Author: **Dufek, Daniel J.**

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STUDENT:

NAME Daniel J. Dufek **DATE: 5/10/13**

ADVISOR: (Committee Chair if MS Plan A or EdS Thesis or Field Project/Problem):

NAME James Keyes, Ph.D. **DATE: 5/10/13**

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1. **CMTE MEMBER'S NAME:** **DATE:**

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Dufek, Daniel J. ***Validation of a Gas Nitriding Supplier***

Abstract

Switching suppliers can be a difficult decision for any company to make. Federal-Mogul, a world class supplier of piston rings, was investigating switching the supplier for their nitriding operation to a new source.

This research examines the validation process of switching from one nitriding supplier to another. Information was examined on both the existing supplier and the potential new suppler. A literature review was conducted to gather previous knowledge on supplier selection. The literature review also educated the researcher on the nitriding process, and why it is done.

Data collection then commenced on the current supplier to establish baseline data. A new supplier was then contacted and nitriding trials started. Once the supplier and Federal-Mogul felt they had an acceptable process, production orders were released. Each of the orders received from the new source were analyzed and compared to the baseline data from the current supplier.

Federal-Mogul has found that there is no statistical difference between the product nitrided at either supplier, so the new supplier has been given the green light to continue nitriding select orders.

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Chapter I: Introduction

Federal-Mogul Powertrain Systems in Manitowoc, Wisconsin is a world-class supplier of piston rings to the heavy duty diesel engine market. The Manitowoc division currently employs approximately 700 employees and has $10 million in monthly revenues. The Federal-Mogul Manitowoc plant is a division of the Federal-Mogul Corporation. The corporation is a $6.9 billion global supplier of powertrain, chassis and safety technologies, serving the world's foremost original equipment manufacturers of automotive, light commercial, heavy-duty, agricultural, marine, rail, off-road and industrial vehicles, as well as the worldwide aftermarket (Federal-Mogul Corporation, 2010, p. 1).

One of the piston rings in a diesel engine is an oil control ring (oil ring). These oil rings are formed from steel wire and then gas nitrided to improve the wear characteristics. Federal-Mogul Manitowoc introduced nitrided oil ring into mass production in July of 2006.

Federal-Mogul Manitowoc's contracts provide a yearly ring price reduction for their customers who continue their business with Federal-Mogul. The manufacturing plant has consistently reduced scrap as a percentage of started pieces, as well as implemented productivity improvements over the life of this product type. One of the largest cost factors of manufacturing a nitrided steel oil ring is the actual nitriding costs. Nitriding is a process to improve the wear characteristics of a piston ring. Improvements must be made to the nitriding costs to prevent this product type from becoming a revenue losing product type.

The current gas nitriding operation is completed at an outside source located 80 miles from the Federal-Mogul manufacturing site. The nitriding operation is performed by Treat All Metals, an outsourced vendor. Federal-Mogul Manitowoc has also used Treat All Metals for heat treating (quench and tempering) of their cast iron raw materials. This heat treating operation has since moved to Federal-Mogul's Sparta, MI foundry, and the business they have with Treat All Metals has been reduced. Treat All Metals was being removed as an approved supplier to Federal-Mogul. It was necessary to procure a lower cost supplier.

Statement of the Problem

Federal-Mogul Powertrain Systems must develop a strategic plan to validate a new nitriding supplier.

Federal-Mogul needed to locate and validate a new supplier for the nitriding of their oil rings. A potential candidate, Nitrex, had been employed by sister plants in Wausau, Wisconsin and Burscheid, Germany to provide gas nitride automotive type compression rings. It was not known if this supplier could meet the requirements for diesel oil control rings, as the nitriding process and specifications are different between the two piston ring types. The goal was to reduce nitriding cost, while maintaining or exceeding current quality standards and maintaining or improving delivery times.

Purpose of the Study

This study was completed to create a plan to validate a new supplier and then move the gas nitriding operation from Treat All Metals to a new supplier. Nitrex, being a qualified supplier at other locations, was identified as the supplier of choice in developing this plan. The Nitrex company not only nitrides product for their customers, but also provides nitriding equipment. Results from this study will help Federal-Mogul purchase their own Nitrex nitriding equipment and relocate the nitriding operation in house. The first step was to validate Nitrex as a supplier and this process will be covered in this research paper. The second step was to purchase their equipment and move the nitriding operation within the Federal-Mogul Manitowoc site. The purchase of capital equipment will not be explored in this paper.

Assumptions of the Study

It was assumed that Nitrex will be the sole nitriding supplier for Federal-Mogul. Other nitriding suppliers existed, but these suppliers will be excluded from this research paper.

It was also assumed that the current customer of the oil control rings would approve the supplier change if there was sufficient data presented that validated the change.

Definition of Terms

Nitriding. A case hardening process that is completed in an ammonia gas enriched furnace. Nitriding provides a product that has high surface hardness, increased wear and abrasive resistance as well as anti-galling properties. Nitriding a product also improves the product's fatigue life (Darbellay, 2006).

Free gap. Free gap is the measured distance between the piston ring gap ends, when the piston ring is in the free state, or not confined to bore diameter (*ISO Standards Handbook*, 2006). See measurement (m) in Figure 1.

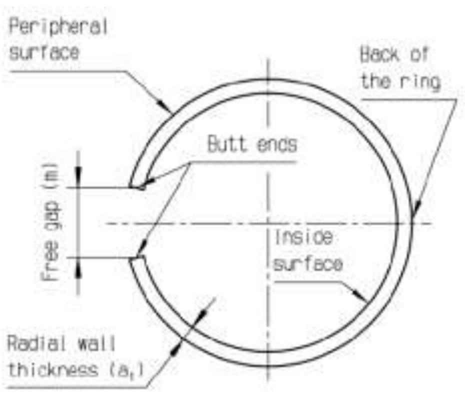


Figure 1. Free Gap (*ISO Standards Handbook*, 2006, p. 18)

Axial Width. Axial width is the height of the oil control ring. Axial width is generally depicted as h_1 on engineering drawings as seen in Figure 2.

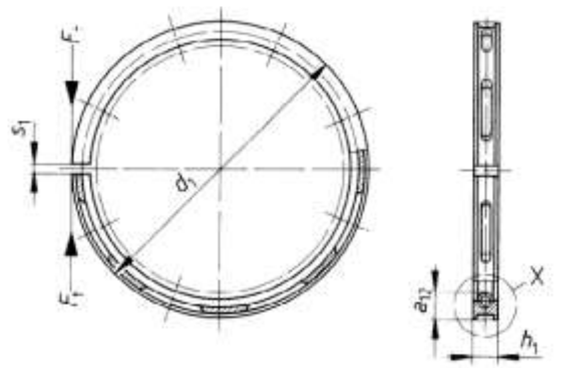


Figure 2. Axial Width (*ISO Standards Handbook*, 2006, p. 380)

Nitriding Depth. The depth of the nitrided layer is the thickness of the surface layer with a hardness value greater or equal to 700HV (Hardness Vickers) when measured perpendicular to the ring outside diameter (OD) or perpendicular to the side face of the ring (*ISO Standards Handbook*, 2006). In the case of an oil ring, nitriding depth is also measured on the inside diameter (ID) as the nitrided layer provides protection from coil spring wear against the oil ring body. Figure 3 shows the Nitriding depth on the OD as well as the sides of an example oil ring. The black diamonds are the indentations from the hardness checking machine.

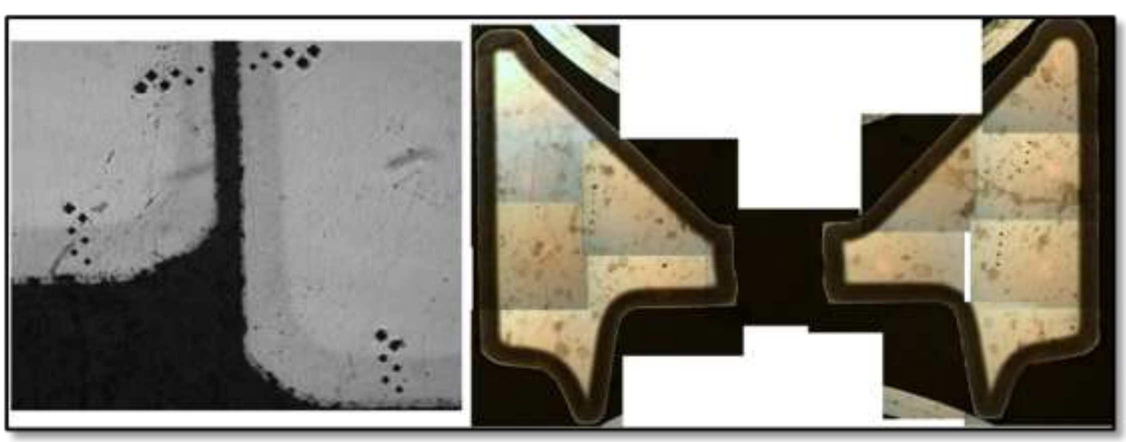


Figure 3. Nitriding Depth.

White Layer Thickness. The White Layer is a byproduct of the nitriding operation. This white colored layer is actually a thin layer of extremely hard, highly saturated nitrogen enriched iron nitride. This White Layer is normally sand blasted away during post nitriding machining operations, but is checked during incoming inspection from nitriding. White Layer is measured perpendicular to the face of the oil ring, Figure 4.

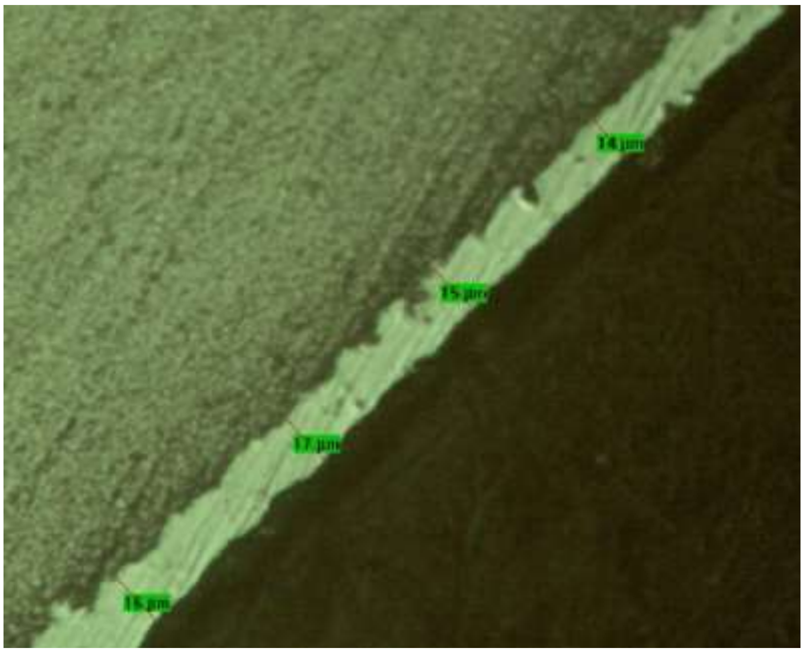


Figure 4. White Layer Thickness.

Limitations of the Study

It was not in the scope of the project to eliminate the nitriding operation by switching to a higher technology wear coating. Other higher technology wear coatings exist to protect the oil control ring, but these technologies were not explored in this paper.

Methodology

Federal-Mogul took critical steps to validate a new nitriding supplier. Federal-Mogul referred to these critical steps as key actions, and were the roadmap to success. Some of the key actions took place simultaneously. The key actions included setting up cross functional teams, gathering information from other Federal-Mogul manufacturing plants, contacting Nitrex company with project specifications, involving the customers that purchase the finished oil ring, chose an oil ring part number and ran trials, analyzed and documented data, conducted engine validation tests, submitted change approval documentation, and finally implement the change.

The first step was to set up a cross functional team within Federal-Mogul Manitowoc. Team members chosen were representatives from process engineering, quality assurance, incoming material inspection, purchasing, application engineering, as well as manufacturing operators that ran the product.

Federal-Mogul then began to gather information from Wausau, Wisconsin and Burscheid, Germany. There was no reason to reinvent the nitriding process when sister plants had experience with Nitrex as a supplier.

After information was gathered from existing Federal-Mogul manufacturing plants, Nitrex was contacted with project specifications and expectations. The initial contact was made via teleconference with process engineering, quality assurance, and purchasing representatives from Federal-Mogul Manitowoc. Nitrex had representatives from their engineering departments, sales department, as well as the president of the company.

Federal-Mogul also wanted to involve the customers that purchase nitrided oil rings. The highest volume oil ring customer, “Diesel 1” was notified that Federal-Mogul was looking for a new nitriding supplier. Diesel 1 was very receptive to the change, anticipating a cost reduction in the oil ring price.

The next step was to choose oil ring part numbers and run trials. The highest volume nitrided oil ring was selected. The high production volume gave Federal-Mogul an ample supply of oil rings to test.

After the highest volume part number was selected, Federal-Mogul began to analyze and document data. Each variable collected was analyzed using the most current statistical analysis tools in Minitab®. Everything was stored electronically, and saved on a central server; allowing all team members access to the data. All paper documents received were scanned into an electronic format and stored on the server.

The next key action was to conduct engine validation tests. Diesel 1 would require Federal-Mogul to validate the new oil ring nitriding supplier by performing an engine test. The engine test would be carried out at the test facility at Diesel 1, and the engine test costs were to be covered by Diesel 1. Once all the data was gathered and analyzed Federal-Mogul submitted the official change approval documentation to the customer. Diesel 1 would require a full Production Part Approval Process (PPAP) to approve changing nitriding suppliers. All PPAP documentation was handled through the quality assurance department.

The final step was to fully implement the change. Process engineering would make the required changes to the manufacturing process steps, and the change would be implemented.

Summary

Federal-Mogul was looking to validate a new supplier for the nitriding of their oil rings. After years of forced price reductions this product type was close to becoming a revenue losing product type. Federal-Mogul looked to reduce the nitriding cost to remain profitable in the diesel oil ring market. This study created a plan to validate a new supplier and then move the gas nitriding operation from the current supplier to a new supplier. Chapter II will contain a review of literature that reviews supplier selection processes and quality validation methodology that has been documented in prior research.

Chapter II: Literature Review

A review of related literature was conducted to examine available information and relevant studies that pertain to the selection and validation of a new supplier. The literature review was completed on quality, cost, and delivery. The researcher then examined information on what nitriding is, and how it is completed. This literature review helped Federal-Mogul make an educated decision on switching to a new nitriding supplier.

"Choosing the right supplier can spell the difference on how your product can compete in both quality and price" (Gardner, n.d., para. 1). Choosing the wrong supplier can degrade the quality and dependability of product thus, costing the company money through lost sales, product recalls and warranty issues.

Quality, cost, and on-time delivery (QCD) are the three most important criteria in supplier selection (Muralidharan, Anantharaman, & Deshmukh, 2002). In this project, Federal-Mogul agreed with the authors. Each of these criteria had equal weight when validating a nitriding supplier. Considering that suppliers are the best intangible assets of any organization, each one of these criteria were researched and evaluated for the intended supplier.

Quality

Per Federal-Mogul's procedure, two quality actions needed to take place when switching suppliers. The new supplier's product should be evaluated against existing specifications. This means that the product should be statistically analyzed against current specifications to ensure product conformance. The other action that needed to take place was the gathering of base line data on the current supplier. Long term data was collected on the current supplier to develop a baseline to which the new supplier will be compared. All specifications were checked and documented. Pekar addresses supplier integration in his book *Total Quality Management* by stating "organizations that consider their suppliers to be part of their overall business strategy are going to be way ahead of their competition" (Pekar, 1995, p.40).

Cost

"Supplier performance is about more than just a low purchase price. The costs of transactions, communication, problem resolution and switching suppliers all impact overall cost" (Okes & Westcott, 2001, p. 245). As illustrated in point number four of Deming's 14 Points for Management (1986) the lowest cost supplier is not always the best supplier. The old adage 'you get what you pay for' definitely applies to supplier selection. Having a low priced supplier with poor problem resolution or poor communication may end up costing the company more in the long run by having increased inspections and/or rework, missed shipments, or new product development issues. The goal is to balance the actual cost of the product with the required level of service from this supplier.

Delivery

Murray (1995) states that the most common buyer complaint is a supplier's delay in delivering the actual product. Delays of months are not uncommon and shipments can be delayed beyond one year in some cases. "There are solutions to the problem, but a buyer must pay attention to delivery time at the time a contract is made" (Murray, 1995, p.31). Great quality at a fair price together does not complete the Quality, Cost, Delivery triangle. This is where supplier delivery becomes a factor. Delivery expectations should be documented and accepted before the business is awarded to the supplier. These terms must be agreed upon by both supplier and buyer before the contract is signed.

QCD Triangle Summary

Quality, cost, and delivery are the three key performance indicators for Federal-Mogul. Each individual side of this Quality, Cost, Delivery triangle is no more important than the other. All sides of the triangle must be in balance for both the supplier and buyer to succeed. In Cushman and Sanderson King's book (2003) *Communication Best Practices at Dell, General Electric, Microsoft, and Monsanto* it is stated that communication between customer, worker, manager, and supplier gives Dell Computer Corporation a substantial advantage over their competitors (p.4-5). Federal-Mogul is hoping to build the foundation of the Quality, Cost, Delivery triangle on open supplier-buyer communication. Just as Microsoft did in Cushman and Sanderson King's book, Federal-Mogul is looking to make communication the backbone to its success with Nitrex.

Supplier Selection – Team Rolls

According to the American Society for Quality (n.d.) supplier selection should be defined by a 'cross functional' team of members from different areas of an organization. An example is given from a manufacturing company. Suggested team members include representatives from purchasing, quality, engineering and production. Federal-Mogul chose team members from each of these areas, as well as representatives from the incoming inspection department and application engineering.

The American Society for Quality (n.d.) also recommends reviewing the supplier's 'track record' for supplying business-performance improvements. Federal-Mogul is interested in partnering with a supplier that consistently and continually improves their business-performance. Although the Manitowoc division is not currently being supplied by Nitrex, data was reviewed from other Federal-Mogul manufacturing locations that are supplied by Nitrex. Nitrex has shown continual improvements at each of the manufacturing locations reviewed. The improvements included price-downs, quality improvements, lead-time reductions, and scrap reduction.

What is Nitriding?

"Nitriding is a surface-hardening heat treatment that introduces nitrogen into the surface of steel at a temperature range (500 to 550°C, or 930 to 1020°F) while it is in the ferrite condition" (Key to metals, 2003, para. 1). In other words, steel is heated to a high temperature inside a furnace. While the actual temperature used to nitride oil control rings is a trade secret, it is within reason of the temperatures listed in the article. When the parts are being heated inside a furnace a gas rich in nitrogen is introduced. This gas is usually ammonia. "Nitrogen has partial solubility in iron. It can form a solid solution with ferrite at nitrogen contents up to about 6%" (Key to metals, 2003, para. 2). It is the ammonia gas that increases the nitrogen content at the surface of the steel, thus increasing the steel hardness. The outer layer of increased hardness on the steel is known as the case hardening or case depth.

What Types of Base Materials can be Nitrided?

According to Key to metals (2003), "Nitrided steels are generally medium-carbon (quenched and tempered) steels that contain strong nitride-forming elements such as aluminum, chromium, vanadium, and molybdenum" (para. 6). This is true of Federal-Mogul's steel oil ring material. The steel used in the manufacture of the oil rings has been quenched and tempered by Federal-Mogul's steel wire supplier. Although the chemical composition of the steel wire cannot be shared, the steel composition is high in the element chromium, which allows the steel to be successfully nitrided.

Why Nitride?

Key to metals (2003), explains there are five principle reasons for nitriding steel. Each of these principles will be discussed in regards to oil control piston rings.

The first principle reason to nitride steel is to obtain high surface hardness (Key to metals, 2003, para. 5). One way an oil control ring can fail in an engine is from coil spring embedment. Coil spring embedment happens when the coil spring wears into the inside diameter of the steel oil ring body. This embedment of the coil spring into the steel oil ring body does not allow the oil ring to fully expand and apply pressure to the engine cylinder. Once oil ring pressure is lost against the engine cylinder the engine starts to lose (burn) engine oil. Although this is not a catastrophic engine failure, the engine will burn too much oil and be deemed unacceptable. Nitriding an oil control ring will increase the surface hardness on all areas of the oil ring, including the inside diameter. This high surface hardness nearly eliminates coil spring embedment into the inside diameter of the oil control ring.

The second principle reason to nitride steel is to increase wear resistance (Key to metals, 2003, para. 5). Federal-Mogul’s customer, Diesel 1, markets their engine as a million mile engine. This means that the piston rings in the engine must last for one million miles before they need replacement. The primary reason an oil control ring fails is from outside diameter wear against the engine cylinder. Nitriding increases the wear resistance of the outside diameter of the oil control ring, allowing Federal-Mogul to exceed the million mile engine life expectancy of the oil control ring.

The third principle reason to nitride steel is to improve the fatigue life of the metal (Key to metals, 2003, para. 5). An oil control ring is constantly in motion, and is subject to engine environmental stresses. The oil ring flexes to cylinder bore distortions, and is subject to combustion pressures and gasses, as well as movement from the piston. Over time, these engine stresses begin to fatigue an oil control ring. Once an oil control ring is pushed beyond its fatigue limit, the oil control rings breaks, and a catastrophic engine failure occurs. Nitriding an oil control ring improves its fatigue life, eliminating this type of catastrophic failure.

The fourth principle reason to nitride steel is to improve the resistance to corrosion (Key to metals, 2003, para. 5). Corrosion resistance is not a large concern once the oil control ring is installed into the engine. The engine oil will immerse the oil control ring and provide any corrosion resistance required. The benefit is realized during handling and transportation between Federal-Mogul and the customer. The oil control rings are dipped into rust preventive oil before the rings are packaged for shipment, but the nitriding provides extra insurance against rust and corrosion.

The final principle reason to nitride steel is “to obtain a surface that is resistant to the softening effect of heat at temperatures up to the nitriding temperature” (Key to metals, 2003, para. 5). Through diesel engine testing at Federal-Mogul’s test facilities, engineers have learned that the oil control ring will never see operating temperatures exceeding 600° F. The nitriding process subjected to the oil control ring is executed in an atmosphere close to 1000° F. The engine customer’s risk to oil ring surface softening due to temperature is non-existent.

How to Measure Nitriding Depth

According to the *ISO Standards Handbook, Piston Rings and Pins* (2006) a reliable non-destructive way of measuring nitrided case depth is not known up to now (p.69). This means the ring must be cross-sectioned and a piece of the ring is placed in a metallurgical mount. While reviewing Totten, Funatani, and Xie’s (2004) book *Handbook of Metallurgical Process Design* it is stated that the most popular method of preparing a metallurgical mount is to embed the specimen in a thermosetting plastic (p.895). This is also the method that Federal-Mogul uses to prepare a nitrided oil ring specimen. An oil ring is cross-sectioned and a piece of the oil ring is then set in a red thermosetting plastic powder. The oil ring cross-section and the thermosetting plastic powder is then heated and compressed until the plastic melts and encompasses the oil ring. This mount is cylindrical in shape, approximately one inch in diameter. One metallurgical mount can contain multiple cross-sections of an oil ring if necessary. Placing more than one specimen in one mount will help reduce the overall cost of checking nitriding depth on oil rings.

After the metallurgical mount has cooled, the mount will be ground and polished. According to Totten, Funatani, and Xie (2004) the sample should be ground and polished to provide a surface that is suitable for observation at low and high levels of magnification (p.897). Federal-Mogul uses various grades of sandpaper to grind and then polish the mount, starting with the coarsest grade first, and finishing with a wet sanding polish paper. Once the mount has been polished, it is washed and then dried with clean compressed air. The mount has now been prepared, and the specimen is ready to be measured.

It is required by the *ISO Standards Handbook, Piston Rings and Pins* (2006) to measure the micro hardness at various distances from the peripheral or side face surfaces (p.68). Micro hardness is checked by making small indentations into the oil ring with a calibrated indenter. The harder the material is, the smaller the indentation will be. When the material being tested is soft, the indenter penetrates more deeply. The *ISO Standards Handbook, Piston Rings and Pins* (2006) recommend hardness measurement increments of 0.01/0.015/0.02mm (p.68). Federal-Mogul is compliant with these recommendations. Reference Figure 5 for an example of the indentation made on a nitrided oil ring. The indentations are very small where the material is hardest, the nitrided layer, and the indentations become larger as the material becomes softer.

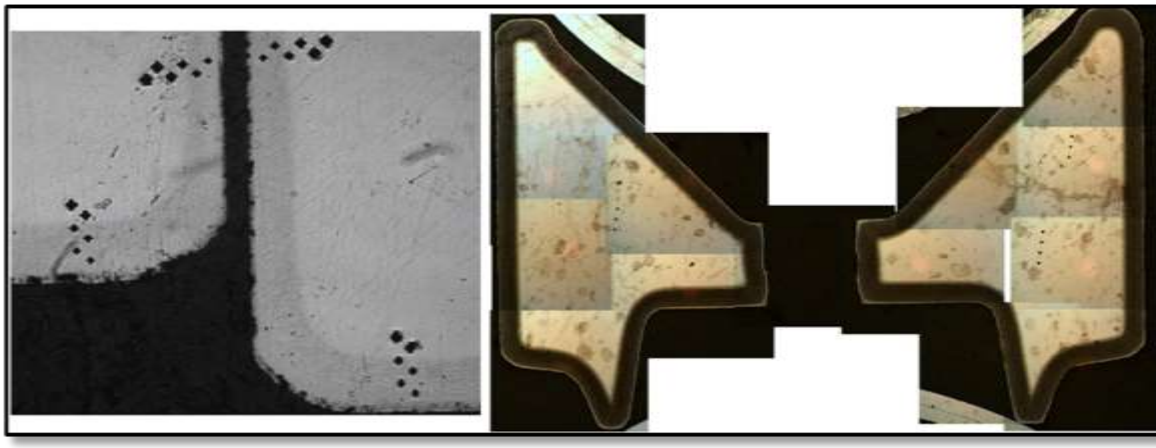


Figure 5. Nitriding Depth.

These hardness values are then plotted on an X-Y type coordinate system to develop a hardness curve. On the Y-axis, HV (Hardness Vickers) is plotted. On the X-axis, distance traveled is plotted. The travel distance is measured from an edge of the ring. For example, if nitriding depth was measured on the outside diameter of the ring, the distance traveled would be from the outside diameter edge to the indentation mark. The same would hold true measuring the inside diameter nitriding depth, as well as the side face nitriding depth. With multiple hardness values and the associated distances, a curve is plotted. See Figure 6 for an example of two hardness curves.

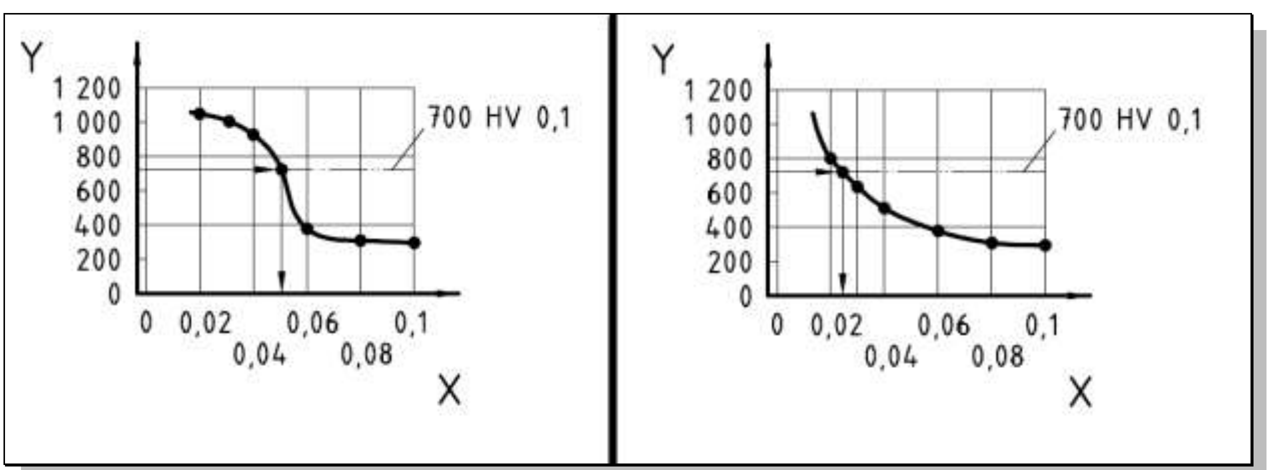


Figure 6. Hardness Curves (ISO Standards Handbook, 2006, p. 68)

Once the hardness curves are established, a horizontal line is drawn at the 700 HV level. 700 HV is the hardness level for a nitrided oil ring. The intersection of the hardness curve with the 700 HV line will result in the nitriding depth, or case depth. In Figure 6, the left hardness curve would have a nitriding depth of 0.05mm. The hardness curve on the right would have a nitriding depth of 0.025mm.

White Layer

The white layer is a byproduct of the nitriding operation. Post nitriding, the white layer is measured on the same cross-section mounts that are used to measure nitriding depth. White layer hardness is not checked, but the thickness is measured with a microscope. This white colored layer is actually a thin layer of extremely hard, highly saturated nitrogen enriched iron nitride. Sharma (1996) suggests that this white layer may form to depths of up to 0.05mm. Federal-Mogul and Treat All Metals have developed a nitriding process to minimize the white layer to a thickness of 0.01-0.02mm. The thinner white layer is easier to remove at subsequent processing operations. If the white layer is not removed, Sharma (1996) suggests that the white layer is brittle and my spall under service loads. White layer spalling in a diesel engine would scratch the cylinder wall and cause engine failure. The white layer must be removed.

Removal of White Layer

Federal-Mogul currently removes the white layer by abrasive blasting the oil control rings. Once the oil rings are received back in house from Treat All Metals, they are unpackaged from the shipping materials and brought to the abrasive blasting area. The rings are then stacked into a cylinder and the outside diameter and inside diameter are blasted at the same time. The side faces of the oil rings will be surface ground later in process to remove the white layer. Sharma (1996) suggests an alternate way of removing the white layer. Research has shown that white layer can be removed by chemical dissolution. It is suggested that soaking nitrided parts in a hot alkaline solution of NaOH and hot water can help remove the white layer. Federal-Mogul will need to start a new project to investigate this phenomenon as a potential way to ease white layer removal. The alkaline soaking method of white layer removal will not be explored in this research paper.

Summary

In this chapter, literature review was conducted and presented to understand how a supplier affects quality, cost, and delivery. Each side of this Quality, Cost, and Delivery triangle must be in balance for both the supplier and buyer to succeed. Communication is the foundation on which the Quality, Cost, Delivery triangle is built.

A review of literature was also conducted to examine what nitriding is, why it is done, and what materials can be nitrided. This information provided the researcher with the building blocks to manufacture a world class oil control ring for Federal-Mogul's customer.

In Chapter III, methodology procedures will be discussed. Data collection is only as accurate as the measurement system, so measuring procedures will also be documented. Once the data is collected, data analysis will commence and be summarized.

Chapter III: Methodology

Federal-Mogul Powertrain Systems in Manitowoc, WI is a world class supplier of piston rings to the heavy duty diesel engine market. One of the piston rings in a diesel engine is an oil control ring (oil ring). These oil rings are formed from steel wire and then gas nitrided to improve the wear characteristics. Federal-Mogul Manitowoc was in need of a new supplier, Nitrex, for the nitriding of their oil rings. The purpose of this research was to validate a strategic plan to move the gas nitriding operation from the current supplier Treat All Metals, to a new supplier, Nitrex.

Data Required

When switching suppliers, Federal-Mogul required two quality assurance actions to take place.

The first quality assurance action required was the new supplier's product should be evaluated against the current specifications. This means that the product would be statistically analyzed against the required specifications to ensure product conformance. Federal-Mogul must ensure that the characteristics that could be affected by switching nitriding suppliers were within tolerance. A blue print of the oil control ring was shared between the customer and Federal-Mogul. When the blue print was drawn, both the customer and Federal-Mogul signed off on this blue print, stating that the customer agreed with the specifications, and Federal-Mogul signed off promising they will manufacture the parts to the required specifications. Just holding parts within the blue print specifications was no longer acceptable. Federal-Mogul must show statistical capability to manufacture all the rings within the given specifications.

The other necessary quality assurance action was base line data collection on the current supplier. Long term data was collected on the current supplier to develop a baseline to which the new supplier was compared. Federal-Mogul continually showed statistical capability to achieve the specifications set by the customer. Having a historical base line of data allowed Federal-Mogul to compare the new supplier's results with the current supplier's capability.

Four specifications are normally checked on a nitrided oil ring after the nitriding operation: Free gap, Axial Width, Nitriding Depth (checked on the Outside Diameter (OD), Inside Diameter (ID), and side face of the oil ring), and White Layer Thickness.

Measuring Procedures

Procedures to measure each of the nitrided oil ring specifications are listed below.

Free gap. Free gap was measured on a 20x magnification tool makers microscope with a Mitutoyo digital micrometer head. The digital micrometer head has the capability of reading out to the third decimal place when measuring in millimeters. Free gap was measured from the center of the radial wall of one gap end to the center of the radial wall on other gap end. As shown in Figure 7 as the m dimension.

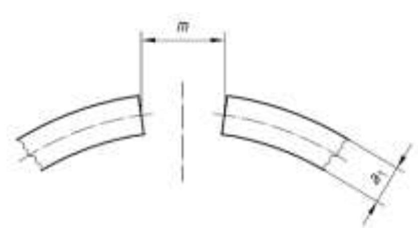


Figure 7. Free Gap (*ISO Standards Handbook*, 2006, p. 53)

Nitriding Depth. Nitriding depth was measured on a digital Vickers hardness machine. Nitriding case depth was checked on the outside diameter, inside diameter, and side face of the oil ring.

Axial Width. Axial width was measured in one location on the oil ring. All axial width measurements were taken 180° from the oil ring gap end and centered on the oil ring radial wall. Axial width was measured on a Mitutoyo width gage that has 1μm resolution. Axial width is depicted as h_1 in the cross section as shown in Figure 8.

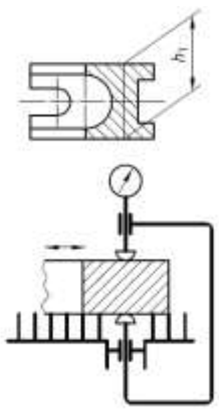


Figure 8. Axial Width (*ISO Standards Handbook*, 2006, p. 50)

White Layer. White layer was measured by cross sectioning the oil ring and measuring under a microscope. Oil rings were evaluated under a magnification of 200x. The measurement gage is capable of reading white layer thickness to 1μm. Each oil ring was cross sectioned in one location, 180° from the gap ends.

Data Collection

The first set of data collected was baseline data on the oil rings before nitriding. This data was collected to determine the change in axial width from the nitriding operation, as well as the change in free gap from nitriding. Fifty random rings were pulled from five production shop orders from June 4, 2012 to June 25, 2012. The average lot size of a production order was 1,700 oil rings.

The second set of data collected was baseline data on the oil rings after nitriding, from the current supplier. The following features were measured:

- Free Gap: 50 random rings from 5 production orders from June 4, 2012 to August 30, 2012.
- Axial Width: 50 random rings from 5 production orders June 4, 2012 to August 30, 2012.
- Nitriding Case Depth and White Layer: 4 random rings were cross sectioned from 5 production orders June 4, 2012 to August 30, 2012. Nitriding case depth was measured on the OD, ID, and the side face of the ring. White Layer was measured on the ID of the oil ring.

The third data set included measurements after nitriding from the new supplier. The following features were measured:

- Free Gap: 50 random rings from each trial order received.
- Axial Width*:* 50 random rings from each trial order received.
- Nitriding Case Depth and White Layer: 4 random rings were cross sectioned from each trial order received. Nitriding case depth was measured on the OD, ID, and the side face of the ring. White Layer was measured on the ID of the oil ring.

A Microsoft Excel audit sheet was developed to record and track all data collected. The audit sheet was printed and the audit results were written in the spaces provided. Once the audit was complete, the data was entered into Minitab for analysis. Figure 9 shows an example of the audit sheet used.

Part Number: ____________

Order Number: ____________

Before Nitriding ✓

After Nitriding ☐

Ring Number	Free Gap	Axial Width
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		

Figure 9. Audit Sheet.

Data Analysis

After the data was collected, data analysis commenced. Each one of the data sets was first examined for normality. Running and successfully passing a normality test will help to ensure the data collected was normally distributed. Having normally distributed data allows Federal-Mogul to minimize risks associated with having a non-stable process while accepting a certain probability value (P-Value). Federal-Mogul currently uses a P-Value of 0.05 for acceptance. This means that if the P-Value is 0.05, or higher, Federal-Mogul will consider the data to be normal. Each data set normality test was completed in Minitab. An example of a Minitab normality test is shown in Figure 10. In this example data, the P-Value (0.335) is larger than 0.05, so we would consider this data be normal.

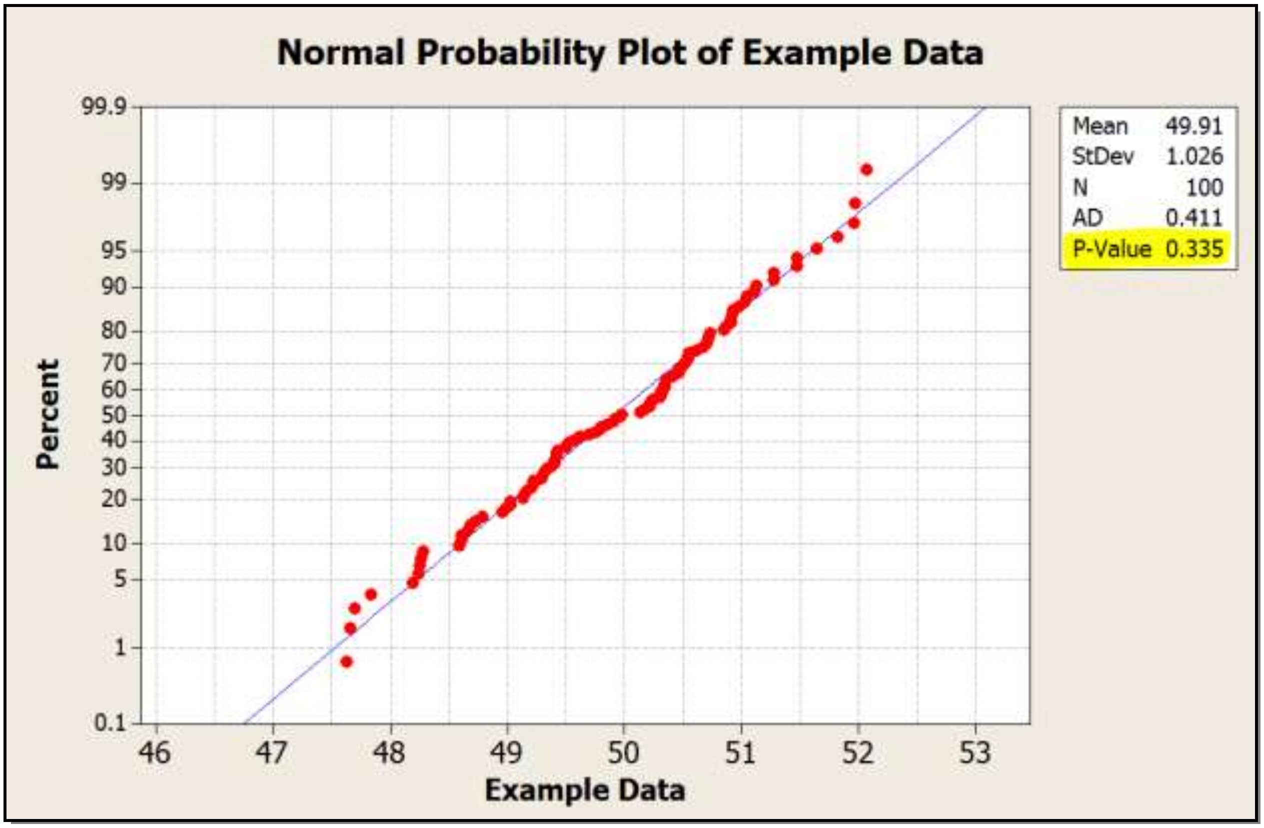


Figure 10. Example of Normal Data.

After normality tests were completed, each of the three data sets were analyzed to determine the mean and standard deviation for each feature measured. Minitab software was used to calculate each statistic.

Once the mean and standard deviations were determined, a two sample t-test was conducted to reinforce the following null hypothesis: There is no statistical difference between the oil rings nitrided at Treat All Metals and the oil rings nitrided at Nitrex. The alternative hypothesis was that there is a statistical difference between each of the suppliers and further investigation will be needed. Federal-Mogul's standard is to use a P-value of 0.05 for running t-tests. If the P-value is over 0.05 the null hypothesis will be accepted. If the P-value is lower than

0.05, the null hypothesis will be rejected. Each of the two sample t-tests were completed in Minitab.

Summary

Throughout this chapter the methodology of research was presented. Data collection processes were discussed as well as the measuring procedures. Data analysis techniques were also discussed to accurately validate the findings and allow Federal-Mogul to have confidence in their decisions. In Chapter IV, the results of the nitriding trials will be discussed.

Chapter IV: Results

Federal-Mogul Powertrain Systems, Manitowoc Division, is a manufacturer of world class piston rings. Federal-Mogul was seeking to switch the nitriding source for one of their oil control rings from Treat All Metals to Nitrex. An introduction to the problem was given and then a review of literature was conducted. After this foundation of information was formed, the methodology of evaluation was detailed. In this chapter we will examine the results of all data collected.

The first step to validate Nitrex as a supplier was to collect baseline data on the oil rings before nitriding. This data was used to determine the change in axial width and the change in free gap caused by the nitriding operation. Fifty random rings were pulled from five production shop orders from June 4, 2012 to June 25, 2012. A Microsoft Excel audit sheet was developed to help record and keep track of all data collected. The audit sheet was printed and the audit results were written in the spaces provided. Once the audit was complete, the data was entered into Minitab for analysis. Figure 11 shows a completed audit sheet.

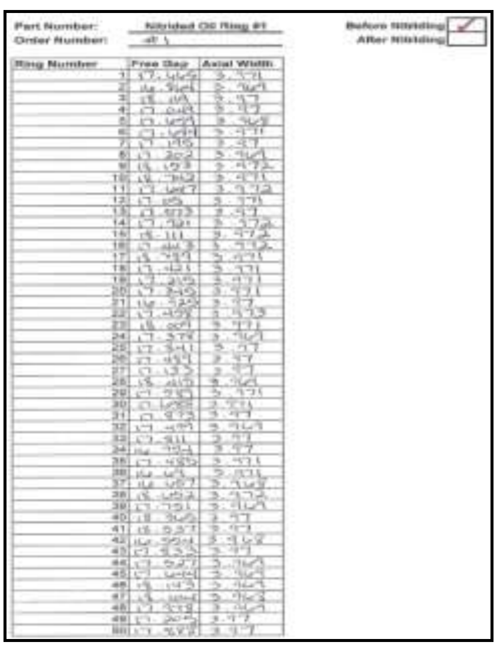


Figure 11. Completed Audit Sheet.

After the pre-nitriding data was entered into Minitab, an individual value plot was generated to provide an overview of the data. Federal-Mogul uses individual value plots to visually evaluate the data collected, looking for abnormal results. It was difficult to examine each of the readings collected from all five shop orders, but an individual value plot gave a snapshot of the results. See Figure 12 for the free gap data and Figure 13 for the axial width.

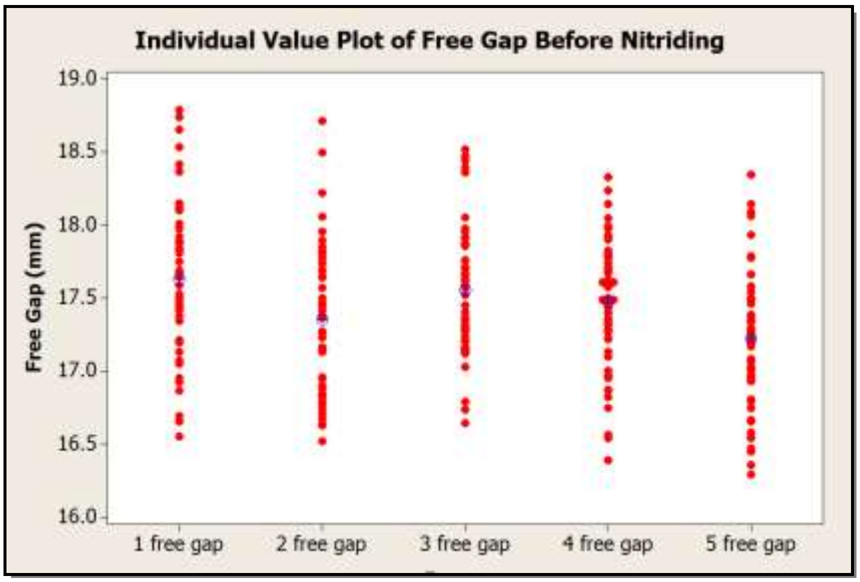


Figure 12. Individual Value Plot of Free Gap Before Nitriding.

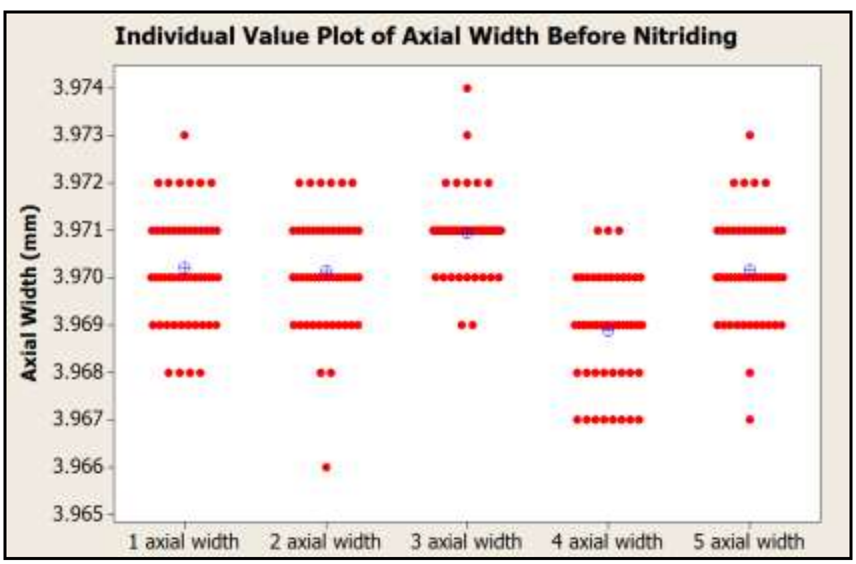


Figure 13. Individual Value Plot of Axial Width Before Nitriding.

The individual value plots for free gap and axial width were acceptable. There was no abnormal data found visually. Causes for concern would include an odd reading that flies out of the normal range of data. This data looked to have a normal distribution. The individual value plot was only a visual snapshot of the data, so normality tests were then completed to confirm this fact using statistics.

Running and successfully passing a normality test helped ensure the data collected was normally distributed. Having normally distributed data allows Federal-Mogul to minimize risks associated with having a non-stable process while accepting a certain probability value (P-Value). Federal-Mogul used a P-Value of 0.05 for acceptance. This means that if the P-Value is 0.05, or higher, Federal-Mogul will consider the data to be normal. A normality test was completed all five orders. Figure 14 shows a normality test conducted on the free gap results of order number two.

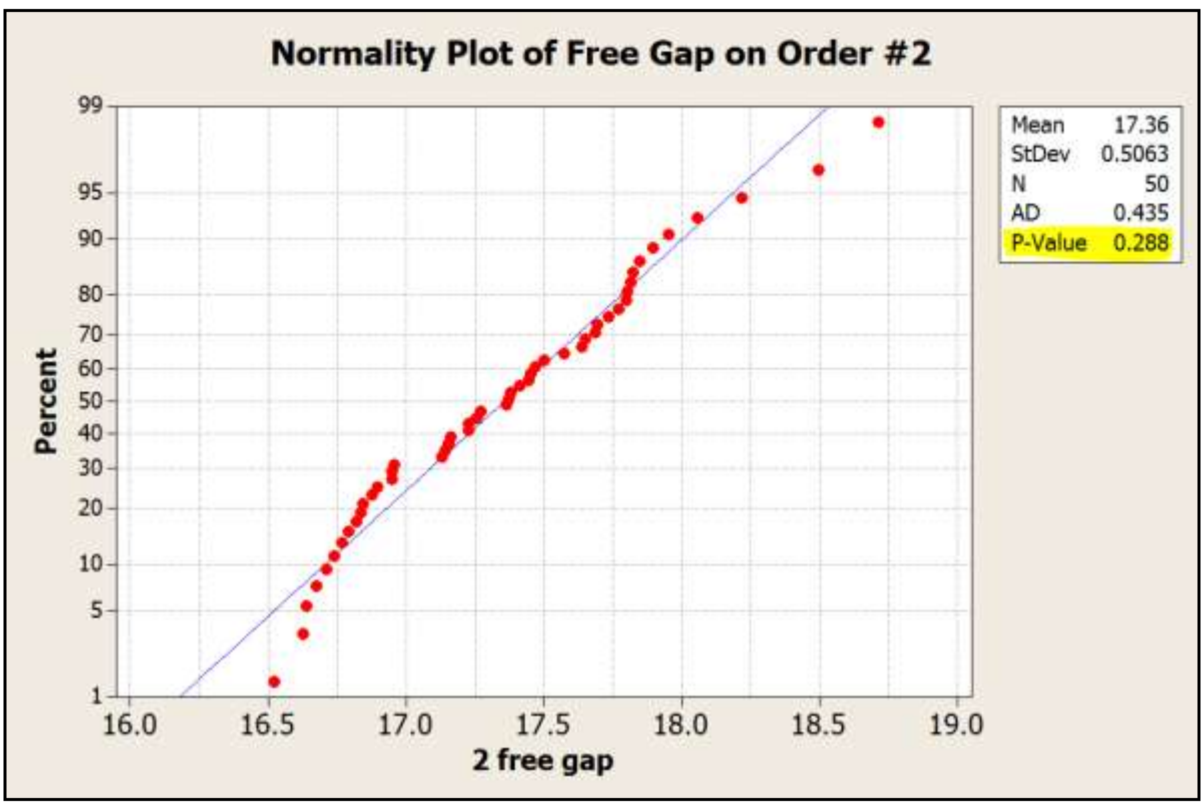


Figure 14. Normality Plot of Free Gap on Order #2.

The P-value of 0.288 is greater than 0.05. Federal-Mogul considered this data to be normally distributed. Normality tests were then completed on the remaining data. The results of the tests were summarized in Figure 15. The results showed each P-Value to be greater than 0.05, so all data collected was normally distributed.

Normality - Before Nitriding	
Order #	Free Gap P-Value
1	0.950
2	0.288
3	0.175
4	0.572
5	0.890

Figure 15. Normality Plot Results.

Once the data collected was determined to be normally distributed, descriptive statistics were calculated on free gap and axial width. These values were used to determine the change in axial width and the change in free gap from the nitriding operation. The descriptive statistics are listed in Figure 16. Federal-Mogul was interested in the mean value, as this value was used to determine the average change in free gap and axial width due to the nitriding operation.

Descriptive Statistics: Free Gap, All Rings, Axial Width, All Rings

Variable	Total Count	Mean	StDev	Minimum	Maximum	Range
Free Gap, All Rings	250	17.447	0.502	16.293	18.789	2.496
Axial Width, All Rings	250	3.9701	0.00128	3.9660	3.9740	0.00800

Figure 16. Descriptive Statistics Before Nitriding.

After the pre-nitriding data was collected, data collection began on the existing supplier Treat All Metals. The first item measured was free gap. Fifty random rings from five production orders from June 4, 2012 to August 30, 2012 were audited and analyzed in Minitab. Individual value plots were generated to visually examine the data. The data appeared normal with no fliers found, Figure 17.

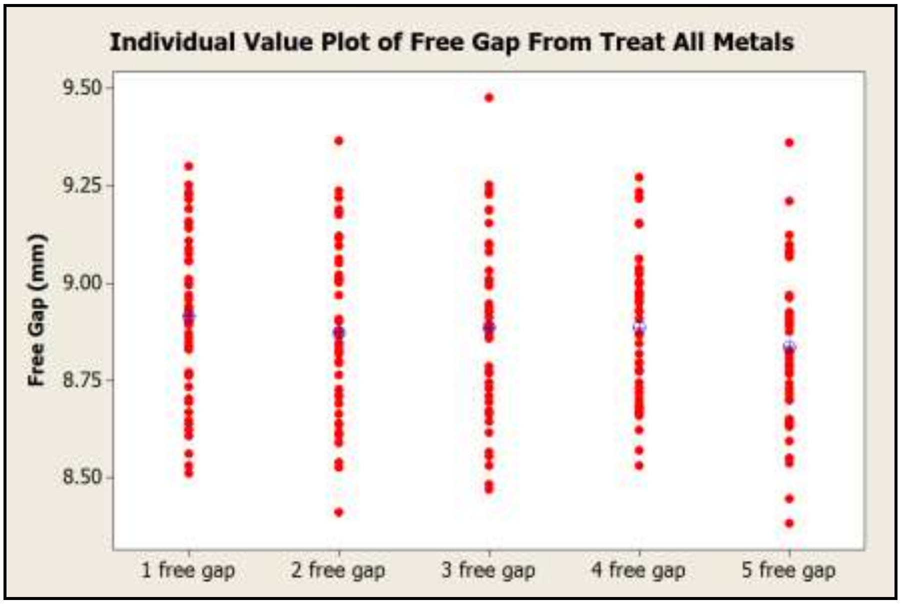


Figure 17. Individual Value Plot of Free Gap From Treat All Metals.

Axial Width was then collected on fifty random rings from five production orders from June 4, 2012 to August 30, 2012. Individual value plots were generated in Minitab to visually examine the data. Figure 18 shows the axial width with normal variation found.

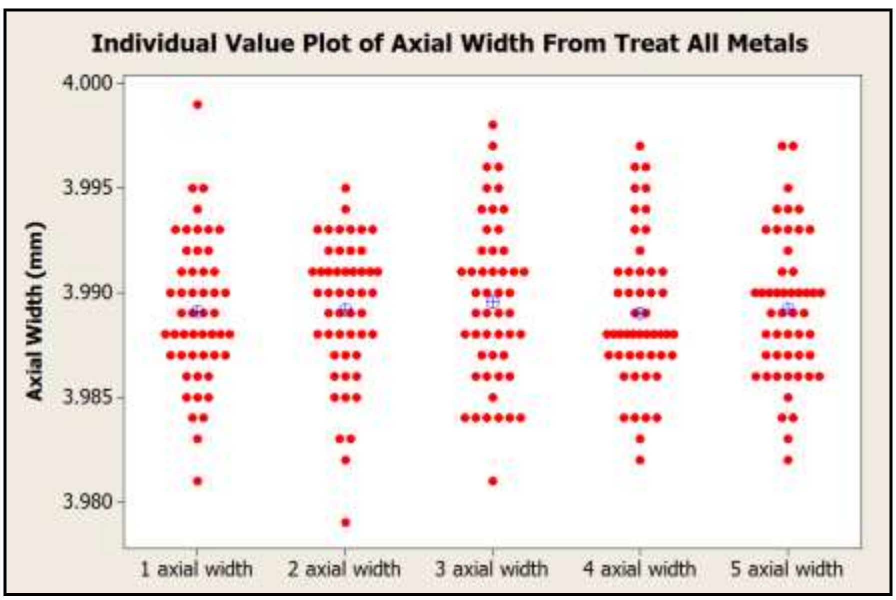


Figure 18. Individual Value Plot of Axial Width From Treat All Metals.

Nitriding case depth and white layer thickness were then measured from orders received from Treat All Metals. Four random rings were cross sectioned from five production orders spanning June 4, 2012 to August 30, 2012. Nitriding case depth was measured on the outside diameter, inside diameter, and the side face of the oil ring. White Layer was measured on the inside diameter of the oil ring. These four random rings were selected from the beginning of the shop order, first third of the shop order, second one-third of the shop order, and the last rings on the shop order. The data collected was summarized in Figure 19. The data shows all values and all shop orders to be within specification. This data was then used to compare Treat All Metals to Nitrex.

Descriptive Statistics: OD Nitriding, OD Nitriding, OD Nitriding, ...

Variable	Total Count	Mean	StDev	Minimum	Maximum	Range
OD Nitriding 1	4	117.42	2.12	114.92	120.08	5.16
OD Nitriding 2	4	124.87	4.83	118.07	129.04	10.97
OD Nitriding 3	4	121.28	7.11	116.26	131.79	15.52
OD Nitriding 4	4	119.45	4.13	113.74	123.16	9.42
OD Nitriding 5	4	119.85	2.03	117.85	121.89	4.04
OD All Rings	20	120.57	4.71	113.74	131.79	18.05
ID Nitriding 1	4	104.29	5.12	100.16	111.59	11.43
ID Nitriding 2	4	101.99	4.70	99.44	109.04	9.60
ID Nitriding 3	4	102.85	4.09	100.20	108.94	8.74
ID Nitriding 4	4	103.34	5.90	94.98	108.25	13.27
ID Nitriding 5	4	104.88	5.17	97.54	108.51	10.97
ID All Rings	20	103.47	4.59	94.98	111.59	16.61
Side Nitriding 1	4	103.92	6.48	98.40	112.87	14.47
Side Nitriding 2	4	106.21	2.85	102.85	109.09	6.24
Side Nitriding 3	4	103.72	3.82	99.68	108.74	9.06
Side Nitriding 4	4	102.70	5.22	95.05	106.47	11.42
Side Nitriding 5	4	106.62	11.01	93.94	120.33	26.39
Side All Rings	20	104.63	6.01	93.94	120.33	26.39

White Layer

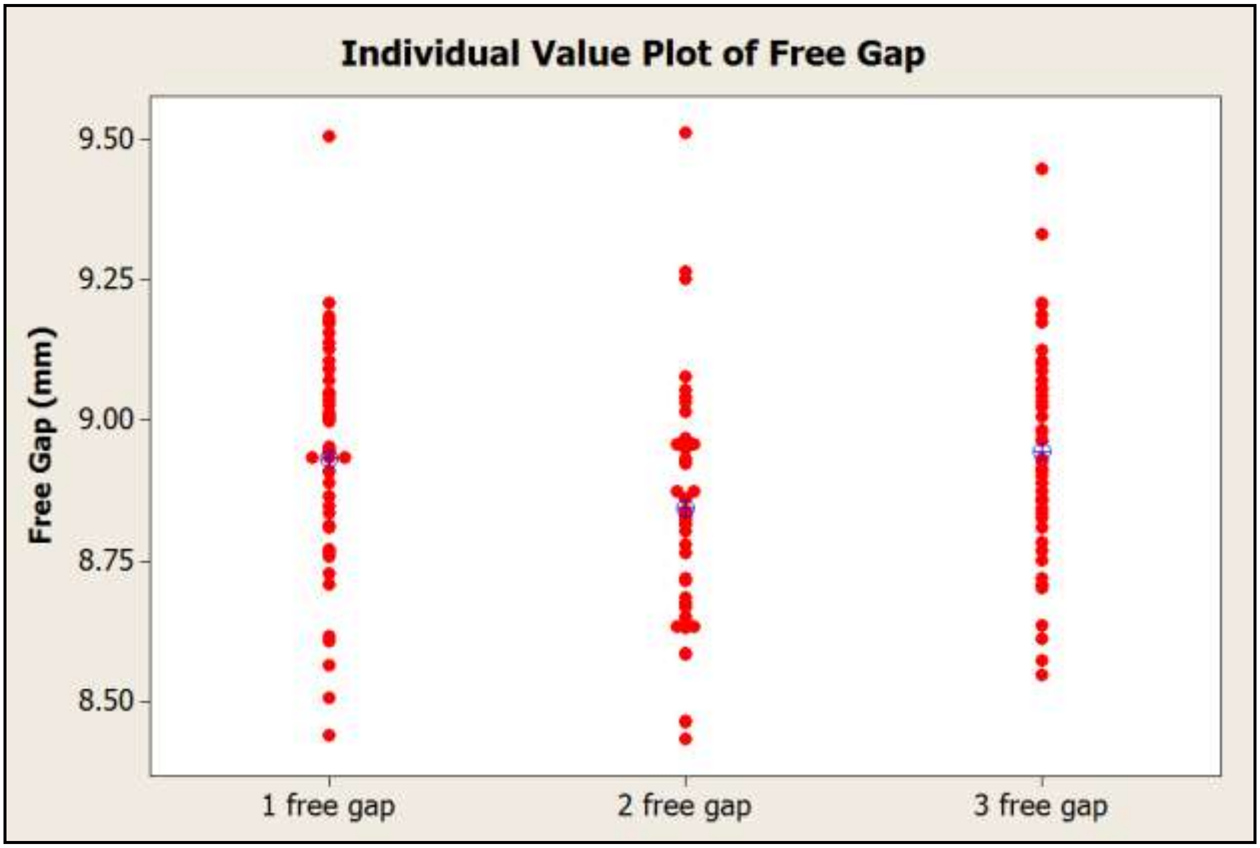
Descriptive Statistics: Order 1, Order 2, Order 3, Order 4, Order 5, All Orders

Variable	Total Count	Mean	StDev	Minimum	Maximum	Range
Order 1	4	0.009500	0.001732	0.008000	0.011000	0.003000
Order 2	4	0.013000	0.001633	0.011000	0.015000	0.004000
Order 3	4	0.01100	0.00356	0.00600	0.01400	0.00800
Order 4	4	0.009500	0.001732	0.008000	0.012000	0.004000
Order 5	4	0.00925	0.00250	0.00600	0.01200	0.00600
All Orders	20	0.010450	0.002544	0.006000	0.015000	0.009000

Figure 19. Nitriding Results From Treat All Metals.

Trials then began with Nitrex to develop a process, furnace program, and recipe that met or exceeded the Treat All Metal results. Federal-Mogul shipped Nitrex hundreds of oil rings, at no cost, for this development work. After three months of nitriding trials, a suitable set of parameters were found. Federal-Mogul then shipped Nitrex three production size trial orders.

The three production size sample orders were nitrided, sent back to Federal-Mogul, and data collection commenced. The first specification measured was free gap. Fifty random rings were measured from each of the three trial orders received. This data was plotted in an individual value plot, checked for normality, and summarized in Figure 20. The data appeared normal, and passed the normality tests in Minitab.

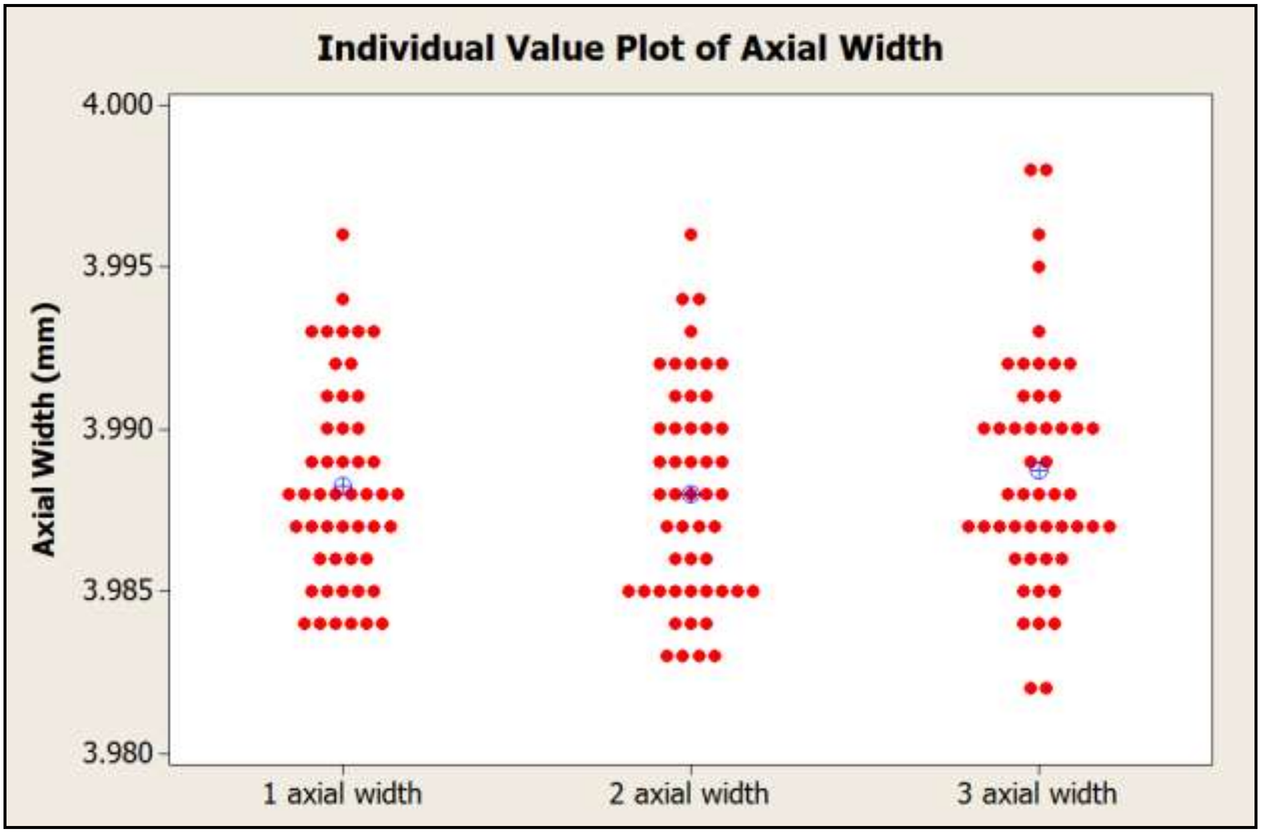


Descriptive Statistics: 1 free gap, 2 free gap, 3 free gap, All Free Gap

Variable	Total Count	Mean	StDev	Minimum	Maximum	Range
1 free gap	50	8.9316	0.2004	8.4390	9.5060	1.0670
2 free gap	50	8.8428	0.2155	8.4320	9.5130	1.0810
3 free gap	50	8.9456	0.1914	8.5460	9.4490	0.9030
All Free Gap	150	8.9066	0.2064	8.4320	9.5130	1.0810

Figure 20. Free Gap Results From Nitrex.

Axial width was then measured on fifty random rings from each of the three trial orders received. Each of the orders were plotted in an individual value plot, and the data was summarized. Figure 21 contains the axial width results with normal variation found.



Descriptive Statistics: 1 axial widt, 2 axial widt, 3 axial widt, Axial Width,

Variable	Total Count	Mean	StDev	Minimum	Maximum	Range
1 axial width	50	3.9883	0.00307	3.9840	3.9960	0.0120
2 axial width	50	3.9880	0.00331	3.9830	3.9960	0.0130
3 axial width	50	3.9887	0.00357	3.9820	3.9980	0.0160
Axial Width, All Rings	150	3.9883	0.00332	3.9820	3.9980	0.0160

Figure 21. Axial Width Results From Nitrex.

The last parameters evaluated from Nitrex were the nitrided case depth. For this evaluation, four random rings were cross sectioned from each trial order received. Nitriding case depth was measured on the outside diameter, inside diameter, and the side face of the ring. White Layer was measured on the inside diameter of the oil ring. Figure 22 captured all the data. The data shows all values and all shop orders to be within specification. This data was then used to compare Nitrex to Treat All Metals.

Descriptive Statistics: OD Nitriding, OD Nitriding, OD Nitriding, ...

Variable	Total Count	Mean	StDev	Minimum	Maximum	Range
OD Nitriding 1	4	117.78	3.36	114.45	122.30	7.85
OD Nitriding 2	4	118.85	8.72	106.80	127.51	20.71
OD Nitriding 3	4	124.38	5.23	117.98	130.13	12.15
OD All Rings	12	120.34	6.36	106.80	130.13	23.33
ID Nitriding 1	4	107.65	5.87	101.06	113.42	12.36
ID Nitriding 2	4	104.77	3.58	100.37	108.80	8.43
ID Nitriding 3	4	107.28	3.79	101.63	109.80	8.17
ID All Rings	12	106.57	4.31	100.37	113.42	13.05
Side Nitriding 1	4	101.46	1.75	99.52	103.63	4.11
Side Nitriding 2	4	100.74	2.04	98.56	103.38	4.82
Side Nitriding 3	4	97.88	3.78	94.50	102.07	7.57
Side All Rings	12	100.03	2.91	94.50	103.63	9.13

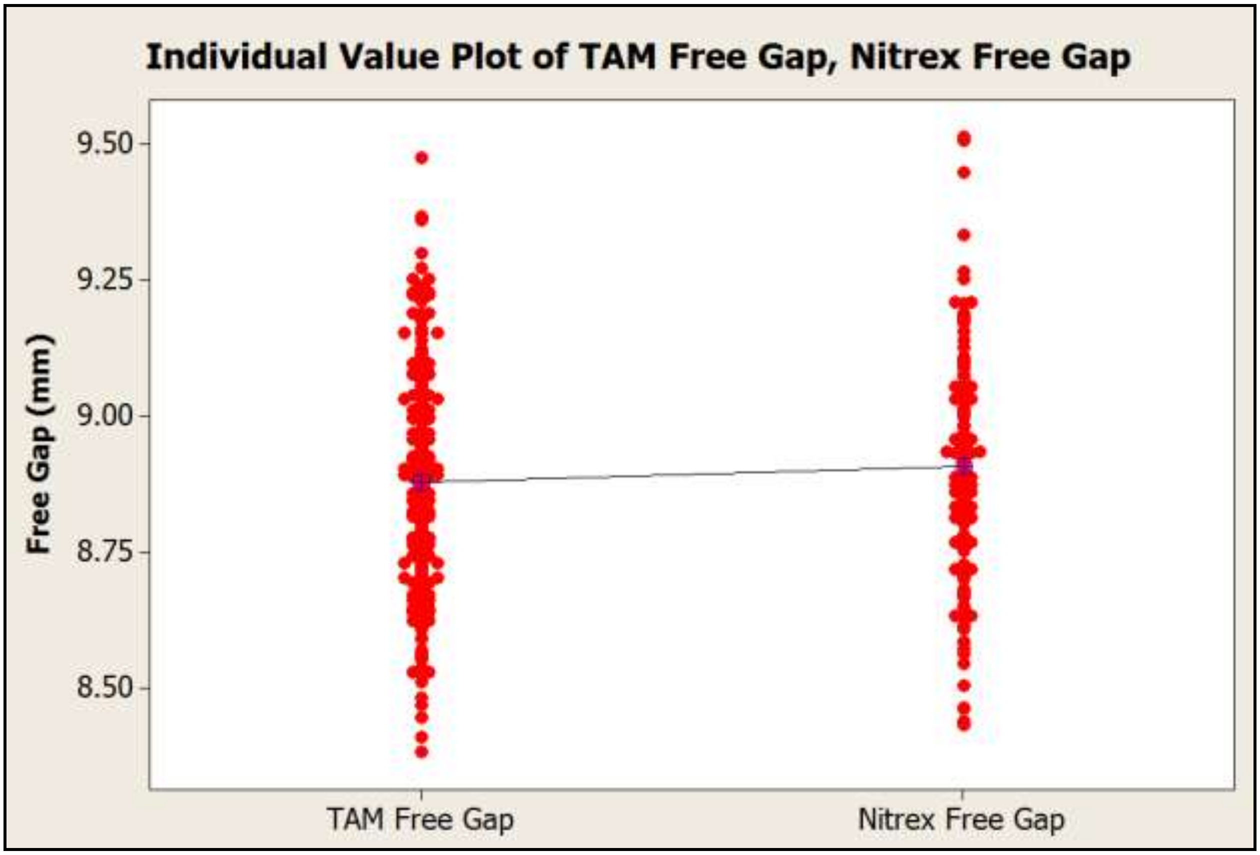
Descriptive Statistics: Order 1, Order 2, Order 3, All Orders

Variable	Total Count	Mean	StDev	Minimum	Maximum	Range
Order 1	4	0.008250	0.000957	0.007000	0.009000	0.002000
Order 2	4	0.00750	0.00332	0.00300	0.01100	0.00800
Order 3	4	0.00825	0.00206	0.00600	0.01100	0.00500
All Orders	12	0.008000	0.002132	0.003000	0.011000	0.008000

Figure 22. Nitriding Results From Nitrex.

All of this data was then compiled and two sample t-tests were conducted to reinforce the following null hypothesis: There was no statistical difference between the oil rings nitrided at Treat All Metals and the oil rings nitrided at Nitrex. The alternative hypothesis was that there was a statistical difference between each of the suppliers and further investigation will be needed. Federal-Mogul's standard is to use a P-value of 0.05 for running t-tests. If the P-value was over 0.05 the null hypothesis will be accepted. If the P-value is lower than 0.05, the null hypothesis will be rejected. Each of the two sample t-tests were completed in Minitab.

The first specification reviewed was free gap. Above documented data assures the data was normally distributed and acceptable for Minitab analysis. A two sample t-test was conducted on all of the data/orders nitrided at Treat All Metals and Nitrex. Figure 23 displays the results of the two sample t-test. The individual value plot shows the data mean values to be very close. The dispersion in the data is also similar from Treat All Metals and Nitrex.



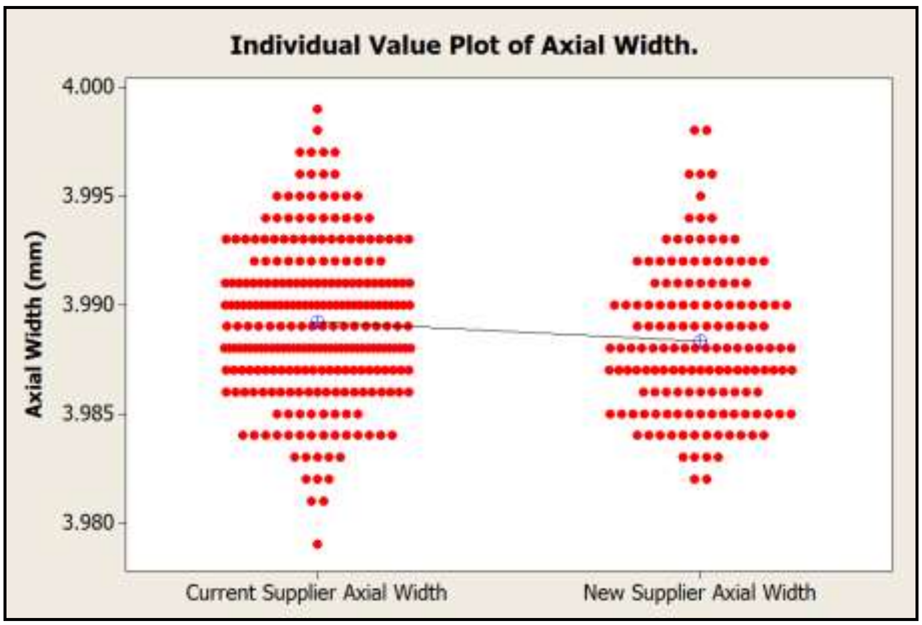

```
Two-sample T for TAM Free Gap vs Nitrex Free Gap

                    N   Mean  StDev  SE Mean
TAM Free Gap      250  8.879  0.205    0.013
Nitrex Free Gap   150  8.907  0.206    0.017


Difference = mu (TAM Free Gap) - mu (Nitrex Free Gap)
Estimate for difference:  -0.0281
95% CI for difference:  (-0.0700, 0.0137)
T-Test of difference = 0 (vs not =): T-Value = -1.32  P-Value = 0.187  DF = 312
```
Figure 23. Two Sample T-Test for Free Gap.

The data shows that the P-Value of 0.187 to be higher than the Federal-Mogul standard of 0.05. This means Federal-Mogul will accept the hypothesis that there is no statistical difference between the oil rings nitrided at Treat All Metals and the oil rings nitrided at Nitrex for free gap.

The next specification analyzed was axial width. A two sample t-test was conducted with the following null hypothesis: There was no statistical difference between the axial width on oil rings nitrided at Treat All Metals and the axial width on oil rings nitrided at Nitrex. After looking at the individual value plot for axial width, there appeared to be a slight reduction with the new nitriding supplier. There also appeared to be less variation in axial width using the new supplier.




```
Two-sample T for Current Supplier Axial Width vs New Supplier Axial Width

                            N     Mean    StDev  SE Mean
Current Supplier Axial W  250  3.98921  0.00352  0.00022
New Supplier Axial Width  150  3.98833  0.00332  0.00027


Difference = mu (Current Supplier Axial Width) - mu (New Supplier Axial Width)
Estimate for difference:  0.000881
95% CI for difference:  (0.000192, 0.001571)
T-Test of difference = 0 (vs not =): T-Value = 2.51  P-Value = 0.012  DF = 328
```

Figure 24. Two Sample T-Test for Axial Width.

The data showed that the P-Value of 0.012 to be lower than the Federal-Mogul standard of 0.05. This means Federal-Mogul will reject the hypothesis that there is no statistical difference between the oil rings nitrided at Treat All Metals and the oil rings nitrided at Nitrex for axial width. The alternative hypothesis was that there was a statistical difference between each of the suppliers. In this case, the new supplier's mean axial width after nitriding was lower than the current supplier's axial width after nitriding. This was a positive outcome for Federal-Mogul. The lower axial width on the new supplier oil ring was a result of a lower white layer thickness. This lower white layer thickness was easier to remove at post machining operations.

Results Summary

The first specification analyzed was oil ring free gap. Baseline data was collected before the nitriding operation to determine the amount the free gap was reduced due to nitriding. Comparing the average free gap pre-nitriding to the average free gap post-nitriding, the average reduction in free gap is 8.5mm. The reduction in free gap was consistent between both Treat All Metals and Nitrex.

The post-nitriding free gap readings were then compared between Treat All Metals and Nitrex. A two sample t-test was conducted, and the results showed that there was no statistical difference between the free gap on the oil rings nitrided at Treat All Metals and the oil rings nitrided at Nitrex.

The next specification to be analyzed was nitriding case depth. Four rings, from five production lots, over a three month timeframe, were cross-sectioned and analyzed from Treat All Metals. The average, standard deviation, minimum, maximum, and range were calculated on data collected. The Treat All Metal data was then compared to the specifications. All readings were within specifications. Data collection then began on Nitrex orders. Only three production sized lots were received to date, but the average, standard deviation, minimum, maximum, and range were calculated on each of these orders. The data showed that all oil rings were within specifications, and there was not a statistical difference between the oil rings nitrided at Nitrex and the rings nitrided at Treat All Metals.

The last item to be analyzed was axial width. Fifty random Treat All Metals nitrided oil rings, from five production lots, were gathered over a three month time period. Axial width was measured and recorded in Minitab. Three production lots were then sent to Nitrex, nitrided, and then shipped back to Federal-Mogul. Axial width was then measured and compared to the Treat All Metal nitrided rings. A two sample t-test was conducted to determine if there was a statistical difference in axial width between the rings nitrided a Treat All Metals and the oil rings nitrided at Nitrex. The two sample t-test showed there was a statistical difference between the two suppliers. Data analysis then commenced and it was determined that the mean axial width on the Nitrex oil rings was lower than the axial width of the Treat All Metals oil rings. This reduction in axial width was due to a lower white layer thickness. A thinner white layer was easier to remove at post machining operations. Federal-Mogul considered this reduction in white layer to be benefit to the rings nitrided by Nitrex.

Summary

This chapter presented all data collected from Treat All Metals and Nitrex. Tests were conducted to determine if there was any stastitical difference beween the two suppliers. The only difference found was in axial width. Nitrex had a lower average axial width value compared to Treat All Metals. Although the test failed, the results were in fact beneficial to Federal-Mogul.

The next chapter will review the limitations of the information. Conclusions will be drawn, and recommendations will be made from the study.

Chapter V: Discussion

Federal-Mogul Powertrain Systems in Manitowoc, WI is a world class supplier of piston rings to the heavy duty diesel engine market. Federal-Mogul was looking to develop a new supplier, Nitrex, for the nitriding of their oil rings. The purpose of this research was to validate a strategic plan to move the gas nitriding operation from the current supplier Treat All Metals, to a new supplier, Nitrex.

Chapter I introduced Federal-Mogul as a world class piston ring supplier. Information was presented describing what an oil control ring is, and their function. The current nitriding supplier, Treat All Metals, was introduced and supplier information was documented. A new potential nitriding supplier, Nitrex, was discussed and the advantages of this new supplier were detailed. Later in Chapter I, the selection of Federal-Mogul's team was discussed, and the methodology of making a supplier change was documented.

Literature was researched in Chapter II to provide Federal-Mogul with the best possible information to validate a supplier change. Quality, cost, and delivery considerations were discussed, as well as team member rolls. Research was also conducted on the nitriding process itself. Items documented included what materials can be nitrided, how they are nitrided, and why materials are nitrided. Nitriding by-products, a white layer, was also researched and documented.

Chapter III documented the methodology in which a supplier change would be validated. Oil ring features that needed to be measured were presented. Data collection was only as good as the measuring procedures, so research was conducted to document how to measure each oil ring feature. Examples of the data collection methods were detailed and discussed throughout this chapter.

In Chapter IV, the results of the data collection were documented. The first step to validate Nitrex as a supplier was for Federal-Mogul to collect baseline data on the oil rings before nitriding. This baseline data allowed Federal-Mogul to determine the change in axial width and the change in free gap caused by the nitriding operation. Normality tests were conducted on the data to ensure all oil ring features exhibited normal process variation. After the pre-nitriding baseline data was collected, data analysis commenced on Federal-Mogul's current supplier Treat All Metals. Nitriding case depth was measured on all faces of the oil ring, as well as oil ring free gap and white layer. All results were within established specifications. Trials were then conducted with Nitrex and the same features were measured on the oil rings. Two sample t-tests were conducted to verify there was no statistical difference between the rings nitrided at Treat All Metals and the rings nitrided at Nitrex.

Limitations

As with any research project, there are limitations to what can be studied. The researcher found three such limitations. The first limitation was the length of time for the study. Federal-Mogul was comfortable with the baseline data collected over three months from Treat All Metals. The reason for the confidence was the supplier history with Treat All Metals. Treat All Metals had been supplying Federal-Mogul with nitrided oil rings for seven years. Each of the production lots is audited from Treat All Metals, and nearly zero quality issues had been found. Upon the rare occasion a quality issue was discovered, Treat All Metals had been excellent in rapid resolution and finding permanent corrective actions. Nitrex only completed three production lots for Federal-Mogul Manitowoc. Having only three production lots did not provide Federal-Mogul with enough data to build a history. Each of the lots were within specifications, but more time was needed to build a solid history with Nitrex.

A second limitation was choosing other nitriding suppliers. There are thousands of nitriding suppliers throughout the world. Federal-Mogul chose Nitrex because of their history with other piston ring manufacturing plants. There may be other superior nitriding suppliers, but Federal-Mogul did not look into these. It is beneficial to have all of the piston ring manufacturing plants using one company for nitriding. One worldwide supplier (although multiple locations) helps to eliminate variation, helps in the sharing of lessons learned, and can be a cost benefit. Federal-Mogul chose to limit the potential supplier to just Nitrex.

The last limitation was to explore eliminating nitriding entirely. There were other oil ring wear coatings available within Federal-Mogul. Oil rings can be coated with various types of chrome on outside and inside diameters for wear resistance. Federal-Mogul also offers a physical vapor deposition (PVD) as a wear coating option. Switching to a different oil ring design or a different wear coating was not explored in this study.

Conclusions

Concluding this study, Federal-Mogul was able to validate a new nitriding supplier. Research was conducted on new supplier validation, and data was collected on the current supplier. After baseline data was collected, a new supplier was contacted and trials commenced. Once a nitriding process was established at Nitrex, production lots were nitrided and analyzed. After all the data was collected, Nitrex was compared to Treat All Metals.

Free Gap. As discussed in Chapter IV, free gap measurements were collected from rings before nitriding, after nitriding at Treat All Metals, and after nitriding at Nitrex. The data collected was analyzed for normality, and each of the trials exhibited normal process variation. Federal-Mogul learned that the free gap was reduced from an average of 17.4mm before nitriding to an average of 8.9mm after Treat All Metals nitrided the oil rings. The change in free gap was 8.5mm.

Free gap data was then analyzed from Nitrex. Oil rings nitrided at Nitrex also underwent normality tests and only normal process variation was found. The average free gap after nitriding at Nitrex was also 8.9mm. This gave Federal-Mogul the same 8.5mm reduction in free gap, regardless of supplier. Nitrex had approved free gap readings.

Axial width. Similar to the free gap data, baseline data was collected on rings before the nitriding operation. The baseline data allowed Federal-Mogul to calculate the average growth in axial width due to nitriding. Normality tests were conducted, and all data showed normal process variation. The mean axial width before nitriding was found to be 3.970mm

Two hundred and fifty rings were then measured after nitriding at Treat All Metals. The data was analyzed for variation, and normal process variation was found. The mean axial width was then calculated and returned a value of 3.989mm. Treat All Metals oil rings grew an average of 0.009mm due to nitriding.

One hundred and fifty rings were measured and analyzed from Nitrex. The oil rings nitrided at Nitrex also showed normal process variation, with no fliers found. The mean axial width was 3.988mm. The oil rings Nitrided at Nitrex only grew an average of 0.008mm when compared to 0.009mm when nitrided at Treat All Metals. A two sample t-test confirmed the fact that Nitrex and Treat All Metals were different when comparing axial width. The difference rested with the white layer thickness. Nitrex had a lower white layer thickness than Treat All Metals, resulting in a lower growth in axial width. This lower white layer thickness was a benefit to Federal-Mogul. The white layer was removed at subsequent machining operations, so a thinner coating was easier to remove. Nitrex was approved on axial width.

Nitriding Case Depth. Nitriding case depth was more labor intensive to measure. Measuring nitriding case depth was a destructive test. The oil rings were cross sectioned, placed in a metallurgical mount, and then analyzed under a microscope. Currently, there is not a non-destructive test to measure case depth on all faces of an oil ring. Due to the increased cost and labor, fewer samples were collected from each supplier. Four oil rings were collected from the beginning of each shop order, first third of each shop order, second one-third of each shop order, and the last part of each shop order. Referencing the results from Chapter IV, there was not a statistical difference between Nitrex and Treat All Metals on nitriding case depth. Nitrex was approved for nitriding case depth.

Summary. Nitrex had met and or exceeded all requirements Federal-Mogul had established. The Federal-Mogul team agreed that only a limited number of production sized orders had been nitrided at Nitrex, but Nitrex has been approved to provide additional orders for validation. Each new order received from Nitrex will be heavily analyzed to ensure continued compliance.

Recommendations

The researcher has two recommendations after conducting this study. The first is extending the time of validation. Federal-Mogul does not feel comfortable switching all of their production based upon three orders received from Nitrex. The results are positive, but additional orders must be completed to gain confidence in the new supplier. Long term process capability must also be established with Nitrex.

The final recommendation for future studies is to research the removal of white layer by soaking nitrided parts in an alkaline solution of NaOH and hot water. Federal-Mogul currently uses the traditional method of abrasive blasting the oil rings to remove the white layer. Soaking the rings may prove to be a labor savings for Federal-Mogul. This opportunity for improvement has been discovered through this research.

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