Length (ARL)

Waiting time to signal "out of control"

Two important questions when dealing with control charts are:

1. How often will there be false alarms where we look for an assignable cause but nothing has changed?
2. How quickly will we detect certain kinds of systematic changes, such as mean shifts?

The ARL tells us, for a given situation, how long on the average we will plot successive control charts points before we detect a point beyond the control limits. For an $\bar{X}$ chart, with no change in the process, we wait on the average 1/*p* points before a false alarm takes place, with *p* denoting the probability of an observation plotting outside the control limits. For a normal distribution, *p* = .0027 and the ARL is approximately 371.

2.14 CENTRAL LIMIT THEOREM

The central limit theorem can be stated as follows:
Irrespective of the shape of the distribution of the population or universe, the distribution of average values of samples drawn from that universe will tend toward a normal distribution as the sample size grows without bound. (AJsupF & Watson, 1993)

It can also be shown that the average of sample averages will equal the average of the universe and that the standard deviation of the averages equals the standard deviation of the universe divided by the square root of the sample size. Shewhart performed experiments that showed that small sample sizes were needed to get approximately normal distributions from even wildly non-normal universes. Figure 2.8 was created by Shewhart using samples of four measurements.

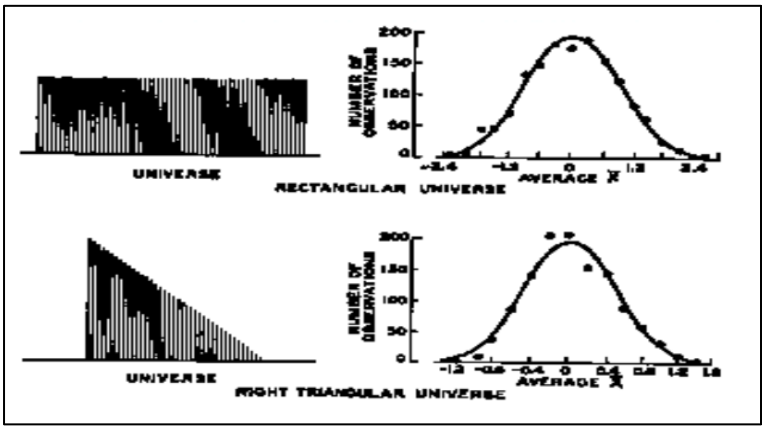

Figure 2.8 : Illustration of the central limit theorem.

Source : AJ sup and Watson, 1993

The practical implications of the central limit theorem are immense. Consider that without the central limit theorem effects, we would have to develop a separate statistical model for every non-normal distribution encountered in practice. This would be the only way to determine if the system were exhibiting chance variation. Because of the central limit theorem we can use averages of small samples to evaluate any process using the normal distribution. The central limit theorem is the basis for the most powerful of statistical process control tools, Shewhart control charts.

2.15 CONTROL CHARTS INTERPRETATION

Control charts provide the operational definition of the term *special cause*. A special cause is simply anything which leads to an observation beyond a control limit. However, this simplistic use of control charts does not do justice to their power. Control charts are running records of the performance of the process and, as such, they contain a vast store of information on potential improvements. While some guidelines are presented here, control chart interpretation is an art that can only be developed by looking at many control charts and probing the patterns to identify the underlying system of causes at work.

1. Freaks Pattern

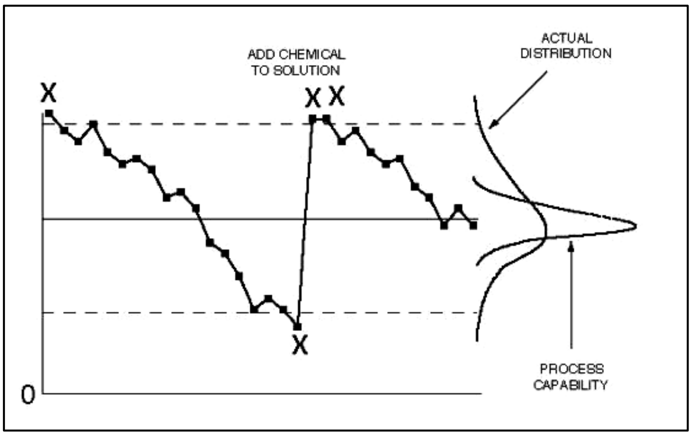

Figure 2.9 : Control chart patterns: *freaks*.

Source : Does et al, 1997

Freak patterns are the classical special cause situation. Freaks result from causes that have a large effect but that occur infrequently. When investigating freak values look at the cause-and-effect diagram for items that meet these criteria. The key to identifying freak causes is timelines in collecting and recording the data. If we have difficulty, get sampling more frequently.

2. Drift Pattern

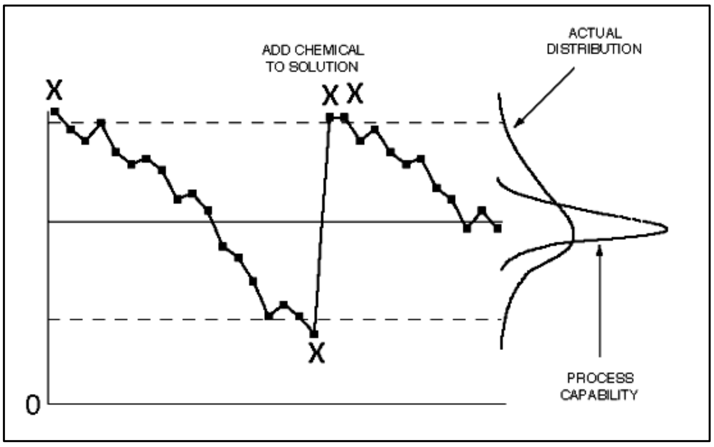

Figure 2.10 : Control chart patterns: *drift*.

Source : Does et al, 1997

Drift is generally seen in processes where the current process value is partly determined by the previous process state. For example, if the process is a plating bath, the content of the tank cannot change instantaneously, instead it will change gradually. Another common example is tool wear: the size of the tool is related to its previous size. Once the cause of the drift has been determined, the appropriate action can be taken. Whenever economically feasible, the drift should be eliminated, e.g., install an automatic chemical dispenser for the plating bath, or make automatic compensating adjustments to correct for tool wear. Note that the total process variability increases when drift is allowed, which adds cost. When this is not possible, the control chart can be modified in one of two ways:

1. Make the slope of the center line and control limits match the natural process drift. The control chart will then detect departures from the natural drift.

2. Plot *deviations* from the natural or expected drift.

3. Cycles Pattern

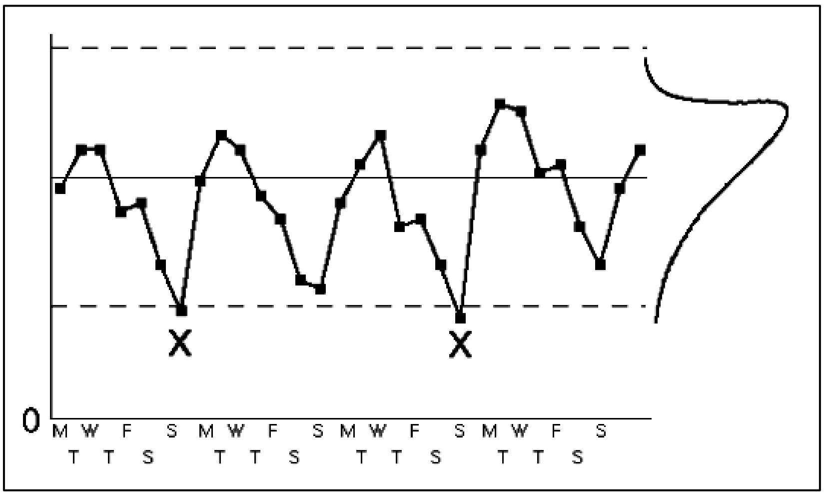

Figure 2.11: Control chart patterns: *cycles*.

Source : Does et al, 1997

Cycles often occur due to the nature of the process. Common cycles include hour of the day, day of the week, month of the year, quarter of the year, week of the accounting cycle, etc. Cycles are caused by modifying the process inputs or methods according to a regular schedule. The existence of this schedule and its effect on the process may or may not be known in advance. Once the cycle has been discovered, action can be taken. The action might be to adjust the control chart by plotting the control measure against a variable base. For example, if a day-of-the-week cycle exists for shipping errors because of the workload, you might plot shipping errors per 100 orders shipped instead of shipping errors per day. Alternatively, it may be worthwhile to change the system to smooth out the cycle. Most processes operate more efficiently when the inputs are relatively stable and when methods are changed as little as possible.

4. Repeating Pattern

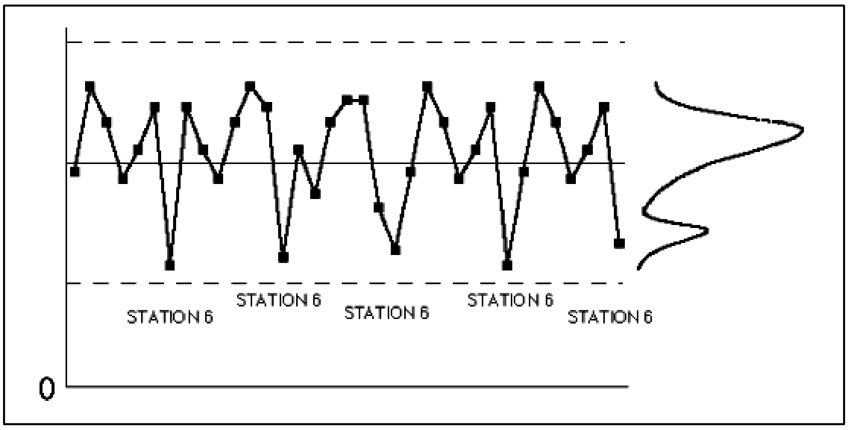

Figure 2.12 : Control chart patterns: *repeating patterns*.

Source : Does et al, 1997

A controlled process will exhibit only "random looking" variation. A pattern where every nth item is different is, obviously, non-random. These patterns are sometimes quite subtle and difficult to identify. It is sometimes helpful to see if the average fraction defective is close to some multiple of a known number of process streams. For example, if the machine is a filler with 40 stations, look for problems that occur 1/40, 2/40, 3/40, etc., of the time.

5. Discrete data Pattern

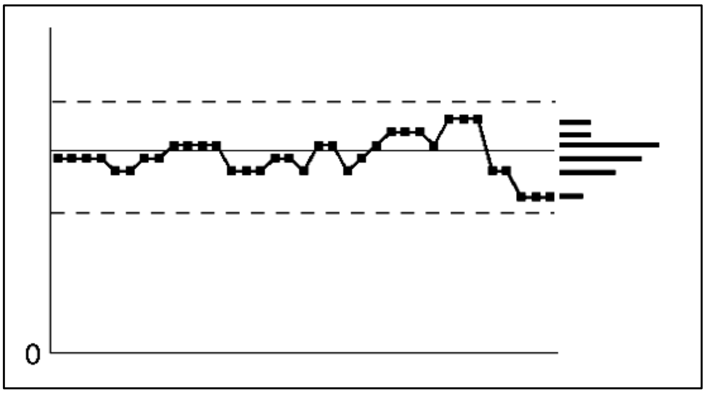

Figure 2.13 : Control chart patterns: *discrete data*.

Source : Does et al, 1997

When plotting measurement data the assumption is that the numbers exist on a continuum, i.e., there will be many different values in the data set. In the real world, the data are never completely continuous. It usually doesn't matter much if there are, say, 10 or more different numbers. However, when there are only a few numbers that appear over-and-over it can cause problems with the analysis. A common problem is that the R chart will underestimate the average range, causing the control limits on both the average and range charts to be too close together. The result will be too many "false alarms" and a general loss of confidence in SPC.

The usual cause of this situation is inadequate gage resolution. The ideal solution is to obtain a gage with greater resolution. Sometimes the problem occurs because operators, inspectors, or computers are rounding the numbers. The solution here is to record additional digits.

6. Planned Changes Pattern

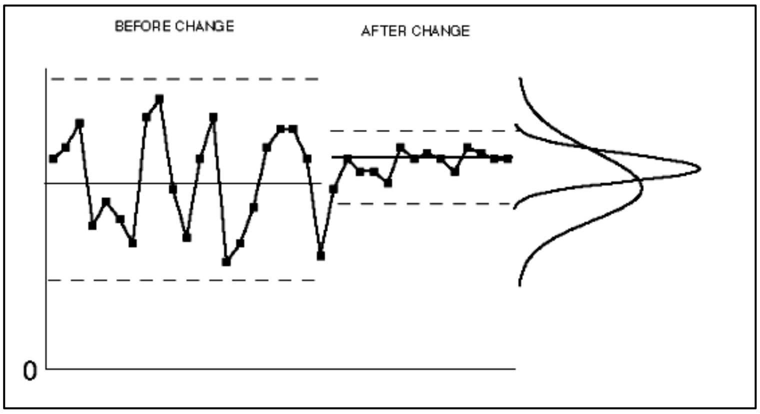

Figure 2.14 : Control chart patterns: *planned changes*.

Source : Does et al, 1997

The reason SPC is done is to accelerate the learning process and to eventually produce an improvement. Control charts serve as historical records of the learning process and they can be used by others to improve other processes. When an improvement is realized the change should be written on the old control chart; its effect will show up as a less variable process. These charts are also useful in communicating the results to leaders, suppliers, customers, and others interested in quality improvement.

7. Suspected Differences Pattern.

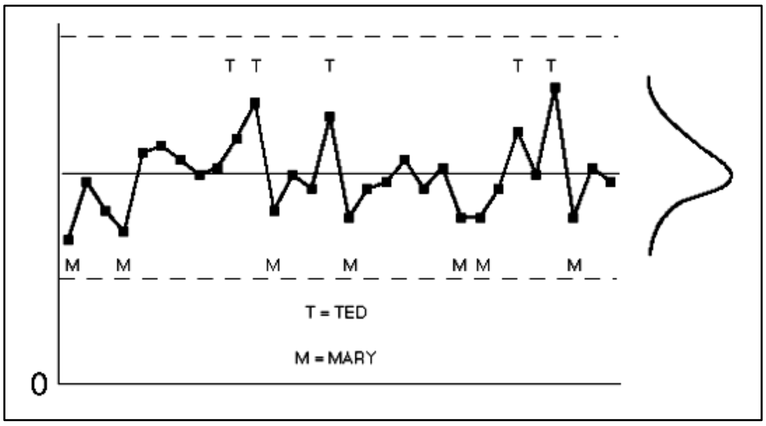

Figure 2.15 : Control chart patterns: *suspected differences*

Source : Does et al, 1997

Seemingly random patterns on a control chart are evidence of unknown causes of variation, which is not the same as *uncaused* variation. There should be an ongoing effort to reduce the variation from these so-called common causes. Doing so requires that the unknown causes of variation be identified. One way of doing this is a retrospective evaluation of control charts. This involves brainstorming and preparing cause and effect diagrams, then relating the control chart patterns to the causes listed on the diagram. For example, if "operator" is a suspected cause of variation, place a label on the control chart points produced by each operator. If the labels exhibit a pattern, there is evidence to suggest a problem. Conduct an investigation into the reasons and set up controlled experiments (prospective studies) to test any theories proposed. If the experiments indicate a true cause and effect relationship, make the appropriate process improvements. Keep in mind that a statistical *association* is not the same thing as a causal *correlation*. The observed association must be backed up with solid subject-matter expertise and experimental data.

8. Mixture Pattern

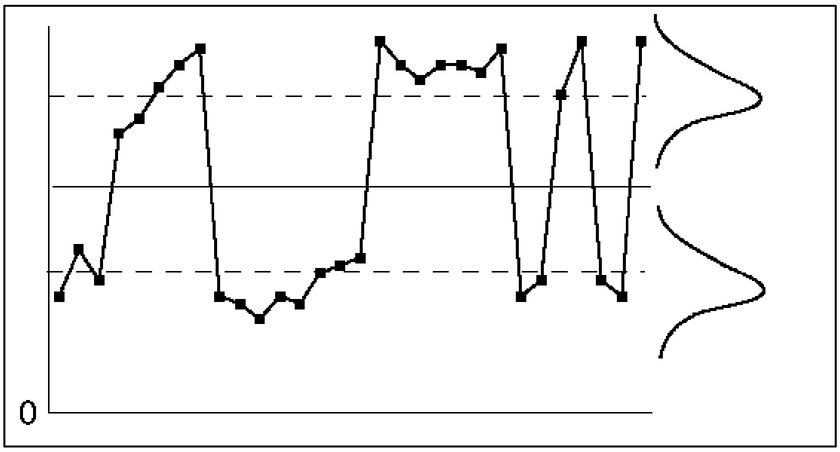

Figure 2.16 : Control chart patterns: *mixture*.

Source : Does et al, 1997

Mixture exists when there data from two different cause-systems are plotted on a single control chart. It indicates a failure in creating rational subgroups. The underlying differences should be identified and corrective action taken. The nature of the corrective action will determine how the control chart should be modified. (Does et al, 1997)

2.16 THE MINITAB SOFTWARE

MINITAB is a statistics and analytics software package developed by Minitab Inc. MINITAB provides a selection of data analysis, data management, data mining, and data visualization procedures. Features of the software include basic and multivariate statistical analysis, quality control modules, neural networks, and a collection of data mining techniques. All of these tools are provided in an open architecture with a single software platform. So that all the all the statistical analysis including analysis on basic SPC tools such Pareto, control charts, run charts, etc. can be analyzed comprehensively with interactive graphics. (Minitab Inc.; http://www.minitab.com/en-US/default.aspx)

2.17 CHAPTER SUMMARY

From the literature study on SPC and its applications in a manufacturing industry, its identified that the X-bar and R charts are the best preventive SPC tool for monitoring manufacturing processes. By implementing this preventive tools according to its methods and fundamental rules, the efficiency of a process can be measured. (Does et al, 1997)

SPC provide a magnificent analysis on a process. Aiding the SPC outcome, a process with out of control behavior can be determined. This will help the process operator to take countermeasures to bring back the process on its track. The process flow identification where does its lies at the time will reduce the overall production cost by avoiding the waste product produced.

All analysis conducted manually and verified using MINITAB software. MINITAB software is known as among the best SPC software and very easy to use. Its analysis methods are follows all the SPC fundamental rules. The specification of the software where controls all the analysis variables automatically and ability to code in the manual calculation data in the MINITAB analysis make the software more reliable.

Comparisons were done between the analysis output obtained from MINITAB and the manual calculations. Further screening on the X-bar and R chart trend will be analyzed. Its will be compared with the ideal trend and the root causes will be identified.

Its is important for SKF Bearing Industries (Malaysia) SDN. BHD. for implementing SPC tools in their manufacturing processes and achieve the ‘de facto standard’ requirement in order to compete the global arena.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In order to drive the research according to its path, research flowchart is drafted. The framework of how the research will conducted is planed using the flowchart. All the steps of research involved and the analyzing methods are arranged in the flowchart according to its stage by stage. With the company supporting data and information, several steps control chart implementation process was designed. The research process is start with literature review, product selection, process performance study, continuously monitoring of the process and ending with conclusion and recommendations for the future works as improvement of the project.

3.2 THE METHODOLOGY

Methodology is the part where all the plans of the research is carried out. The method of research conducted is described until the end in this part. It contains several steps that must be followed before proceeding to the next steps. Completion of each step is vital in order to avoid any errors occurred on the next step.

In this case study, the investigation is started with literature review about Statistical Process Control and its applications in manufacturing industry. Then, a visit to SKF Bearing Industries (Malaysia) SDN. BHD. is carried to understand the application of SPC. The usage of SPC and its guide lines of process control in the bearing manufacturing is observed. SPC application at quality control (QC) department at SKF Bearing SDN. BHD. observed and the QC data were obtained for further study.

Using the data that obtained, the related control chart is constructed in order to transform the current bearings outer ring production process to a graphical chart to graphically record of the outer ring dimension tolerance characteristic. The investigation is preceded with some analysis on the constructed control chart and the capability analysis. At the end, some improvements and recommendations will be made on the current process for better outcome. Conclusion is made as a whole idea and findings of the investigation. Figure 3.1 shows the flow charts of the case study. The analysis processes well represent by each processes by the flow chart.

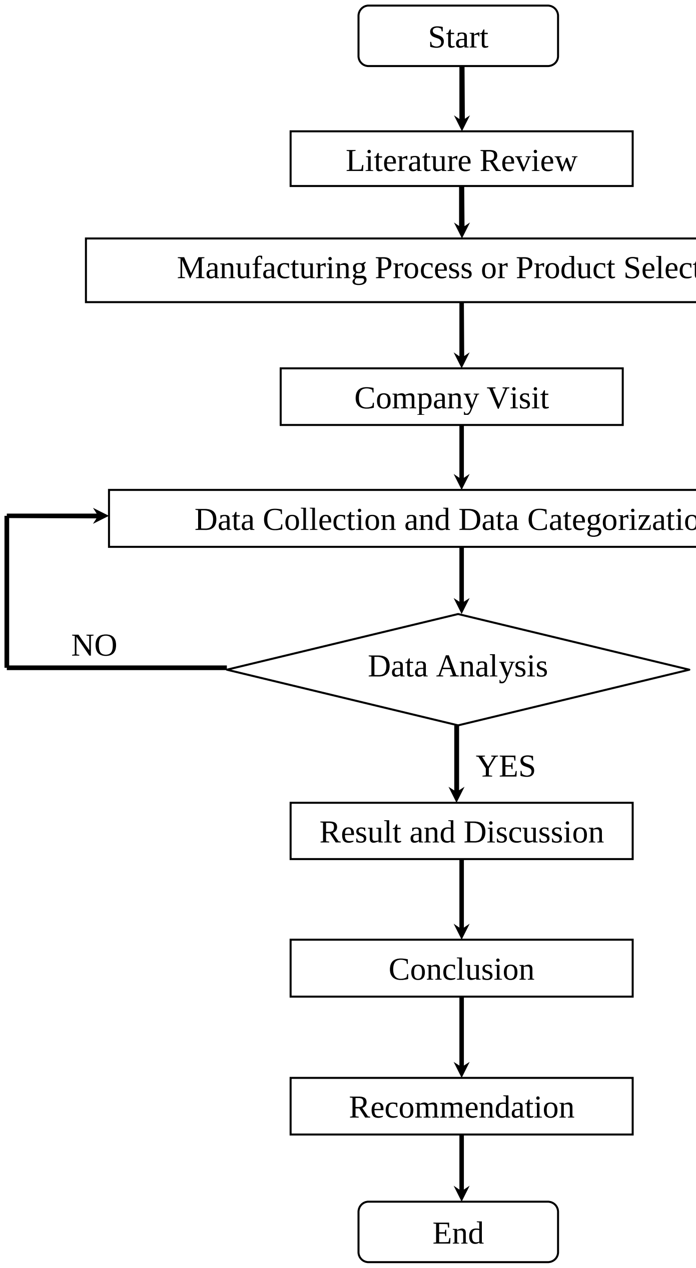

Figure 3.1 : Flow Chart of the Project

3.3 LITERATURE REVIEW

The case study is begin with the literature review. A critical study on statistical process control (SPC) was done on how it is implemented in manufacturing practice. The literature review consist of, what is SPC, benefit of implementation of SPC, basic tools of SPC, central limit theorem, control charts interpretation, $\bar{X}$ and R chart, establishing centerline and control limits, out of control points, in control process, capability study and comments on C_p and C_{pk} values. Through the findings in literature review, the concept of SPC is get known. The specific tool that usually use in manufacturing practice is known and further investigation is carried forward by the following steps.

3.4 MANUFACTURING PROCESS SELECTION

A correct product selection for the case study is critical process. A correct product which strictly follow the SPC method were searched. After done some research and findings, bearing were selected as the product to be studied on the processes of manufacturing the bearing.

Bearing consist of several parts as shown Figure 3.2 below. Namely; outer ring, inner ring, cage, steel ball or roller and metallic shield. In all those parts, outer ring and inner ring fabrication is the most critical process of the whole bearing production.

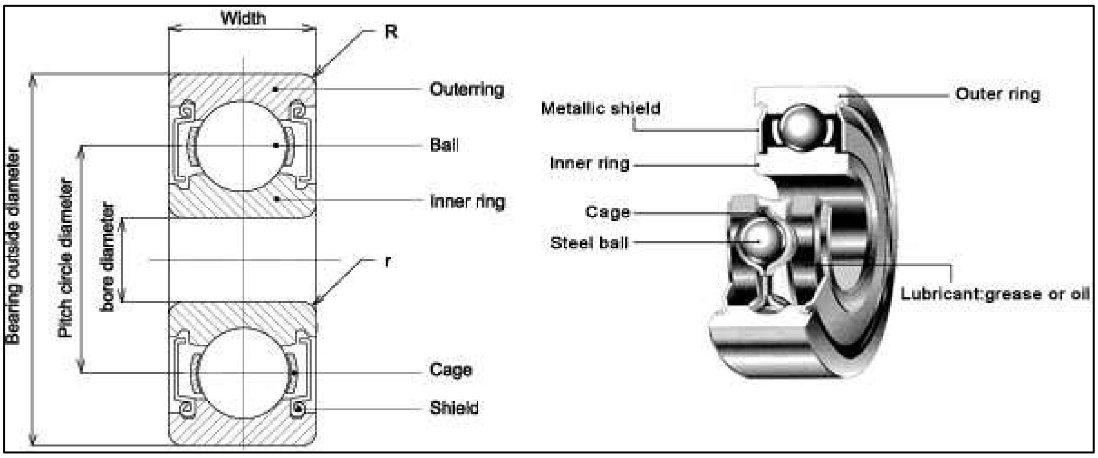

Figure 3.2 : Parts of the bearing

Source : SKF Bearing SDN.BHD.

The grade or quality of the bearing with very minimal rate of vibration is determined by the outer rings and inner rings diameter tolerance. So that, either outer ring or inner ring of the bearing can be select as the parameter of the case study. The investigation is done on the effectiveness of SPC and its implementation in the bearings fabrication. To choose in between outer ring or inner ring of a bearing as a case study product, a company visit is necessary.

3.5 COMPANY VISIT

In order to get a clear view about the manufacturing process and the difficulties that encounter during the bearing parts manufacturing process, a side visit were done to famous and established bearing manufacturer, SKF Bearing Malaysia SDN. BHD. From the visit, were decided that the product to be study in this project is outer ring of the bearing. The product that selected is 6206-2Z. The 6206-2Z bearings are custom made bearings where specifically used for high speed machines.

From the company visit, its get known that the outer ring making process is the most critical and always produce more reject part then the other. The machineries and some of the internal problems in producing the outer ring process become harder. Thus, bearing outer ring were taken for further study. The manufacturing processes were observed carefully. Three months of QC data were obtained specifically for the bearings outer ring.

3.6 BEARING MAKING PROCESS IN SKF BEARING (MALAYSIA) SDN. BHD.

According to SKF, the production line of the bearing making process is start with two divisions. One is outer ring fabricating line and another one is inner ring fabricating line. Bothe lines will be merged at bearings assembly line. The bearing making processes are as Figure 3.3 follows.

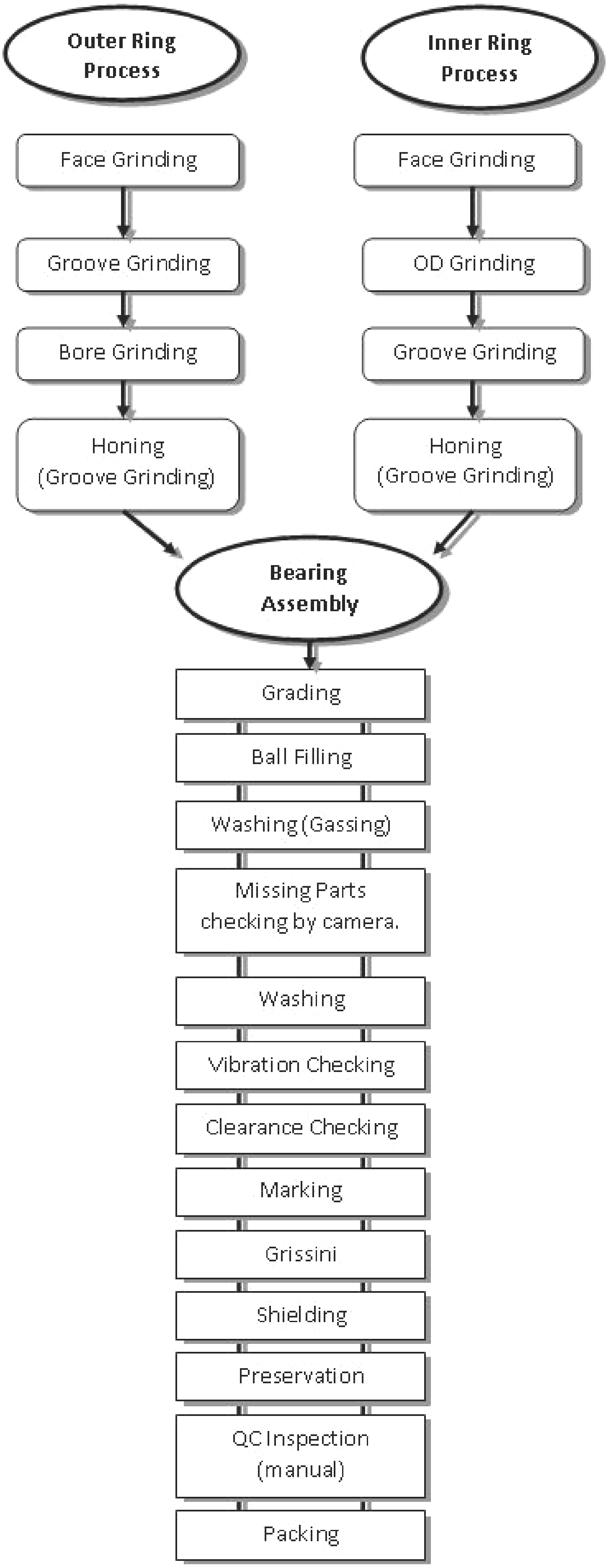

Figure 3.3 : Bearing Manufacturing Process

Source : SKF Bearing SDN.BHD.

The outer ring starts to be fabricated with face grinding process. The ring which already cut will be grinded at the outside of the outer ting to make it event and shine. The next step is groove grinding and followed by bore grinding. In this process the outer ring is shaped well where the ovality control and grinding the inner part of the outer ring is carried in this processes. At last; before the ring is passed to assembly line, the outer ring is went through honing process. In this process the tapper level, especially at the inner part of the bearing is controlled and grinded well. The inner ring of the bearing also go through the same processes as the outer ring. Its just have OD grinding instead of bore grinding. OD stand for over depth. The slight depth for placing the metal balls of the bearing is made in this process. All the while of this processes, in each machine the inner and outer ring is closely measured with integrated measuring tool to make sure the part is not over grinded.

The next stage of the production line is bearing assembly line. The process start with grading where the inner ring and the outer ring is measured their allowances again and graded according to the best fit bearing balls. The process continue with ball fitting. In this process, the inner ring and outer ring is assembled completely with the metal bolls in between them. The next processes are washing with high pressure gas, missing parts checking and washing again. After that, the bearing will be checked on its vibration level. Then its will go through clearance checking. In this process, the well operation of the bearing is checked. The sliding level of the metal balls in between the inner ring and outer ring is checked. Then the bearing is marked using laser machine with its product code and SKF company name with the batch number. Then, the bearing is go through grissing process and shielding process. In grissing process, the bearing is injected with gris as a lubricant in between the balls. The bearing is covered with metal or plastic shield in shielding process. Then the bearing is send to preservation process. In this process, the bearing is sprayed with a special chemical and kept in optimum pressure and temperature. At the end of the production, the bearing is selected randomly by the number of 8 per batch and the parameters were measured or calibrated manually by the quality control operator. The standard operation procedure of measuring the bearing parts is can be viewed in Appendix section. Then the bearing is send to packing section.

3.7 SPC PRACTICE IN SKF BEARINGS (MALSYSIA) SDN. BHD.

Each outer ring and inner ring grinding process is strictly observed using SPC control tools. The machine with auto measuring ability after each process done is make sure the allowance of the parts are in control. In case of disallowance, with the count of three fabricated part, the whole process will be stopped and the problematic production line will be notified.

At the end of the production, the bearing is once again measured under quality check department. In this QC checking process, 8 bearings per batch is picked randomly and all its parameters were measured once again. The values were noted in the QC check list. Highly sensitive GME 2+ gauge and UV gouge is used to measure the parameters of the bearings.

3.7.1 Product or part selection for the case study.

According to the quality control engineer at SKF Bearings SDN.BHD, the outer ring making process is much more harder then inner ring making process. Normally outer ring is the part which will be problematic where the allowances is ran out. This is because, the machine system that the company use for the outer ring making process is older then the inner ring making machine. Other than that 0° tapering of the inner side of the outer ring is a difficult process and its gave effect to the bearings performance.
So that; for this case study outer ring was selected as the product or part to be investigated under statistical process control, SPC.

3.8 DATA COLLECTION AND DATA ANALYSIS

QC data is collected from the SKF. Found that lot of parameters and variables are noted in the QC checklist. The needed data for the case study where the data of the outer ring diameter is selected. The corresponding values where tabulated and categories according to the subgroup. Several steps were taken to produce the analysis. The steps of the analysis and computation is as below :

3.8.1 Determination of quality characteristics

Quality of a product is defined by two sources, one is by the customer and another is by the manufacturer itself. A quality product is always hits the demand in the market. To ensure the product that produce by the manufacturer is in good position in order of quality, the manufacturer is having some criteria to follow. A quality product manufacturer always have a good name and get a position of satisfaction to the customer list.

So that, SKF Bearing SDN.BHD. strictly control their production using SPC. Each parts of the bearing fabrication process is controlled by a measuring tool with integrated SPC controlling system. The bearing manufacturing processes are as the Figure 3.3. After each process is done by the main machine, the measuring tool that attached to the machine will calibrate the dimension of the part. The dimensions must be in between the upper control limit and lower control limit of the process chart that set in the SPC system. If the dimension of the part is beyond the limits, the part is automatically rejected to a side. The maximum number of rejected part can be exceed is three. If the dimension of the part is not corrected in that limit, the whole process of fabrication will be stopped with an alarm.

The dimensions of the bearing parts are very much important to ensure its working life and its safety purposes. So that, the dimensions is controlled in the very early fabrication process. To measure the overall specifications of the bearing, 25 bearings taken from packaging department randomly and all the parts are measured once again in metrology lab. Vibration test also will be applied on the selected bearing as a quality check for the whole batch products. The tolerance of the bearing parts is measured using GME 2+ gauge and UV gouge. When the bearing part(outer ring) is placed on the calibrated surfacing table with the dial indicator, the measuring meter will show the dimension of the part. The measurement changes of plus, minus(±) is in micrometer (µm).

3.8.2 Determination of inspection frequency/sampling size.

Frequency of sampling of a product is base on the experience of the production line controllers such as the operators and the engineers. Each product have different sampling type and frequency. The method of analyzing the samples also differs. The inspection data are recorded down on the cheek sheet. Data will be collected for a certain period(basically month) to calculate the trial limits of control chart and data are plotted on the chart that we decide to use.

For research purpose in this case study, subgroup size of 8 samples per day is used. According to studies, sample size more than 5(reasonable) is seen to give better and accurate result.(Lai K Chan and T K Mak , 1993; Does et al, 1997) Furthermore, the central limit theorem explained that, if the subgroup size is equal to or more than 4, the process are similar or as close as normal distribution. Thus, all the related SPC parameters can be obtain and control chart can be constructed according to its calculation by using it. In 9 hours continuous operation per day, 8 samples were taken in every interval of time for manual inspection. All data has collected for 30 days and filled in by using check sheets.

3.8.3 Determination of Control chart to be used.

The bearings outer ring fabrication shows some variances where the dimension is not always with the fixed dimension. The run out of the dimension must be controlled. In order to measure and represent the variances, the control charts are used. Variable control charts interprets the variations in dimension, weight, length, height etc; it is the best tool of SPC to represent the process and tell us what is happening on the process. $\overline{\mathbf{X}}$ and R charts are one of the variable control charts and its chosen instead of using $\overline{\mathbf{X}}$ and S charts because the sample size is less then 10 samples. By definition, to use $\overline{\mathbf{X}}$ and S chart the smaple size must be atleast 10. Thus, $\overline{\mathbf{X}}$ and R chart is choosen for the analysis in this case study. .(Lai K Chan and T K Mak , 1993)

3.8.4 Establishing Centerline and control limits.

From the inspection data sheet, the data were gatherd and tabulated in order to find the average for $\overline{\mathbf{X}}$ and Range, R. Then, the control limits and central line of $\overline{\mathbf{X}}$ and Range, R chart are calculated. From the table 2.2 fro the previous chapter, we obtain the factor for computing control limits, A2 = 0.373, D3 = 0.136 and D4 = 1.864 for the subgroup of 8. By using this variables, the centerline and control limits can be obtain by using the formulas that discussed in Chapter 2. All the analysis conducted using Statistica Software in order to get a accurate result.

3.8.5 Process Capability and Performance Study

After make sure the process is stable, where there is no subgroup data out of specification limits and also out of control limits on both $\overline{\mathbf{X}}$ and R chart, then process capability and performance study can be proceed.

If the process is is not stable, the root causes of any out of specification and control limits points will be solved and discarded. Then the control limits and central line are recalculated in order to capture the actual random variation of the process. In addition, if any unwanted results were occurred to the process from the control charts trend; further analysis will be carried out in order to bring the process back to stable and capable path.

Normally, process performance studies are done to findout the variation occurred in production with present of all sources of variation in place. Process performance study had proved that out of tolerance parts are being mase on a production basis require immediate action for improvement. By the fast action and implimentation, the process will be more productive with less defects. The action taken must include working with parameters involve in machining, machine parts modifying, difference in product, measuring tools and etc.

3.9 CHAPTER SUMMARY

This chapter is mainly about the methods used to carry forward the project. Each steps and processes were described. Several steps were followed in order to analysis of the process capability and plan the countermeasure actions to be taken. By following the steps correctly, the expected result can be obtained.

Through careful observation and comparison between the results of three months QC data, the trend of the processes cab be identified. The trend will compare between the ideal trend. Then all the SPC rules will be applied on each analysis. Then the root problems occurring points will be determined. By this, the problematic process identified accurately by time.

The identified process is screen more deeply to get know the main causes. Then a troubleshooting action can be taken upon the processes. By this a better, stable and profitable bearing outer ring production process will be produced.

All the experimental design processes were followed as discussed above in this chapter to produce the outcome of the study. The experiment flow counter checked with SPC applications at SKF Bearing Industries (Malaysia) SDN. BHD.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the analysis of the QC data obtained from SKF Bearing Industries (Malaysia) Sdn. Bhd. The data analyzed manually and with aid of MINITAB software. The output of each month is observed and compared with each other. The core problems are discussed further.

4.2 $\bar{X}$ AND R CHART INTERPRETATION

The process performance study can be conducted by constructing $\bar{X}$ and R chart. Further analysis on this both graphs and the processes carried out in this chapter. By using $\bar{X}$ and R charts, the entire process can be monitored directly whether the plotted points are in control or out of control. Each plotted data according the months can be compared and its process variation can be determined. The analysis begin with test for normality in order to determine whether the process follows normal distribution or not. (Evgene L Grantt and Richard Leaven worth, 1996)

4.3 TEST OF PROCESS NORMALITY

In order to implement SPC, the normal curve is very important. We need to determine the process is normal distributed to apply and analyze a control process using SPC technique. If the process not normal distributed, we cannot use the usual $\bar{X}$ and R charts calculation group to analyze the process performance.

By aiding central limit theorem and assuming the data is normal distributed, the QC data of SKF Bearing Sdn. Bhd. is analyzed. The populations of the taken data is assumed normal distributed and the distribution of samples averages will tend toward normality provided that the sample size, n is more then 5. In this case, the sample is 8. This determined that the process is following the normal distribution or approximately normal distributed. (Evgene L Grantt and Richard Leaven worth, 1996)

4.4 $\bar{X}$ AND R CHART ANALYSIS

The analysis was conducted according to its respective months. Analysis on the $\bar{X}$ and R Chart is conducted in two different ways; analysis manually on the charts and MINITAB analysis. (Evgene L Grantt and Richard Leaven worth, 1996) The purpose of these both analysis is to verify manual analysis whether it is conducted accordingly and accurately or not. MINITAB analysis then is conducted in order to verify the manual analysis. Tabulated bearing outer ring data and its analysis are as in following sub topics.

4.5 BEARING OUTER RING DIAMETER OF MONTH SEPTEMBER

Table 4.1 : Bearings outer ring measurement records for month September.

Sub Group No	Readings (Subgroups)								Sum	$\bar{X}$	R
	1	2	3	4	5	6	7	8			
1	62.75	62.85	62.75	62.60	62.75	62.65	62.50	62.45	501.30	62.66	0.40
2	62.65	62.75	62.65	62.55	62.60	62.55	62.60	62.40	500.75	62.59	0.35
3	62.60	62.75	62.65	62.50	62.65	62.55	62.55	62.60	500.85	62.61	0.25
4	62.65	62.80	62.70	62.40	62.65	62.50	62.65	62.55	500.90	62.61	0.40
5	62.60	62.75	62.65	62.55	62.60	62.55	62.70	62.35	500.75	62.59	0.40
6	62.55	62.65	62.55	62.65	62.65	62.65	62.65	62.50	500.85	62.61	0.15
7	62.55	62.70	62.60	62.40	62.70	62.50	62.50	62.50	500.45	62.56	0.30
8	62.65	62.85	62.70	62.40	62.65	62.50	62.45	62.65	500.85	62.61	0.45
9	62.65	62.85	62.70	62.55	62.75	62.60	62.70	62.40	501.20	62.65	0.45
10	62.65	62.75	62.65	62.55	62.80	62.55	62.55	62.40	500.90	62.61	0.40
11	62.75	62.85	62.75	62.60	62.70	62.65	62.40	62.55	501.25	62.66	0.45
12	62.70	62.95	62.80	62.60	62.60	62.70	62.65	62.55	501.55	62.69	0.40
13	62.70	62.80	62.75	62.60	62.50	62.65	62.95	62.65	501.60	62.70	0.45
14	62.60	62.85	62.70	62.45	62.80	62.50	62.75	62.60	501.25	62.66	0.40
15	62.55	62.65	62.55	62.40	62.60	62.45	62.60	62.65	500.45	62.56	0.25
16	62.75	62.95	62.80	62.60	62.50	62.70	62.85	62.60	501.75	62.72	0.45
17	62.65	62.75	62.65	62.55	62.70	62.55	62.95	62.55	501.35	62.67	0.40
18	62.45	62.60	62.50	62.35	62.80	62.40	62.70	62.55	500.35	62.54	0.45
19	62.60	62.85	62.70	62.50	62.80	62.60	62.60	62.65	501.30	62.66	0.35
20	62.65	62.95	62.75	62.50	62.50	62.65	62.90	62.60	501.50	62.69	0.45
21	62.65	62.70	62.65	62.70	62.70	62.75	62.95	62.65	501.75	62.72	0.30
22	62.55	62.60	62.55	62.45	62.80	62.45	62.65	62.65	500.70	62.59	0.35
23	62.70	62.90	62.80	62.50	62.70	62.60	62.75	62.40	501.35	62.67	0.50
24	62.75	62.95	62.80	62.60	62.45	62.70	62.80	62.55	501.60	62.70	0.50
25	62.45	62.65	62.50	62.50	62.70	62.60	62.75	62.55	500.70	62.59	0.30
26	62.85	62.70	62.60	62.55	62.80	62.50	62.70	62.60	501.30	62.66	0.35
27	62.65	62.55	62.55	62.55	62.50	62.60	62.65	62.65	500.70	62.59	0.15
28	62.95	62.40	62.75	62.60	62.70	62.55	62.50	62.75	501.20	62.65	0.55
29	62.75	62.60	62.65	62.60	62.80	62.75	62.45	62.45	501.05	62.63	0.35
30	62.60	62.65	62.45	62.60	62.75	62.65	62.70	62.60	501.00	62.63	0.30
										1879.08	11.25
										62.636 $\bar{\bar{X}}$	**0.375** $\bar{R}$

4.5.1 Manual Calculation

$UCL = \bar{\bar{X}} + A_2\bar{R}$
$LCL = \bar{\bar{X}} - A_2\bar{R}$
} $\bar{X}$ - Chart

$UCL = D_4\bar{R}$
$LCL = D_3\bar{R}$
} $\bar{R}$- Chart

1) $\bar{X}$ - Chart Calculation

$\bar{\bar{X}}$ = **62.636 (Centre Limit)**

$\bar{R}$ = **0.375**

$UCL = \bar{\bar{X}} + A_2\bar{R}$

= 62.636 + (0.373)(0.375)

= **62.77588**

$LCL = \bar{\bar{X}} - A_2\bar{R}$

= 62.636 – (0.373)(0.375)

= **62.49613**

2) $\bar{R}$ - Chart Calculation

$\bar{R}$ = **0.375**

$UCL = D_4\bar{R}$

= (1.864)(0.375)

= 0.699

$LCL = D_3\bar{R}$

= (0.136)(0.375)

= 0.051

4.5.2 MINITAB Analysis on $\bar{X}$ and R Chart for month September

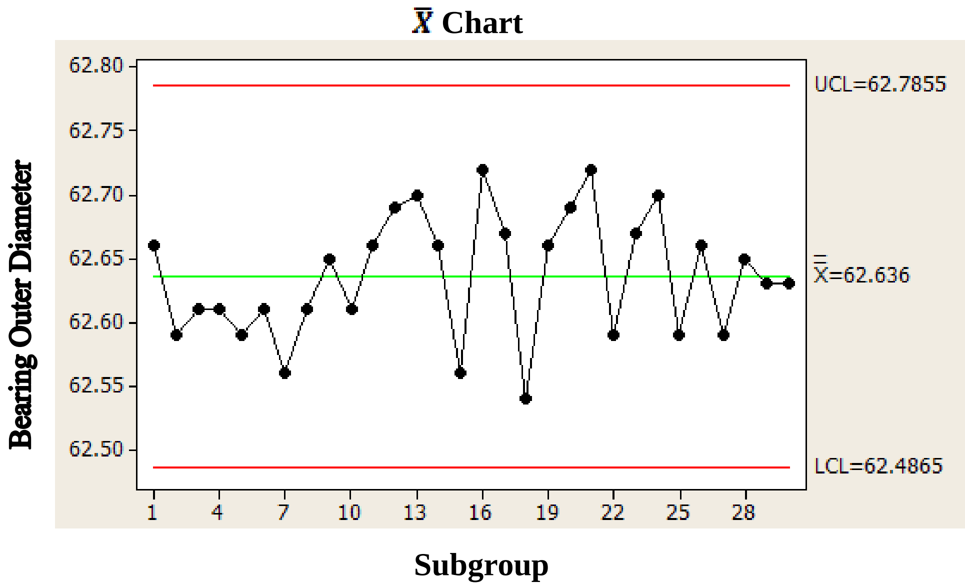

Figure 4.1 : $\bar{X}$ Chart of month September

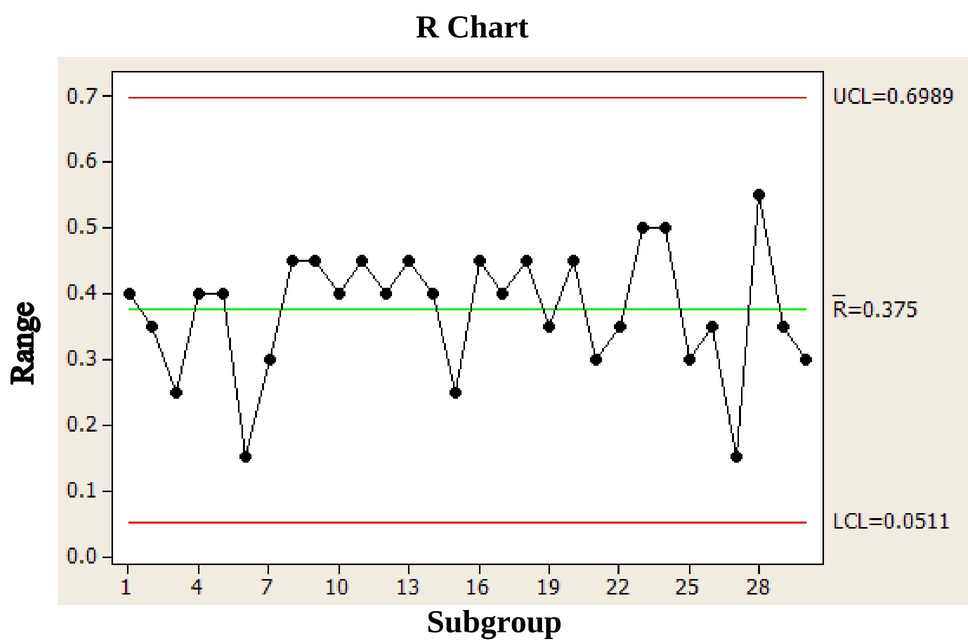

Figure 4.2: R Chart of month September

The MNITAB analysis for month September shows that the process is under control. None of the process were out of upper and lower control limits. Although some of the points, notably point number 6, 15, 16, 18 and 21. This variation of derivatives are give a type of pattern which known as suspected differences pattern. The range graph did not shows much variables due to short range of variable differences. The suspected difference pattern made the process unpredictable. Its hard to determine the cause of the variability. The varied point can be identify and the cause of the deviation can be determined by further screening and experiments on more discrete samples.

The deviated points 6, 15, 16, 18 and 21 are approaching sigma 2 value of the chart. Point 16 and 18 are the most deviated points. Although the approaches toward sigma 2 value is higher, the process is consider under control because the points are relay alternately from the centre line. Thus, the deviation cause by one critical root problem is eliminated.

The R chart of month September did not show much variances with one another until process point 26. At the process point 27, the range value get deviated from the centre line. The next process point, 28 were pointed at opposite of the point 27 alternately at the bottom of the process centre line. This shows that the process range is still under tolerance level and the process points distributions are stable.

Both X-bar and R charts of month September are under control. Although the processes still in between the process limits, the tendency of the process get out of control is higher. This is because some of the points are approaching 2 sigma value. The Range, R value is get deviated at the end of the process also shows that the process range get wider. This will make the outer ring diameter deviate lot from the diameter tolerance level. Lack of attention will make the process get worse and out of control.

4.6 BEARING OUTER RING DIAMETER OF MONTH OCTOBER

Table 4.2 : Bearings outer ring measurement records for month October.

Sub Group No	Readings (Subgroups)								Sum	$\bar{X}$	R
	1	2	3	4	5	6	7	8			
1	62.70	62.90	62.80	63.00	62.80	63.00	62.90	62.60	502.70	62.84	0.30
2	62.90	63.00	62.95	62.50	62.80	62.90	62.85	62.80	502.70	62.84	0.50
3	62.90	63.10	63.00	62.60	62.80	63.00	62.90	62.70	503.00	62.88	0.50
4	62.60	62.80	62.70	62.80	62.70	62.90	62.80	62.95	502.25	62.78	0.35
5	62.80	62.90	62.85	62.70	62.70	62.80	62.75	62.70	502.20	62.78	0.20
6	62.80	63.00	62.90	62.95	62.70	62.90	62.80	62.95	503.00	62.88	0.30
7	62.90	62.90	62.85	62.70	62.70	62.80	62.75	62.65	502.25	62.78	0.25
8	62.60	63.10	63.00	62.95	62.70	62.90	62.80	62.90	502.95	62.87	0.50
9	62.40	62.80	62.70	62.65	62.50	62.60	62.60	62.90	501.15	62.64	0.50
10	62.70	62.60	62.50	62.80	62.50	62.70	62.90	62.80	501.50	62.69	0.40
11	62.70	62.90	62.80	62.70	62.60	62.80	62.40	62.80	501.70	62.71	0.50
12	62.90	63.10	63.00	62.60	62.80	63.00	62.70	63.00	503.10	62.89	0.50
13	62.40	62.60	62.50	62.80	62.30	62.50	62.90	62.70	500.70	62.59	0.60
14	62.50	62.70	62.60	62.50	62.60	62.80	62.80	62.60	501.10	62.64	0.30
15	62.70	62.90	62.80	62.80	62.80	63.00	62.85	62.50	502.35	62.79	0.50
16	62.60	62.80	62.70	62.60	62.70	62.90	62.80	62.70	501.80	62.73	0.30
17	62.90	63.10	62.95	62.40	62.70	63.00	62.85	62.60	502.50	62.81	0.70
18	62.60	62.80	62.70	62.70	62.70	62.90	62.75	62.70	501.85	62.73	0.30
19	62.90	63.00	62.95	62.70	62.80	62.90	62.70	62.70	502.65	62.83	0.30
20	62.60	62.70	62.65	62.90	62.70	62.80	62.90	62.90	502.15	62.77	0.30
21	62.50	62.70	62.60	62.40	62.60	62.80	62.60	62.80	501.00	62.63	0.40
22	62.70	62.90	62.80	62.40	62.80	63.00	62.90	62.90	502.40	62.80	0.60
23	62.60	62.80	62.70	62.70	62.50	62.70	62.65	62.60	501.25	62.66	0.30
24	62.70	62.90	62.80	62.90	62.80	63.00	62.70	62.70	502.50	62.81	0.30
25	62.70	62.80	62.75	62.80	62.60	62.70	62.80	62.80	501.95	62.74	0.20
26	62.50	62.60	62.40	62.70	62.60	62.80	62.70	63.00	501.30	62.66	0.60
27	62.70	62.80	62.70	62.60	62.70	63.00	62.70	62.50	501.70	62.71	0.50
28	62.60	62.70	62.90	62.70	62.90	62.50	62.80	62.65	501.75	62.72	0.40
29	62.90	62.80	62.80	62.70	62.80	62.60	62.70	62.70	502.00	62.75	0.30
30	62.60	62.90	62.85	62.90	63.10	62.80	62.50	62.80	502.45	62.81	0.60
										1882.74	12.30
										62.758 $\bar{\bar{X}}$	**0.410** $\bar{R}$

4.6.1 Manual Calculation

1) $\bar{X}$ - Chart Calculation

$\bar{\bar{X}}$ = **62.758 (Centre Limit)**

$\bar{R}$ = **0.410**

UCL = $\bar{\bar{X}} + A_2\bar{R}$

= 62.758 + (0.373)(0.410)

= 62.91093

LCL = $\bar{\bar{X}} - A_2\bar{R}$

= 62.758 – (0.373)(0.410)

= 62.60507

2) $\bar{R}$ - Chart Calculation

$\bar{R}$ = 0.410

UCL = $D_4\bar{R}$

= (1.864)(0.410)

= 0.76424

LCL = $D_3\bar{R}$

= (0.136)(0.410)

= 0.05576

4.6.2 MINITAB Analysis on $\bar{\bar{X}}$ and R Chart for month October

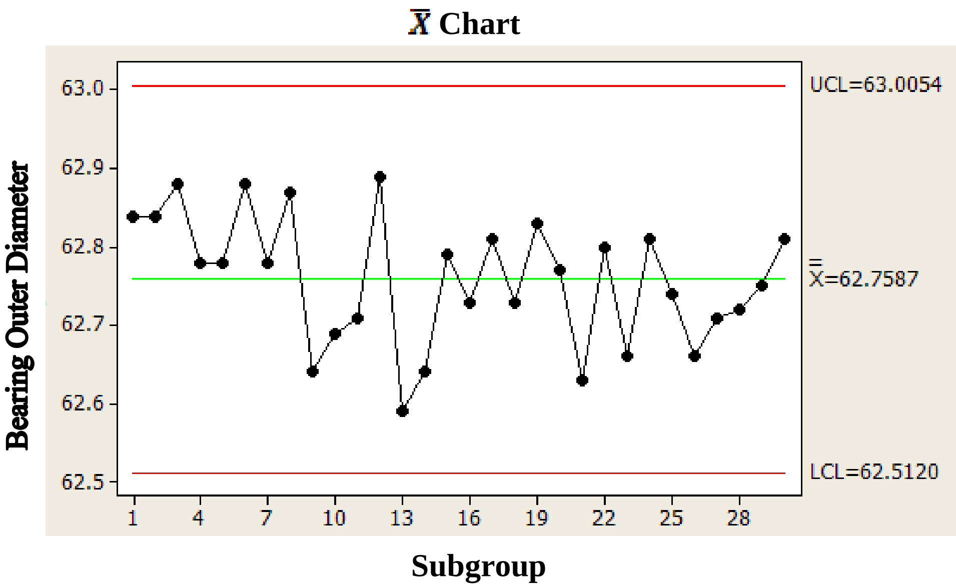

Figure 4.3 : $\bar{\bar{X}}$ Chart of month October

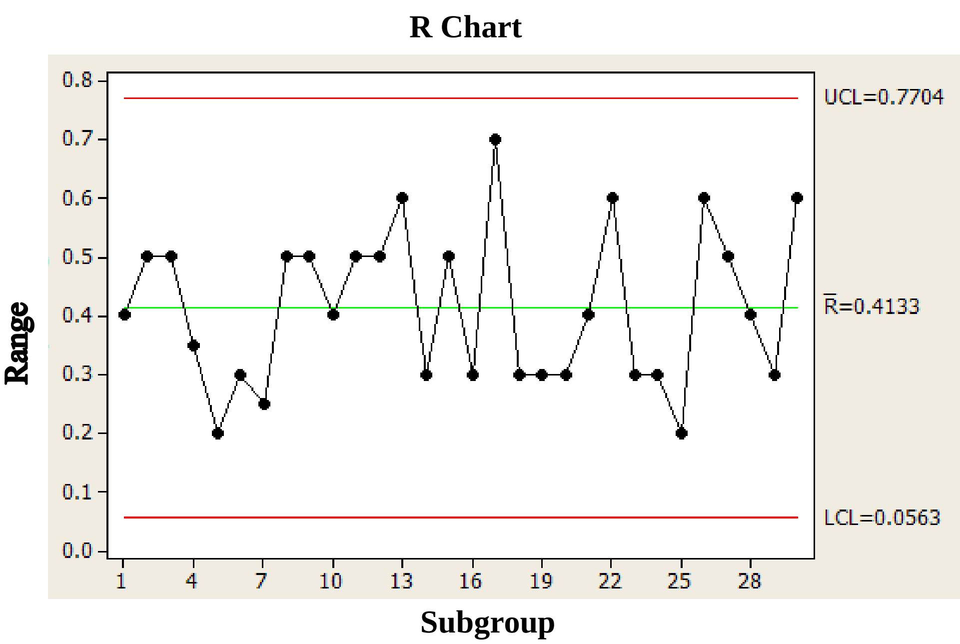

Figure 4.4: R Chart of month October

The MINITAB analysis for data month October is as above. The process is still under control since all the subgroups diameter values are between the upper and lower control limits. The points distributions are balance as the month September data, the data distributions are more deviated from the centre limit. Its very much obvious in the range chart. Comparing the range chart of month September, we can identify the range deviations of data of months October. The obvious deviations of the points in $\bar{X}$ charts are 9, 10, 11, 12, 13 and 14. The points are deviated more compared to the other points. The points are considered still under control because the points are balanced up by laying on upper side and lower side of the central limit.

The X-bar chart of month October also shows suspected differences pattern. Thus, a specific error or defect range cannot find. The process variability is cause by lot of factors. Although the points are distributed evenly on both side of the centre line, the deviation towards the process limits are noticeably more. By this can be concluded that the process getting unstable and the tendency that the process to fail at any time is higher. The failing point of the process cannot be determined by pointing or predicting the next point because the process is not follow a identical trend. Its various distribution of the points make the process more harder to be predicted. Thus, careful observation and following of the process methods is prominent.

The Range chart of month October is deviated more from the centre line. Is can be notice that all the process points are distributed far from the centre line. The process range distribution also deviated more compare to one point to another. Although the process average range of month October is higher than month September, the range deviation is recorded more. This shows that the tendency of the process to be out of control is very high. The process is starting to approach maximum or minimum range of the outer rings tolerances where at any point will fail the outer ring manufacturing process. Extra attention is required to make the process more stable.

4.7 BEARING OUTER RING DIAMETER OF MONTH NOVEMBER

Table 4.3 : Bearings outer ring measurement records for month November.

Sub Group No	Readings (Subgroups)								Sum	$\bar{X}$	R
	1	2	3	4	5	6	7	8			
1	62.70	62.90	62.80	62.60	62.80	62.70	62.50	62.60	501.60	62.70	0.40
2	62.80	63.00	62.90	62.70	62.60	62.65	62.50	62.60	501.75	62.72	0.50
3	62.50	62.90	62.70	62.40	62.80	62.60	62.60	62.60	501.10	62.64	0.50
4	62.50	62.70	62.60	62.40	62.60	62.50	62.60	62.60	500.50	62.56	0.30
5	62.60	63.00	62.80	62.50	62.90	62.70	62.60	62.60	501.70	62.71	0.50
6	62.60	62.80	62.70	62.70	62.90	62.80	62.60	62.60	501.70	62.71	0.30
7	62.60	62.90	62.75	62.50	62.80	62.65	62.60	62.70	501.50	62.69	0.40
8	62.60	62.90	62.75	62.50	62.80	62.65	62.60	62.40	501.20	62.65	0.50
9	62.60	62.80	62.70	62.50	62.70	62.60	62.60	62.90	501.40	62.68	0.30
10	62.60	62.90	62.70	62.60	63.00	62.80	62.60	62.60	501.80	62.73	0.40
11	62.60	62.80	62.70	62.70	62.90	62.80	62.80	62.50	501.80	62.73	0.40
12	62.60	62.80	62.70	62.50	62.80	62.65	62.50	62.70	501.25	62.66	0.30
13	62.60	62.90	62.75	62.50	62.80	62.65	62.70	62.80	501.70	62.71	0.40
14	62.70	62.90	62.80	62.60	62.80	62.70	62.40	62.80	501.70	62.71	0.50
15	62.40	62.80	62.80	62.50	62.90	62.70	62.60	62.70	501.40	62.68	0.50
16	62.90	63.10	62.60	62.70	62.90	62.80	62.50	63.00	502.50	62.81	0.60
17	62.60	63.00	63.00	62.60	63.00	62.80	62.70	62.90	502.60	62.83	0.40
18	62.50	63.00	62.80	62.60	63.00	62.80	62.60	62.80	502.10	62.76	0.50
19	62.70	62.90	62.75	62.80	63.00	62.90	62.70	62.80	502.55	62.82	0.30
20	62.60	62.90	62.80	62.50	62.80	62.65	62.70	62.80	501.75	62.72	0.40
21	62.80	63.00	62.75	62.70	62.90	62.80	62.80	62.90	502.65	62.83	0.30
22	62.70	62.90	62.90	62.40	62.60	62.50	62.80	62.90	501.70	62.71	0.50
23	62.50	62.70	62.80	62.60	62.80	62.70	62.80	63.00	501.90	62.74	0.50
24	62.60	62.80	62.60	62.50	62.70	62.60	62.90	62.90	501.60	62.70	0.40
25	62.60	62.80	62.70	62.70	62.90	62.80	62.65	62.70	501.85	62.73	0.25
26	62.60	62.40	62.70	62.60	62.70	62.70	62.80	62.80	501.30	62.66	0.40
27	63.00	62.50	62.80	62.70	62.80	62.40	62.80	62.80	501.80	62.73	0.60
28	62.80	62.70	62.50	62.40	62.80	62.90	62.60	62.40	501.10	62.64	0.50
29	62.75	62.50	62.60	62.90	62.80	62.60	63.00	62.50	501.65	62.71	0.50
30	63.00	62.50	62.70	62.60	62.90	62.50	62.80	62.70	501.70	62.71	0.50
										1881.36	12.85
										62.712 $\bar{\bar{X}}$	**0.428** $\bar{R}$

4.7.1 Manual Calculations

1) $\bar{X}$ - Chart Calculation

$\bar{\bar{X}}$ = 62.712 (Centre Limit)

$\bar{R}$ = 0.428

UCL = $\bar{\bar{X}} + A_2\bar{R}$

= 62.712 + (0.373)(0.428)

= 62.87164

LCL = $\bar{\bar{X}} - A_2\bar{R}$

= 62.712 – (0.373)(0.428)

= 62.55236

2) $\bar{R}$ - Chart Calculation

$\bar{R}$ = 0.428

UCL = $D_4\bar{R}$

= (1.864)(0.428)

= 0.797792

LCL = $D_3\bar{R}$

= (0.136)(0.428)

= 0.058208

4.7.2 MINITAB Analysis on $\bar{\bar{X}}$ and R Chart for month November

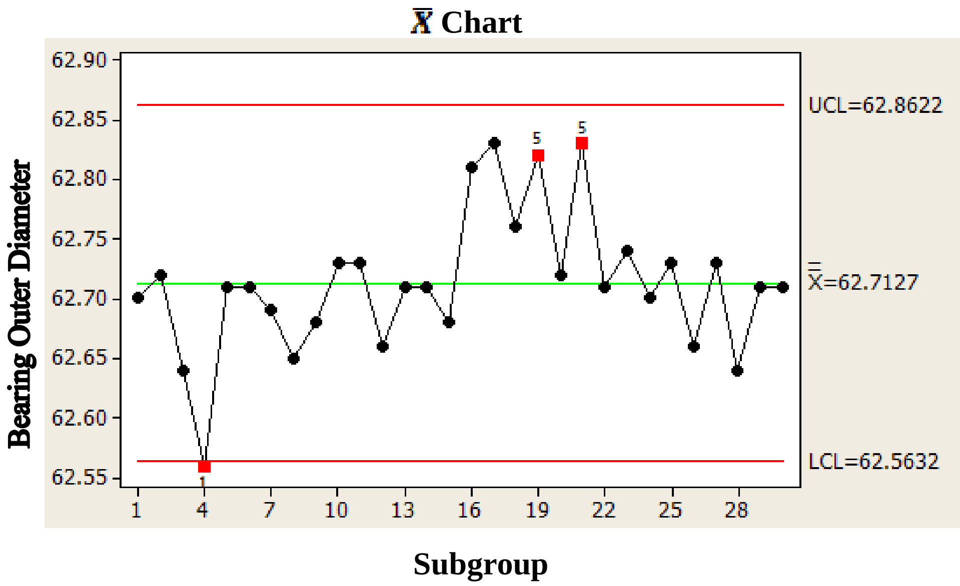

Figure 4.5 : $\bar{\bar{X}}$ Chart of month November

TEST 1. One point more than 3.00 standard deviations from center line.

Test Failed at points: 4

TEST 5. 2 out of 3 points more than 2 standard deviations from center line (on one side of CL).

Test Failed at points: 19, 21

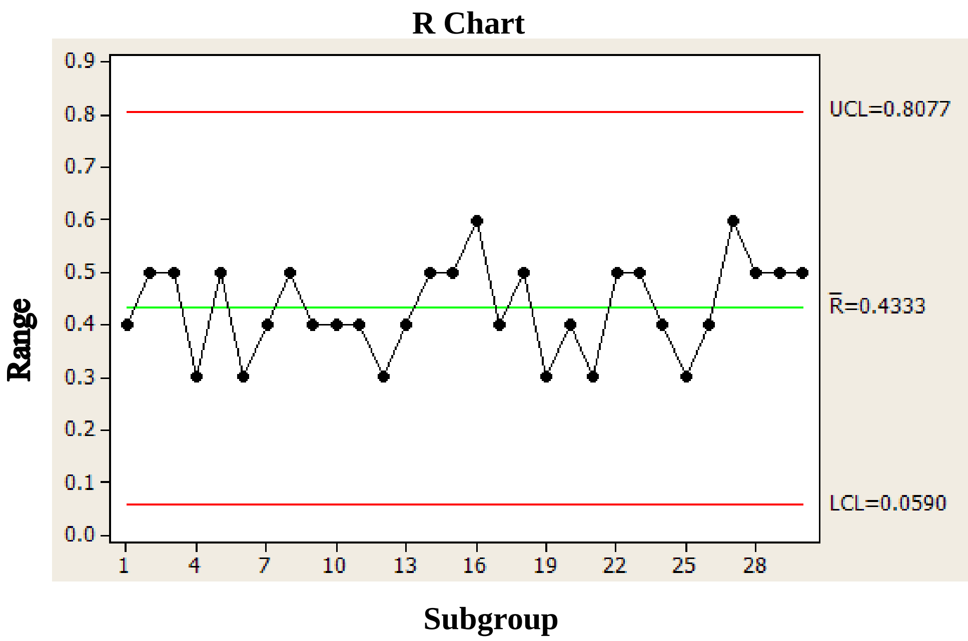

Figure 4.6 : R Chart of month November

The MINITAB analysis of data month November is as above. The process is under control but in critical condition. Its tendency to become not in control is very high. The $\bar{X}$ chart shows that the point number four is failed the process where its lay at more then 3 sigma value. Point number 19 and 21 failed the process too where they lay more then 2 sigma value. When the points are indicated that lay more then 2 sigma and 3 sigma values, the process on that period of time can be out of control. Its also can effect the other continues processes where lack of observations and attention can make the process become uncontrollable.

Deviation of the X-bar and R charts average values from one month o another has shows that the process become unstable at last. At month November the deviations of the X-bar chart from its centre line is high. But the range chart shows that the distribution of the range points are stable. This shows that the process is still around the range value. Fast troubleshooting will eliminate all the process defects and bring back the process on track. Extra attention and deep screening towards the root causes of the problems occur in the process will make the process more efficient and stable.

4.8 INTERPRETATION OF $\bar{X}$ AND R CHART

Using the $\bar{X}$ chart we can identify whether the process is centered or not. The chart also represent the average of the distribution created by the process. If the centre of the distribution shifts, the pattern of the $\bar{X}$chart will also shift. Meanwhile the range, R chart measures the process uniformity and reacts to changes in variation or spread. When the process is constant and all units of the product get the same treatment, the R chart signals that the process is out of control, this means that some units are being treated differently than others. The uniformity of a process is reflected by the magnitude of the R chart data. The lower the magnitude, the better is the process.

4.9 COMPARISON OF THE $\bar{\bar{X}}$ AND R CHART

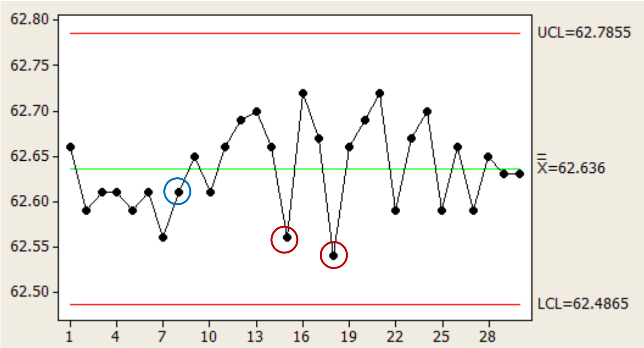

Figure 4.7 : $\bar{\bar{X}}$ Chart of month September

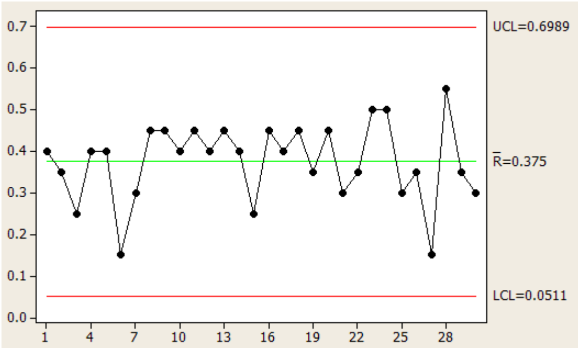

Figure 4.8 : R Chart of month September

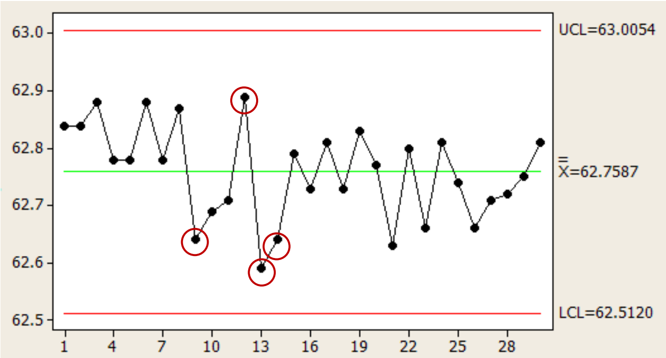

Figure 4.9 : $\bar{\bar{X}}$ Chart of month October

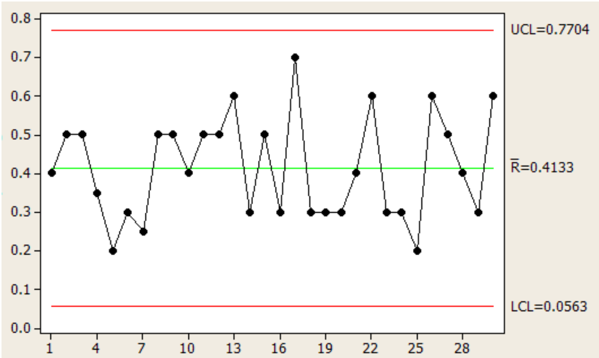

Figure 4.10 : R Chart of month October

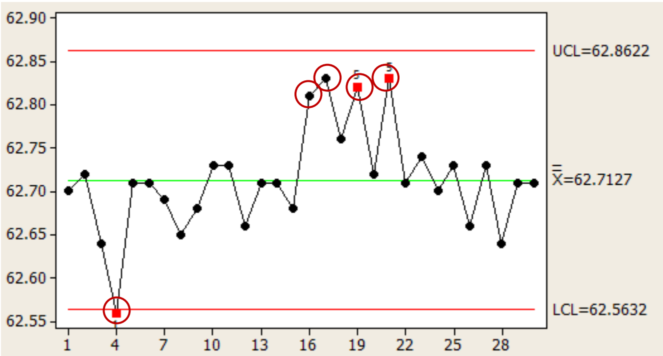

Figure 4.11 : $\bar{\bar{X}}$ Chart of month November

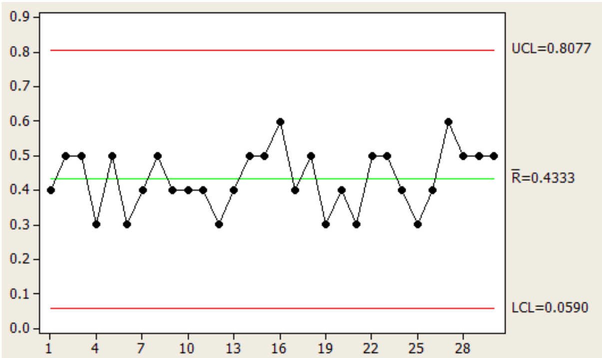

Figure 4.12 : R Chart of month November

By observing the three months $\bar{X}$ and R charts of process we can determine the deviations of process variables very clearly. The $\bar{X}$ chart shows that the process of month September and October is under control. The month November is become quit uncontrolled at point 4, 19 and 21. The $\bar{\bar{X}}$ value of the months increasing from 62.363 at month September, 62.759 at month October and 62.713 at month November. The deviation of process is significant where the $\bar{\bar{X}}$ value of each months are different and they increasing from a month to month. This shows that the tendency of the process become uncontrolled is very high.

At the month September, the process is under control where all its process variables are not more then 2σ value. At the same time the process variables are equally distributed at above and bottom of the process center limit. Although the point 15 and 18 is approaching 2σ value at bottom of the centre limit, the process is balanced up again with the next process where placed above of the center limit. Its also notice that the point number 8 is pointed at seventh consecutive point on the same side of the center limit line.

Comparing with the $\bar{X}$ chart of month October, the $\bar{\bar{X}}$ value has increase. The variables distributions are more likely approaching 2σ of the chart. Point 9, 12, 13 and 14 are more likely will violent the 2σ value. The tendency of this points to fail are very high. The process variables of month October also varies more from the center limit value. Its distributions are wider from the center limit compared with September $\bar{X}$ chart. However the process did not have any consecutive points on the same side of the average line.

The $\bar{X}$ chart of month November shows that 9th process is not under control. The point 4 is out of the 3σ value. At this respective time, the process become out of control. At point 19 and 21, the process pointed more than 2σ value. Its about to be uncontrolled process. Although the points are alternated, but the points are occurred at the same side above the centre limit value. This shows that the out of control process very tend to happen again because of the same reason. Its should given some attention and the problem must be identify. This will make the process more relievable and the tendency of centrality is high. The point 16 and 17 are about to fail the 2σ value of the process. These points are approaching continuously to the 2σ value. This will make the process become more unstable if not given attention to the process flow.

The R chart of each month are varies then one another. The range of the process is increasing from one another. On month September, the average range is 0.375, month October the average range is 0.4133 and on month November the average range is 0.4333. This shows a consecutive growth in the range of process each month.

The variable distributions on the range graph on month September is not much deviate from the average range value. Its more concentrated at the side of the line. This indicate that the range is more controlled and the process can be made to more perfect with even distribution.

The range chart of month October big diversion of the values from the average range value. Most of the points are distributed very far from the average range value. This proves that the process is diverting and becoming unstable compare to its previous month. More attention is needed on the process before its become critical.

Range chart of month November is more stable. Although its average range value is higher than the other months, the points distributions are more balance on both side of its average range line. The process is controllable but unstable in overall view.

Indeed, the lowest range is better. The lower the range of the process the better the process it is. The lower range process is stable, in control and not deviated a lot from the outer rings tolerance. Lower range process is more easily manageable. Its core problem can be identified and solved. If the range is deviated very much from the actual, the problem is because of the human error. Its may course by human activity not by the system or machines.

4.10 CAUSE OF THE PROCESS MEAN SHIFTED

After studying all the processes and comparing the pattern of the charts, we can concluded that there are two main causes of variation occurred. Namely random and common causes. Common causes also known as assignable causes. Assignable causes can be identify and eliminate economically, but random variations problem could not be solve in this method without basic changes in the process or system. Random variations are coursed by lot of small influences on the process which lying behind a particular measurement. Fine screening on the production process will help us to identify the real problem and where does it is occurs. The chain effect of a problem also can lead to random variability. For example, if a bearings outer ring is measured not meets its specified diameter although keeps all conditions as consistent as possible; its may because of operator influence, measuring tool malfunction, incapable machining operation and other small sources of variations that we cannot even detect.(K S Chen, R K Liao, 2002)

Identifying a problem from its root cause will eliminate the specified error and defect its self permanently. By using SPC the instantaneous problematic process point can be determined. The process point can be analyzed further and the cause of deviation can be determined specifically. Action taken towards the problems will prevent the same cause of defect occur again and again. At the same time correct methods and continues following of the countermeasures also will promise stable outer ring production. Detail problems might effect the process is represented by Ishikawa diagram or **cause-and-effect diagrams as shows by** Figure 4.13.

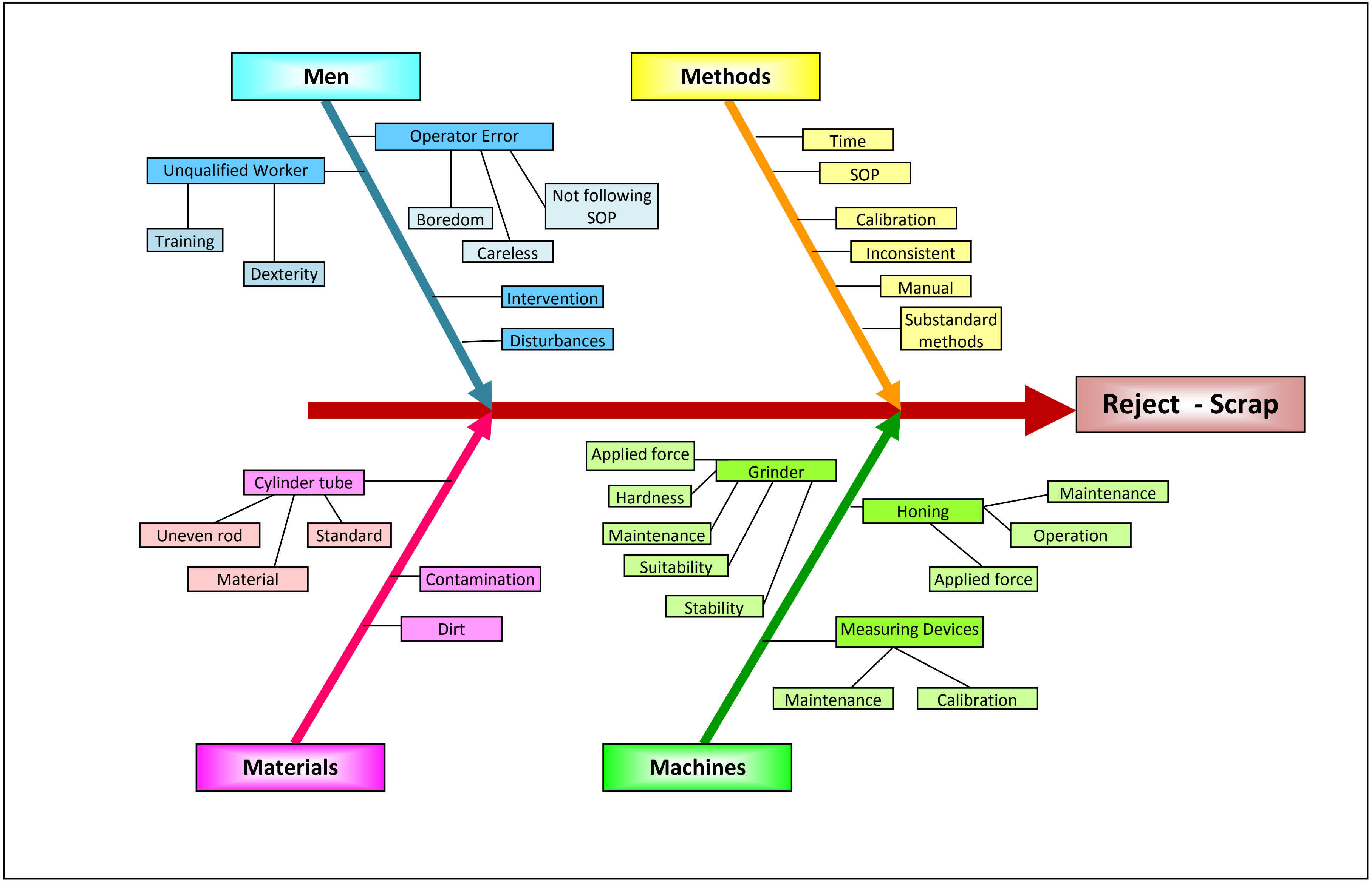

Figure 4.13 : Ishikawa diagram of factors that affect mean to be shifted

4.11 THE CAUSE-EFFECT OF 4M AND RECOMMENDATIONS

Complex production process involves the usage of material, standard method of processing or applying materials, machines to process the materials and men to monitor and interrupt the process. All this factor are related with each other and can be classified as 4M cause-effect factors. Further recommendations on this factors are discussed in order to determine the sources of variation and necessary action needed to be taken.

4.11.1 Men

Men needed to perform an operation. Different men have different judgment where its depends on their knowledge and skills. When a bearings outer ring is cut from a long rod, its have to go through face grinding. . (K S Chen, R K Liao, 2002)
A operated need to observe and measure the thickness of the ring after grinding. The part should be in between the standard tolerance level. An experience and skilled worker will know the grinding machines operation and will adjust the grinding dept accordingly. This will reduce the rejection units. A new or unskilled worker is lack of practice on the particular machine and may face difficulties in handling according to the grinding depth. This will increase the defects parts and lead to uncontrollable process.

Besides that, when the operator is continuously working and concentrated on a single operation, he might get tired and boredom. This natural feeling will lead the operator to do mistakes where they might not take the measurements well. . (K S Chen, R K Liao, 2002) The careless of taking the measurements well also will lead to defects outer ring produced.

Disturbances because of the surrounding and over work load also lead to human error. When an operator is disturbed and given extra works, they cannot concentrate on their work. They may do their work in simply without following the proper instruction just for settle down all their works. This will make them more careless and operate the machine wrongly.

4.11.2 Methods

The bearing outer ring production is started with cutting the cylindrical tubing to its appropriate length. After the cutting process, the ring will under go surface grinding. A operator will always monitor the thickness of the ring before and after surface grinding in order to control the grinding depth of the machine. Operator will follow the fixed grinding depth tolerance. Good observation and inspection is very important in order to make sure the process in on flow and under control. The outer ring will be placed on the standard jig with the needed measurement. The measuring jig is as in the Figure 4.14 below. Good following and referring to the SOP will make the process more controllable.(E.V.Gijo and P.K. Perumallu, 2003)

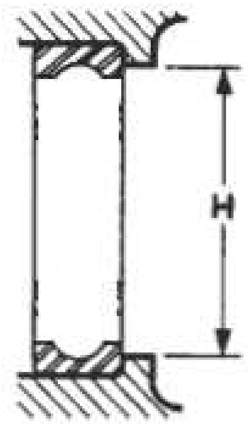

Figure 4.14 : Outer ring diameter measuring jig

Source : SK Vermani, 2003

After the surface grinding operation, the bearing outer ring will be measured of its inner diameter for the further process, groove grinding. In order to get a perfect fit to the bearing balls with the inner ring, the flatness of the inner surface of the outer ring is very important.(E.V.Gijo and P.K. Perumallu, 2003) The flatness of the surface is inspected by the standard jig. The ring is placed on the jig and the fitting tightness is inspected by the operator. The jig and its standard inspection method is as Figure 4.15 below.

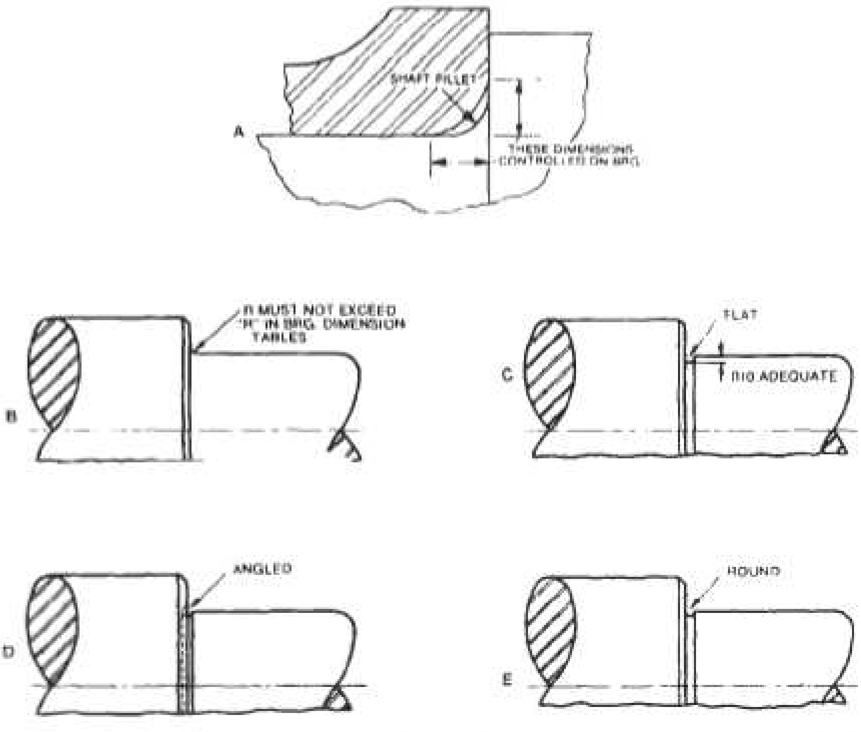

Figure 4.15 : Outer ring inner surface flatness inspection methods

Source : SK Vermani, 2003

As shown in the figure (A), after insert the ring to the jig, the inner surface of the ring must touch the surface of the jig. By rotating the ring slowly in the jig will locate the ring firmly inside the jig well as shown in (B). The ring which not fit to the jig is not suitable for the further process. The defect are flat(C), angle(D) and round(E). Operator must aware of all this defects and separate them accordingly. Careless inspection and segregation will make wrong selection and this will make the further process is become uncontrollable.

Using the standard jigs and calibration devices for years will make the measurement tip of the machine to erode. This will give inaccurate measurement result and the operator can make a wrong decision on it. In order to get a correct measurement, the measuring devices and jigs must be recalibrated and all the substandard must be removed often.(E.V.Gijo and P.K. Perumallu, 2003). Figure 4.16 shows example of eroded measurement jig.

Figure 4.16 : Example of **e**roded and good condition section of a measurement jig.

Source : SK Vermani, 2003

As shown on the picture, this sectional eroded jig will produce angled defect ring when the outer inner surface flatness inspection is carried out. This can make the operator to take wrong decision and reject a good part.

4.11.3 Materials

There are two type of material used for producing sealed bearing by SKF Bearing Industries (Malaysia) Sdn. Bhd. namely steel and stainless steel. Standard material is used for producing the bearing. All the bearings parts including bearings outer ring are made by the same type of standard material. The properties of material are as below.

Table 4.4 : Properties of bearing materials

Items	Units	Bearing Steel	Stainless Steel
Density	g/cm^3	7.85	7.90
Coefficient of linear expansion	10^{-6}/ K	10.0	11.0
Young's Modulus	GPa	208	200
Poisson's ratio	--	0.30	0.30
Hardness	$Hv_{10}HRc$	700 62	66
Bending strength	MPa	2400	--
Fracture toughness	$MPam^{-1/2}$	25	--
Thermal conductivity	W/mk	30~40	15
Special electrical resistance	Omm^2/m	0.1~1	0.75
Heat resistance	C	120	300
Corrosion resistance	--	Low	Medium
Stress cycles(50% failed)	--	10×10^7	--
Non lubrication friction	--	High	High
Magnetism	--	magnetic	magnetic
Centrifugal force	--	Very high	Very high
Operate temperature increasing	--	high	high
Size stability	--	Low	Low
Conductivity	--	conductor	conductor

Source : SKF Bearing Sdn. Bhd.

To ensure the quality of the product, tight material quality controlling is very important. The bearings outer ring production is started with cutting specified steel tubing. The cutting process is done by machining similar to lath. The cylindrical tube must have a event dimension with the bearings appropriate outer rings specified thickness. Normally the thickness of the cylindrical tube is slightly bigger then the actual outer ring thickness. This is for the next machining processes. When the tubing is found not event wall thickness, the feeding of the tubing for needed cutting process will excess. This will produce a reject part.

Contamination and heavy dirt on the material also will make the outer ring production to be rejected. The dirt or extra material on the outer surface of the ring which under going surface grinding will interface the process. This will make the ring that produce is out of the specified measurement. When the ring is bring forward to the next process it is not suitable and the tendency of its being rejected is very high.

4.11.4 The Machines

Part of factor that contributes to rejection of outer ring production is machining. The major machining process that involve in bearing outer ring production is grinding, honing and all the measurement devices. The correct operation of the machines and the measuring devices will promise stable process flow. (P.Nagesh and M S Prabhuswamy, 2004)

After cut the needed ring according to its fixed standard size from the cylindrical tube using lath machining process, the ring will go through surface grinding process. The surface of the ring will be grinded with 6 micron fine. (P.Nagesh and M S Prabhuswamy, 2004) In order to get a flat surface the grinding wheel must be in good condition. Crack and uneven grinding wheel surface will produce uneven outer ring surface too. The figure shows the grinding method used by SKF Bearing Industries (Malaysia) Sdn. Bhd.

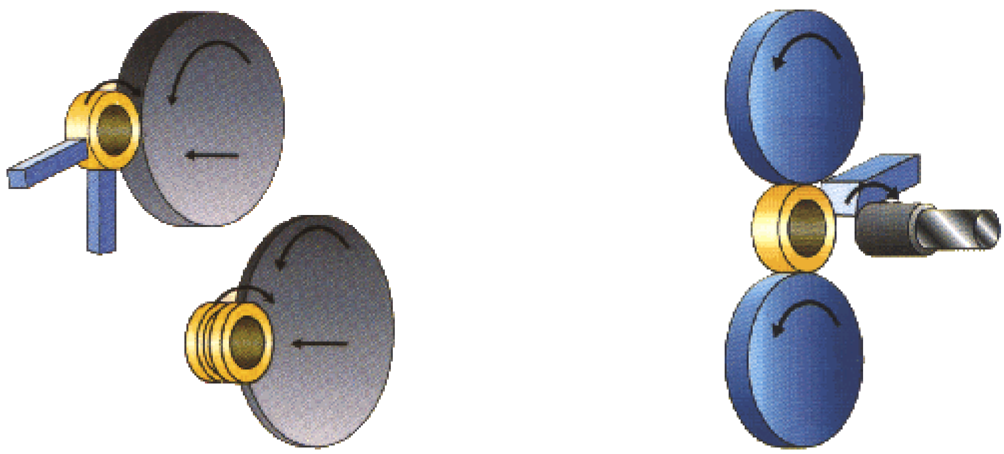

Figure 4.17 : Bearing outer ring grinding and grooving method

Source : SKF Bearing Sdn. Bhd.

The same method is used for groove grinding, inner surface grinding and honing process. Controlling and regular inspection on the grinding wheel and good maintenance of the grinding and honing machines will ensure the stability of the process.

The measurement devices needs correct calibration in order to measure the real condition of the outer rings produced. Wrong calibrations and malfunctioning of the measurement devices will make the operator to face difficulties to take decision and they may made mistakes. Often inspection on the condition of the measuring devices and maintenance will keep the them in good condition and the process will lay in between the needed control area.

4.12 CHAPTER SUMMARY

Implementing SPC tools such as control chart for variables, $\bar{X}$ and R chart proved to be the best monitoring tool for a process. The compatibility and stability of a process can be monitor through the $\bar{X}$ and R charts.(Michael V Petrovich). After producing the charts, the trend of the process is clearly can be observe. The process can be improve by identifying all the core problems. In order to find out the causes, 4M effects are approached. Countermeasure actions are discussed to decrease the process variations. This will produce a finer bearings outer ring production process.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

In this chapter a wise discussion on the whole topic is made. The conclusion made will round of the implement of SPC on bearing outer ring process. Some possible future works suggestions also made in this chapter.

5.2 CONCLUSION

Statistical Process Control (SPC) is a powerful tool to closely monitor and predict a manufacturing process. Monitoring a manufacturing process on its flow will help us to determine whether the process will really gives the expected outcome or not. This is called as controlled and uncontrolled process. Controlled process is a successive process where the number of rejection part produced are very minimal. Uncontrolled process is out of production limit and its will produce more rejected part. If a production trend which is monitor through $\bar{X}$ chart is more then 2σ, 7 successive points at the same side and successive 7 points are declining; the process can be predicted. (P.Nagesh and M S Prabhuswamy, 2004) This can make the process to be predictable and changes can be made on the process before its become more critical.

SPC will analyze and monitor the process significantly. This will help early detection of defect parts and this will reduce overall production cost and decrease waste. Meanwhile later detection of faulty process will lead to lot of material wastage due to increasing number of rejects.(Michael V Petrovich) This will increase the overall production cost. Implementing SPC by the person involve in the process its self is a good practice. This will make the person to accurately identify the real cause of a problem to take place and eliminate it at early stage with the aid of SPC.

The bearings outer ring production is varies from month to month. The differences are cause by lot of factors. Identifying the core causes of the problem can make the processes finer. This will reduce the rejection rate. Identifying the core causes of the problems is made easier with SPC where its will significantly notice the point of the defect occurred. This will converge the focusing point and the identification process can be made easily. (Does et al, 1997)

Indeed, the overall comparison between the three months data shows slow deviation from one another. At last it's become out of control where its start to produce reject parts. Although the process become out of control, the range of the points distribution shows minimal deviation from the centre line. .(Does et al, 1997) This shows that the process just become out of control. More attention and prevention steps taking as discussed in chapter 4 will bring back the process to its track. Stable and efficient process can be produced then.

5.3 FUTURE WORKS

More finer and stable manufacturing process can be implemented to SKF Bearing Industries (Malaysia) Sdn. Bhd. by applying SPC. Collaboration between university and the company conducting more research to the workers and all the other bearing manufacturing processes will benefit both parties.

The company also can take university as its quality consultant for its product manufacturing base on SPC implementation. The SPC application not only applicable to quality assurance base on the material and product but also can be implemented to worker operation and managements. University also can provide quality seminar for educate the company workers and make them more aware on importance of SPC. This will make the company activities to be more efficient.

By collaborating with the company, university also can apply all its new findings and research on the company processes. University theories and new findings on SPC applications also can be straightly apply on the company.

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APPENDIX A1 (QC Data of Month September)

SKF
MALAYSIA

MEASUREMENT RECORD

Product Type : 6206 - 2Z/C3
Manufacturing Date : 3-Sep-08
Sampled Qty: 25

Report No: DGBB 02 08 36
Report By: Nora

Channel : 2

	OUTER RING																										
No	DmU				DmL				Dm	VD		VDm		Be				VBe		Kre		Sm		Se		Gr	
	max	min	avg	cl	max	min	avg	cl	cl	max	cl		cl	max	min	avg	cl	max	cl	max	cl	max	cl	max	cl	max	cl
1	-7	-8	-7.5	5	-6	-7	-6.5	4	5	1	4	1	4	-29	-31	-30.0	4	2	4	4	4	2	4	4	4	28	7
2	-6	-7	-6.5	4	-5	-6	-5.5	4	4	1	4	1	4	-29	-30	-29.5	4	1	4	6	5	2	4	3	4	29	7
3	-6	-7	-6.5	4	-5	-6	-5.5	4	4	1	4	1	4	-38	-39	-38.5	4	1	4	4	4	2	4	3	4	26	7
4	-6	-8	-7	4	-4	-6	-5	4	4	2	4	2	4	-27	-28	-27.5	4	1	4	5	4	1	4	4	4	28	7
5	-6	-7	-6.5	4	-5	-6	-5.5	4	4	1	4	1	4	-29	-31	-30.0	4	2	4	5	4	1	4	4	4	29	7
6	-5	-6	-5.5	4	-6	-7	-6.5	4	4	1	4	1	4	-26	-27	-26.5	4	1	4	10	6	1	4	3	4	27	7
7	-5	-7	-6	4	-4	-6	-5	4	4	2	4	1	4	-41	-43	-42.0	4	2	4	4	4	2	4	4	4	28	7
8	-6	-8	-7	4	-4	-6	-5	4	4	2	4	2	4	-27	-29	-28.0	4	2	4	4	4	3	4	4	4	26	7
9	-6	-8	-7	4	-5	-7	-6	4	4	2	4	1	4	-31	-32	-31.5	4	1	4	3	4	1	4	5	4	24	7
10	-6	-7	-6.5	4	-5	-6	-5.5	4	4	1	4	1	4	-30	-31	-30.5	4	1	4	4	4	1	4	4	4	26	7
11	-7	-8	-7.5	5	-6	-7	-6.5	4	5	1	4	1	4	-41	-42	-41.5	4	1	4	5	4	1	4	3	4	25	7
12	-7	-9	-8	5	-6	-8	-7	4	5	2	4	1	4	-31	-32	-31.5	4	1	4	5	4	1	4	5	4	27	7
13	-7	-8	-7.5	5	-6	-7	-6.5	4	5	1	4	1	4	-36	-37	-36.5	4	1	4	6	5	2	4	6	5	28	7
14	-6	-8	-7	4	-4	-6	-5	4	4	2	4	2	4	-28	-29	-28.5	4	1	4	4	4	1	4	4	4	25	7
15	-5	-6	-5.5	4	-4	-5	-4.5	4	4	1	4	1	4	-29	-31	-30.0	4	2	4	5	4	1	4	5	4	26	7
16	-7	-9	-8	5	-6	-8	-7	4	5	2	4	1	4	-30	-31	-30.5	4	1	4	8	5	1	4	5	4	24	7
17	-6	-7	-6.5	4	-5	-6	-5.5	4	4	1	4	1	4	-29	-30	-29.5	4	1	4	4	4	1	4	10	5	25	7
18	-4	-6	-5	4	-3	-5	-4	4	4	2	4	1	4	-28	-29	-28.5	4	1	4	4	4	2	4	4	4	26	7
19	-6	-8	-7	4	-5	-7	-6	4	4	2	4	1	4	-33	-34	-33.5	4	1	4	4	4	1	4	4	4	28	7
20	-6	-9	-7.5	5	-5	-8	-6.5	4	5	3	4	1	4	-32	-33	-32.5	4	1	4	3	4	1	4	5	4	27	7
21	-6	-7	-6.5	4	-7	-8	-7.5	5	5	1	4	1	4	-43	-44	-43.5	4	1	4	4	4	1	4	5	4	26	7
22	-5	-6	-5.5	4	-4	-5	-4.5	4	4	1	4	1	4	-43	-44	-43.5	4	1	4	6	5	2	4	4	4	25	7
23	-7	-9	-8	5	-5	-7	-6	4	5	2	4	2	4	-25	-26	-25.5	4	1	4	4	4	2	4	3	4	24	7
24	-7	-9	-8	5	-6	-8	-7	4	5	2	4	1	4	-40	-41	-40.5	4	1	4	4	4	1	4	5	4	26	7
25	-4	-6	-5	4	-5	-7	-6	4	4	2	4	1	4	-36	-37	-36.5	4	1	4	5	4	1	4	4	4	25	7
MEAN	-5.96	-7.52	-6.74		-5.04	-6.6	-5.82			1.56		1.16		-32.44	-33.64	-33.04		1.2		4.8		1.4		4.4		26.32	
MAX	-4	-6	-5		-3	-5	-4			3		2		-25	-26	-25.5		2		10		3		10		29	
MIN	-7	-9	-8		-7	-8	-7.5			1		1		-43	-44	-43.5		1		3		1		3		24	
Std			0.93				0.90			0.58		0.37				5.58		0.41		1.53		0.58		1.41		1.52	

	IR				OR			
	ri	Vri	bri	Ra Di	Vre	bre	Ra de	re
1	4.888	2.4	8.334	0.020	2.3	8.147	0.029	5.063
2	4.889	2.5	8.333	0.021	2.4	8.153	0.030	5.060
3	4.884	2.3	8.333	0.020	2.3	8.147	0.030	5.063
4								
5								
AVG	4.887	2.4	8.333	0.020	2.3	8.149	0.029	5.062
MAX	4.889	2.5	8.334	0.021	2.4	8.153	0.030	5.063
MIN	4.884	2.3	8.333	0.020	2.3	8.147	0.029	5.060
UTL	4.890	2.5	8.3	0.05	2.5	7.7	0.05	5.080
LTL	4.860	0	0	0	0	0	0	5.020
%Conf.	100%	100%	100%	100%	100%	100%	100%	100%

	Outer Ring											
QUAL.	Dm		VD	Sm	VDm	Be		Kre	VBe	Se	Gr	
CLASS	Max	Min	Max	Max	Max	Max	Min	Max	Max	Max	Max	Min
P4	0	-7	6	4	4	0	-60	5	3	5		
P5	0	-9	7	8	5	0	-60	8	6	10		
P6	0	-11	7	17	6	0	-60	13	12	20		
N	0	-11	7	17	6	0	-60	13	12	20	30	20

SKF
MALAYSIA

MEASUREMENT RECORD

Product Type : 6206 - 2Z/C3
Manufacturing Date : 3-Sep-08
Sampled Qty: 25

Report No: DGBB 02 08 36
Report By: Nora

Channel : 2

No	dmU				dmL				dm	Vd		Vdm	
	max	min	avg	cl	max	min	avg	cl	cl	Value	cl	Value	cl
1	-2	-3	-2.5	4	-3	-4	-3.5	4	4	1	4	1	4
2	-4	-5	-4.5	4	-4	-5	-4.5	4	4	1	4	0	4
3	-3	-4	-3.5	4	-2	-3	-2.5	4	4	1	4	1	4
4	-3	-4	-3.5	4	-2	-3	-2.5	4	4	1	4	1	4
5	-2	-3	-2.5	4	-3	-4	-3.5	4	4	1	4	1	4
6	-4	-5	-4.5	4	-2	-3	-2.5	4	4	1	4	2	4
7	-5	-6	-5.5	5	-3	-4	-3.5	4	5	1	4	2	4
8	-2	-3	-2.5	4	-1	-2	-1.5	4	4	1	4	1	4
9	-2	-3	-2.5	4	-2	-3	-2.5	4	4	1	4	0	4
10	-3	-4	-3.5	4	-4	-5	-4.5	4	4	1	4	1	4
11	-4	-5	-4.5	4	-5	-6	-5.5	5	5	1	4	1	4
12	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4
13	-6	-7	-6.5	6	-5	-6	-5.5	5	6	1	4	1	4
14	-3	-5	-4	4	-2	-4	-3	4	4	2	4	1	4
15	-3	-4	-3.5	4	-2	-3	-2.5	4	4	1	4	1	4
16	-1	-2	-1.5	4	-1	-2	-1.5	4	4	1	4	0	4
17	-2	-3	-2.5	4	-3	-4	-3.5	4	4	1	4	1	4
18	-4	-5	-4.5	4	-3	-4	-3.5	4	4	1	4	1	4
19	-3	-4	-3.5	4	-2	-3	-2.5	4	4	1	4	1	4
20	-5	-6	-5.5	5	-4	-6	-5	4	5	2	4	0.5	4
21	-3	-4	-3.5	4	-4	-5	-4.5	4	4	1	4	1	4
22	-1	-3	-2	4	-2	-4	-3	4	4	2	4	1	4
23	-1	-2	-1.5	4	-2	-3	-2.5	4	4	1	4	1	4
24	-2	-3	-2.5	4	-1	-2	-1.5	4	4	1	4	1	4
25	-3	-4	-3.5	4	-2	-3	-2.5	4	4	1	4	1	4
MEAN	-3.04	-4.12	-3.58		-2.72	-3.84	-3.28	4.08		1.12		0.94	
MAX	-1	-2	-1.5		-1	-2	-1.5	5		2		2	
MIN	-6	-7	-6.5		-5	-6	-5.5	4		1		0	
Std			1.3124				1.18			0.33		0.46	

No	Bi				VBi		Kri		Ks		Si		Rm	
	max	min	avg	cl	Value	cl	Value	cl	Value	cl	Value	cl	Value	cl
1	-58	-59	-58.5	4	1	4	3	4	8	5	4	4	0.4	5
2	-57	-58	-57.5	4	1	4	3	4	4	4	3	4	0.6	5
3	-55	-56	-55.5	4	1	4	3	4	4	4	4	4	0.4	5
4	-57	-58	-57.5	4	1	4	2	4	5	5	4	4	1.0	5
5	-58	-59	-58.5	4	1	4	4	5	6	5	3	4	0.8	5
6	-59	-60	-59.5	4	1	4	3	4	4	4	4	4	0.6	5
7	-56	-57	-56.5	4	1	4	5	6	4	4	4	4	0.4	5
8	-55	-57	-56.0	4	2	4	4	5	3	4	3	4	0.6	5
9	-59	-60	-59.5	4	1	4	4	5	4	4	2	4	0.4	5
10	-57	-58	-57.5	4	1	4	3	4	5	5	2	4	0.6	5
11	-51	-52	-51.5	4	1	4	3	4	6	5	3	4	0.4	5
12	-55	-56	-55.5	4	1	4	2	4	6	5	4	4	0.6	5
13	-57	-58	-57.5	4	1	4	2	4	4	4	4	4	0.4	5
14	-58	-59	-58.5	4	1	4	3	4	5	5	4	4	0.6	5
15	-58	-59	-58.5	4	1	4	3	4	4	4	3	4	0.4	5
16	-57	-58	-57.5	4	1	4	4	5	3	4	4	4	0.6	5
17	-56	-57	-56.5	4	1	4	4	5	3	4	6	5	0.4	5
18	-59	-60	-59.5	4	1	4	3	4	4	4	4	4	0.6	5
19	-55	-56	-55.5	4	1	4	5	6	6	5	4	4	0.4	5
20	-54	-55	-54.5	4	1	4	4	5	6	5	3	4	0.6	5
21	-54	-55	-54.5	4	1	4	4	5	8	5	3	4	0.4	5
22	-51	-52	-51.5	4	1	4	3	4	4	4	2	4	0.4	5
23	-58	-59	-58.5	4	1	4	3	4	10	6	4	4	0.6	5
24	-53	-54	-53.5	4	1	4	4	5	4	4	3	4	0.8	5
25	-53	-54	-53.5	4	1	4	4	5	4	4	3	4	1.0	5
MEAN	-56	-57.04	-56.52		1.04		3.4		4.96		3.48		0.56	
MAX	-51	-52	-51.5		2		5		10		6		1	
MIN	-59	-60	-59.5		1		2		3		2		0.4	
Std	.		2.34		0.20		0.82		1.72		0.87		0.18	

INNER RING											
QUAL.	dm		Vd	Vdm	Bi		Kri	Ks	Si	Rm	VBi
CLASS	max	min	max	max	max	min	max	Max	max	Max	Max
P4	0	-5	2.5	2.5	0	-60	3	4	4	2	2.5
P5	0	-6	3	3	0	-60	4	8	8	2	5
P6	0	-8	4	4	0	-60	8	10	20	2	12
N/NBS	0	-8	4	4	0	-60	8	10	20	2	12

APPENDIX A2 (QC Data of Month October)

SKF
MALAYSIA

MEASUREMENT RECORD

Product Type : 6206 - 2Z/C3 *
Manufacturing Date : 8-Oct-08
Sampled Qty: 25

Report No: DGBB 02 08 41
Report By: Nora

Channel : 2

	OUTER RING																										
No	DmU				DmL				Dm	VD		VDm		Be				VBe		Kre		Sm		Se		Gr	
	max	min	avg	cl	max	min	avg	cl	cl	max	cl		cl	max	min	avg	cl	max	cl	max	cl	max	cl	max	cl	max	cl
1	-7	-9	-8	5	-6	-8	-7	4	5	2	4	1	4	-38	-40	-39.0	4	2	4	5	4	1	4	5	4	30	7
2	-8	-10	-9	5	-7	-6	-6.5	4	5	2	4	2.5	4	-39	-40	-39.5	4	1	4	4	4	1	4	4	4	29	7
3	-5	-9	-7	4	-4	-8	-6	4	4	4	4	1	4	-36	-37	-36.5	4	1	4	5	4	2	4	6	5	30	7
4	-5	-7	-6	4	-4	-6	-5	4	4	2	4	1	4	-38	-39	-38.5	4	1	4	3	4	1	4	5	4	27	7
5	-6	-10	-8	5	-5	-9	-7	4	5	4	4	1	4	-37	-38	-37.5	4	1	4	3	4	1	4	5	4	25	7
6	-6	-8	-7	4	-7	-9	-8	5	5	2	4	1	4	-37	-39	-38.0	4	2	4	3	4	1	4	4	4	30	7
7	-6	-9	-7.5	5	-5	-8	-6.5	4	5	3	4	1	4	-39	-40	-39.5	4	1	4	5	4	2	4	6	5	30	7
8	-6	-9	-7.5	5	-5	-8	-6.5	4	5	3	4	1	4	-39	-40	-39.5	4	1	4	4	4	1	4	5	4	29	7
9	-6	-8	-7	4	-5	-7	-6	4	4	2	4	1	4	-41	-42	-41.5	4	1	4	3	4	2	4	4	4	30	7
10	-5	-9	-7	4	-6	-10	-8	5	5	4	4	1	4	-38	-39	-38.5	4	1	4	4	4	2	4	4	4	28	7
11	-6	-8	-7	4	-7	-9	-8	5	5	2	4	1	4	-38	-39	-38.5	4	1	4	3	4	1	4	5	4	28	7
12	-6	-8	-7	4	-5	-8	-6.5	4	4	3	4	0.5	4	-35	-36	-35.5	4	1	4	3	4	1	4	5	4	30	7
13	-6	-9	-7.5	5	-5	-8	-6.5	4	5	3	4	1	4	-40	-41	-40.5	4	1	4	4	4	1	4	3	4	30	7
14	-7	-9	-8	5	-6	-8	-7	4	5	2	4	1	4	-34	-35	-34.5	4	1	4	3	4	1	4	4	4	29	7
15	-4	-8	-6	4	-5	-9	-7	4	4	4	4	1	4	-43	-44	-43.5	4	1	4	4	4	1	4	5	4	27	7
16	-9	-11	-10	6	-7	-9	-8	5	6	2	4	2	4	-46	-47	-46.5	4	1	4	5	4	1	4	4	4	26	7
17	-6	-10	-8	5	-6	-10	-8	5	5	4	4	0	4	-44	-45	-44.5	4	1	4	3	4	1	4	3	4	28	7
18	-5	-10	-7.5	5	-6	-10	-8	5	5	5	4	0.5	4	-39	-40	-39.5	4	1	4	3	4	1	4	5	4	30	7
19	-7	-9	-8	5	-8	-10	-9	5	5	2	4	1	4	-39	-40	-39.5	4	1	4	4	4	2	4	4	4	30	7
20	-6	-9	-7.5	5	-5	-8	-6.5	4	5	3	4	1	4	-34	-36	-35.0	4	2	4	4	4	1	4	4	4	30	7
21	-8	-10	-9	5	-7	-9	-8	5	5	2	4	1	4	-42	-43	-42.5	4	1	4	3	4	1	4	5	4	29	7
22	-7	-9	-8	5	-4	-6	-5	4	5	2	4	3	4	-38	-39	-38.5	4	1	4	4	4	1	4	4	4	30	7
23	-5	-7	-6	4	-6	-8	-7	4	4	2	4	1	4	-38	-40	-39.0	4	2	4	4	4	2	4	4	4	27	7
24	-6	-8	-7	4	-5	-7	-6	4	4	2	4	1	4	-42	-43	-42.5	4	1	4	3	4	2	4	3	4	30	7
25	-6	-8	-7	4	-7	-9	-8	5	5	2	4	1	4	-40	-41	-40.5	4	1	4	4	4	2	4	4	4	29	7
MEAN	-6.16	-8.84	-7.5		-5.72	-8.28	-7			2.72		1.1		-38.96	-40.12	-39.54		1.16		3.72		1.32		4.4		28.84	
MAX	-4	-7	-6		-4	-6	-5			5		3		-34	-35	-34.5		2		5		2		6		30	
MIN	-9	-11	-10		-8	-10	-9			2		0		-46	-47	-46.5		1		3		1		3		25	
Std			0.94				1.01			0.94		0.60				2.85		0.37		0.74		0.48		0.82		1.46	

	IR				OR			
	ri	Vri	bri	Ra Di	Vre	bre	Ra de	re
1	4.887	2.3	8.333	0.038	1.9	8.157	0.041	5.054
2	4.883	2.4	8.334	0.031	2.5	8.156	0.035	5.052
3	4.885	2.2	8.333	0.031	2.4	8.158	0.035	5.051
4								
5								
AVG	4.885	2.3	8.333	0.034	2.3	8.157	0.037	5.053
MAX	4.887	2.4	8.334	0.038	2.5	8.158	0.041	5.054
MIN	4.883	2.2	8.333	0.031	1.9	8.156	0.035	5.051
UTL	4.890	2.5	8.3	0.05	2.5	7.7	0.05	5.080
LTL	4.860	0	0	0	0	0	0	5.020
%Conf.	100%	100%	100%	100%	100%	100%	100%	100%

	Outer Ring											
QUAL.	Dm		VD	Sm	VDm	Be		Kre	VBe	Se	Gr	
CLASS	Max	Min	Max	Max	Max	Max	Min	Max	Max	Max	Max	Min
P4	0	-7	6	4	4	0	-60	5	3	5		
P5	0	-9	7	8	5	0	-60	8	6	10		
P6	0	-11	7	17	6	0	-60	13	12	20		
N	0	-11	7	17	6	0	-60	13	12	20	30	20

SKF
MALAYSIA

MEASUREMENT RECORD

Product Type : 6206 - 2Z/C3 *
Report No: DGBB 02 08 41
Channel : 2
Manufacturing Date : 8-Oct-08
Report By: Nora
Sampled Qty: 25

No	dmU				dmL				dm	Vd		Vdm	
	max	min	avg	cl	max	min	avg	cl	cl	Value	cl	Value	cl
1	-2	-3	-2.5	4	-1	-2	-1.5	4	4	1	4	1	4
2	-3	-4	-3.5	4	-2	-3	-2.5	4	4	1	4	1	4
3	-4	-5	-4.5	4	-5	-6	-5.5	5	5	1	4	1	4
4	-3	-4	-3.5	4	-4	-5	-4.5	4	4	1	4	1	4
5	-4	-5	-4.5	4	-3	-4	-3.5	4	4	1	4	1	4
6	-2	-3	-2.5	4	-1	-2	-1.5	4	4	1	4	1	4
7	-1	-2	-1.5	4	-3	-4	-3.5	4	4	1	4	2	4
8	-2	-4	-3	4	-3	-5	-4	4	4	2	4	1	4
9	-1	-3	-2	4	-2	-4	-3	4	4	2	4	1	4
10	-5	-7	-6	5	-3	-5	-4	4	5	2	4	2	4
11	-3	-4	-3.5	4	-4	-5	-4.5	4	4	1	4	1	4
12	-5	-6	-5.5	5	-6	-7	-6.5	6	6	1	4	1	4
13	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4
14	-3	-5	-4	4	-4	-6	-5	4	4	2	4	1	4
15	-3	-4	-3.5	4	-4	-5	-4.5	4	4	1	4	1	4
16	-6	-7	-6.5	6	-5	-6	-5.5	5	6	1	4	1	4
17	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4
18	-2	-4	-3	4	-1	-3	-2	4	4	2	4	1	4
19	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4
20	-7	-8	-7.5	6	-6	-8	-7	6	6	2	4	0.5	4
21	-4	-5	-4.5	4	-5	-6	-5.5	5	5	1	4	1	4
22	-3	-4	-3.5	4	-4	-5	-4.5	4	4	1	4	1	4
23	-4	-5	-4.5	4	-3	-4	-3.5	4	4	1	4	1	4
24	-1	-3	-2	4	-3	-5	-4	4	4	2	4	2	4
25	-5	-7	-6	5	-4	-6	-5	4	5	2	4	1	4
MEAN	-3.52	-4.8	-4.16		-3.52	-4.84	-4.18	4.28		1.32		1.1	
MAX	-1	-2	-1.5		-1	-2	-1.5	6		2		2	
MIN	-7	-8	-7.5		-6	-8	-7	4		1		0.5	
Std			1.5527				1.38			0.48		0.35	

No	Bi				VBi		Kri		Ks		Si		Rm	
	max	min	avg	cl	Value	cl	Value	cl	Value	cl	Value	cl	Value	cl
1	-40	-41	-40.5	4	1	4	4	5	5	5	3	4	0.4	5
2	-38	-39	-38.5	4	1	4	2	4	4	4	4	4	0.6	5
3	-31	-33	-32.0	4	2	4	3	4	4	4	4	4	1.0	5
4	-34	-36	-35.0	4	2	4	3	4	4	4	3	4	0.8	5
5	-35	-38	-36.5	4	3	5	2	4	3	4	3	4	0.4	5
6	-31	-32	-31.5	4	1	4	5	6	3	4	3	4	0.6	5
7	-30	-31	-30.5	4	1	4	2	4	4	4	2	4	0.8	5
8	-37	-38	-37.5	4	1	4	2	4	5	5	4	4	1.0	5
9	-28	-29	-28.5	4	1	4	2	4	4	4	2	4	0.8	5
10	-30	-31	-30.5	4	1	4	2	4	4	4	3	4	1.0	5
11	-30	-31	-30.5	4	1	4	2	4	4	4	4	4	0.8	5
12	-29	-30	-29.5	4	1	4	3	4	3	4	3	4	0.6	5
13	-29	-30	-29.5	4	1	4	2	4	6	5	3	4	0.4	5
14	-31	-32	-31.5	4	1	4	2	4	4	4	4	4	0.4	5
15	-23	-24	-23.5	4	1	4	2	4	4	4	5	5	0.6	5
16	-30	-31	-30.5	4	1	4	3	4	3	4	3	4	0.8	5
17	-29	-30	-29.5	4	1	4	3	4	4	4	4	4	1.0	5
18	-32	-33	-32.5	4	1	4	2	4	4	4	5	5	1.0	5
19	-30	-31	-30.5	4	1	4	2	4	5	5	3	4	0.8	5
20	-31	-32	-31.5	4	1	4	2	4	4	4	3	4	1.0	5
21	-34	-36	-35.0	4	2	4	2	4	3	4	4	4	0.6	5
22	-28	-29	-28.5	4	1	4	4	5	4	4	4	4	1.0	5
23	-30	-31	-30.5	4	1	4	3	4	6	5	5	5	0.4	5
24	-34	-35	-34.5	4	1	4	2	4	3	4	5	5	0.6	5
25	-29	-30	-29.5	4	1	4	2	4	5	5	4	4	0.4	5
MEAN	-31.32	-32.52	-31.92		1.2		2.52		4.08		3.6		0.71	
MAX	-23	-24	-23.5		3		5		6		5		1	
MIN	-40	-41	-40.5		1		2		3		2		0.4	
Std			3.68		0.50		0.82		0.86		0.87		0.23	

INNER RING

QUAL.	dm		Vd	Vdm	Bi		Kri	Ks	Si	Rm	VBi
CLASS	max	min	max	max	max	min	max	Max	max	Max	Max
P4	0	-5	2.5	2.5	0	-60	3	4	4	2	2.5
P5	0	-6	3	3	0	-60	4	8	8	2	5
P6	0	-8	4	4	0	-60	8	10	20	2	12
N/NBS	0	-8	4	4	0	-60	8	10	20	2	12

APPENDIX A3 (QC Data of Month November)

SKF
MALAYSIA

MEASUREMENT RECORD

Product Type : 6206-2Z
Manufacturing Date : 6-Nov-08
Sampled Qty: 25

Report No: DGBB 02 08 45
Report By: Nora

Channel : 2

	OUTER RING																										
No	DmU				DmL				Dm	VD		VDm		Be				VBe		Kre		Sm		Se		Gr	
	max	min	avg	cl	max	min	avg	cl	cl	max	cl		cl	max	min	avg	cl	max	cl	max	cl	max	cl	max	cl	max	cl
1	-7	-9	-8	5	-8	-10	-9	5	5	2	4	1	4	-30	-32	-31.0	4	2	4	5	4	1	4	5	4	14	7
2	-9	-10	-9.5	6	-8	-9	-8.5	5	6	1	4	1	4	-34	-37	-35.5	4	3	4	4	4	1	4	4	4	16	7
3	-9	-11	-10	6	-8	-10	-9	5	6	2	4	1	4	-35	-36	-35.5	4	1	4	5	4	1	4	4	4	20	7
4	-6	-8	-7	4	-7	-9	-8	5	5	2	4	1	4	-35	-36	-35.5	4	1	4	5	4	1	4	5	4	22	7
5	-8	-9	-8.5	5	-7	-8	-7.5	5	5	1	4	1	4	-37	-39	-38.0	4	2	4	5	4	1	4	4	4	22	7
6	-8	-10	-9	5	-7	-9	-8	5	5	2	4	1	4	-33	-34	-33.5	4	1	4	4	4	2	4	5	4	20	7
7	-8	-9	-8.5	5	-7	-8	-7.5	5	5	1	4	1	4	-37	-38	-37.5	4	1	4	5	4	2	4	5	4	19	7
8	-9	-11	-10	6	-7	-9	-8	5	6	2	4	2	4	-37	-38	-37.5	4	1	4	3	4	1	4	4	4	20	7
9	-6	-8	-7	4	-5	-7	-6	4	4	2	4	1	4	-36	-37	-36.5	4	1	4	4	4	1	4	6	5	19	7
10	-4	-6	-5	4	-5	-7	-6	4	4	2	4	1	4	-32	-34	-33.0	4	2	4	5	4	2	4	4	4	18	7
11	-7	-9	-8	5	-6	-8	-7	4	5	2	4	1	4	-36	-37	-36.5	4	1	4	6	5	2	4	6	5	20	7
12	-9	-11	-10	6	-8	-10	-9	5	6	2	4	1	4	-36	-38	-37.0	4	2	4	10	6	2	4	10	5	16	7
13	-4	-6	-5	4	-3	-5	-4	4	4	2	4	1	4	-34	-35	-34.5	4	1	4	8	5	3	4	4	4	17	7
14	-5	-7	-6	4	-6	-8	-7	4	4	2	4	1	4	-34	-35	-34.5	4	1	4	4	4	2	4	4	4	20	7
15	-7	-9	-8	5	-8	-10	-9	5	5	2	4	1	4	-37	-38	-37.5	4	1	4	5	4	1	4	4	4	18	7
16	-6	-8	-7	4	-7	-9	-8	5	5	2	4	1	4	-37	-38	-37.5	4	1	4	4	4	1	4	4	4	15	7
17	-8	-11	-9.5	6	-7	-10	-8.5	5	6	3	4	1	4	-35	-36	-35.5	4	1	4	5	4	1	4	3	4	18	7
18	-6	-8	-7	4	-7	-9	-8	5	5	2	4	1	4	-36	-38	-37.0	4	2	4	5	4	1	4	5	4	20	7
19	-9	-10	-9.5	6	-8	-9	-8.5	5	6	1	4	1	4	-36	-37	-36.5	4	1	4	4	4	2	4	4	4	21	7
20	-6	-7	-6.5	4	-7	-8	-7.5	5	5	1	4	1	4	-35	-36	-35.5	4	1	4	3	4	2	4	6	5	20	7
21	-5	-7	-6	4	-6	-8	-7	4	4	2	4	1	4	-35	-36	-35.5	4	1	4	3	4	1	4	4	4	22	7
22	-7	-9	-8	5	-8	-10	-9	5	5	2	4	1	4	-32	-33	-32.5	4	1	4	4	4	1	4	4	4	18	7
23	-6	-8	-7	4	-5	-7	-6	4	4	2	4	1	4	-36	-39	-37.5	4	3	4	5	4	2	4	5	4	20	7
24	-7	-9	-8	5	-8	-10	-9	5	5	2	4	1	4	-35	-36	-35.5	4	1	4	4	4	2	4	3	4	21	7
25	-7	-8	-7.5	5	-6	-7	-6.5	4	5	1	4	1	4	-35	-36	-35.5	4	1	4	3	4	3	4	2	4	19	7
MEAN	-6.92	-8.72	-7.82		-6.76	-8.56	-7.66			1.8		1.04		-35	-36.36	-35.68		1.36		4.72		1.56		4.56		19	
MAX	-4	-6	-5		-3	-5	-4			3		2		-30	-32	-31		3		10		3		10		22	
MIN	-9	-11	-10		-8	-10	-9			1		1		-37	-39	-38		1		3		1		2		14	
Std			1.49				1.26			0.50		0.20				1.76		0.64		1.54		0.65		1.47		2.14	

	IR				OR			
	ri	Vri	bri	Ra Di	Vre	bre	Ra de	re
1	4.881	2.5	8.334	0.030	2.4	8.190	0.031	5.040
2	4.889	2.3	8.329	0.032	2.3	8.184	0.032	5.035
3	4.883	1.4	8.332	0.030	2.2	8.183	0.038	5.050
4								
5								
AVG	4.884	2.1	8.332	0.031	2.3	8.186	0.034	5.041
MAX	4.889	2.5	8.334	0.032	2.4	8.190	0.038	5.050
MIN	4.881	1.4	8.329	0.030	2.2	8.183	0.031	5.035
UTL	4.890	2.5	8.3	0.05	2.5	7.7	0.05	5.080
LTL	4.860	0	0	0	0	0	0	5.020
%Conf.	100%	100%	100%	100%	100%	100%	100%	100%

	Outer Ring											
QUAL.	Dm		VD	Sm	VDm	Be		Kre	VBe	Se	Gr	
CLASS	Max	Min	Max	Max	Max	Max	Min	Max	Max	Max	Max	Min
P4	0	-7	6	4	4	0	-60	5	3	5		
P5	0	-9	7	8	5	0	-60	8	6	10		
P6	0	-11	7	17	6	0	-60	13	12	20		
N	0	-11	7	17	6	0	-60	13	12	20	22	12

SKF
MALAYSIA

MEASUREMENT RECORD

Product Type : 6206-2Z
Manufacturing Date : 6-Nov-08
Sampled Qty: 25

Report No: DGBB 02 08 45
Report By: Nora

Channel : 2

No	dmU				dmL				dm	Vd		Vdm			Bi				VBi		Kri		Ks		Si		Rm	
	max	min	avg	cl	max	min	avg	cl	cl	Value	cl	Value	cl		max	min	avg	cl	Value	cl	Value	cl	Value	cl	Value	cl	Value	cl
1	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-23	-24	-23.5	4	1	4	3	4	4	4	3	4	0.8	5
2	-6	-7	-6.5	6	-4	-5	-4.5	4	6	1	4	2	4		-27	-29	-28.0	4	2	4	2	4	3	4	2	4	0.4	5
3	-4	-6	-5	4	-3	-5	-4	4	4	2	4	1	4		-30	-31	-30.5	4	1	4	4	5	4	4	2	4	0.6	5
4	-4	-5	-4.5	4	-5	-6	-5.5	5	5	1	4	1	4		-26	-27	-26.5	4	1	4	3	4	5	5	4	4	0.6	5
5	-6	-7	-6.5	6	-4	-5	-4.5	4	6	1	4	2	4		-31	-32	-31.5	4	1	4	3	4	6	5	3	4	1.0	5
6	-7	-8	-7.5	6	-6	-7	-6.5	6	6	1	4	1	4		-30	-31	-30.5	4	1	4	4	5	4	4	3	4	0.8	5
7	-5	-6	-5.5	5	-3	-4	-3.5	4	5	1	4	2	4		-26	-27	-26.5	4	1	4	3	4	6	5	2	4	0.4	5
8	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-24	-25	-24.5	4	1	4	4	5	6	5	2	4	0.6	5
9	-6	-7	-6.5	6	-5	-6	-5.5	5	6	1	4	1	4		-24	-25	-24.5	4	1	4	4	5	5	5	4	4	1.0	5
10	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-23	-24	-23.5	4	1	4	5	6	4	4	4	4	0.8	5
11	-6	-7	-6.5	6	-3	-4	-3.5	4	6	1	4	3	5		-22	-23	-22.5	4	1	4	3	4	4	4	5	5	0.4	5
12	-5	-7	-6	5	-4	-6	-5	4	5	2	4	1	4		-30	-31	-30.5	4	1	4	3	4	3	4	3	4	0.6	5
13	-4	-5	-4.5	4	-3	-4	-3.5	4	4	1	4	1	4		-23	-24	-23.5	4	1	4	2	4	5	5	3	4	1.0	5
14	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-18	-19	-18.5	4	1	4	2	4	8	5	2	4	0.8	5
15	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-31	-32	-31.5	4	1	4	2	4	4	4	4	4	0.8	5
16	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-27	-29	-28.0	4	2	4	4	5	8	5	6	5	0.6	5
17	-4	-5	-4.5	4	-3	-4	-3.5	4	4	1	4	1	4		-25	-26	-25.5	4	1	4	4	5	4	4	4	4	0.8	5
18	-5	-6	-5.5	5	-3	-4	-3.5	4	5	1	4	2	4		-29	-30	-29.5	4	1	4	3	4	5	5	3	4	1.2	5
19	-4	-5	-4.5	4	-3	-4	-3.5	4	4	1	4	1	4		-32	-33	-32.5	4	1	4	2	4	4	4	2	4	0.8	5
20	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-25	-26	-25.5	4	1	4	3	4	3	4	2	4	0.6	5
21	-6	-8	-7	6	-5	-7	-6	5	6	2	4	1	4		-30	-31	-30.5	4	1	4	3	4	4	4	4	4	1.0	5
22	-5	-6	-5.5	5	-4	-5	-4.5	4	5	1	4	1	4		-27	-28	-27.5	4	1	4	4	5	5	5	3	4	0.6	5
23	-7	-8	-7.5	6	-6	-7	-6.5	6	6	1	4	1	4		-30	-32	-31.0	4	2	4	3	4	5	5	4	4	0.6	5
24	-6	-8	-7	6	-5	-7	-6	5	6	2	4	1	4		-28	-29	-28.5	4	1	4	2	4	6	5	4	4	0.6	5
25	-4	-5	-4.5	4	-3	-4	-3.5	4	4	1	4	1	4		-25	-26	-25.5	4	1	4	2	4	8	5	5	5	0.4	5
MEAN	-5.16	-6.32	-5.74		-4	-5.16	-4.58	4.32		1.16		1.24			-26.64	-27.76	-27.2		1.12		3.08		4.92		3.32		0.71	
MAX	-4	-5	-4.5		-3	-4	-3.5	6		2		3			-18	-19	-18.5		2		5		8		6		1.2	
MIN	-7	-8	-7.5		-6	-7	-6.5	4		1		1			-32	-33	-32.5		1		2		3		2		0.4	
Std			0.9256				0.95			0.37		0.52					3.50		0.33		0.86		1.47		1.11		0.22	

INNER RING											
QUAL.	dm		Vd	Vdm	Bi		Kri	Ks	Si	Rm	VBi
CLASS	max	min	max	max	max	min	max	Max	max	Max	Max
P4	0	-5	2.5	2.5	0	-60	3	4	4	2	2.5
P5	0	-6	3	3	0	-60	4	8	8	2	5
P6	0	-8	4	4	0	-60	8	10	20	2	12
N/NBS	0	-8	4	4	0	-60	8	10	20	2	12

APPENDIX B1

Gantt chart of Final Year Project One.

No.	Activities	Week	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
	Project progress																
1	**Obtain FYP title**		■														
2	**Setting appointment with the supervisor**			■													
3	**Visit to company (SKF Bearing, Nilai)**				■	■				■							
4	**Searching for journal and reference books**			■	■												
5	**Select one product for improvement**				■	■	■										
6	**Study about Statistical Process Control**						■	■	■	■	■	■	■	■			
7	**Presentation preparation**													■	■	■	
8	**Submission of Draft 1 with logbook**																■
9	**FYP 1 presentation**																■
1	**Thesis writing progress**																
2	**Chapter 1: Introduction**				■	■	■										
3	**Chapter 2: Literature review**					■	■	■	■	■	■						
4	**Chapter 3: Methodology**										■	■	■	■			
5	**Chapter 4: Conclusion**													■	■		
6	**Finalizing thesis as Draft 1**														■	■	

APPENDIX B2

<u>Gantt chart of Final Year Project Two.</u>

No.	Activities	Week	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
	Project progress																
1	**Visit to company (SKF Bearing, Nilai)**		■	■			■						■	■			
2	**Obtain QC data from SKF Bearing, Nilai**			■													
3	**Observing and screening the QC data**				■	■											
4	**Retabulating QC data**					■	■										
5	**Manual calculations on SPC**							■	■								
6	**MINITAB Software verification**								■	■							
7	**Comparing the analysis output**								■	■	■	■	■				
8	**Root problems identification (SKF Bearing, Nilai)**										■	■	■	■			
9	**Recommendations for the problems**												■	■	■		
10	**FYP 2 presentation**																■
1	**Thesis writing progress**																
2	**Chapter 4: Result and Discussion**					■	■	■	■	■	■	■	■	■	■		
3	**Chapter 5: Conclusion**										■	■	■	■	■		
4	**Thesis draft completion**														■	■	
5	**Finalyzing thesis**																■

APPENDIX C

Site Photo

Prepared by :
Approved by :

Type	VEx	dex (OR)		VEi	Dex (IR)		D	d4	d5	d	K1	Sm	R (Nom)	r	r1
							SETTING HEIGHT								
22215	7	7	24	9	9	22	5	26	5	5	5 / 26	5 / 26	2.5	1.5 ~ 2.5	1.5 ~ 4.[illegible]
22216	7	7	26	9.5	9.5	23.5	5.5	27.5	5.5	5.5	5.5 / 27.5	5.5 / 27.5	3	2.0 ~ 3.5	2.0 ~ 4.[illegible]
22217	8	8	28	10	10	26	6	30	6	6	6 / 30	6 / 30	3	2.0 ~ 3.5	2.0 ~ 4.[illegible]
22218	9	9	31	11.5	11.5	28.5	6	34	6	6	6 / 34	6 / 34	3	2.0 ~ 3.5	2.0 ~ 4.[illegible]
22220	10	10	36	13	13	33	7.5	38.5	7.5	7.5	7.5 / 38.5	7.5 / 38.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22222	11	11	42	15	15	38	7.5	43.5	7.5	7.5	7.5 / 43.5	7.5 / 43.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22224	12	12	46	17	17	41	7.5	50.5	7.5	7.5	7.5 / 50.5	7.5 / 50.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22226	14	14	50	18	18	46	9.5	54.5	9.5	9.5	9.5 / 54.5	9.5 / 54.5	4	3.0 ~ 5.0	3.0 ~ 6.4
22312	10	10	36	14	14	32	7.5			7.5	7.5 / 38.5	7.5 / 38.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22313	10	10	38	14	14	34	7.5			7.5	7.5 / 40.5	7.5 / 40.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22314	10.5	10.5	40.5	15	15	36	7.5			7.5	7.5 / 43.5	7.5 / 43.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22315	11	11	44	16	16	39	7.5	47.5	7.5	7.5	7.5 / 47.5	7.5 / 47.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22316	12	12	46	17	17	41	7.5			7.5	7.5 / 50.5	7.5 / 50.5	3.5	2.1 ~ 4.0	2.1 ~ 5.[illegible]
22317	12	12	48	18	18	42	9.5			9.5	9.5 / 50.5	9.5 / 50.5	4	3.0 ~ 5.0	3.0 ~ 6.4
22318	13	13	51	19	19	45	9.5	54.5	9.5	9.5	9.5 / 54.5	9.5 / 54.5	4	3.0 ~ 5.0	3.0 ~ 6.4
22319	14	14	53	20	20	47	9.5			9.5	9.5 / 57.5	9.5 / 57.5	4	3.0 ~ 5.0	3.0 ~ 6.4
22320	15	15	58	21.5	21.5	51.5	9.5			9.5	9.5 / 63.5	9.5 / 63.5	4	3.0 ~ 5.0	3.0 ~ 6.4

BEARING TYPE
NOMINAL VALUES OF THE PARAMETER
D | B | @ angle | d1 | D1 | d | B1 | D1

Figure 1 : Bearing parts tolerance, for fast references of the operator

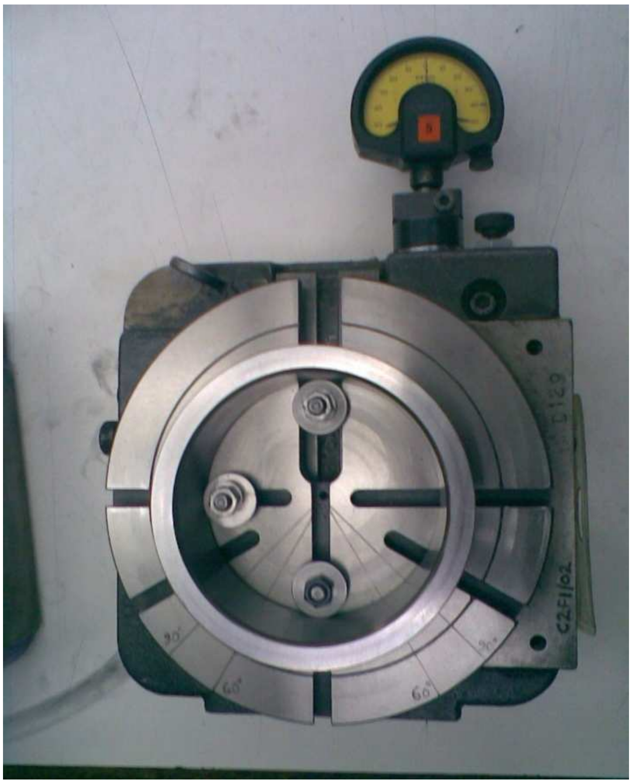

Figure 2 : Bearing outer ring inner diameter measuring device.

Figure 3 : Bearing outer ring thickness measuring device.

Figure 4 : Measuring device front tip. Operator must make sure correct fitting of the ring with the tip.

Figure 5 : Bearing outer ring draft measuring device.

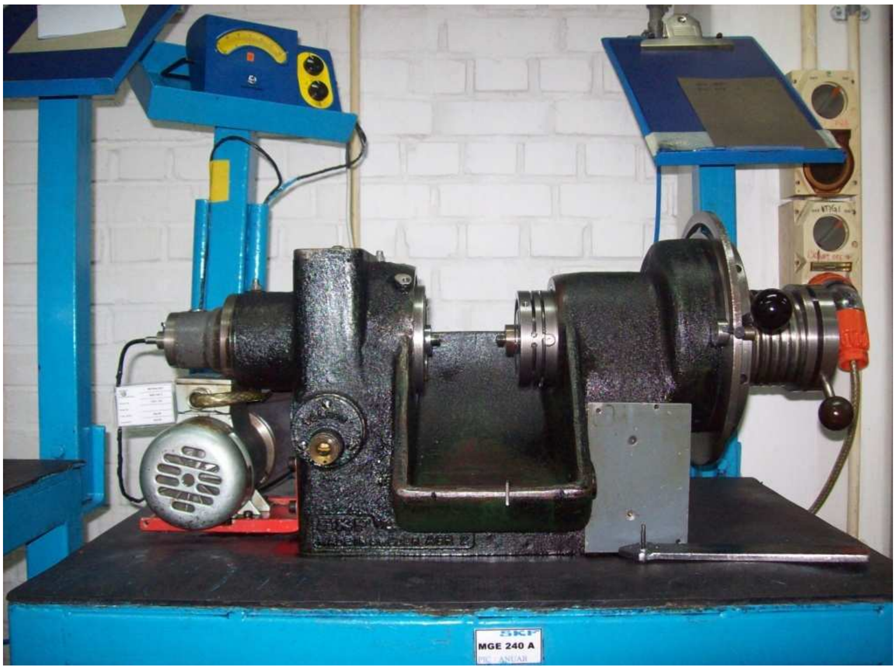

Figure 6 : Bearing outer ring surface grinding device.

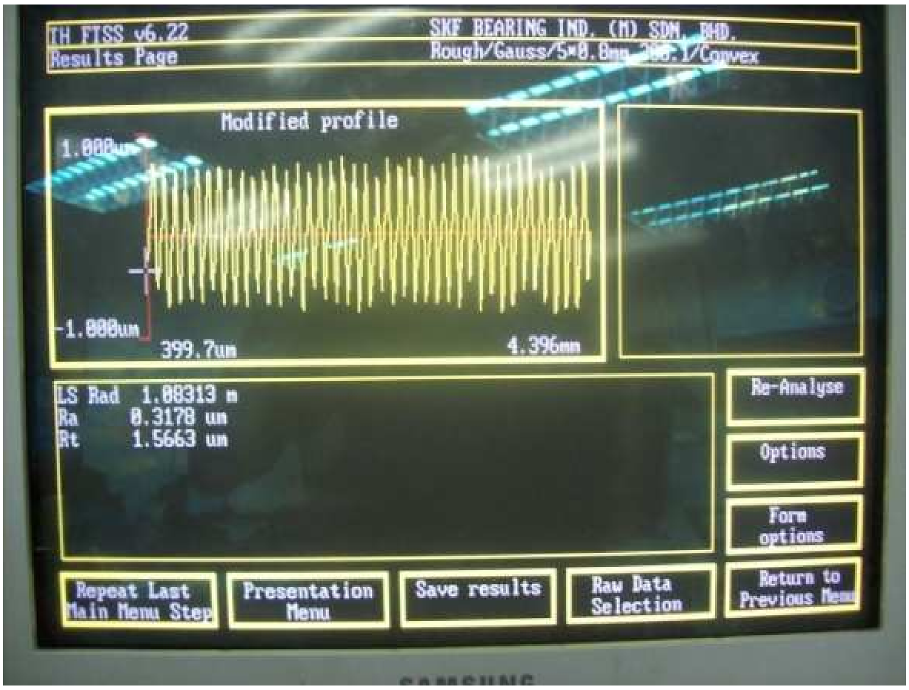

Figure 7 : Bearing outer ring diameter measurements monitor (X-bar Chart)

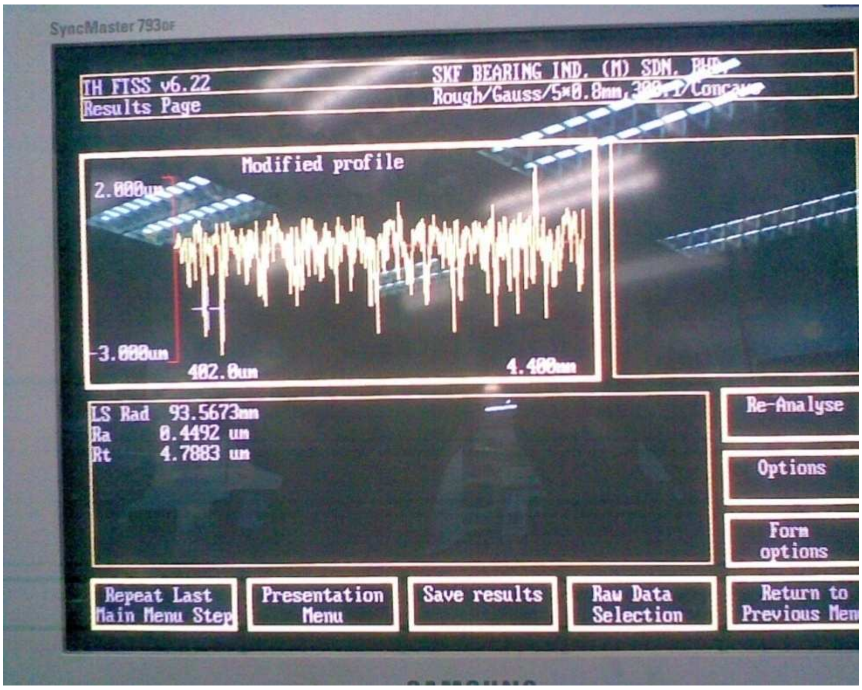

Figure 8 : Bearing outer ring diameter tolerance range measurements monitor (R Chart)

APPENDIX D

Standard Outer Ring measuring Procedure, SKF Bearings (M) SDN. BHD.)

SKF	Component Process Specification	Section : D2.CS.QA.008	Page : 1 (1)
SKF BI (Malaysia) Sdn Bhd		Issue date : 1998/12/28	
HB – Handbook Quality Assurance	IR 6306 Groove Grinding - SGB 55	Compiled : SIN / Verified : MANU / Approved : QA	
Issue no. / date :	1 / 07-2001 · 2 / 04.03 · 3 / · 4 /	5 / · 6 /	

MEASURING PRINCIPLE	PARAMETER	SPECIFICATION	FREQ.	RESP	MEAS. EQUIP.	NOM. DIM.	TOL. TABLE	MEASURING PROCEDURE
MP 200:201	Land Diam. [Dk]	0 / -25 µm	3 pcs/ Hour	OPER.	U.D	44.60 mm	D11-1A (Pg:1047)	1. calibrate ud with master ring. 2.place ring on the ud and push it between 2 measuring washer until it stops at the third measuring washer. 3.the height of measuring washer is at the center of land. 4.turn the ring one round. 5.take note the maximum and minimum value. 6.Dk is the average of maximum and minimum value.(Dk1) 7.VDk is the difference between maximum and minimum value 8.overturn the ring and measure it again.(repeat 4-6) 9.the average of maximum and minimum value is Dk2. 10.the difference of Dk1 and Dk2 is the taper VDk. 11.all measured value should be inside the tolerance stated in CPS.
MP 201	Land Ovality [VDk]	MAX 3 µm	3 pcs/ Hour	OPER.	U.D		PRO. TOL.	
Dk1 Dk2 MP 201	Land Taper [Dk1-Dk2]	MAX 3 µm	3 pcs/ Hour	OPER.	U.D		PRO. TOL.	
MP 501 101	Groove Diam. [Di]	AIM : 0 ± 10 µm (AIM to land dia.)	PMC PLOT 3 pcs/ Hour	OPER.	U.D	39.697 mm	PRO. TOL. CRC:03/49	1.calibrate ud with master ring. 2.place ring on the ud and push it between 2 measuring washer until it stops at the third measuring washer. 3.the height of measuring washer is at the center of groove. 4.turn the ring one round. 5.take note the maximum and minimum value. 6.Di is the average of maximum and minimum value. 7.VDi is the difference between maximum and minimum value.
MP 501 101	Groove Oval. [VDi]	MAX 2 µm (MWA L1 DECISIVE)	3 pcs/ Hour	OPER.	U.D		PRO. TOL.	
MP 531 001	Groove Loc. [Ai1-Ai2]	MAX 20 µm	3 pcs/ Hour	OPER.	SLA		PRO. TOL.	1.place ring onto SLA and push it onto SLA washer. 2.take note of the reading (Ai 1). 3.overturn the ring and push into SLA washer again. 4.take note of the value again .(Ai 2) 5.groove location is the difference of 2 and 4.(Ai 1-Ai 2)
MP 531 001	Groove Loc. Variation [Vai]	MAX 4 µm	3 pcs/ Shift	OPER.	SLA		PRO. TOL.	1.place ring onto SLA and push it onto SLA washer. 2.turn the ring one round take note of maximum and minimum value. 3.Vai is the difference of maximum and minimum value.
	Visual Inspection	THE RACEWAY MUST BE FREE FROM SCRATCHES & MARKS	3 pcs/ Shift	OPER.	NAKED EYE		D11-1A	
MP 989 102	Roughness [Ra]	MAX 0.8 µm	1 pc / Day	INSP.	FORM TALY-SURF		PRO. TOL.	refer to quality procedure --Form Talysurf - 50
MP 527 201	Groove radius [ri]	± 15µm	1 pc / Day	INSP.	FORM TALY-SURF	6.285mm	D11-1A (Pg:1028,4) (CRC:0203)	refer to quality procedure –Form Talysurf - 120
MP 527 201	Radius Var. [Vri]	MAX 8 µm	1 pc / Day	INSP.	FORM TALY-SURF		PRO TOL.	refer to quality procedure –Form Talysurf - 120
MP 526 0	Waviness [MDi]	SPC CONTROL LIMITS	PMC PLOT 3 pcs/ Shift	INSP.	MWA 160		PRO TOL. CRC:03/49	refer to quality procedure –MWA

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SAMPLING INSTRUCTIONS:-

1 Collect Sample According To The Proposed Sample Quantity And Frequency.
2 If Only One pc. Is Out Please Take The second Sampling To Reconfirm The Result.
3 If The Second Sampling Is Out Then Stop Machine and Do Adjustment To The Machine And Take New Sample.
4 Quarantine And Reconfirm The Product Which Being Produced Before The Previous Sampling
5 If The Result Is Good then Continue The Process And Perform Investigation On The Defective pc.If Needed.

GENERAL INSTRUCTIONS:-

- *The machine tech. shall ensure that all defective Components placed in the Identified red scrap box*
- *Calibrate All Gauges At The Beginning Of Every Shift. (Refer To MFC Chart If Available)*
- *Each sample must be made up of Component that have been machined consecutively.*
- *The Tech / Channel Quality must ensure that a successful " First Off " is carried out After any machine Break Down*
- ** The Tech. is responsible for keeping the inspection area clean and tidy.*

REMARK:

Plot Only those with PMC. The rest of the parameter do not require any recording.

D:\CPSDGBB\6306\09