ANALYSIS OF TOOL WEAR AND TOOL LIFE OF CUTTING TOOL INSERTS USING STATISTICAL PROCESS CONTROL CHARTS: A CASE STUDY

A Thesis
Presented to
the Faculty of the College of Business and Technology
Morehead State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
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April 28, 2017

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Accepted by the faculty of the College of Business and Technology, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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The purpose of this study is to investigate tool wear and tool life of cutting tool inserts in machining. Statistical process control charts are used in this study. The focus of the analysis was an applied case study in an automotive plant located in the United States of America. For confidentiality purposes, the name of the plant will not be disclosed. The plant currently uses cutting tool inserts in CNC lathe machines to cut the metallic rods for shock shafts.

The current practice of replacing the worn-out tool inserts is based on the experience of the operator which has several limitations. Often, the inserts are either being underutilized which is not very cost-effective, or being over utilized negatively affecting the quality of the parts. Thus, there is a need to develop a more scientific approach to determine the frequency of tool replacement.

Several studies have been performed previously on insert wear. But most of these studies were either focused on specific applications or were limited in their use for practical usability at the operator level. This study attempts to address the limitation of existing studies by recommending a statistical control chart based approach that can be generalized for a variety of applications.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Nilesh Joshi for his willingness to assist in this thesis as well as his guidance in its production. Dr. Zargari was instrumental in providing inspiration and insight throughout my three semesters at Morehead State University. Finally, Dr. Chapman's courses on quality control provided me with the foundation for a successful career as an engineer.

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Chapter I

Introduction

1.1 Problem Statement

Tool life is a concern for many companies in the manufacturing industry. Since cutting tool inserts are used to cut away material of parts as they pass through machines, the inserts will naturally wear. It is common practice for the operators of the machines to change out the inserts at regular intervals as not to produce defective parts. The type of part being cut, the type of insert, and the amount of material being removed all determine how quickly the insert will wear. It is imperative that operators make frequent checks of the inserts by taking measurements of the part produced by the lathe to determine if the insert needs to be changed. It is also important to note that each machine may have a different maximum allotted life for its inserts.

1.2 Definition of Terms

The terms that follow will be used in greater depth in chapter 3 along with photos.

Shank: The smooth area on the piston end of the shock shaft. The diameter of the shank is measured to determine if it is within tolerance.

Inserts: Small metallic tools of varying shapes that cut the rods to form shock shafts

Rod: A cylindrical piece of metal that is sent through a lathe to be processed into a shock shaft

Shock Shaft: The part that is created when a rod is processed through a lathe

Lathe: A machine through which rods are processed to create parts such as shock shafts

Statistical Quality Control (SQC): the use of control charts to make certain that the quality of goods that are being produced is of the intended standard (dictionary.cambridge.org).

1.3 Background

There are five stages in the rod process flow. Rods are metallic cylinders, which when first received to the plant are about 18 meters in length. They are then cut to 395 millimeters, or approximately 1.5 feet. Next, they are sent through a pre-grinder machine. This ensures that the diameter of the rod is consistent throughout the entire length of the rod. Then they are processed through the induction heating machine which uses electric current to quickly harden the rod. This causes the rods to take on a distinctly bluish hue around the area that has been hardened. After the rods are hardened, they are then sent through a straightener which relieves internal stress and makes the rod less prone to cracking. Finally, the rods are sent through a lathe which creates the “top end” and “piston end” of the shock shaft. This is performed through a roughing insert which removes much of the material to create the shank. After the roughing insert has removed all necessary material, a finishing insert then removes a small amount of material and gives the shock shaft a finished look. If the lathe does not also perform threading, the rod will then be sent through a separate machine that specifically performs that function. The cycle time for this whole process varies depending on what part is being made.

The inserts within the tool holders are metallic and cut the rods as the rod passes over the tool. Insert life differs from machine to machine and from part to part. Inserts are generally triangular in shape and are rotated as each corner wears. After each corner is used, the insert is then flipped to the other side and the other three corners are used until the entire insert needs to be replaced.

The more material that is removed, the greater the rate at which the insert will wear when compared to other inserts that remove less material. This is because some parts have greater diameters, and therefore, the inserts that cut these rods remove more material.

1.4 Objectives

The main objectives of this study are listed below:

- To implement proper quality control procedures for the Shock Shaft Machining process that will result in cutting tool cost savings for the company.
- To establish appropriate control charts for continuous monitoring of the tool wear.
- To perform process capability studies.

1.5 Assumptions

There are many variables that can affect data collection. They include operator error, lathe shutdown, mechanical problems with the lathe that need to be fixed, and environmental concerns such as heat or cold. Such uncontrollable variables are not considered in this study as they are classified as standard error.

1.6 Organization of Thesis

This thesis is organized into five chapters: the introduction, literature review, methodology, data and analysis, and discussion and future research. The introduction considered the background of the thesis, assumptions, problem statement, and definitions of terms, and objectives. The literature review will consist of explanations of other studies that have been performed regarding inserts, different materials used to manufacture inserts, and an overview of statistical quality control methods used in various industries. The methodology explains the procedure, rod process flow, and inserts in more detail. The data and analysis chapter will include the data collected, the control charts, the trends, and the process capability study. Finally, the discussion and future research will summarize the study and provide recommendations for further research.

Chapter 2

Literature Review

2.1 Overview of Cutting Tools

The literature is replete with articles regarding insert wear, what their causes are, and how to correct, prevent, and reduce them. Elmagrabi, Shuaeib, and Haron (2007) found that "Gradual wear occurs at two principal locations on a cutting tool: the top rake face and the flank. Accordingly, two main types of tool wear can be distinguished: The crater wear and flank wear". For determining tool life, response surface methodology, and a factorial design experiment worked best. Insert wear will be discussed later in this study.

One study examined ceramic round (RNGN) and ceramic square (SNGN) inserts. Similar to the previous study, it was found that flank wear and crater wear were predominant at high cutting speeds for the square insert. "Minimum flank wear is seen with SNGN tools at low cutting speeds while it is seen with RNGN tools at high cutting speeds" (Altin, Nalbant, and Taskesen, 2007).

Rosa, Diniz, Andrade, and Guesser (2010) observed a carbide insert in a turning machine which they coated with three different coatings including titanium nitride (TiN), aluminum oxide (Al_2O_3) and titanium carbonitride (TiCN). After the coating process, the TiN layer was removed from the rake face using a micro-sandblasting process, which caused the increase of compressive residual stresses of the insert and, consequently, the increase of its toughness (Rosa,et al., 2010).

Another study examined tool wear index (TWI) of the surface roughness finish in finishing operations. This study focused on four main topics: Developing a tool wear index, developing a control model for the surface roughness based on the TWI, creating a tool life model in order to prolong the life of a tool, and creating an ideal control strategy. Often a tool will be used for more than one machine and is not appropriately analyzed.

"With relation to surface roughness, the TWI measures the wear conditions more accurately and comprehensively, and the tool life model enables maximum use of a worn tool and minimum risk for in-process tool failure. The TWI and a surface roughness control model are integrated into an optimal control strategy that shows potential for productivity improvement and reduction of manufacturing cost." (Kwon and Fischer, 2003)

When a tool is used to cut different parts, the primary issue is whether to change the tool when starting a new batch of parts or to keep the tool but "change the machining parameters to adapt to the tool condition and the characteristics of the new operation" (Kwon and Fischer, 2003). The downside of changing a tool often is the incurring of extra cost associated with frequent change. If the tool is still usable, it should not be changed until just before it begins to make defective parts. The limitation of keeping a tool is the possibility that it could begin to create defective parts. Also, it is a difficult task to determine exactly when a tool will create defective parts because neither the machine nor the tool behaves exactly the same each time a new part is created. There will always be some amount of variability despite the best maintenance and monitoring.

The development of the tool wear insert model was derived from International Standardization Organization which states that the tool wear limit should be 0.76 mm of flank wear for roughing and 0.38 mm for finishing. Luo, Cheng, Holt, and Liu (2005) noted that "the economic benefits of using carbide cutting inserts can be offset by rapid tool war or premature tool failure if not used properly". A machine vision system was used for accurate tool positioning and captures and analyzes tool wear data. The vision system was then used to analyze 20 different features of wear areas. It was found that nose wear was one of the most significant forms of wear.

One manufacturing company, Main Manufacturing, which manufactures hydraulic flange found that their cutting tool insert was wearing away at approximately 1.5 parts faster than normal. This was due to the introduction of an interrupted cut that caused significant wear and would eventually chip the edge of the insert. The supplier, Seco, tested a new grade of coating on the insert, a Duratomic turning grade, specifically the TM4000 grade. This type of grade "is designed to maximize toughness in the cutting zone without compromising the strength of the base material. According to the manufacturer, lab tests demonstrated that this construction substantially improved resistance to cratering and edge breakdown" (Danford and Jordan, 2009). By using a microscope to examine why the insert was eroding, suppliers found that the back part of the insert as well as the nose of the insert were eroding. By increasing the nose radius and increasing the feed rate to .016 ipr, the insert wore at a much slower rate. However, despite this success, the supplier noticed another problem under review of a microscope. Now insert failure was due to thermal cracking. "Large differences in temperature between the cutting edge and the insert can cause cracks that run perpendicular to the cutting edge, Mr. Henige explains. These temperature fluctuations are common in interrupted cutting applications, which tend to generate high heat during the cut" (Danford and Jordan, 2009). This was rectified by running the process without coolant which was water. Since water makes thermal cracking worse, it was much more beneficial to the process to run the process dry. What was found was that the tool life actually doubled and cut time was reduced by half. Also, output per hour more than tripled.

2.2 Cutting Tool Materials

There are many types of materials that are used to create the inserts that perform the cutting. The following are the most common types of materials used: carbon steel, high speed steel, cast cobalt alloys, carbides, coatings, cermets, alumina, silicon nitride, cubic Boron nitride, and diamond. Carbon steel is best used for machines that cut wood, such as routers. It acts as a poor metal cutting material because carbon begins to soften around 180 degrees Celsius. High speed steel is used for higher speed cutting. These tools were first used with 12-18% tungsten but were later formed with molybdenum to replace tungsten for economic reasons and higher abrasion resistance. Cast cobalt alloys comprise of about 40 – 55% cobalt, 30% chromium, and 10 – 20% tungsten. While they have good wear resistance, they can only be used at a moderate high rate of speed, but not as high as the high-speed steel tools. Carbides have a high hardness over a range of temperatures making them efficient tool and die materials. Tungsten carbide and titanium carbide are the two classifications of carbides used in machining. "Tungsten carbide tools are commonly used for machining steels, cast irons and abrasive non-ferrous materials" (Grieve, 2009). Titanium carbide is more resistant to wear but is not as tough as tungsten carbide. "With a nickel-molybdenum alloy as the matrix, TiC is suitable for machining at higher speeds than those which can be used for tungsten carbide. Typical cutting speeds are: 30 - 150 m/min or 100 - 250 when coated" (Grieve, 2009). Coatings give a greater life span to tool tips than tips that are uncoated of approximately 10-fold. The most common types of coatings are titanium nitride, titanium carbide, and aluminum oxide of 2 – 15 micrometers thick. Cermets were developed in the 60s and contain 70% aluminum oxide and 30% titanium carbide. Cutting speeds are between 150 – 350 m/min. Ceramics consist of alumina and silicon nitride. Alumina has improved thermal shock resistance, and the tips have high abrasion and built up edge resistance. The weakness however is low toughness. Silicon nitride is not recommended for machining steels but for machining iron. Sialon, a special type of silicon nitride, contains silicon, aluminum, oxygen, and nitrogen. It is highly resistant to thermal shock. Cubic Boron Nitride is the second hardest substance after diamond. This material has high wear resistance cutting edge strength. It is used mostly for machining steels and alloy metals with a hardness of 50 Rc or higher. Diamond, the hardest natural material on the planet, improves toughness of the tool through preventing cracks. Polycrystalline diamond (PCD) is now used instead a single crystal diamond tool which are very brittle. PCD is best used for machining of aluminum at very high speed, 200 – 2000 m/min (Grieve, 2009).

2.3 Application of Statistical Quality Control in Industrial Manufacturing

Six Sigma and DMAIC

Six Sigma was created by an engineer, Bill Smith, at Motorola in 1986 as a means of reducing variability in processes. Since a standard deviation is represented by the Greek letter sigma in statistics, Six Sigma seeks to ensure that all process outputs lie within six standard deviations above the mean and six standard deviations below the mean. In other words, “the idea behind Six Sigma is to achieve a process capability where production is nearly perfect” (Aikens, 2011). Six Sigma can be understood both in a statistical and business sense. Statistically, a process operating at Six Sigma will have 3.4 defects per one million parts. The subsequent breakdown of defects per each sigma yields 233 defects at 5 sigma, 6,210 at 4 sigma, 66,807 defects at 3 sigma, 308,538 defects at 2 sigma, 691,462 defects at 1 sigma, and 933,193 defects at 0 sigma. As a business strategy Six Sigma is used to reduce waste, increase profits, improve process performance, and meet or exceed customer expectations.

In Six Sigma there are three models assisting with incremental, continuous improvement. These include PDSA/PDCA, the scientific method, and DMAIC. Perhaps the most prominent of these is DMAIC. What separates DMAIC from the other two models is its use of toll gates between each phase. At these times, management and project members meet to discuss the progress made and how to stay on target while meeting company goals.

DMAIC consists of five phases, or tactics: define, measure, analyze, improve, and control. The *define* tactic consists of defining the problem, justifying the project, identifying the processes to be used, and weighing the costs and benefits of the project. The *measure* tactic is concerned with how to collect the data and the design of the project. In the *analyze* tactic identifying root causes and the reasons for variability is paramount. This leads to the *improve* tactic in which solutions are proposed and either implemented or discarded. Finally, in the *control* phase project members seek to maintain the newly implemented design by documenting solutions and training workers (Aikens, 2011).

The TFT-LCD industry in Taiwan uses an adhesive to bond the thin film transistor (TFT), color filter (CF), and liquid crystal display (LCD). Another reason for this sealant is that it keeps the liquid crystal from leaking. In the event of a breakdown in the bonding process the panels will have to be scrapped. This malfunction will lead to higher levels of pollution and waste and is called a seal open defect. A Six Sigma project was created to minimize the number of defects. It used DMAIC to guide the project, and the sources of variability were eventually found and removed. Consequently, the seal open defect rate dropped below even the goal level (Tai-chi, Hsiang-chin, and Ming-hsien, 2011).

In the medical device industry, there have been numerous recalls of medical equipment in recent years. Thus, there is a dire need for top quality production of devices since the lives of patients may be at risk. According to Bowers and Hrdarek (2009), "Many experts on the costs of poor quality (COPQ) estimate losses in the range of 20 to 30 percent of gross sales for defective or unsatisfactory products". Some of the challenges faced are regulatory pressures, pricing, small assembly parts, and strict tolerances. Six Sigma helped to cut down on the costs of poor quality which include prevention costs, appraisal costs, internal failure costs, and external failure costs. Primarily, Six Sigma has been combined with quality management systems in the medical industry. Also, medical companies are realizing that design for Six Sigma (DFSS) is not a needless expense but an investment since products devoid of defects produce new income.

Finally, in the chemical industry, many strides have been made in Quality Control. Corporations such as Dow Chemical, DuPont, Rohm and Hass, and Compton Corp. have implemented Six Sigma and reduced defects and increased profits. Many of the projects are spearheaded by champions, and project member are trained by master black belts. According to Challenger (2002), "Key competencies in project management, data measurement and analysis, root cause validation, hypothesis testing, simulation and change management are taught and practiced".

Chapter 3

Methodology

This chapter explains the rod process flow in which rods are processed into shock shafts through a series of five stages. Next will be a description of the types of inserts that were used in the lathe involved in the study. Finally, the procedure will be explained, including how the data was collected.

3.1 Rod Process Flow

There are five stages in the Shock shaft process. The raw material used is 18 meters long steel rods (metallic cylinders). Figure 3.1 shows the stock of raw material received by the plant.

Figure 3.1: 18 meter rods

Figure 3.2 shows the rods being cut to 395 mm length.

Figure 3.2: Rods sent through a machine to be cut at 395 mm length

The rods in figure 3.3 have been cut to 395 mm. After they have been cut to the proper size, the rods are sent through a pre-grinder as shown in figure 3.4. This ensures that the rod diameter is consistent through the entire length of the rod. Figure 3.5 displays the completed pre-grind rod.

Figure 3.3: Rods at 395 mm

Figure 3.4: Pre-grinder

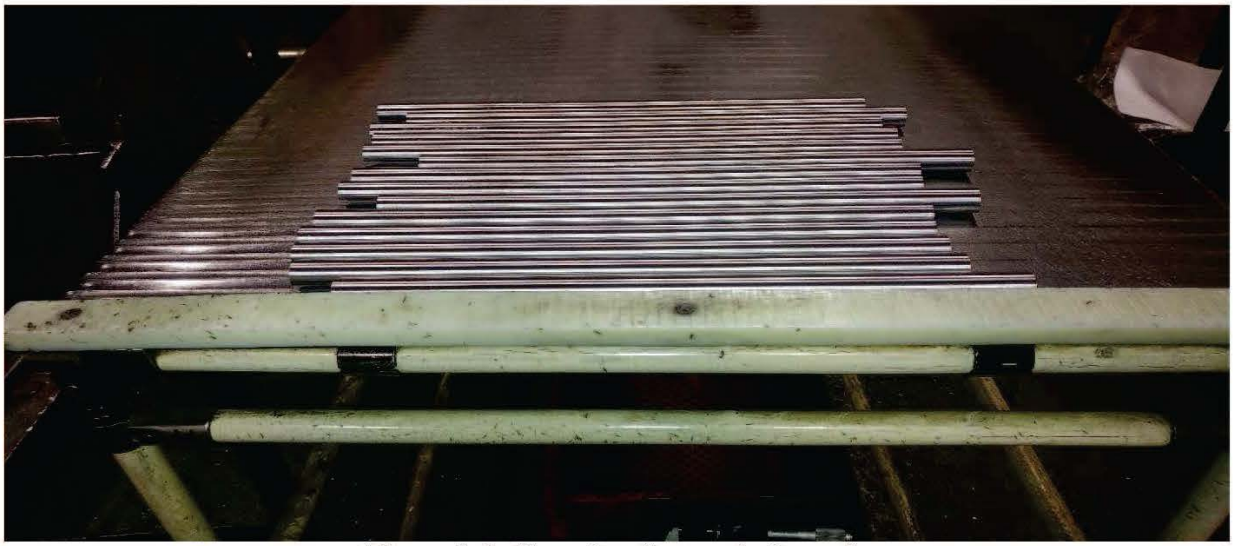


Figure 3.5: Completed pre-grinder rods

The next phase in the process is the induction hardening as shown in figure 3.6. This uses electric current to quickly harden the rod.

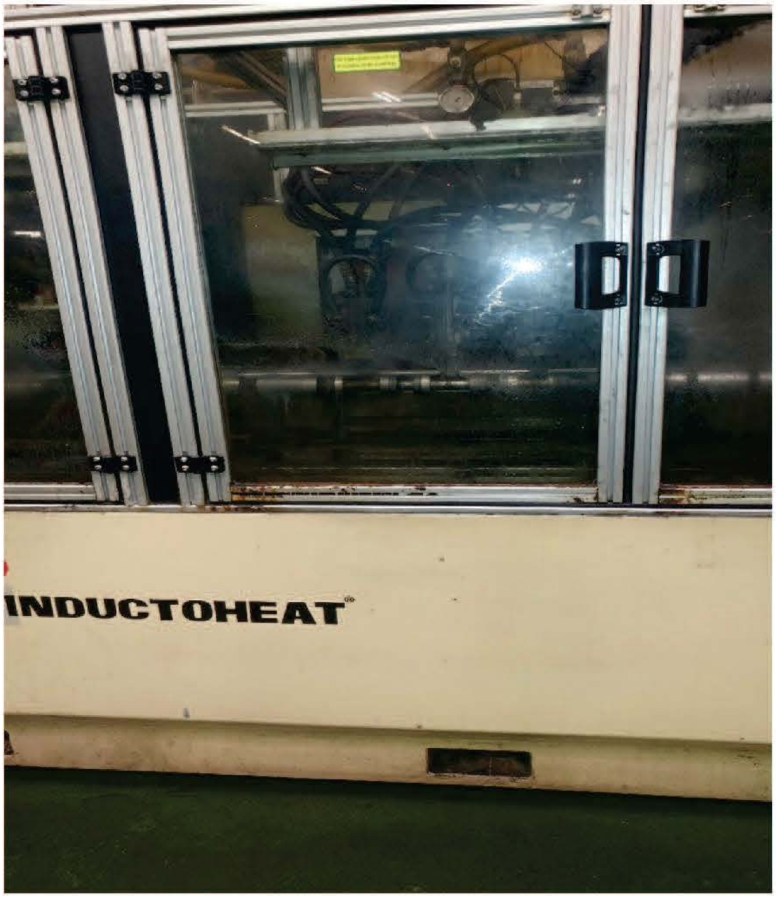


Figure 3.6: Induction Heating

Next, Fig. 3.7 shows the hardened rods. Figure 3.8 shows the rods placed through a straightener machine. This relieves internal stress of the rod, ensuring that the rod is less prone to cracking.

Figure 3.7: Hardened Rods

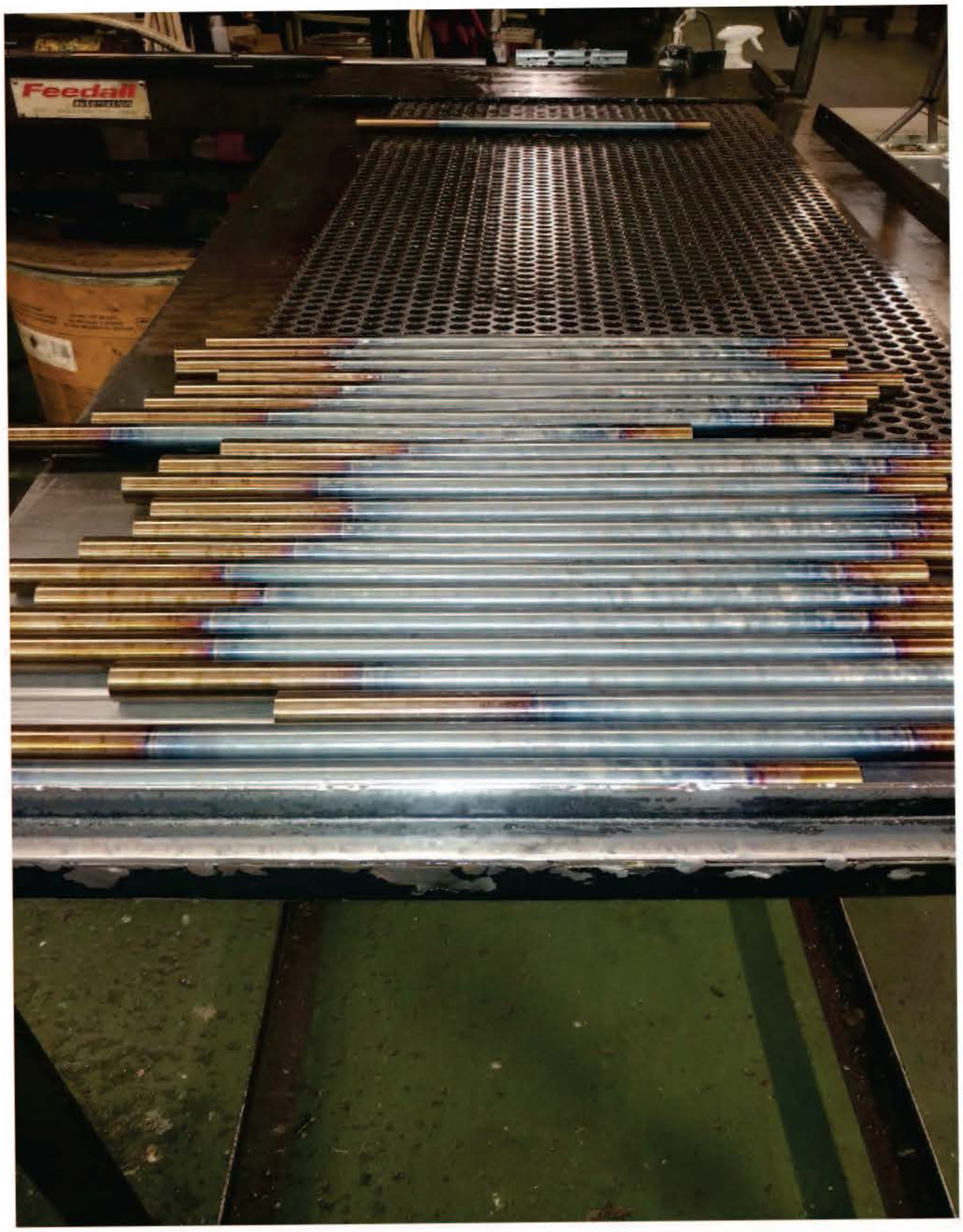


Figure 3.8: Straightened Rods

Finally, the rods are processed through lathes as shown in figure 3.9. Figures 3.10 and 3.11 show the completed shock shafts.

Figure 3.9: Lathe

Figure 3.10: Processed Shock Shafts

Figure 3.11: Shock Shaft

Figure 3.12 shows the finished shock. The piston end has been inserted into the subassembly with the top end exposed.

Figure 3.12: Completed shock (Courtesy: https://www.hitachi-automotive.us/Products/Aftermarket/DCS/Shocks_Struts/index.htm)

Figure 3.13 shows the “top end”, and figure 3.14 shows the “piston end” of the Shock Shaft.

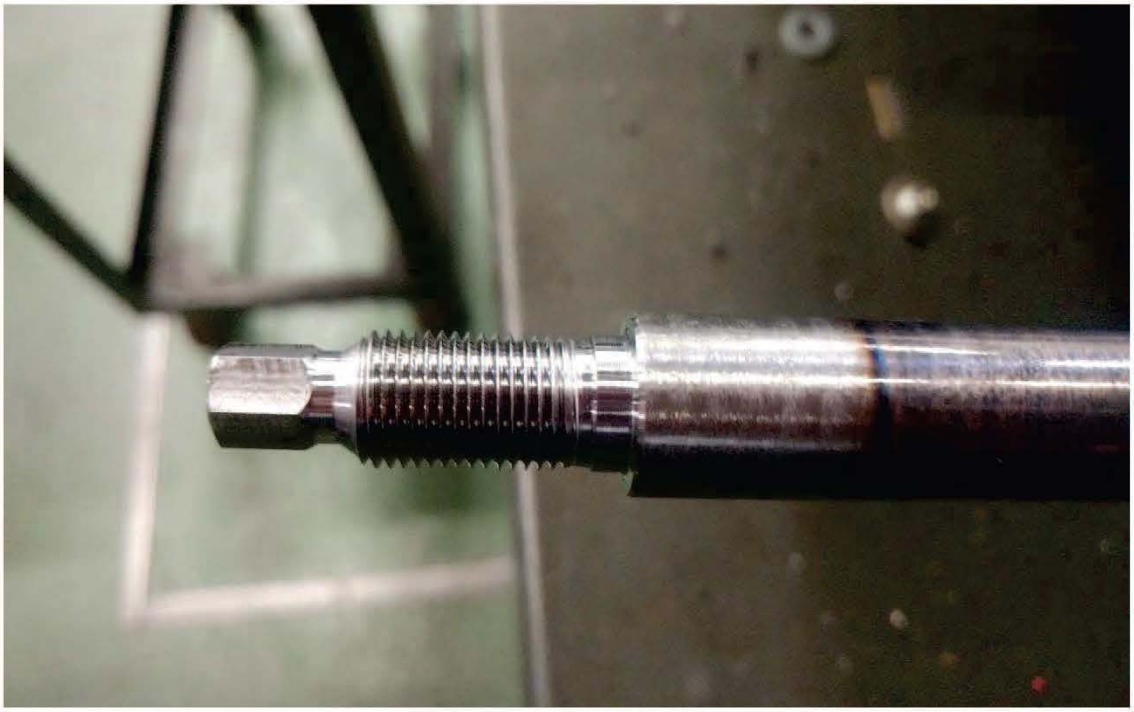


Figure 3.13: Top End of Shock Shaft

Figure 3.14: Piston End of Shock Shaft

The slip gauge in figure 3.15 is inserted onto the piston end in figure 3.16. This test is used to determine if the shank is within tolerance of customer specifications. This eliminates the need to use a micrometer to measure the shank's diameter.

Figure 3.15: Slip Gauge

Figure 3.16: Piston End Inserted into Slip Gauge

3.2 Cutting Tool Inserts

Both the roughing and finishing inserts in figure 3.17 are used to cut the rods as they are processed through the lathes. The plant uses Sandvik brand inserts. The inserts have six corners, three on one face and three on the other face. As a corner wears and becomes ineffective for cutting, the insert is rotated to another corner and used. Sometimes a grooving insert is used as well to create a ring around the rod. This study will focus specifically on the finishing insert since this is the last insert that cuts the rod before the part is completed. To test the roughing insert, the lathe would need to be stopped for each measurement. However, this would cut into cycle time and become very time consuming. Testing the roughing insert would require a separate study altogether.

There are seven different types of insert wear. The most common is flank wear. This is due to abrasion and can be fixed by decreasing the cutting speed or adjusting the direction of the coolant. Crater wear occurs on the rake side of the insert. This is due to a chemical reaction between the workpiece and the insert and is exacerbated by cutting speed. To rectify this problem, one needs to either decrease cutting speed, adjust coolant direction, or use more positive geometry. Built-up edge (BUE) wear occurs when there is "pressure welding of the chip to the insert. It is most common when machining sticky materials, such as low carbon steel, stainless steel and aluminum. Low cutting speed increases the formation of built-up edge" (http://www.techniksusa.com). Increasing cutting speed or feed rate minimizes this type of wear. Notch wear is localized damage to either the rake side or flank side. This is caused by pressure wielding of chips and a deformation of the surface. It can be fixed by decreasing the cutting speed, adjusting coolant direction, or using more positive geometry. Plastic deformation results from high cutting temperatures that melt the plastic, softening the tool. This can be rectified by improving the grade, applying a thicker coating, decreasing the cutting speed, or decreasing the feed rate. Thermal cracks will appear on the insert if the temperature changes too quickly from hot to cold. They are usually at a 90-degree angle to the cutting edge and are the results of interrupted cuts. Stabilizing the temperature or shutting off the coolant entirely should solve the issue. The last type of wear is edge chipping or breakage.

Chipping or breakage is the result of an overload of mechanical tensile stresses. These stresses can be due to several reasons, such as chip hammering, a depth of cut or feed that is too high, sand inclusions in the workpiece material, built-up edge, vibrations or excessive wear on the insert (http://www.techniksusa.com).

There are quite a few ways to remedy breakage. These include checking the tool holder, the tool overhang, the Amax, decreasing the feed, applying a more robust insert, and checking the run-out.

Figure 3.17: Inserts: Finishing (Left) and Roughing (Right)

Figure 3.18 shows the finishing insert. Since the finishing insert has a sharper nose, it removes less material. It wears at a much slower rate than the roughing insert, which has a more rounded nose and a shorter lifespan. Therefore, the finishing insert needs to be rotated less often than the roughing insert.

Figure 3.18: Finishing Insert: Sharper Nose

Figure 3.19 shows a roughing insert with a considerably more rounded nose.

Figure 3.19: Roughing Insert: Rounded Nose

Insert Shapes

Figure 3.20 displays the common types of inserts used in manufacturing. The insert shapes that are used in the lathes of the automotive company are predominantly triangular and diamond shaped.

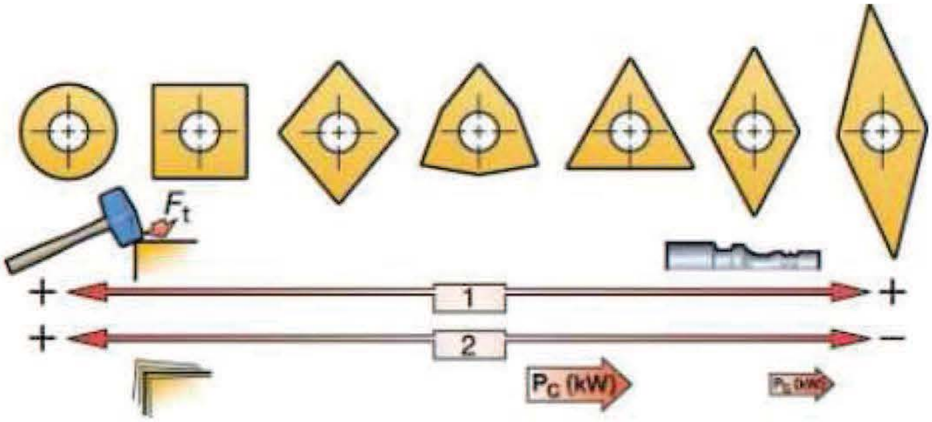


Figure 3.20: Types of Insert Shapes (Courtesy: http://www.sandvik.coromant.com)

Diameter Tolerance

The specifications for each part are set by the customers. For this particular part, the minimum tolerance for the diameter of the shank is 9.91 mm, and the maximum tolerance is 9.97. A micrometer is used to determine whether the shank shown in figure 3.21 is within tolerance.

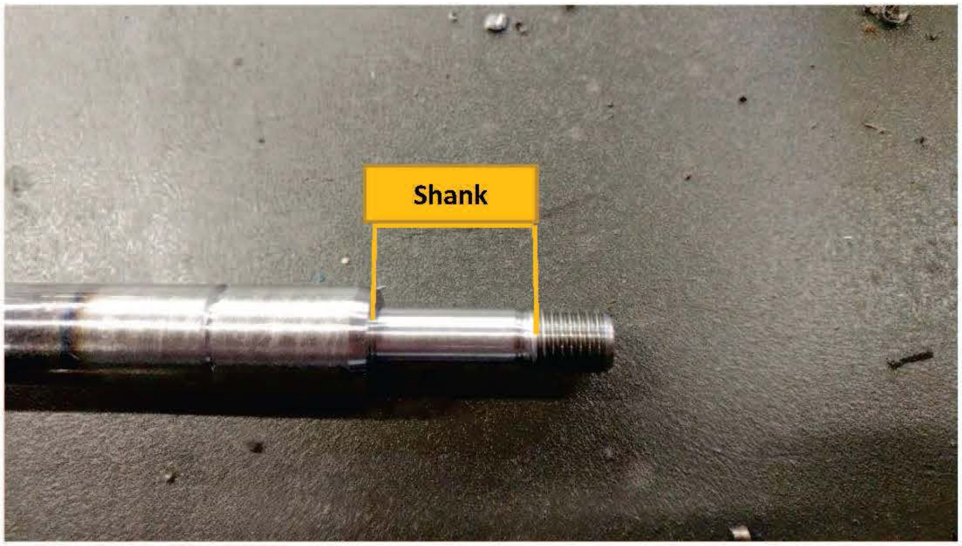


Figure 3.21: Piston End Shank

Figure 3.22 is the technical drawing of the piston end shank that is being studied. The diameter of the shank and the specification limits are shown. The length shown is irrelevant and can vary.

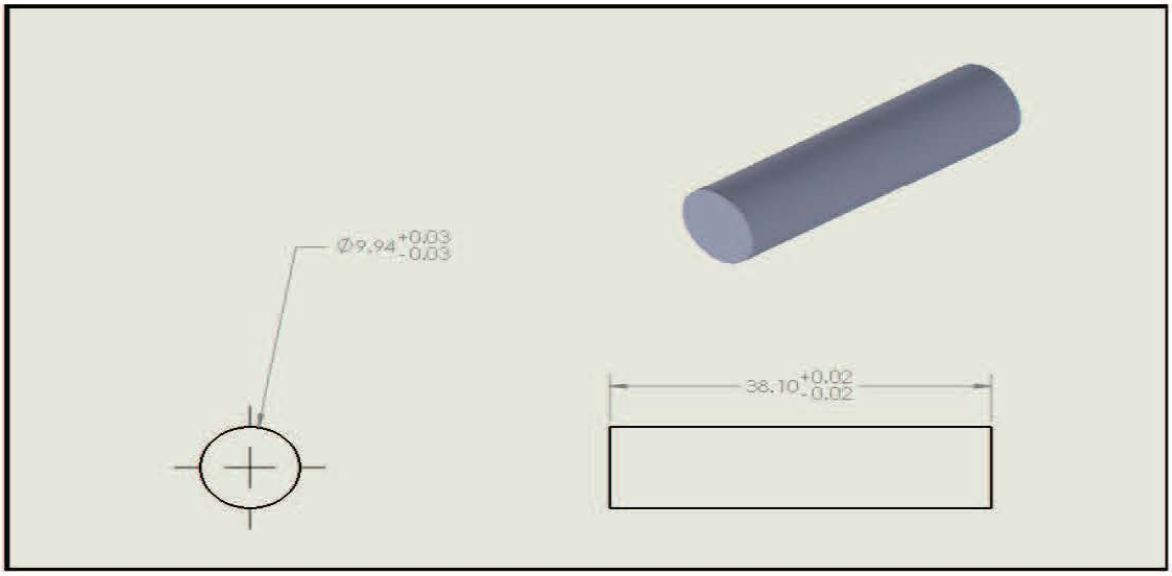


Figure 3.22: Diagram of piston end shank

3.3 Procedure

Figure 3.23 shows the flowchart for the tasks performed including the data collection, control charts development, and process capability study.

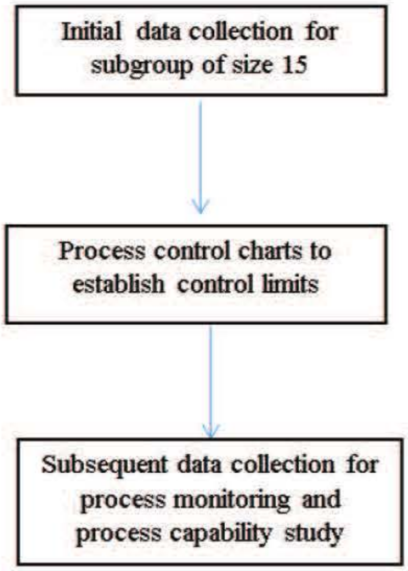


Figure 3.23: Flowchart of tasks

First, the data was collected by measuring the diameter of the shank. This was performed on a subgroup of five parts at every half an hour interval. Two separate data collections were performed for 75 parts each. This was accomplished for a total of 150 parts. The emphasis was on the finishing insert only since that is the last insert that cuts the shock shaft before it is completed.

Chapter 4

Data Collection & Analysis

This chapter will discuss the data collected from measuring the shank, the control charts for monitoring the shank diameter's tolerance, and the process capability study to determine if the process is within specification limits.

Raw Data

Table 4.1 displays all the shank measurement data. There are 30 subgroups with size 5.

Table 4.1: Data collected from the shank measurement

Shank Diameter (9.91 to 9.97 mm)

	1	2	3	4	5	Average	Range
1	9.936	9.923	9.909	9.903	9.908	9.9158	0.033
2	9.914	9.915	9.916	9.915	9.905	9.913	0.011
3	9.916	9.919	9.91	9.914	9.913	9.9144	0.009
4	9.914	9.912	9.914	9.914	9.914	9.9136	0.002
5	9.916	9.916	9.915	9.96	9.913	9.924	0.047
6	9.918	9.918	9.919	9.922	9.915	9.9184	0.007
7	9.923	9.93	9.928	9.924	9.927	9.9264	0.007
8	9.931	9.932	9.926	9.923	9.929	9.9282	0.009
9	9.929	9.929	9.927	9.931	9.925	9.9282	0.006
10	9.927	9.924	9.93	9.924	9.923	9.9256	0.007
11	9.925	9.925	9.927	9.927	9.922	9.9252	0.005
12	9.922	9.922	9.927	9.919	9.924	9.9228	0.008
13	9.922	9.924	9.93	9.928	9.926	9.926	0.008
14	9.927	9.927	9.919	9.92	9.92	9.9226	0.008
15	9.923	9.928	9.92	9.922	9.919	9.9224	0.009
16	9.918	9.911	9.912	9.915	9.911	9.9134	0.007
17	9.911	9.912	9.914	9.913	9.914	9.9128	0.003
18	9.917	9.914	9.917	9.917	9.905	9.914	0.012
19	9.911	9.905	9.906	9.906	9.901	9.9058	0.01
20	9.908	9.904	9.914	9.914	9.908	9.9096	0.01
21	9.911	9.909	9.913	9.912	9.914	9.9118	0.005
22	9.906	9.911	9.914	9.911	9.914	9.9112	0.008
23	9.914	9.907	9.921	9.926	9.924	9.9184	0.019
24	9.924	9.926	9.929	9.917	9.907	9.9206	0.022

25	9.907	9.908	9.926	9.926	9.931	9.9196	0.024
26	9.929	9.924	9.928	9.935	9.929	9.929	0.011
27	9.934	9.915	9.934	9.932	9.91	9.925	0.024
28	9.931	9.939	9.93	9.931	9.929	9.932	0.01
29	9.935	9.933	9.935	9.935	9.913	9.9302	0.022
30	9.938	9.938	9.941	9.935	9.934	9.9372	0.007
					Average	**9.920573**	**0.012333**

Control Charts

Using the statistical software, Minitab, control charts are created. Statistical quality control is considered to have begun with Walter A. Shewart when he created the first control chart in 1924 (Riaz and Muhammad, 2012). A control chart shows the upper and lower control limits as well as the mean. Control limits are three standard deviations above the mean and three standard deviations below the mean. They contain approximately 99.7% of all the data points. Any data that fall outside these limits are considered outliers.

Figure 4.1 shows Xbar and R charts of the data collected from tool inserts. As can be seen from the figure, points 2, 3, and 4 of the Xbar chart are less than the lower control limit while points 1 and 5 of the R-chart are above the upper control limit. These points being outside the control limits renders the process out of control.

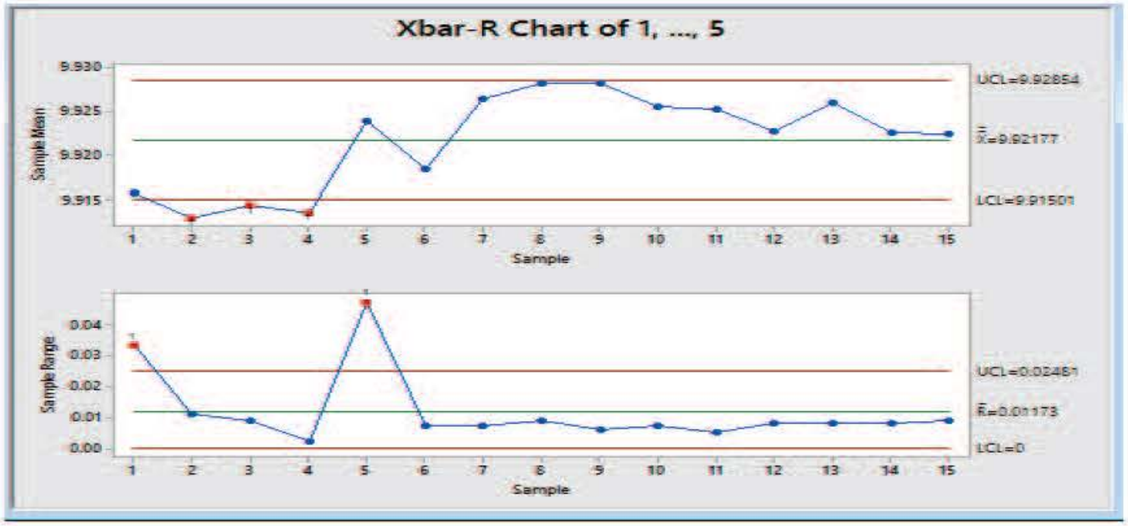


Figure 4.1: Xbar-R Control Chart

Figure 4.2 shows Xbar and S charts in which points 2, 3, and 4 are also outside the control limits for the Xbar chart and points 1 and 5 for the S-chart.

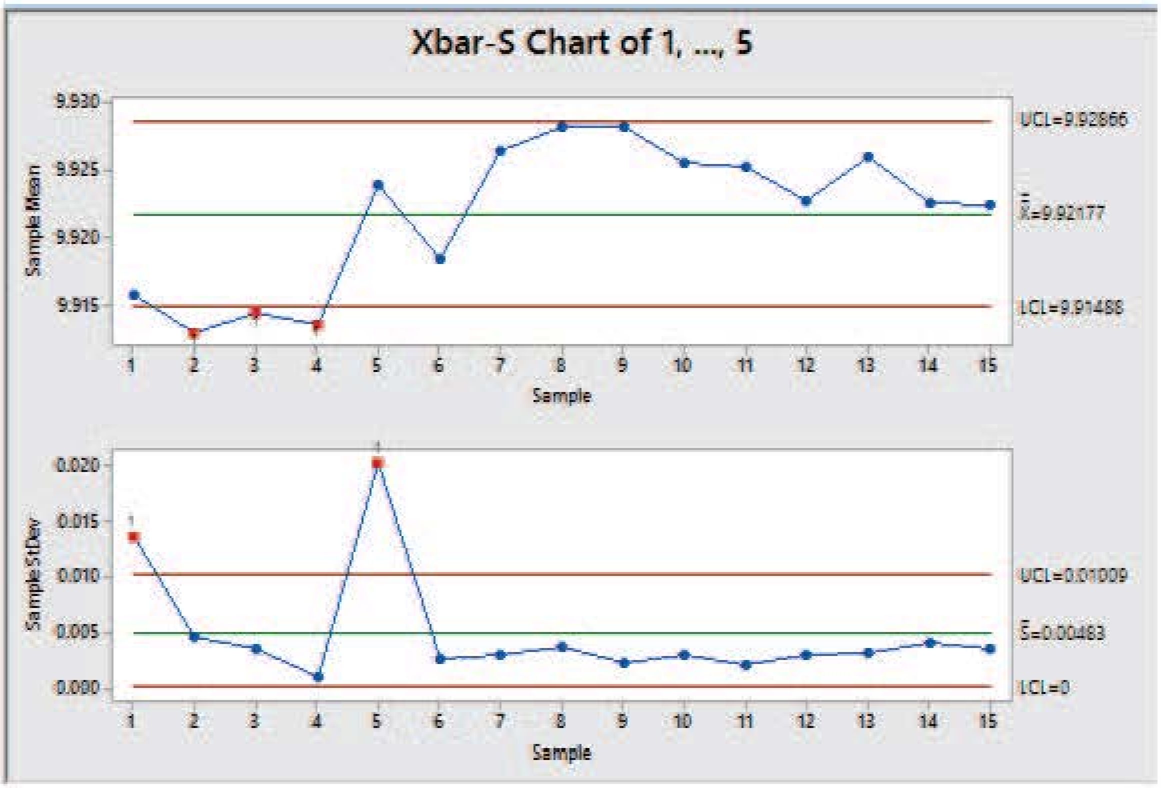


Figure 4.2: Xbar-S Control Chart

Process Capability Study

When considering a process, it is important to determine the process capability. "Process capability compares the output of an *in-control* process to the specification limits by using *capability indices*. The comparison is made by forming the ratio of the spread between the process specifications (the specification "width") to the spread of the process values, as measured by 6 process standard deviation units (the process "width")." (itl.nist.gov)

Process capability can be measured by the following formula:

(USL – LSL)/6*Std.dev

The USL is the Upper Specification Limit and the LSL is the Lower Specification Limit.

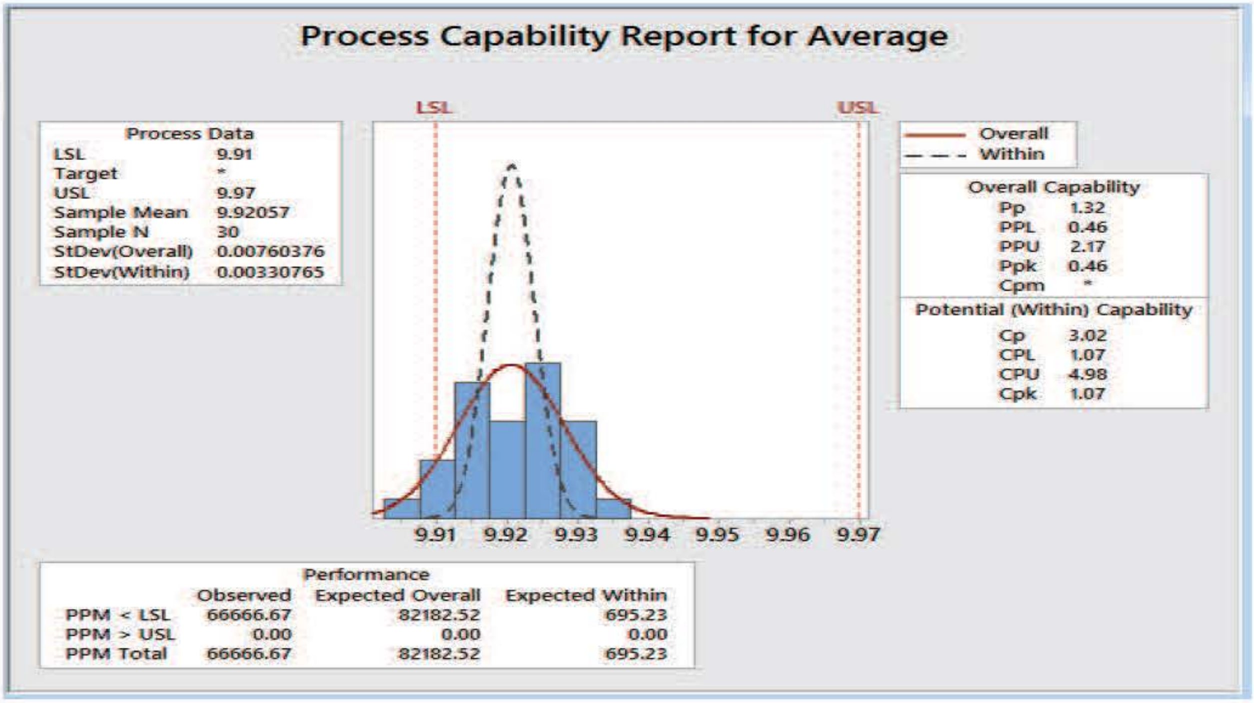
A capable process must have a Cp of least 1.0 while a Cp of 2.0 is necessary for six sigma quality. Cpk is the process capability index. This number shows how close the process is to the specification limits. The equation for Cpk is:

[minimum (mean - LSL, USL - mean)] / (0.5*NT)

Where NT indicates Natural Tolerance.

A process with Cpk of 2.0 renders a ppm (parts per million) of .002. But even with a process shift of +- 1.5 it will have no more than 3.4 defects. Generally, a Cpk of 1.33 or higher is considered capable. A Cpk less than 1 will have a process that is above or below customer specification limits.

The process capability study in figure 4.3 displays the overall statistics for the data collected.



Process Data	
LSL	9.91
Target	*
USL	9.97
Sample Mean	9.92057
Sample N	30
StDev(Overall)	0.00760376
StDev(Within)	0.00330765

Overall Capability	
Pp	1.32
PPL	0.46
PPU	2.17
Ppk	0.46
Cpm	*

Potential (Within) Capability	
Cp	3.02
CPL	1.07
CPU	4.98
Cpk	1.07

Performance

	Observed	Expected Overall	Expected Within
PPM < LSL	66666.67	82182.52	695.23
PPM > USL	0.00	0.00	0.00
PPM Total	66666.67	82182.52	695.23

Figure 4.3: Process Capability for all 30 Sets of Data

Chapter 5

Discussion & Future Research

Concluding Remarks

One objective of this study was to create a statistical control chart based approach at the operator level through which operators could determine when the shank diameter was out tolerance and when they should change the finishing insert. This was performed by implementing Xbar-R and Xbar-S control charts. The operator can then use the developed control charts to monitor the process on an on-going basis. Any measurement taken that is above the upper control limit will signal to the operator that it is time to change the insert.

The data collected show that the current process is not in control but it is capable. There were five data points that were out of control. For the Xbar chart they were samples 2, 3, and 4. This was due to the points falling below the lower control limit. For the Sbar and R-charts the samples were points 1 and 5 because they were above the upper control limit. However, the process was capable because Cpk was 1.07. Since a process is considered capable with a Cpk of 1.0 or greater, the process in this study was barely capable. It can be seen from figure 4.3 in the previous chapter that mean is close to the Lower Specification Limit.

Recommendations

This study is narrowly focused, and as such, there are many elements that are beyond its scope. Some improvements that could be made include performing a separate study of the roughing insert, related cost savings, determining the main type of insert wear for the roughing insert, and a comparative study of different brands of inserts.

The roughing insert removes the majority of the material which forms the shank. What makes the roughing insert particularly difficult to assess is that the lathe must be stopped each time a measurement is taken since the part is still inside the machine after the roughing insert has completed its cutting. Stopping the machine, however, would cut into cycle time, and could only be performed when the machine is not in use. However, if one were to study this insert it would prove to be a great benefit because the roughing insert is changed more often than the finishing insert. Extending the life of this roughing insert would lead to savings for the company over time.

A cost analysis would be helpful since any cost savings can add to the bottom line of the company. The cost of each insert, the number of inserts used per day, and the total annual consumption on inserts across different product lines would all contribute to the savings.

Also, determining the types of insert wear could potentially lead to extending the insert life. Once the type of insert wear is discovered, the appropriate measures can be taken to decrease the potential for that type of wear. These measures may include varying the cutting speed, using a different the angle for the insert, or using a special coating to reduce heat.

Finally, performing a comparative study of the different brands of insert could benefit the company. This study would determine what insert brand is most compatible, most durable, and possess the longest life.

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