

**ANALYSIS OF DEFECTS ASSOCIATED  
WITH LEAKS ON SKID STEER LOADERS**

by

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## **ABSTRACT**

The CNH Wichita Product Center has had a chronic leak problem with the Skid Steer Loaders. The objective of this project was to analyze the manufacturing plant leak data and make improvements to correct the issue. The objective is twofold: 1) to make process or design improvements on current products produced in the plant and 2) to make recommendations for future designs to prevent such leak issues from reoccurring. The manufacturing data had to be transformed into usable form and then it was analyzed mostly by utilizing Pareto Charts. The highest six problem leak points were chosen from the manufacturing data. Process changes were implemented on these particular leak joints and the results were analyzed using two proportions hypothesis tests. The process changes reduced the leak rate by an average percent reduction of 86 percent. The process changes implemented will also be applied to other similar joints, and results documented in the future. The future design recommendations made from the analyzed data included the increased use of o-ring face seal connections at certain locations and where possible, reducing the number of joints per machine.

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## **CHAPTER I: INTRODUCTION**

There are many types of machinery and industrial devices that use hydraulic components to operate. These vehicles consist of all kinds, from automobiles to agricultural combines. They all have one thing in common; they use hydraulic fluid to operate some feature of the machine. The hydraulic fluid has to be transmitted in some form to the correct component. The normal mode of transmitting the hydraulic fluid is using hoses or hard line tubes. At the end of the components there are fittings that connect them to the next component.

CNH America LLC Wichita Product Center (WPC) is a manufacturing plant located in Wichita, KS. This plant produces construction/agricultural units that are known as Skid Steer Loaders (SSL). Most people are not totally familiar with the term SSL; however most people are familiar with the term “Bobcat”, which is a major manufacturer of SSL’s. WPC has Dealer Arrival Reports (DAR’s) that indicate low customer confidence in quality of CASE brand SSL’s attributed to leaking units. This project will analyze the data available from the WPC’s Quality System, ALSTAR in order to make process and design recommendations to reduce leaks in finished units, and serve to enhance reliability of the product to the customer. WPC also produces New Holland SSL within the same manufacturing plant. The data and analysis for this thesis will focus on the CASE brand SSL, but results and future research could and should be done on the New Holland Brand.

The objective of the project is to analyze fluid system leak data coming from within the manufacturing plant. This analysis will determine steps to be taken to eliminate fluid leaks in two main phases. Phase one will consist of current product quality and overall leak



frequency of production units. Phase two will consist of eliminating potential leaks in future product development.

The main objective of this thesis is to discover the predominant causes that are attributing to fluid system leaks in the CASE SSL's. This project will use data mining and other tools such as process control to determine if there are systematic causes that are generating these defects in finished SSL units. This thesis will analyze the data to confirm or reject that there is statistical evidence that can provide insight on what can be changed in the manufacturing process or design to help eliminate these leaks in the future.

The data available from the manufacturing plant has defects included in the record keeping system which is the focus of this research. For the purpose of this project, a fluid system leak will be defined as any internal or working fluid within a SSL (i.e. hydraulic oil, engine oil, fuel, chain tank oil, coolant, etc.) that has migrated beyond standard boundaries. Residue, drips, pools, or streams, found anywhere on the unit and not caused by overfills or spills, will be considered a leak.

These machines are constructed of many connections depending on their size and complexity and number of options. These types of vehicles are known for their complexity and the amount of components compressed into such a small area. Leaks in machinery of this industry are common, but the need to reduce or eliminate leaks is the intent of the manufacturing company and the end customer.

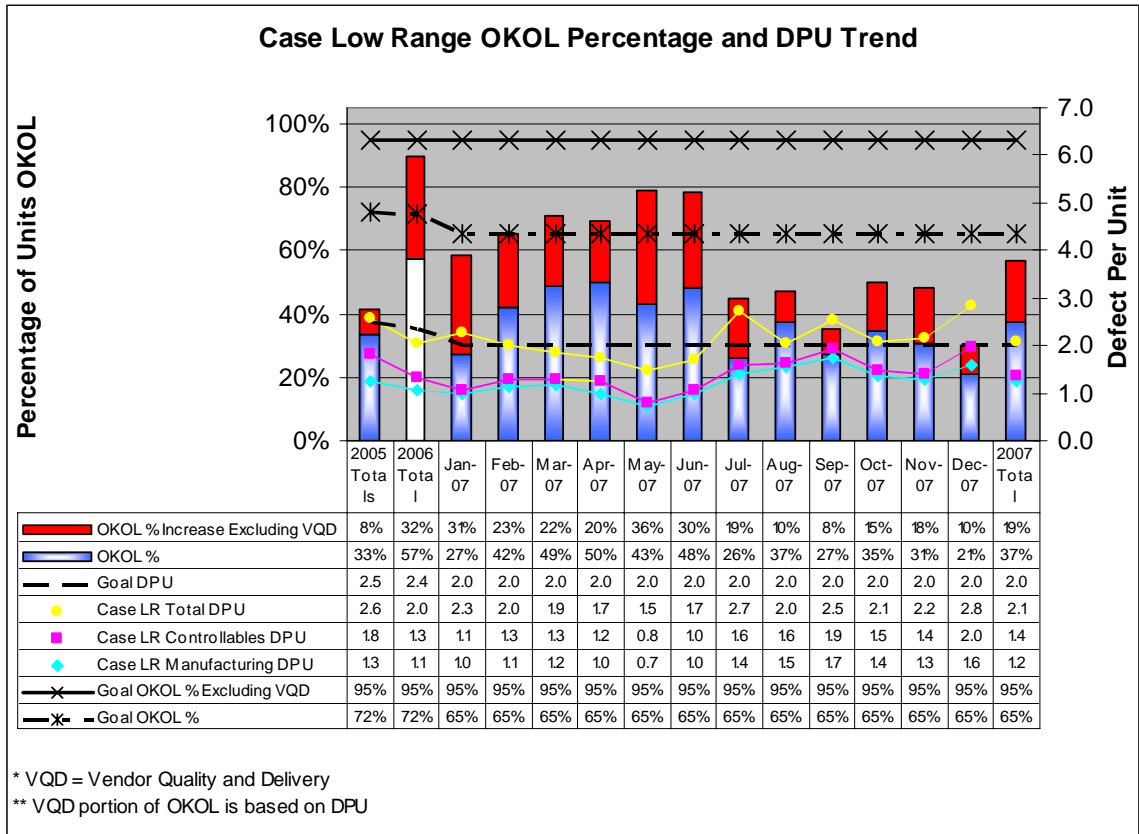
The defect input system that WPC uses is a system called ALSTAR. It is an internal database where unit quality information is stored. All kinds of information about a

unit is stored in the system, such as unit build configuration, load date, serial number of important components like engine, tandem pump, drive motors. ALSTAR also includes information pertaining to defects are stored that are found on the unit that can not be fixed on the assembly line. Most of the time these defects are minor and do not disable the unit from operating. So the unit continues down the assembly line, as any other non-defect unit would.

When the unit comes to the end of the assembly line, it either has defects or does not. If it does have a defect of any kind it is parked in a “rework lot,” if it does not have any defects and is totally complete and ready for shipment to the retail market it is parked in the “sold” lot. There is a term at the plant used to track these rework units versus okay off line units, it is called Okay Off Line (OKOL). This key measure to the plant fluctuates quite a bit, but is typically averages 40 percent. An OKOL of 40 percent means that, on average, 60 percent of the units have to be brought back into the plant to have at least one defect repaired on them. Leaks are only part of these quality defects that have to be repaired, but they are a major concern for the plant and its downstream customers. Figure 1.1 shows CASE SSL OKOL tracking. The overall OKOL is shown with the blue bars; the data are also reported in the table below the chart. For example, Jan 07 had an OKOL of 27 percent and the overall 2007 average is 37 percent. The OKOL percentage uses the left axis of the chart. The OKOL average per month is never the same, but it is also trending downward, which is opposite of what is desired. This figure also shows Defects per Unit, of the units that come off line with defects. The overall defects per unit is shown with the

yellow line, referenced on the right axis for this metric. The Defects per Unit are trending upward for most of the year, which is also the opposite of what is desired.

**Figure 1.1 CASE SSL Total Okay Off Line 2007**



All defect information is stored in the ALSTAR database system. This system is live at all times, and is ever changing. When a unit is completely done and all defects have been repaired, the system is typically not changed again for that unit. The information can be sorted out of the system at any time; however the repair information will not be there until the machine is repaired. The repairs of the units typically occur in the two weeks following the build date. The leak team then sorts the data out of ALSTAR for the defects that are attributed to leaks. ALSTAR has been at use in WPC for about two years, but true

leak data with the leak points identified has only been available from September 2006 to the present.

In order to classify the fluid leak defects, the leak team has identified almost every connection in the SSL with an independent number. That number is entered into ALSTAR when the defect is found. The identification number helps the fluid system leak team to understand where exactly in the machine the leak is coming from. There are a few generic numbers that can be used to write up a possible defect, for example the number 555 is to steam clean the unit again and no leak was found at that location. There are also generic numbers for the lift cylinders and loader valve areas, but most leak location numbers are independent locations in the machine.

There are a tremendous number of variables and conditions that can contribute to leaks in SSL. The leak team brainstormed about the many possible items that could lead to a leak in a finished unit. These possible attributors were listed on a Cause and Effect Diagram, or what is commonly referred to as a Fishbone Diagram. The items were classified into three main groups: Fittings and Hydraulics Leaks, Chain Tank and Weld Leaks, and Engine and Coolant Leaks (Figures 1.2-1.4).

**Figure 1.2 Fitting and Hydraulics Leaks**

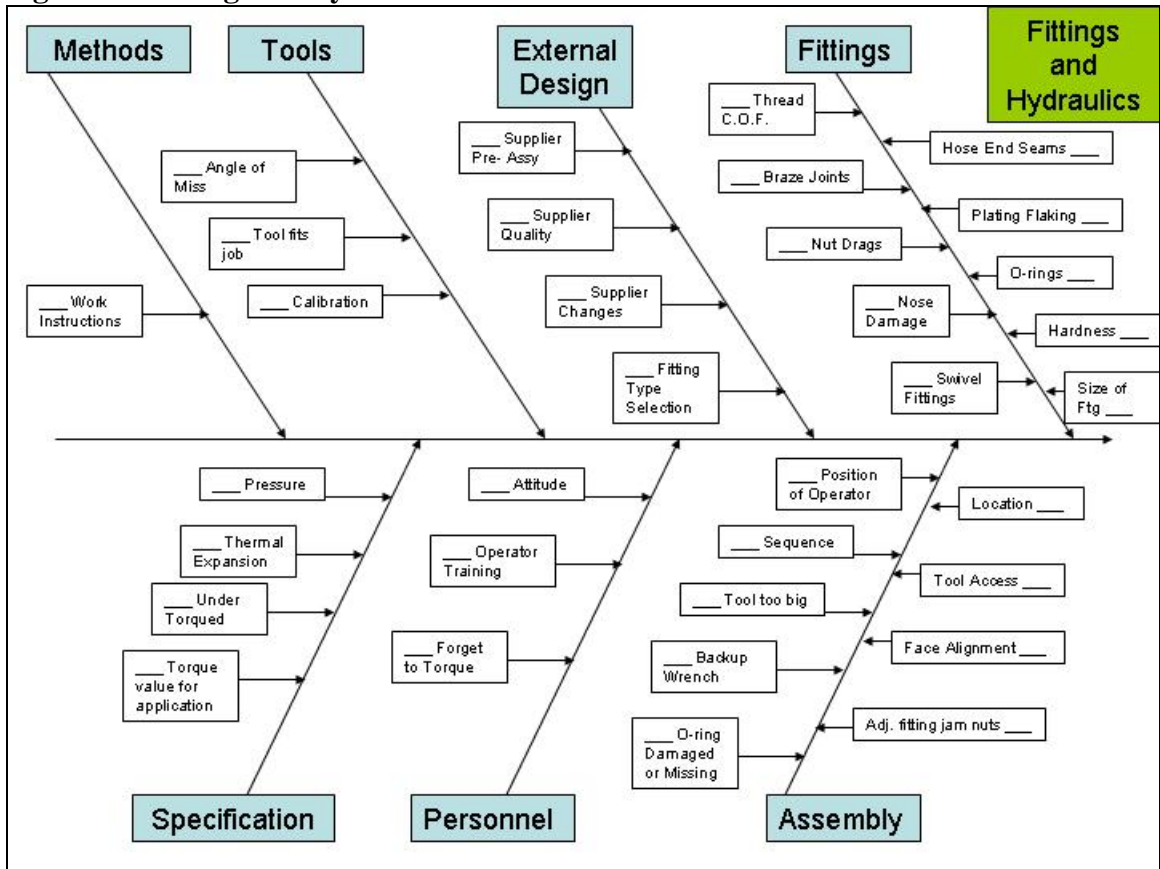


Figure 1.2 shows all the possible causes for the hydraulic fitting leaks that were identified by the leak team. Each joint in the machine could have each of these causes that affect it, or it might just have a couple. Each joint has its own opportunities for leak and should be analyzed separately. Many of these causes are hard to measure as well, but this is the starting place to at least identify them.

Figure 1.3 Chain Tanks and Weld Leaks

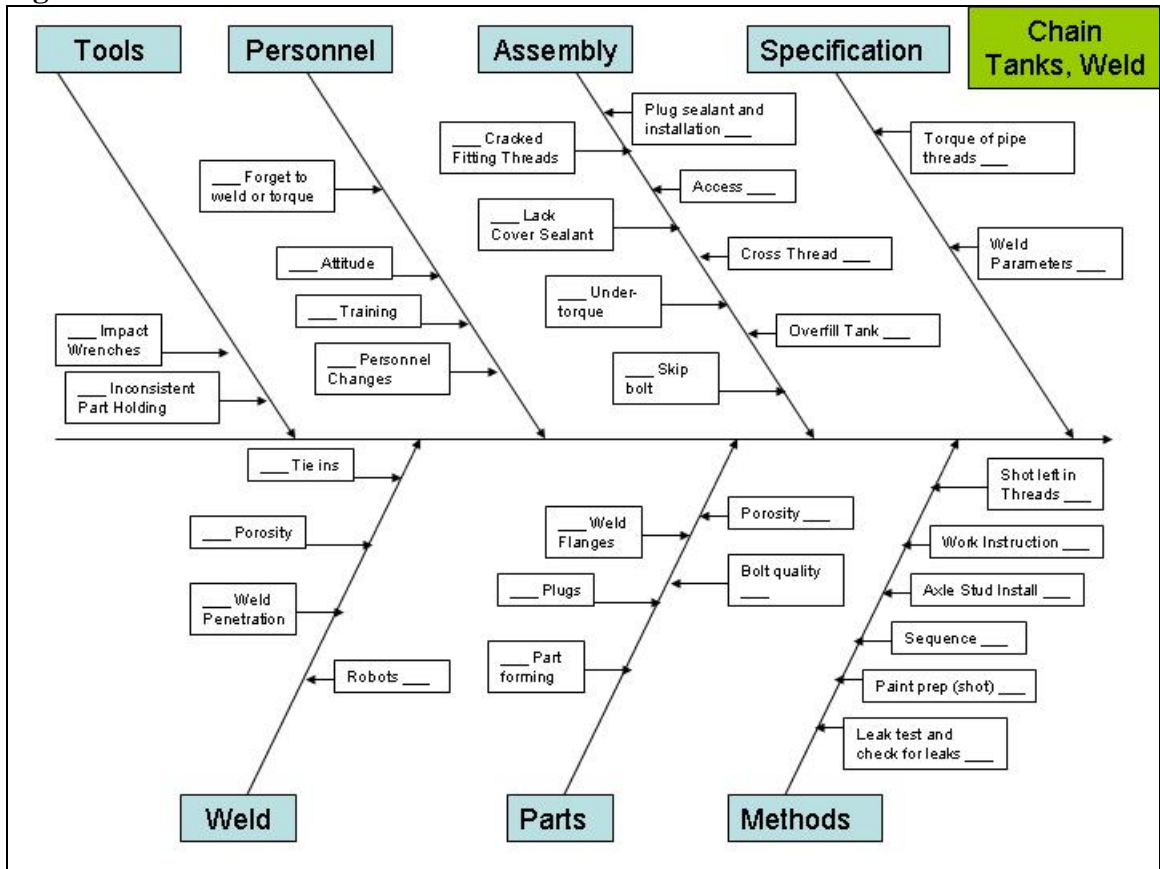


Figure 1.3 shows all the causes that were identified by the leak team for chain tanks and weld operations. Again not all of these causes go with all leak points, so each joint should be analyzed to determine the causes for it.

**Figure 1.4 Engine and HVAC Leaks**

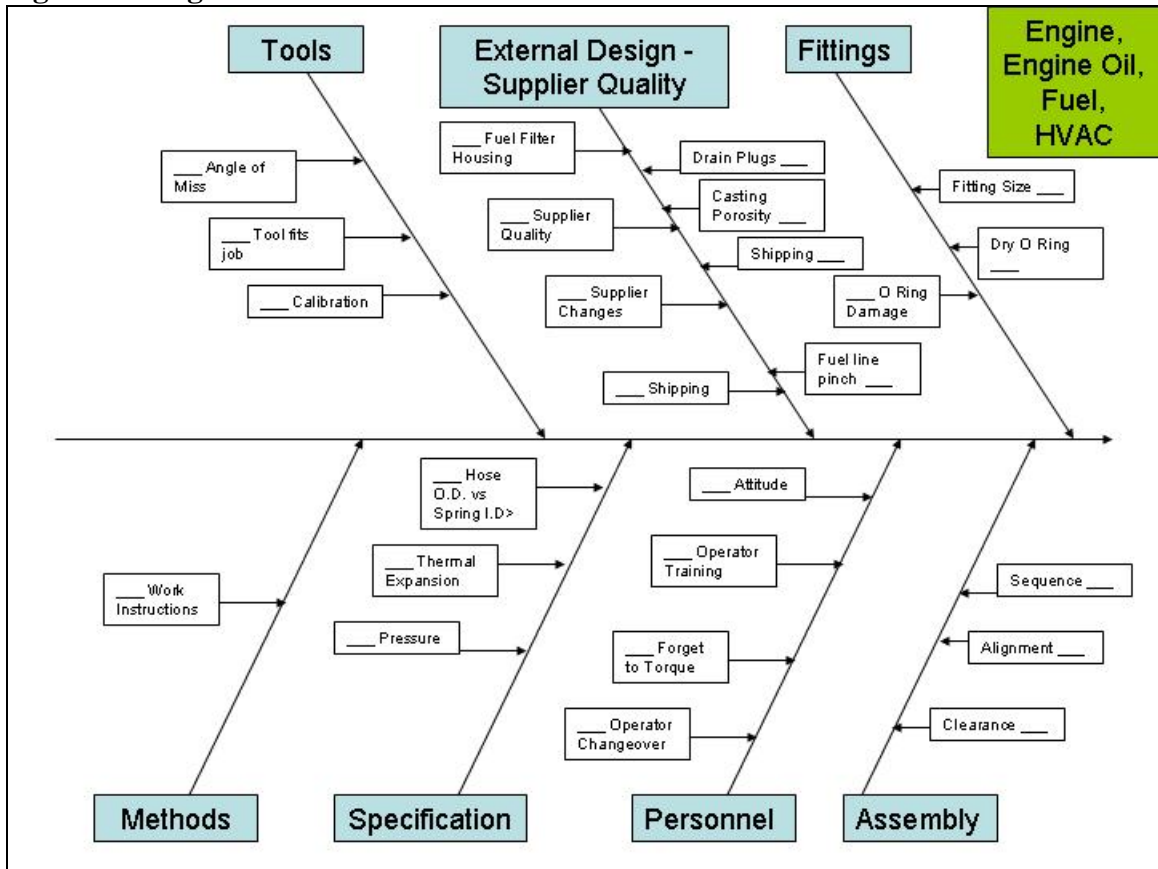


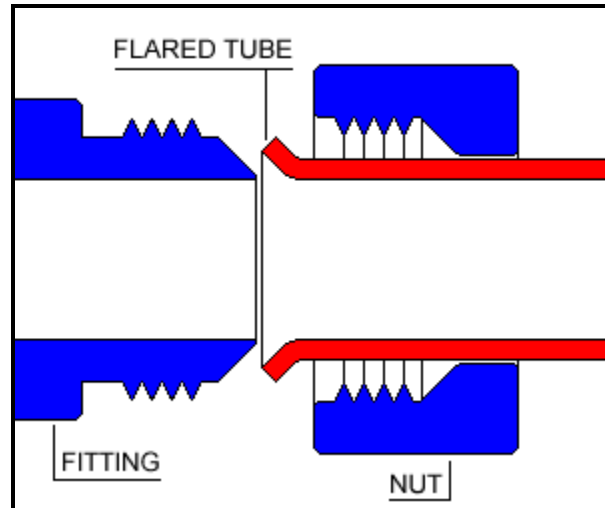
Figure 1.4 shows all the causes that the leak team identified for engine, engine oil, fuel, HVAC. Again not all of these causes go with all leak points, so each joint should be analyzed to determine the causes for it.

### 1.1 Types of Connections

There are many kinds of different fluid system fittings used in the industry today. The most common, and one of the least expensive is known as a flare fitting, commonly known as JIC. Typically these flare fittings have an angled flare of 37 degrees, and are flared on both mating components. This is a metal to metal joint, which under ideal conditions works very well. There is no o-ring to help seal the joint between the two

components. The surfaces have to be free of burrs or any other fails in order to get a good tight leak-free joint (Figure 1.5).

**Figure 1.5 37 Degree Flare Connection**



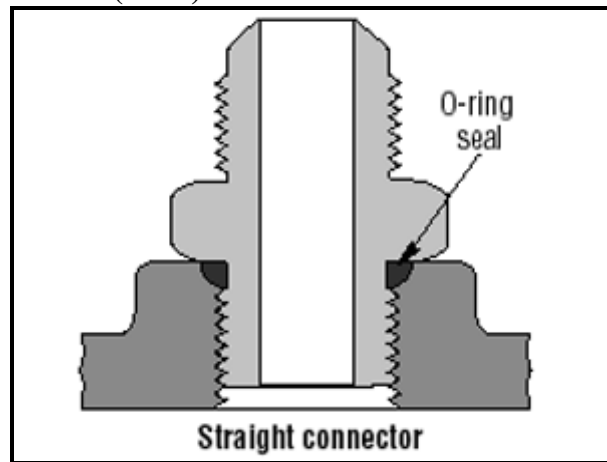
There are also many different kinds of joints that are used. Some of these include: o-ring boss seal, o-ring face seal, compression joint, pipe thread, push on hose barb seal with clamp, and push together type seals. All of the o-ring seals are much more robust in terms of leak prevention than the flare type seal, but are much more expensive because of the extra o-ring part and extra machines that takes place in order to retain the o-ring.

There are certain parameters that allow each of these components to work for specific applications. For example, the push on hose barb seal with clamp joint works very well for low pressure applications, typically less than 200 psi. These type connections are typically used for return lines or what is known as case drain lines. They are also used for suction lines, lines that are used to transmit hydraulic fluid to a pump. Suction lines are extremely low pressure or sometimes negative pressure.



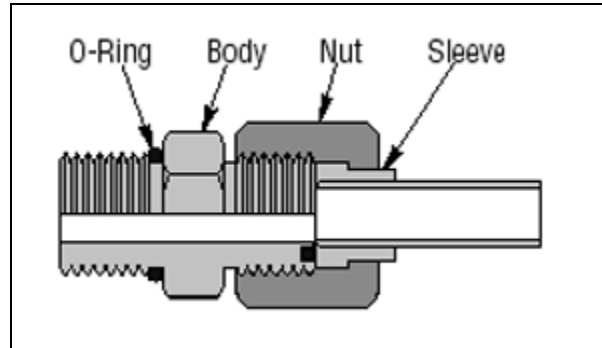
The high pressure connections are on the outlet side of the pump and downstream to other components such as valves, motors, and other components. Typically the connections to components such as pumps and valves are o-ring boss connections (ORB) (Figure 1.6). This allows for simple machining of the typically cast components. This type of connection is typically very robust, and causes little problems with leaks.

**Figure 1.6 O-ring Boss Seal (ORB)**



The other commonly used high pressure seal is o-ring face seals (ORFS) as shown in Figure 1.7. These are used in the same application as the JIC fittings, but are more expensive and typically more robust in term of problems with leaks, although conditions have to be met to not damage the o-ring during assembly. It depends on the application, but commonly these are used significantly less than JIC fittings. The JIC fittings are more commonly found in the industry and are easy and less expensive to procure than the ORFS, and for most applications work without a problem.

**Figure 1.7 O-ring Face Seal Connection**

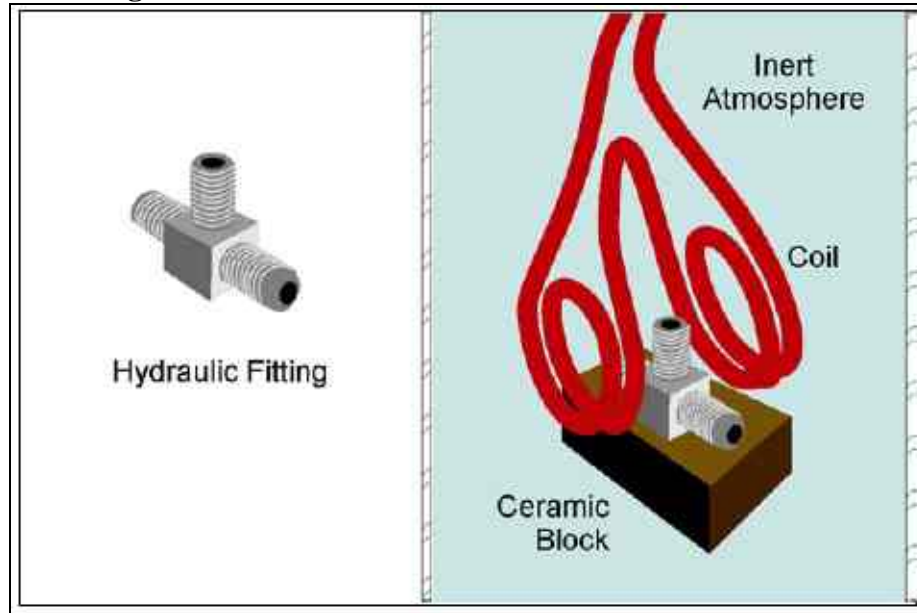


There are different fitting manufacturing processes to construct these specialized components. The straight fittings are typically machined out of straight bar stock material. The ninety degree components and the tee fitting are manufactured by either a brazed process or a forged process.

### **1.2 Brazed Fittings**

The components that are brazed are machined in pieces and then assembled together. The components are then fixed together with a brazing process, which is similar to welding or soldering them together (Figure 1.8). Brazed fittings are typically less robust than forged fittings, however not all fittings can be manufactured as a forged fitting.

**Figure 1.8 Brazing Process**

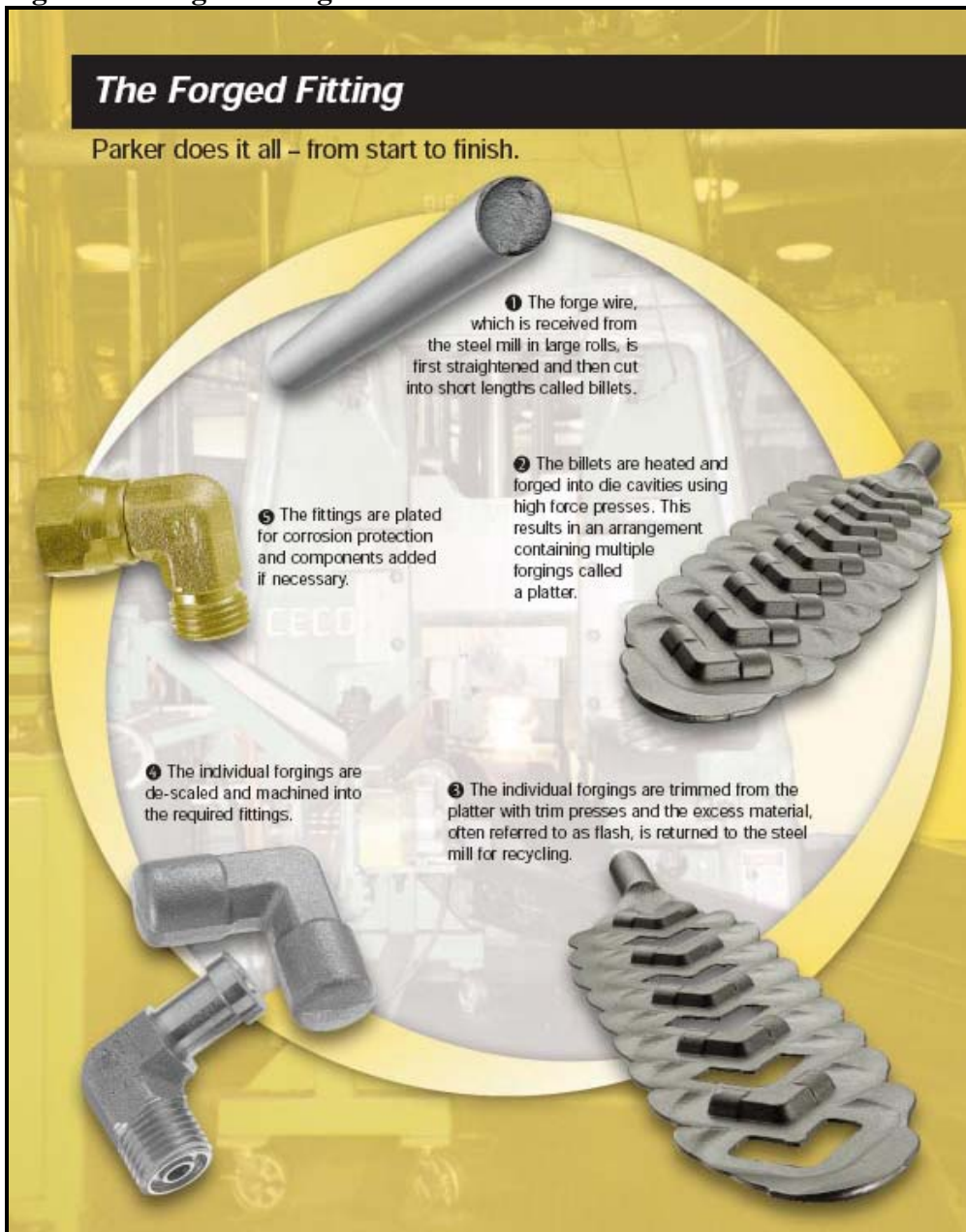


### **1.3 Forged Fittings**

Another way of producing hydraulic fitting is using a forging process (Figure 1.9).

This is where the blank part is forged into the shape required. The forged blank is then machined into the finished part, by machining the through ways, threads, and mating surfaces.

**Figure 1.9 Forged Fitting Process**



## **CHAPTER II: LITERATURE AND CONCEPTUAL METHODS**

There are a number of great benefits in reducing or eliminating the product defects. Quality of product is the main benefit to reducing or eliminated defects in manufactured products. The quality of a product is a direct result of the finished product evaluation. If a product has few defects or has had less rework that has to be done to it, it will have a higher quality rating than a defective product.

If defects are reduced, the corresponding cost of any rework is also reduced. This means the overall cost of producing a complete unit is also reduced. Another benefit of reducing defects is increased Customer Satisfaction. Customers are happier with a quality product that works better or looks better with fewer defects. Finally, company profits are increased when producing fewer defective machines, all else constant.

There are a number of different ways to evaluate manufacturing defects. Recent literature on defect analysis suggests that the use of more than one approach is required to make the analysis most effective (Finlow-Bates et al. 2000). There are many different methodologies that are reported in the literature for improving productivity and quality. A few of these include: Six Sigma, Total Quality Management (TQM), Statistical Process Control (SPC), Root Cause Analysis (RCA), Kepner and Tregoe (K-T). All of them are useful, but none are a complete fix all, they all have their own advantages and disadvantages.

Six Sigma attributes defects or poor quality of products to variability in the production processes of those products. Six Sigma uses process controls to keep variables

within upper and lower specification limits in order to produce quality products. Six Sigma is a rigorous and a systematic methodology that utilizes information (fact-based decisions) and statistical analysis to measure and improve a company's operational performance, practices and systems by identifying and preventing defects in manufacturing and service-related processes in order to anticipate and exceed expectations of all stakeholders to accomplish effectiveness (Pande 2000).

Total Quality Management (TQM) is very similar to Six Sigma and uses a lot of the same tools for defect analysis. It uses upper and lower specification limits as permissible tolerances that customers will allow in their products. It is ultimately impossible to produce everything exactly on the norm every time. Inputs vary in quality, such as feed stocks and purchased parts. Production machinery and operators all have their own variability in performance. Final product quality is a function of dozens, if not hundreds, of such causes deeply embedded in the process (Finlow-Bates 2000). These inputs have variations that sometimes push the finished product towards the upper product specification and sometimes the variations push the product toward the lower product specification.

Within TQM there are two essential concepts that are used to describe product production processes. Capability is the first of these concepts. Capability is described as insuring that the spread of quality during normal operation is within the upper specification limit (USL) and the lower specification limit (LSL). If the process does not stay with this range, then it is deemed to be incapable on producing quality product.

Control is the other concept that is widely used in TQM and Six Sigma. A process or producing of a product is said to be under control when it runs for long periods of time with only general causes that affects it, and it stays within the specification limits. An “in control” process can be plotted over time, and should not change much in character with time, and should remain relatively away from specification limits. If a special cause is added to the process, then it is likely to cause the product characteristics to jump out of the specification range. Some examples of special causes are: poor quality inputs, defective torque wrench, broken pressure gauge, etc.

Statistical Process Control (SPC) is a process to track such product characteristics over time. The USL and LSL are typically three standard deviations away from the mean of a product. If the measured product specification lies outside of the specification limits, then a special cause has been introduced to the process that needs to be addressed.

The plan for this project is to analyze the data available regarding leak points and determine how to proceed. This will be accomplished by determine the leak points that have the highest leak rate and what key variables need to be controlled to reduce the leak rate at those connections.

There are numerous articles and books on defect analysis and process improvement. The majority of the information in the Literature Review has to do with manufacturing defects, but very few articles were found specifically addressing with hydraulic leaks or defects of hydraulic components associated with leaks. However, the concepts that are used to evaluate manufacturing defects can apply to hydraulic leak defects as well.

Most of the information associated with defect analysis is dependent on problem solving and root cause analysis. One method of manufacturing defect analysis is an integrated approach to problem solving where synergies are created between the leading thinking models for defect analysis and quality control. The leading models discussed in this article are known as Total Quality Management (TQM), K-T (Kepner and Tregoe), Root Cause Analysis (RCA), and Total Productive Manufacturing (TPM) Statistical Process Control (SPC).

The intent of this project is to use the Six Sigma Methodology. This process is defined or broken down into five different steps. These steps are Define, Measure, Analyze, Improve, and Control (DMAIC). The first step will be to determine the leak points that have the highest leak rate and define the wanted output. The second step will then be to measure the current state of the process in the “as is” condition. The third step will be to analyze the inputs and outputs to determine the key variables that need to be controlled. The fourth step will be to determine the correct specification limits for those variables in order to minimize the leak rate for respective joints. The fifth and final step will be to put controls in place in order to maintain this new improved process and make sure it does not get back out of control.



### CHAPTER III: DATA AND METHODOLOGY AND ANALYSIS RESULTS

The data for the CASE models 410-440 were collected from ALSTAR and saved in an EXCEL spreadsheet. There are 31 columns of data variables, but the one that is the most important at this point in time is the leak point number for a particular leak. Another very important piece of information is the unit serial number. The leak point data in the ALSTAR are always unorganized and have to be manipulated before they can be analyzed. For example, multiple leak points may have been entered on 1 line of data, i.e. ,64, 65, 210, 222 (Table 3.1). When this occurs the data line is copied 3 times, so that there are 4 lines of data and each leak has its own line of data (Table 3.2). That is, each leak reflects an observation.

**Table 3.1 Example of ALSTAR Data**

repair_comment	repair_code	Repair_descp	repair_hour	cai_flag	assignee_name	part_nbr
tightened clamp	1	ASSEMBLY	0.25	N	NONE	64,65,210,222

**Table 3.2 Example of Corrected ALSTAR Data**

repair_comment	repair_code	repair_descp	repair_hour	cai_flag	assignee_name	part_nbr
tightened clamp	1	ASSEMBLY	0.25	N	NONE	64
tightened clamp	1	ASSEMBLY	0.25	N	NONE	65
tightened clamp	1	ASSEMBLY	0.25	N	NONE	210
tightened clamp	1	ASSEMBLY	0.25	N	NONE	222

Other information in the leak point column sometimes includes text of where the leak was located, for example, EFT 261, EFT10 157, LP 2, (Table 3.3).

**Table 3.3 Example of Unformatted ALSTAR Data**

repair_comment	repair_code	repair_descp	repair_hour	cai_flag	assignee_name	part_nbr
Replaced	1	ASSEMBLY	0.5	N	NONE	eft 261
Tightened sender	1	ASSEMBLY	0.15	N	NONE	EFT10 157
Tightened	1	ASSEMBLY	0.2	N	NONE	LP 2
Loose	1	ASSEMBLY	0.25	N	NONE	EFT 197
tightened and resteamed	1	ASSEMBLY	0.25	N	NONE	238 eft
tighten fitting	1	ASSEMBLY	0.25	N	NONE	140 eft
retorqued	1	ASSEMBLY	0.3	N	NONE	eft 61
retorqued	1	ASSEMBLY	0.25	N	NONE	61 eft

Unfortunately, the format is hardly ever the same, so the cells have to be manually changed over to the leak point number, (Table 3.4).

**Table 3.4 Example of Formatted ALSTAR Data**

repair_comment	repair_code	repair_descp	repair_hour	cai_flag	assignee_name	part_nbr
Replaced	1	ASSEMBLY	0.5	N	NONE	261
Tightened sender	1	ASSEMBLY	0.15	N	NONE	157
Tightened	1	ASSEMBLY	0.2	N	NONE	2
Loose	1	ASSEMBLY	0.25	N	NONE	197
Tightened and resteamed	1	ASSEMBLY	0.25	N	NONE	238
tighten fitting	1	ASSEMBLY	0.25	N	NONE	140
retorqued	1	ASSEMBLY	0.3	N	NONE	61
retorqued	1	ASSEMBLY	0.25	N	NONE	61

When the leak points actually come in as true numbers, EXCEL does not recognize them as numbers, so they have to be converted. There are a number of ways to do this. Typically this was done by creating a new column beside the current leak point column. Then create an equation to multiply the old leak point by 1. As long as the old leak point was truly a number, this action worked well. If the leak point was not a true number, for example if it was a part number like 139492A1, then the new column value would be

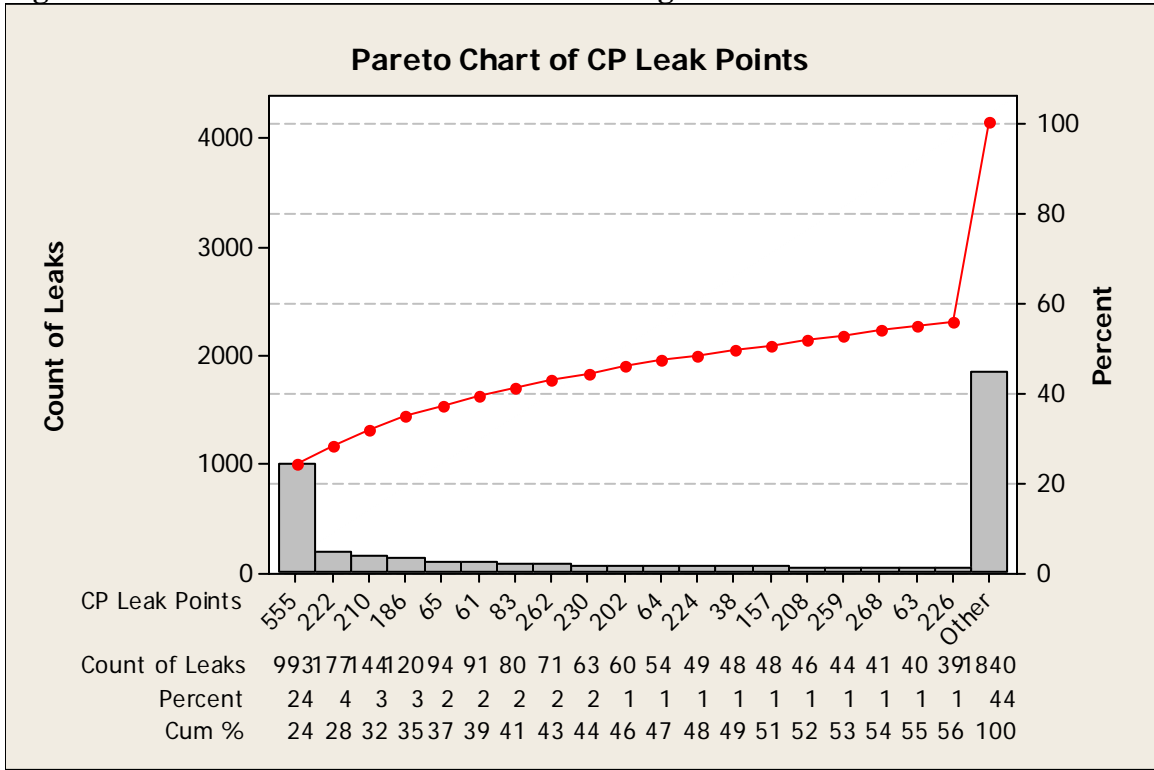
#VALUE! output. This column could then be filtered for this error and corrections made, (Table 3.5).

**Table 3.5 Example of Corrected ALSTAR Data**

repair_comment	repair_code	repair_descp	repair_hour	cai_flag	assignee_name	part_nbr
1				N	NONE	139492A1
0	1	ASSEMBLY	0.15	N	NONE	83
Replaced	1	ASSEMBLY	0.5	N	NONE	261
pinched o-ring	1	ASSEMBLY	0.5	N	NONE	261
Loose	1	ASSEMBLY	0.2	N	NONE	65
	1	ASSEMBLY	0.1	N	NONE	59
Resealed	1	ASSEMBLY	0.3	N	NONE	262
Ok	1	ASSEMBLY	0.01	N	NONE	57
	1	ASSEMBLY	0.1	N	NONE	59
Loose	1	ASSEMBLY	0.5	N	NONE	83

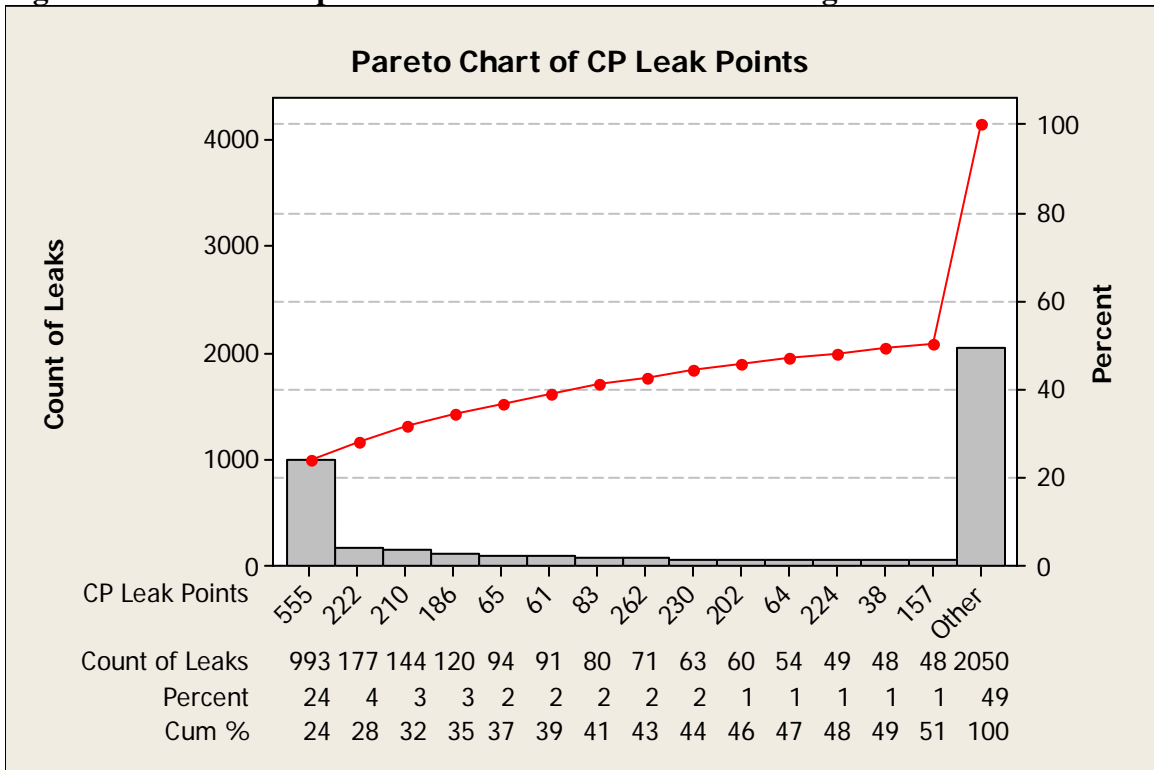
Once the leak point data sets were in useable form, they were analyzed using a Pareto analysis. Pareto Analysis is very simple; it simply counts the number of occurrences and sorts from highest to lowest. The intent of the Pareto Analysis is to find the top 20 percent of issues that are causing 80 percent of the problems. This analysis can be done in EXCEL by using a Pivot table or it can be in Minitab, or a combination of the two. The default in Minitab is to combine the last 5 percent into Other, a miscellaneous category. The problem when this is done with the CP leak point data is that there are over 300 leak points with at least 1 occurrence for the data set analyzed. Figure 3.1 shows this Pareto Chart with 44 percent of the observations in the other category. There are so many leak points that the numbers are hard to read, unless the other category was set to 45 percent or higher. Eighty percent of the occurrences are in first 72 leak points, but this does include 555, which is “no leak” found for this line item.

**Figure 3.1 Pareto of All CP Leak Points Including LP 555**



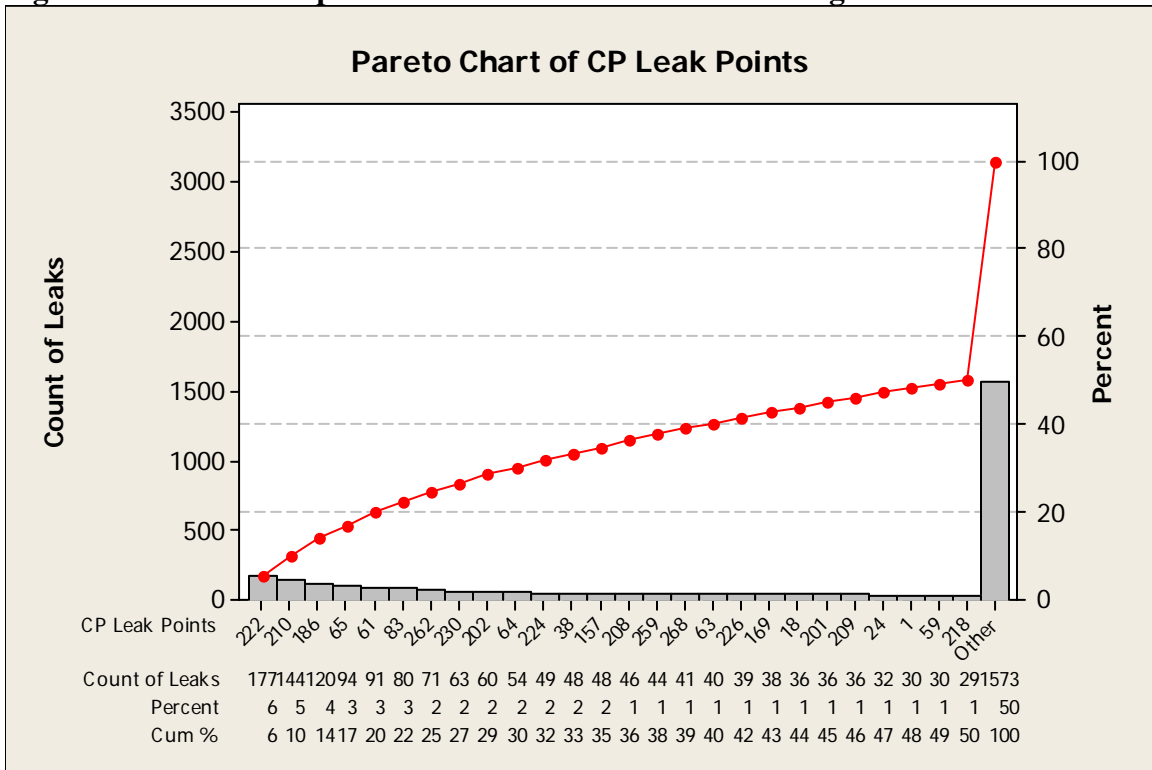
In Figure 3.2 the “Other” category was changed to 50 percent and the Pareto Chart numbers are now all viewable. However, this still includes the 555 “no leak” data, which account for 24 percent of the total leaks written up.

**Figure 3.2 Pareto of Top 50 Percent CP Leak Points Including LP 555**



When the leak point 555 is removed from the data, the top 80 percent of leaks are in the top 93 leak points. Still a very high number of leak points to try and analyze. Even at 50 percent there are 25 leak points to analyze.

**Figure 3.3 Pareto of Top 50 Percent CP Leak Points Excluding LP 555**



After seeing the “Flat Pareto” meaning there was not simply 1 or 2 joints that were causing most of the problem. In a Flat Pareto, there are many joints with each one only accounting for a small percentage of the entire problem. After seeing this type of outcome, it was decided to cut the data differently. Instead of using just the leak point number, the data was sorted by the type of joint: 37 degree flare; ORB; Clamp, Screw, Seal, other; ORFS; and Weld.

**Figure 3.4 Pareto of Leaks by Type of Joint**

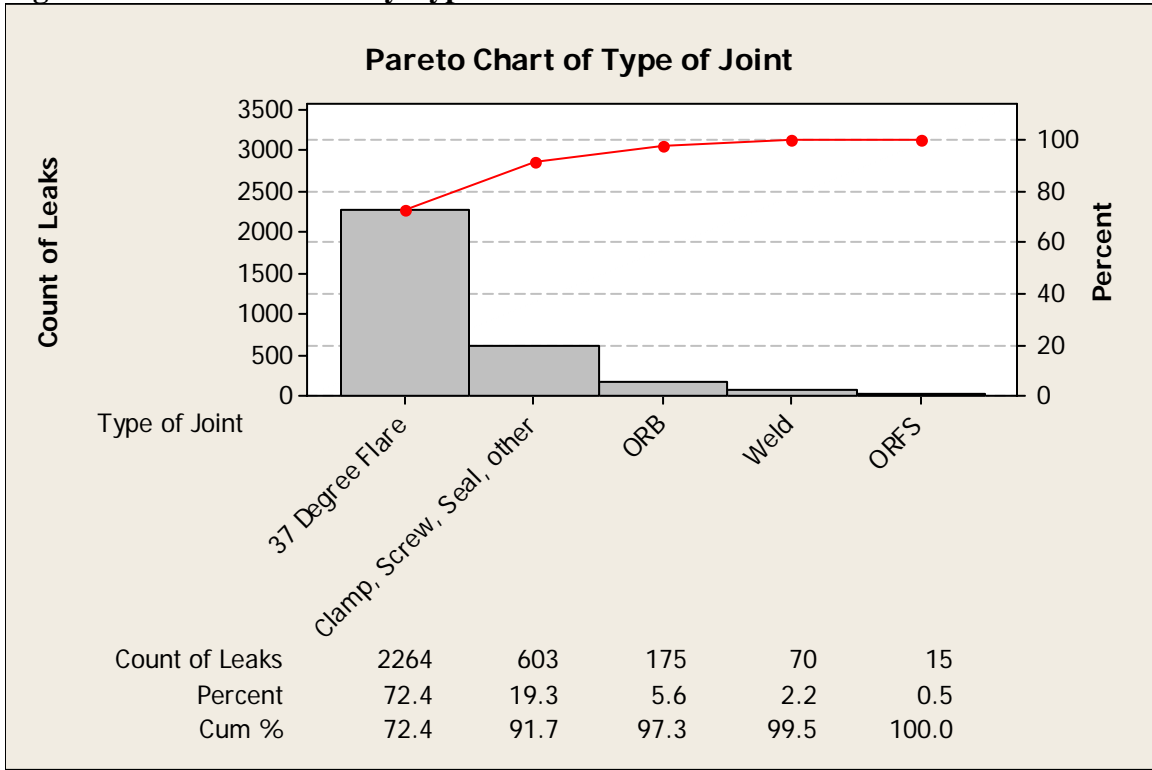


Figure 3.4 shows the Pareto by type of connection. From this analysis 37 degree flare joints or commonly referred to as JIC account for 72.4 percent of the leaks in the data set. This type of connection should be the focus of this project, as it is a key contributor to the number of leaks in the data set.

These 37 degree flare connections can be further classified into the following categories: Fitting to Hose, Fitting to Tube, Hose to Tube, Fitting to Fitting, Tube to Coupler, Fitting to Cooler, Fitting to Cap, Tube to Tube, Hose to Cap, Fitting to Coupler.

**Figure 3.5 Pareto of Leaks by Type of JIC Joint**

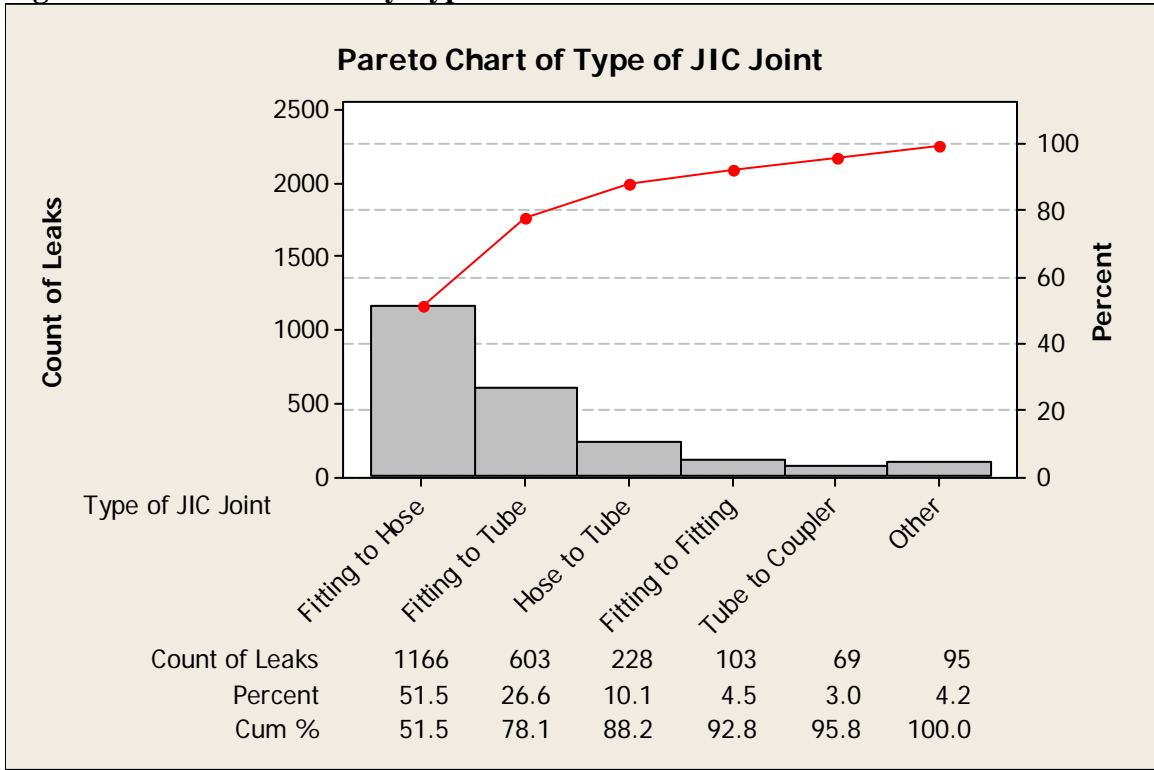


Figure 3.5 shows the Pareto of different types of JIC connections. At 51.5 percent of the occurrences, Fitting to Hose is the highest type of leak point from this data analysis. 37 degree flare connections can also be classified into these size categories for further direction: -4, -6, -8, -10, -12, and -16.



**Figure 3.6 Pareto of Leaks by Size of JIC Joint**

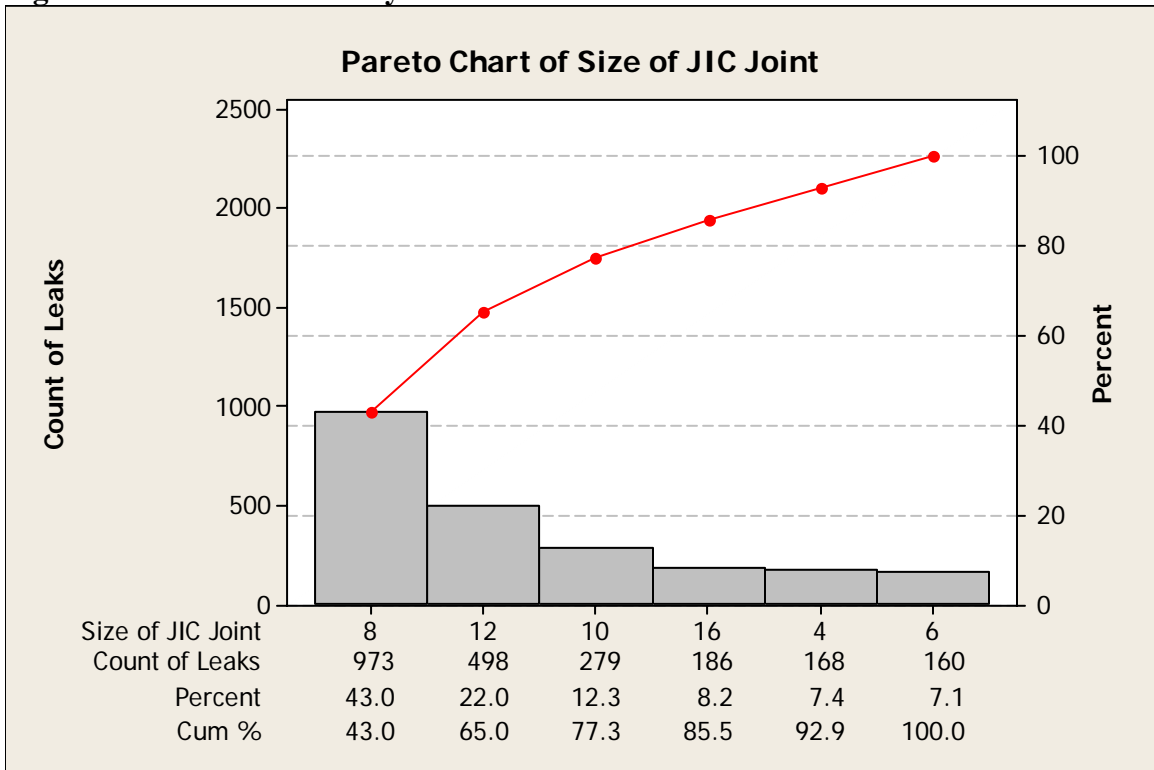


Figure 3.6 shows the Pareto of size of JIC connections. Size categories -8 and -12 are the highest number of leaks, accounting for 65 percent of the total number of 37 degree leaks. Size category -8 are widely used in the loader circuits, while -12 are used widely in the ground drive loop hose circuits.

The 37 degree flare connections can also be classified into these type of pressures categories for further direction: Loader, Charge, Return, Loop, and Drain.

**Figure 3.7 Pareto of Leaks by Type of Pressure of JIC Joint**

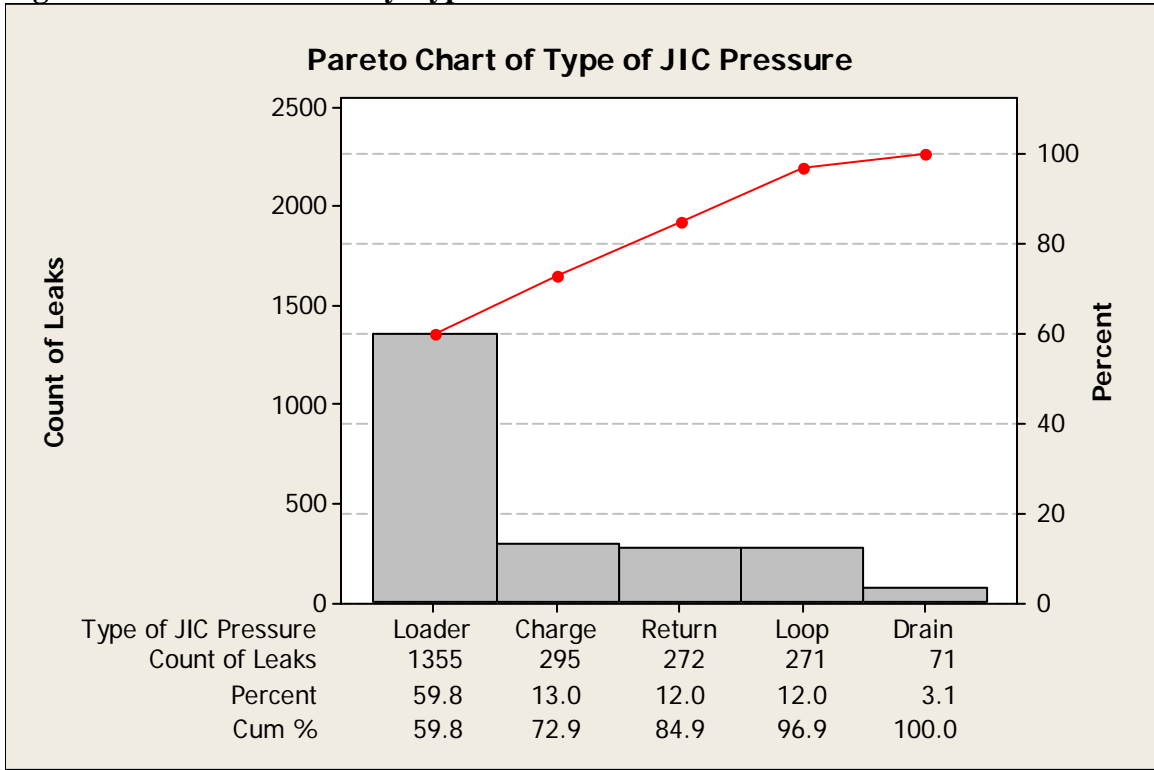


Figure 3.7 shows the Pareto of the pressure of the JIC connections. Loader pressure is the highest, accounting for 59.8 percent of the leak points in this data set. Charge, Return and Loop are very close in quantity, so in order to see more of difference, the data was normalized by the number of opportunities per machine. Therefore, the number of leaks was divided by the number of opportunities per machine for those types of pressure.

**Table 3.6 Normalized Leaks by Type of Pressure of JIC Joint**

Type	Count	Opportunities	Normalized Value
Loop	271	9	30.1
Return	272	13	20.9
Loader	1355	92	14.7
Drain	71	11	6.5
Charge	295	51	5.8

**Figure 3.8 Pareto of Normalized Leaks by Type of Pressure of JIC Joint**

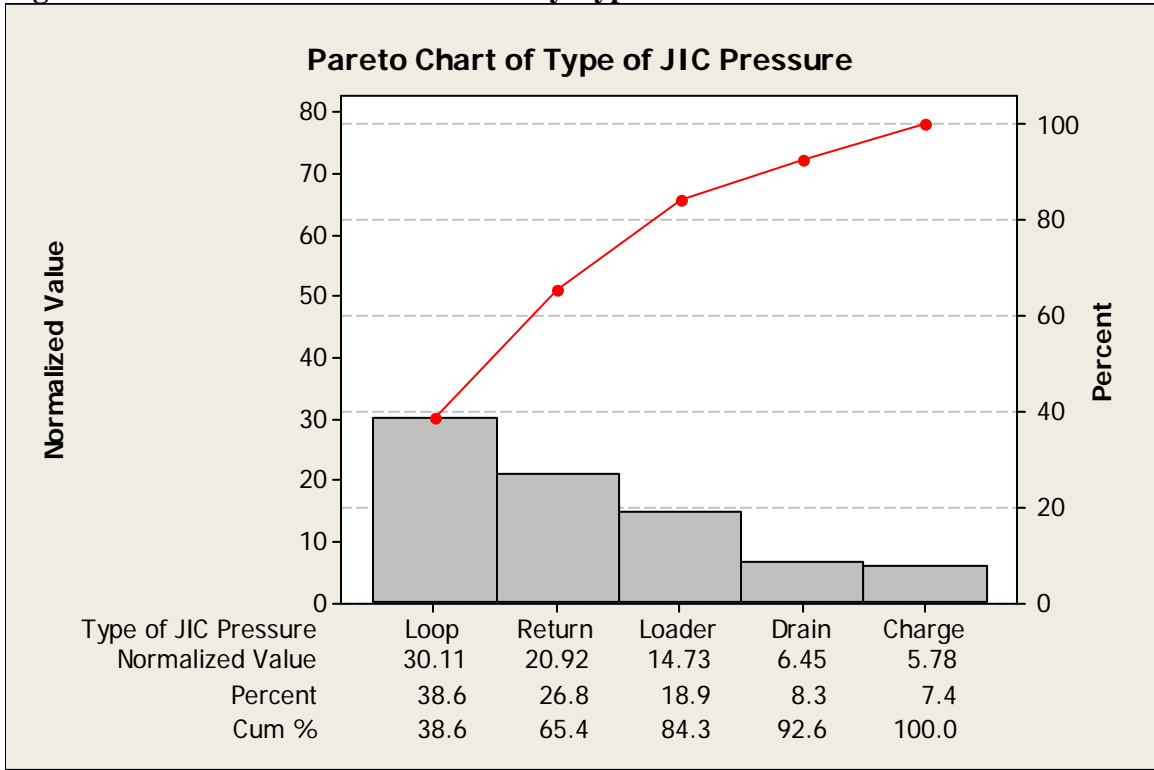


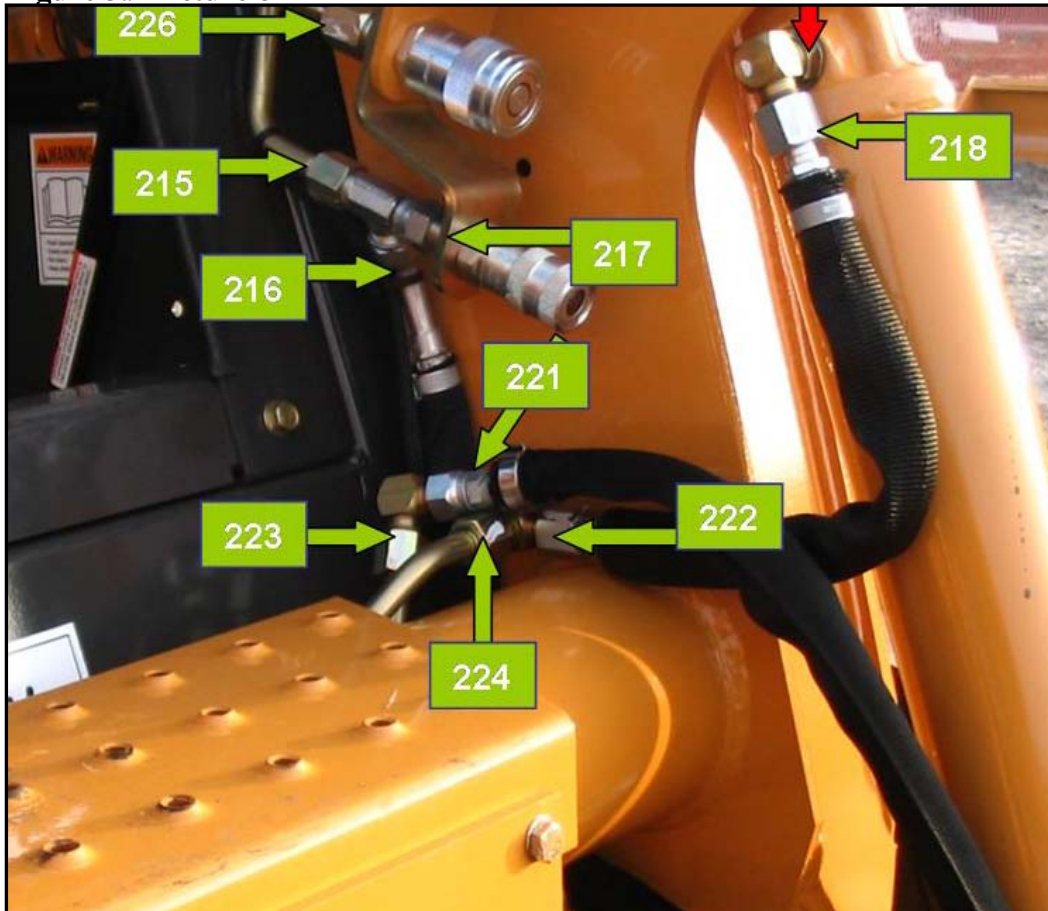
Figure 3.8 shows the Pareto of the normalized leaks by type of pressure of JIC connection. When these leak point data were normalized, Loop Pressure is the highest value, accounting for 38.6 percent of the total. Return and Loader were next in order, accounting for 26.8 percent and 18.9 percent, respectively. The Return was particularly high because of 1 leak point, 186. The design of this joint was changed in August of 2007 and this new design has shown to greatly improve the leak rate for this connection, so it will not be a part of this project.

All of these Pareto Charts were performed to direct the focus of this project to a subset of leak points that could be used for analysis, in the hope that the results could be used across multiple leak points and also could be carried across to the other assembly lines within the CNH Wichita Plant. From the data analyzed it was determined to use leak

points that were 37 degree flare, fitting to hose, -8 and -12 size fittings, and Loader and Loop Pressure. With this type of criteria is mind, the high leak points were reviewed to determine which particular points could be further analyzed. The first few leak points fit this category. These joints include 222, 210, 65, 61, 64, and 62. Pictures of the joints are shown in Figures 3.9-3.12.

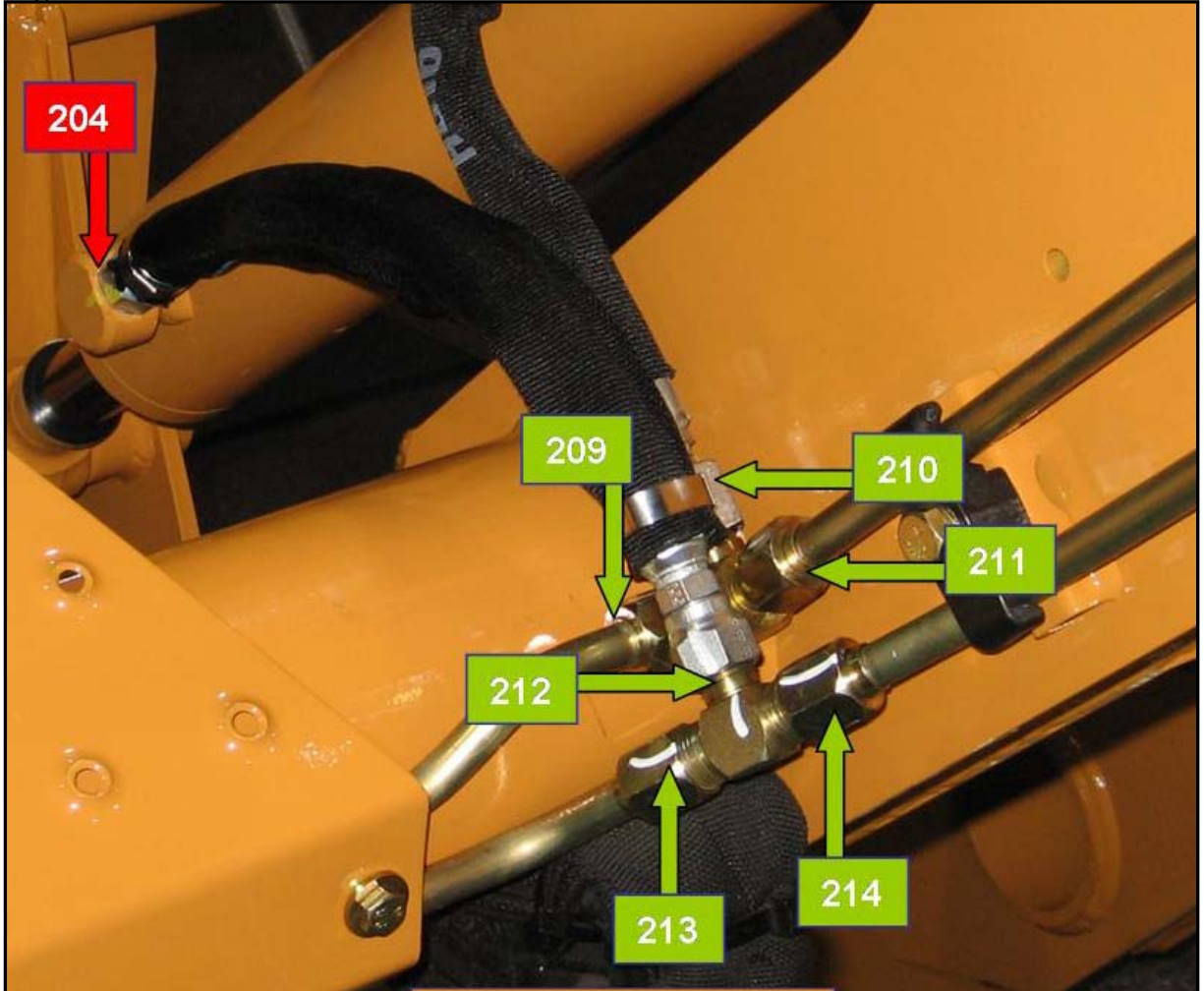
Leak Point 222 met these criteria: 37 Degree Flare, Fitting to Hose, -8, and Loader Pressure

**Figure 3.9 Picture of LP 222**



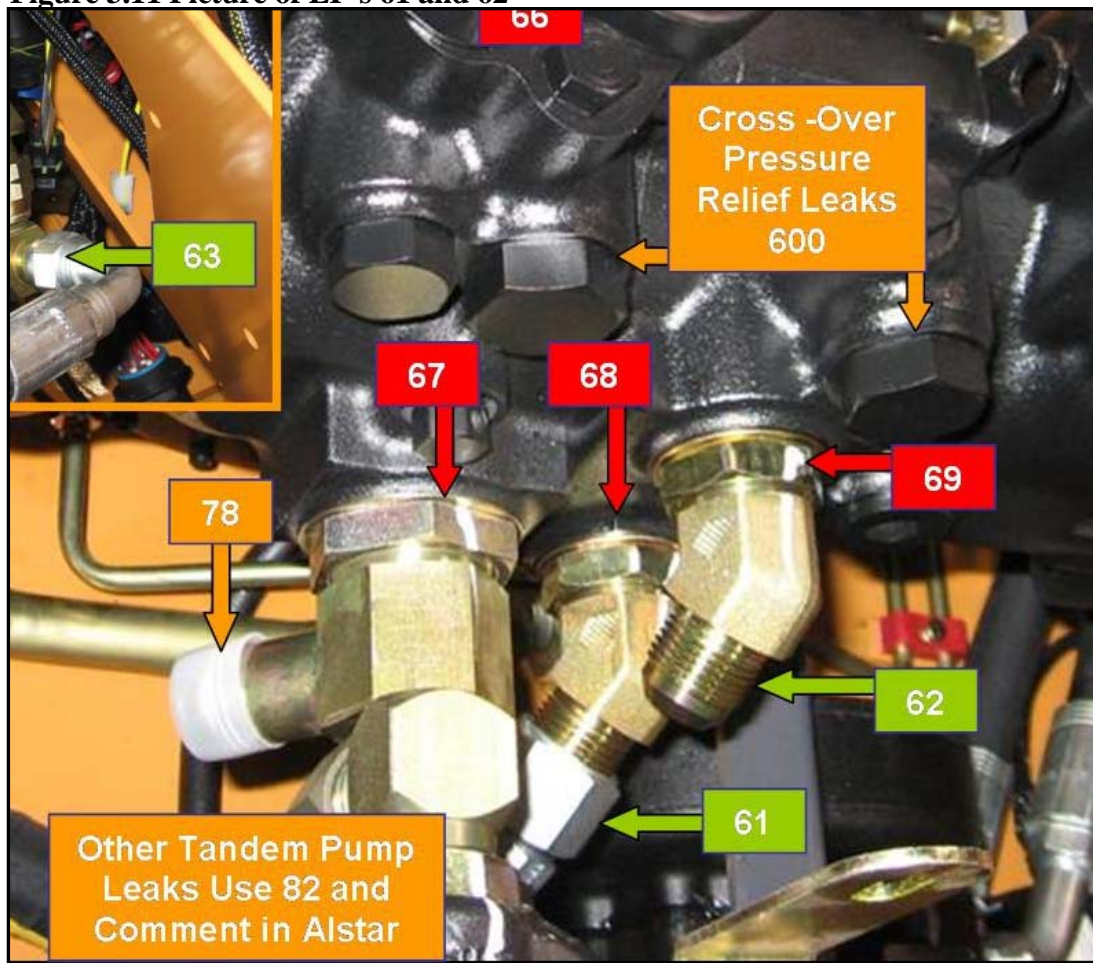
Leak Point 210 met these criteria: 37 Degree Flare, Fitting to Hose, -8, and Loader Pressure

**Figure 3.10 Picture of LP 210**



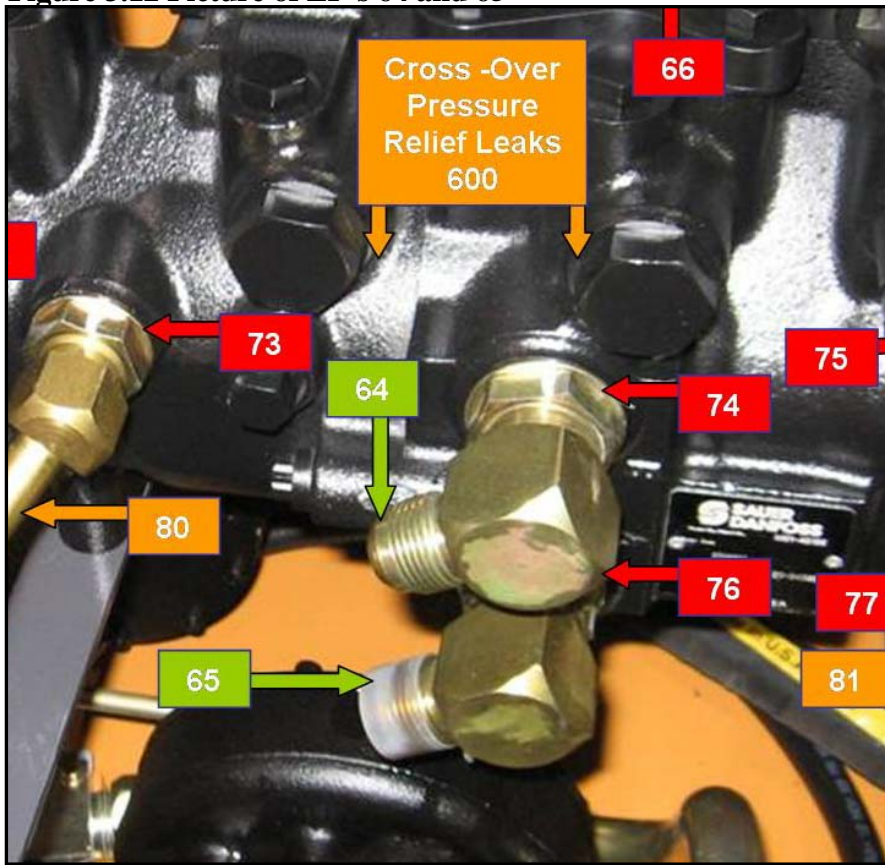
Leak Point 62 met these criteria: 37 Degree Flare, Fitting to Hose, -12, and Loop Pressure

**Figure 3.11 Picture of LP's 61 and 62**



Leak Point 65 met these criteria: 37 Degree Flare, Fitting to Hose, -12, and Loop Pressure

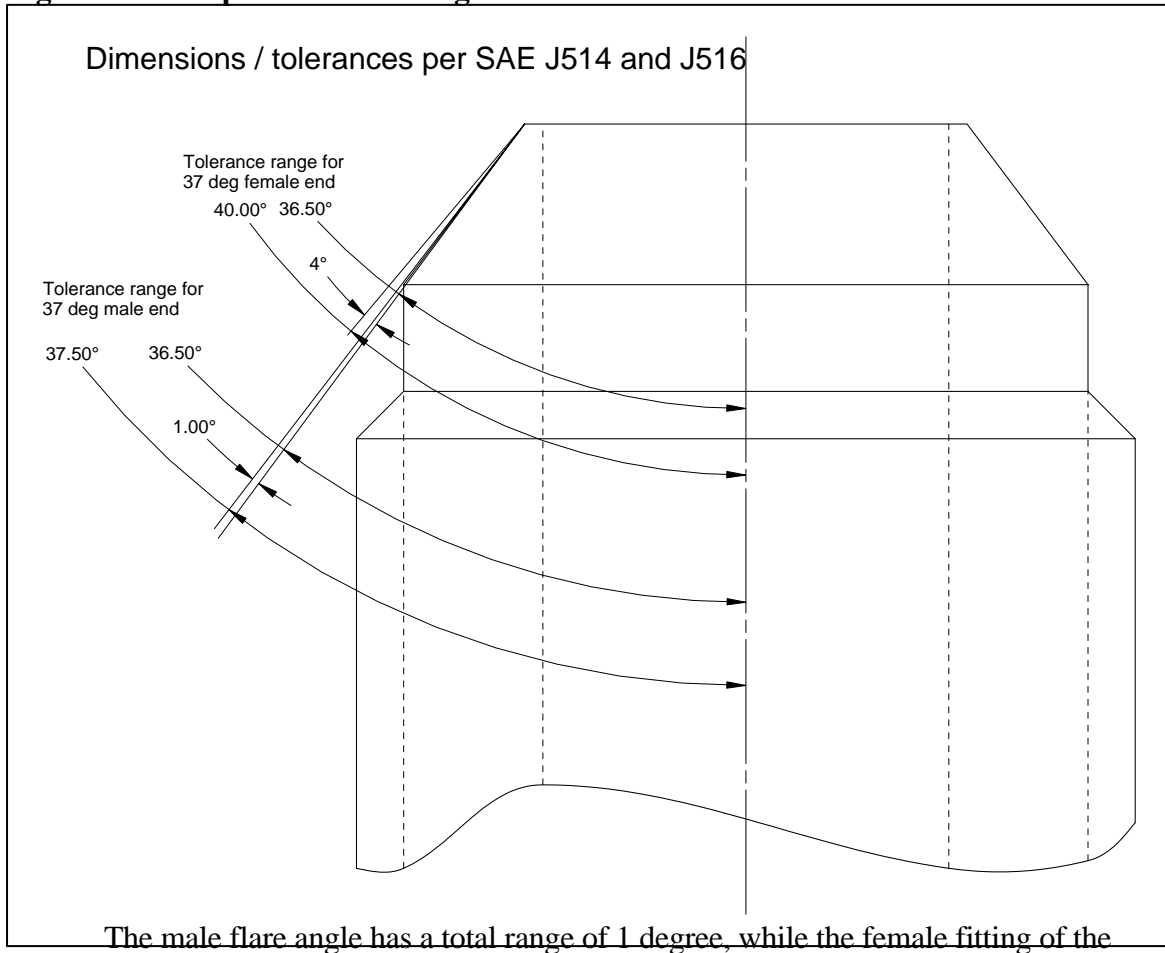
**Figure 3.12 Picture of LP's 64 and 65**



o 40 random  
tment. The

Society of Automotive Engineers (SAE) requirements for the 37 degree flare are show,  
Figure 3.13.

**Figure 3.13 Graphic of JIC Fitting Tolerances**



joint has a total range of 3.5 degrees. The 40 samples that were measured were within the specifications limits. The capability is shown in figures, 3.14 and 3.15.



**Figure 3.14 Process Capability of Male Fittings**

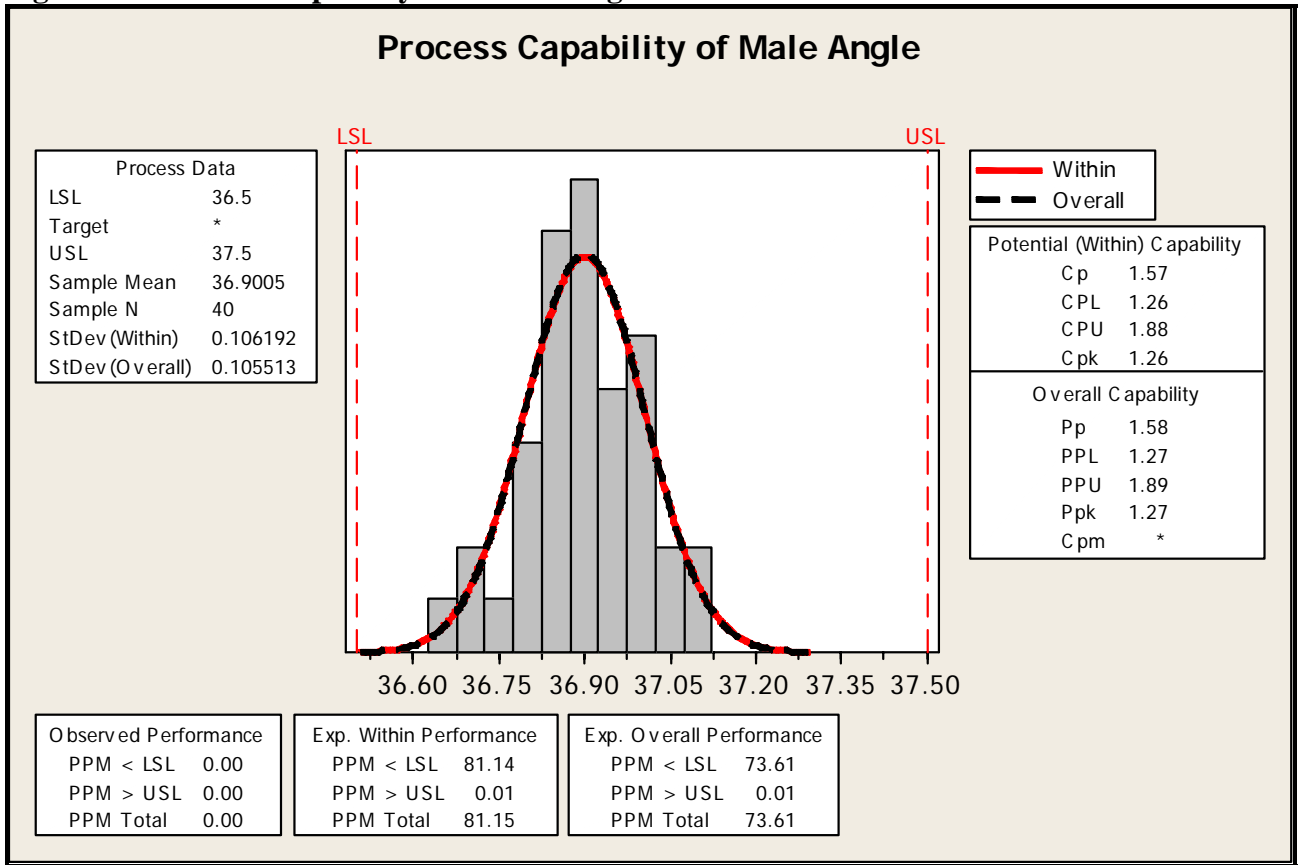


Figure 3.14 shows the distribution of the 40 samples measured. The specification limits are from the previously mentioned SAE requirements. Lower Spec Limit (LSL) is 36.5 degree, while the Upper Spec Limit (USL) is 37.5 degrees. The mean is 36.9005, which is almost in the center of the specification range, 37 degrees. The 40 pieces were all within the specification limits. This is shown in the lower left box, Observed Performance. Overall, the parts measured well and the conclusion is this flare angle is within specifications and is not the reason for caused leaks.

The 40 pieces of the female fitting were measured to see how they fit the specification limits. They were also within the specification limits.

**Figure 3.15 Process Capability of Female Fittings**

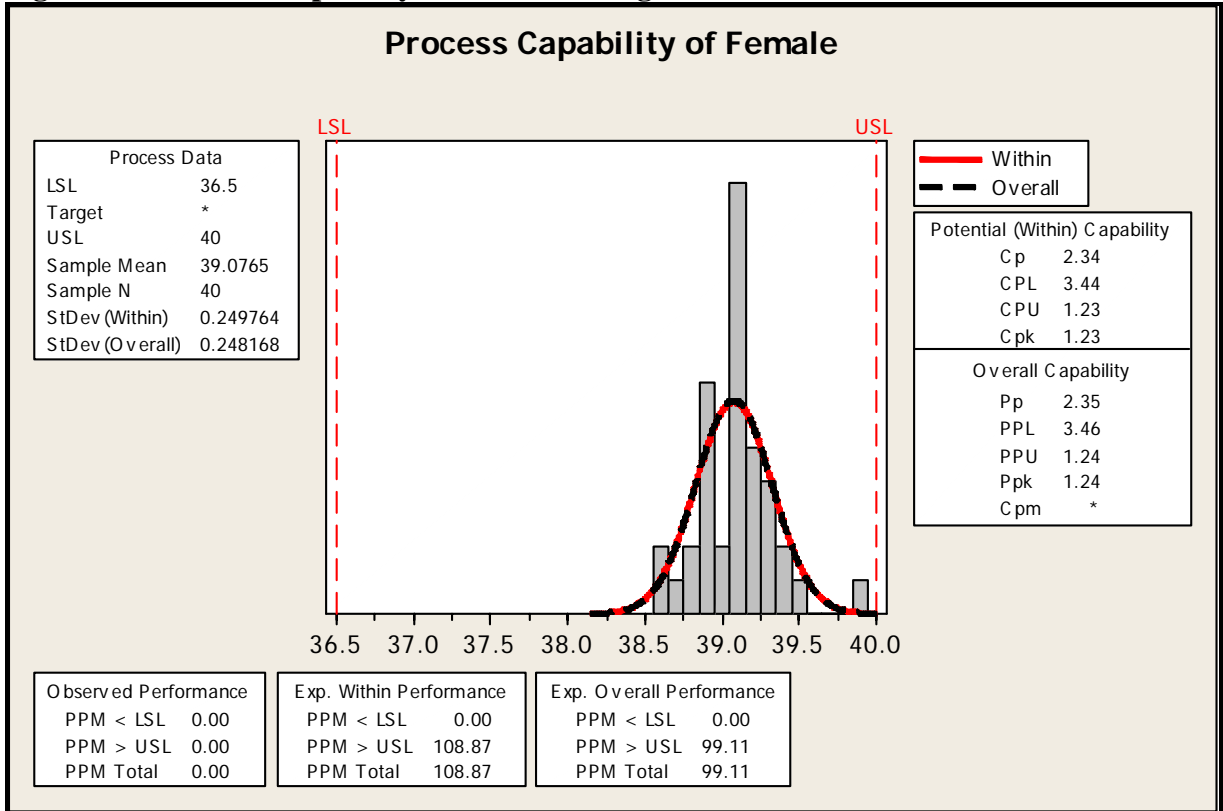


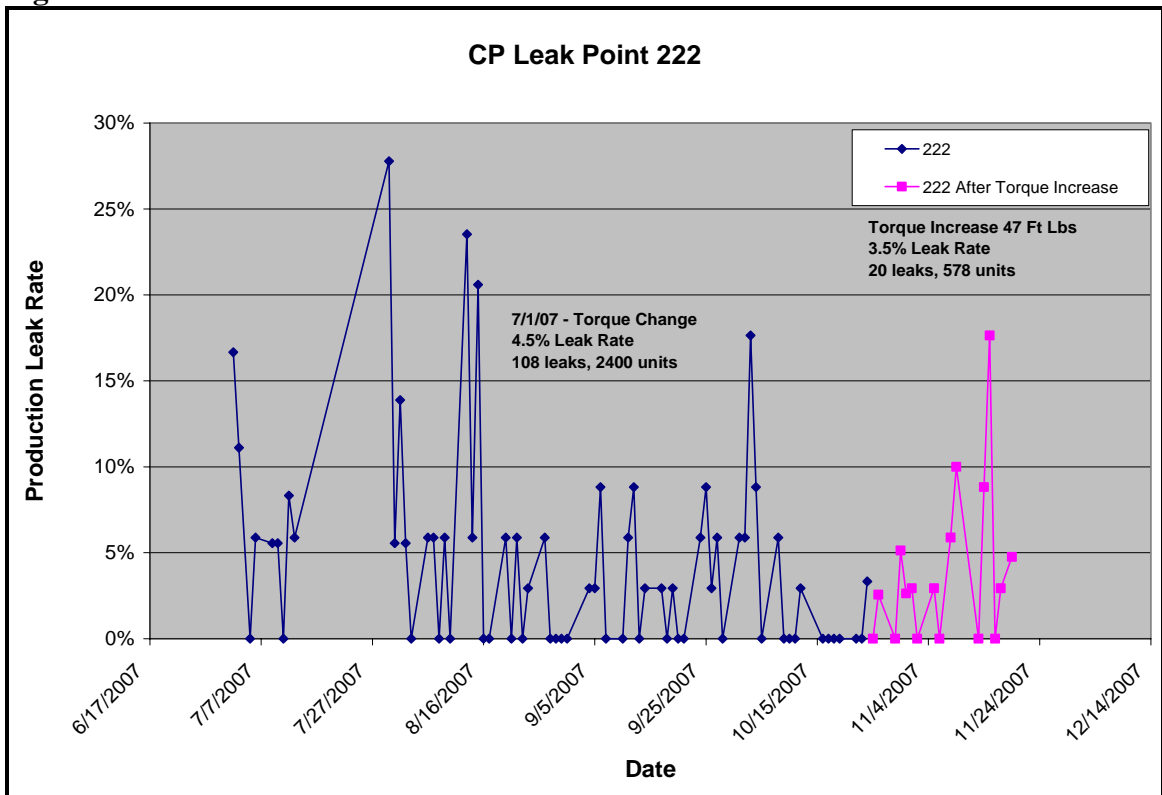
Figure 3.15 shows how this particular female fitting, which was a Gates hose, fits the specification limits. The LSL is 36.5, while the USL is 40. The mean of the 40 samples is 39.0765, which is shifted to the right of the range; however the parts are still within the SAE specification range. The shift to the high end of specification was discussed with Gates and this is the design intent by their company. This forces this joint to seal more on the top of nose of the male, producing more of a point or line seal around the fitting, verses a large surface seal, which is more susceptible to surface defects.

Overall, it was determined that this dimension is within specification limits and does not seem to be the cause of the overall leak issue.

The next thing to do was to lab test components under different assembly conditions: torque valued applied, with and without Loctite 545, brazed vs forged fitting. The three items that were measured in the testing were degrees of turn from hand tight, break away torque after assembled, leak vs not leak. The intent was to find which applied condition caused a joint to leak in the lab. Unfortunately, throughout the lab testing, not one joint leaked. So, even though we could measure differences in degree of turn and break away torque with different assembly conditions, it never could be correlated back to causing a leak or not with this limited sample testing, the sample size was just not large enough.

The next step was to perform hypothesis testing on the assembly line in order to get a large enough sample size and to also get all the true process variation. In a hypothesis test only one variable can be changed at a time and then the response is measured. Then the change in response is analyzed to determine if the change in the one variable made enough of a difference in the output response to be statistically significant. For the testing in this project the output was the leak rate, the number of leaks divided by the number of units built. The variables that were changed were the torque value applied to the joint and the use of Loctite 545 or not. On leak points (LP) 61-65, which are the ground drive loop hoses, the hose type used was also changed during this project. It was changed to a more flexible material, which makes the hoses easier to bend and assemble.

**Figure 3.16 Leak Rate of LP 222**



On LP 222 the leak rate was analyzed for the 6 month period June 2007 through November 2007. Figure 3.16 shows the leak rate per day, which is number of leaks divided by number of units built that day. From July 1<sup>st</sup> through Oct 25<sup>th</sup> nothing in the process was changed, torque applied was 40 ft-lbs, and Loctite 545 was being applied. As can be seen, the leak rate changed almost everyday. The highest rate being 27 percent just after WPC’s two week shut down in July and the lowest being 0 percent on a number of different days in every month. The overall leak rate is 4.5 percent or 108 leaks in 2400 units. When a leak is found on a finished unit, the first thing that is tried in order to fix the leak is to tighten the joint a little bit more. This fixes the majority of the leaks found in the plant. So, it was determined that a 20 percent increase in torque would be a good test to perform to see if it would reduce the leak rate. The torque wrench used to connect LP 222

was changed on Oct 25<sup>th</sup> from 40 ft-lbs to 47 ft-lbs. The wrench was then used for the next few weeks.

After increasing the torque, the overall leak rate average went down to 3.5 percent or 20 leaks in 578 units, although there were days where the leak rate was still over 10 percent. A statistical hypothesis test was done to determine if this difference was statistically significant. These data were analyzed using a two proportions test in Minitab. The Null Hypothesis was that the leak rates are equal, while the Alternative Hypothesis is that the leak rates are not equal. The output of the test is shown, Figure 3.17

**Figure 3.17 Hypothesis Test Results of LP 222**

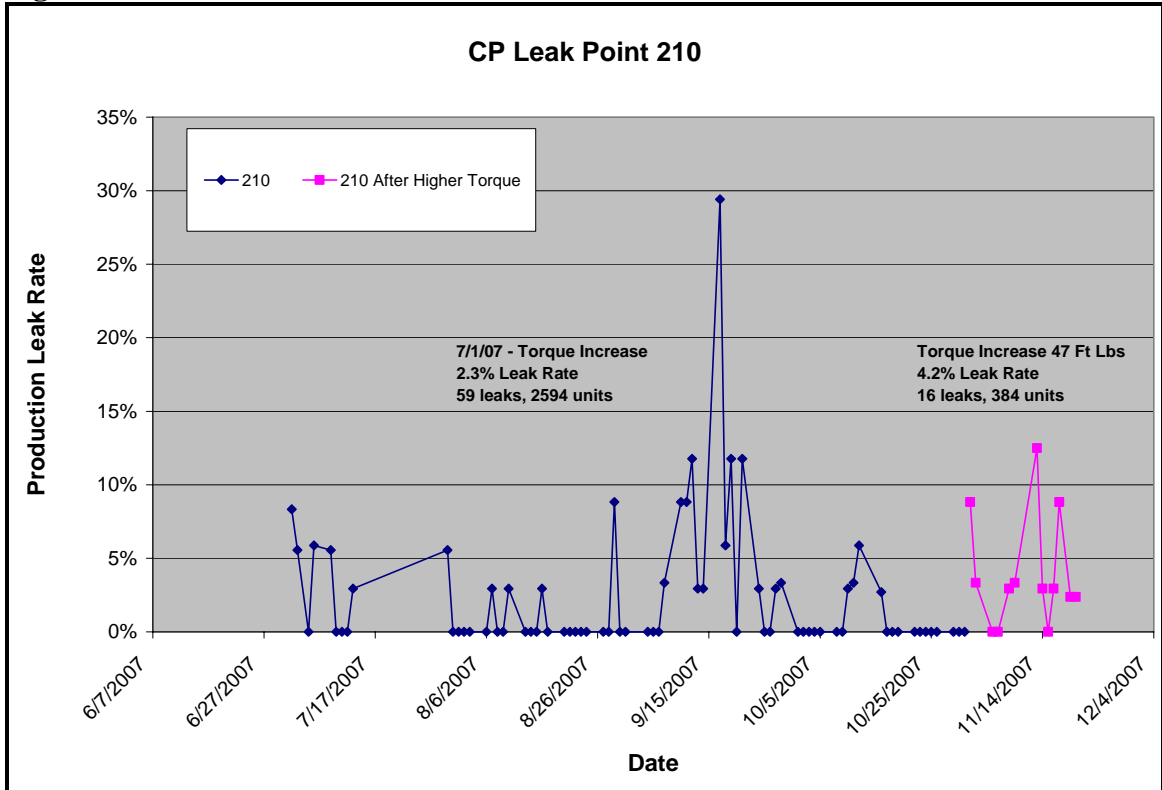
Test and CI for Two Proportions			
Sample	Leaks	Units	Sample p
1	108	2400	0.0450
2	20	578	0.0346
Difference = p(1) - p(2)			
Estimate for difference:			0.0104
95% CI for difference:			(-0.006655, 0.02745)
Test for difference = 0 (vs not = 0): Z = 1.20 P-value = 0.232			

The p-value is above 0.05, which is the value commonly used in this type of test, so therefore the null hypothesis cannot be rejected. Thus, given the sample size used and the leak rate observed, the leak rates are not statistically different. The new rate is lower, but not by enough to be significant at the 95 percent confidence level.

This same torque change was then done to LP 210, as it is a very similar type of joint. The joint actually has the exact same hose, but the fitting is different. LP 222 uses a forged 90 degree fitting, while LP 210 has a brazed side outlet tee. Both are -8 size fitting,

but the brazed verses the forged manufacturing type is the key difference. Figure 3.18 shows the output from the process change.

**Figure 3.18 Leak Rate of LP 210**



LP 210 had an overall leak of 2.3 percent from July 1<sup>st</sup> until the torque increase, which was made Nov 1<sup>st</sup>. This particular joint had more days of 0 percent leak rate, including almost two weeks before the torque increase. The very first day after the torque increase the leak rate jumped to almost 10 percent, but came back down a few days later. The overall leak rate was an average of 4.2 percent, which is almost double that of the previous leak rate. A hypothesis test was performed on this difference. Figure 3.19 shows the outcome from the test.

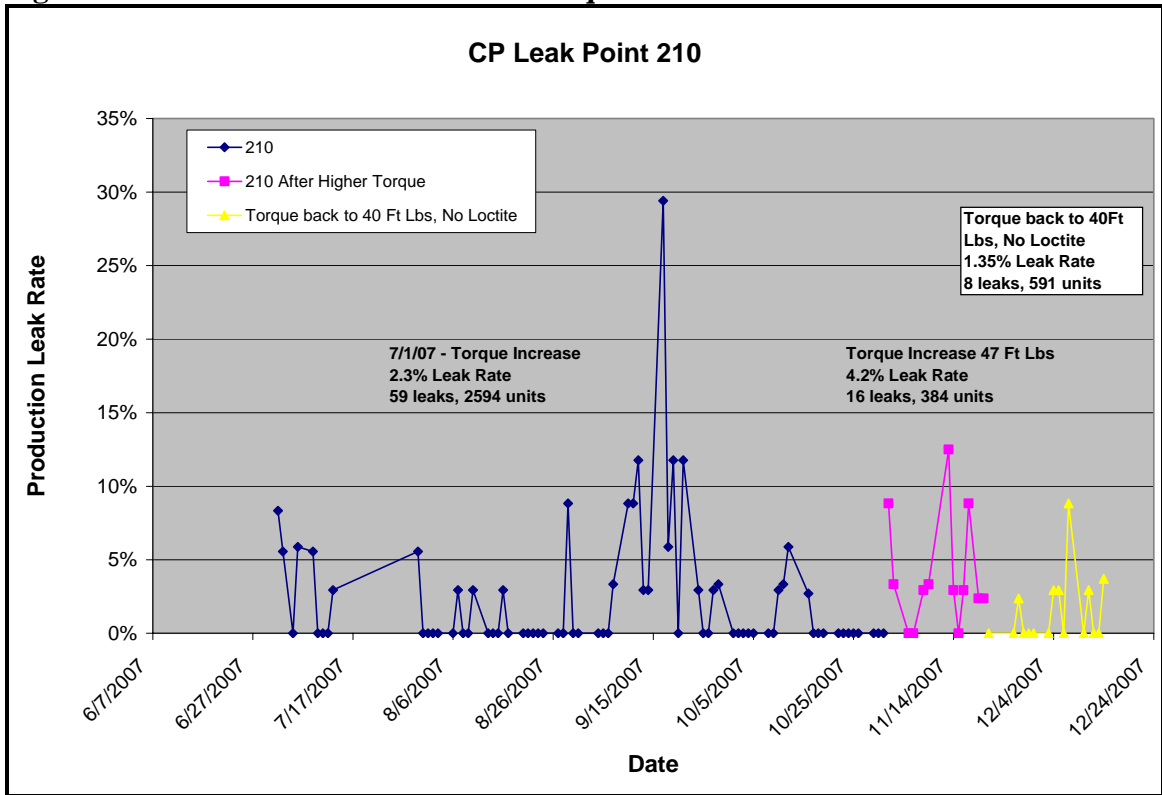
**Figure 3.19 Hypothesis Test Results of LP 210**

Test and CI for Two Proportions			
Sample	Leaks	Units	Sample p
1	59	2594	0.02275
2	16	384	0.04167
Difference = p(1) - p(2)			
Estimate for difference:		-0.01892	
95% upper bound of difference		-0.001471	
Test for difference = 0 (vs < 0):		Z = -1.78	P-value = 0.037

The p-value from the test is 0.037, which is less than 0.05, meaning the null hypothesis is rejected. This means that the difference in leak rate when torque was increased is statistically different; however the leak rate is increasing instead of decreasing.

From this hypothesis testing it was determined for these particular joints the torque increase was not improving the leak rate, especially on LP 210 where it actually got much worse. The leak team then determined the next step was to go back to the 40 ft-lbs of torque and remove Loctite 545 from the process. Figure 3.20 shows the new leak rate with the process change.

**Figure 3.20 Leak Rate of LP 210 After Torque Decrease**



With these new process variables, the leak rate went down to an average of 1.35 percent, definitely less than 4.2 percent, but not much lower than the original 2.3 percent. The hypothesis test between 4.2 percent and 1.35 percent had a p-value of 0.006. Meaning the difference is statistically different. This test result is shown in Figure 3.21.

**Figure 3.21 Hypothesis Test Results of LP 210 After Torque Decrease**

Test and CI for Two Proportions			
Sample	Leaks	Units	Sample p
1	16	384	0.04167
2	8	591	0.01354
Difference = p(1) - p(2)			
Estimate for difference:			0.02813
95% upper bound of difference			0.009624
Test for difference = 0 (vs < 0):			Z = 2.5      P-value = 0.006



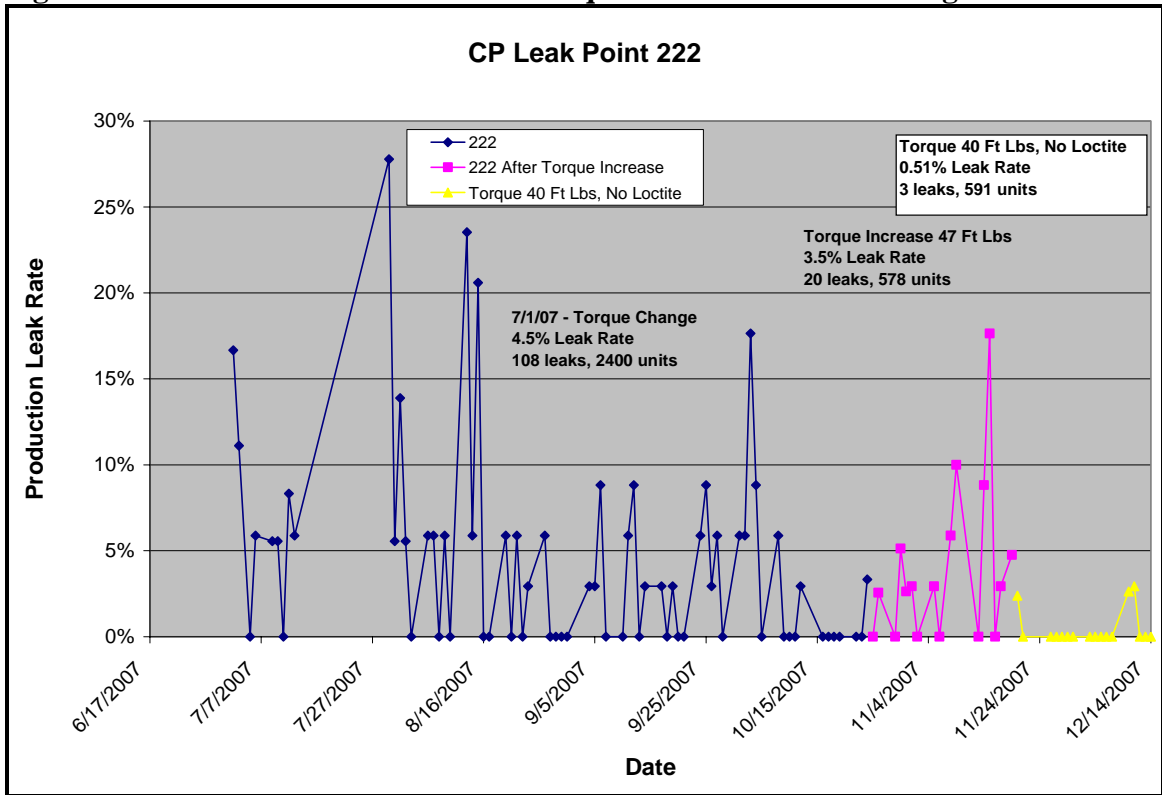
A hypothesis test was also run between the original 2.3 percent and the new 1.35 percent leak rate. The result is a p-value of 0.05, which is right at the limit of being statistically different. The test results are shown in Figure 3.22.

**Figure 3.22 Hypothesis Test Results of LP 210 With and Without Loctite 545**

Test and CI for Two Proportions			
Sample	Leaks	Units	Sample p
1	59	2594	0.02274
2	8	591	0.01354
Difference = p(1) - p(2)			
Estimate for difference:			0.009208
95% upper bound of difference			2.622E-05
Test for difference = 0 (vs < 0):			Z = 1.65 P-value = 0.050

The same process change was made to LP 222, the torque wrench used went back down to 40 ft-lbs from 47 ft-lbs and the Loctite 545 was removed from the assembly process. Figure 3.23 shows the leak rate results after the process change.

**Figure 3.23 Leak Rate of LP 222 After Torque Decrease and Removing Loctite 545**



The leak rate went down to 0.51 percent versus the previous leak rates of 3.5 percent and 4.5 percent, representing a significant reduction in the leak rate. The p-values from the hypothesis tests were both 0.00. The test results are shown in Figures 3.24 and 3.25.

**Figure 3.24 Hypothesis Test Results of LP 222 After Torque Decrease**

Test and CI for Two Proportions			
Sample	Leaks	Units	Sample p
1	20	578	0.0346
2	3	591	0.00508
Difference = p(1) - p(2)			
Estimate for difference:			0.02595
95% upper bound of difference			0.01612
Test for difference = 0 (vs < 0):			Z = 3.63 P-value = 0.000

**Figure 3.25 Hypothesis Test Results of LP 222 With and Without Loctite 545**

Test and CI for Two Proportions			
Sample	Leaks	Units	Sample p
1	108	2400	0.045
2	3	591	0.00508
Difference = p(1) - p(2)			
Estimate for difference:			0.03992
95% upper bound of difference			0.03146
Test for difference = 0 (vs < 0):			Z =7.76 P-value = 0.000

The testing on LP's 222 and 210 proved to be very fruitful and both leak rates were reduced significantly from the original values. The end result was a percent reduction of 89 percent for 222 and 41 percent for 210 from the original middle of year average leak rate. The brazed joint 210 did not benefit from the higher torque being applied to it. Both LP's had reduced leak rates when Loctite 545 was removed from the process, with the drop for 222 being especially significantly.

The same hypothesis test approach was used on LP's 61-65. The first variable that was changed was the hose material type. It was changed from a two wire swivel hose material to a wire mesh material. Both materials meet the pressure requirements for the ground drive loop hose application, but the wire mesh is more flexible. This flexibility allows the hose to be aligned better with the mating hydraulic fitting. This material changed was made October 1<sup>st</sup> on all 4 LP's: 61, 62, 64, and 65. Figures 3.26-3.29 show the leak rate of all 4 loop hose connections.

Figure 3.26 Leak Rate of LP 61

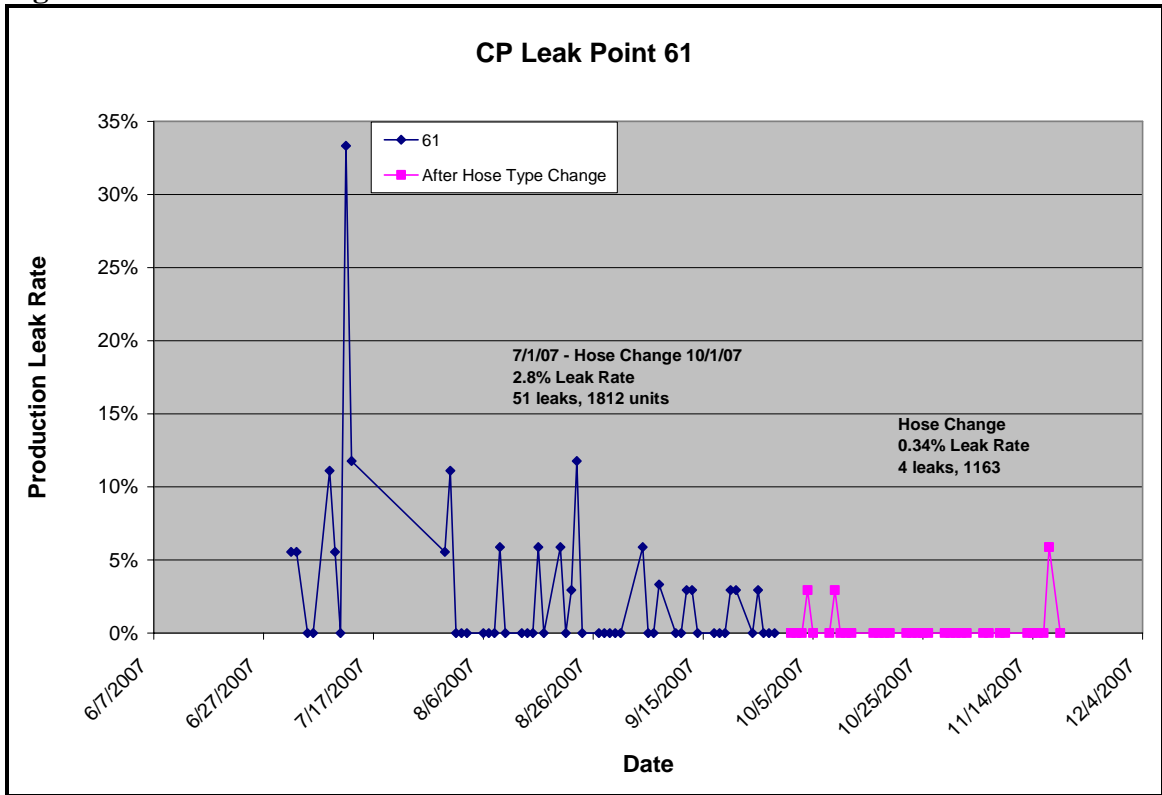


Figure 3.27 Leak Rate of LP 62

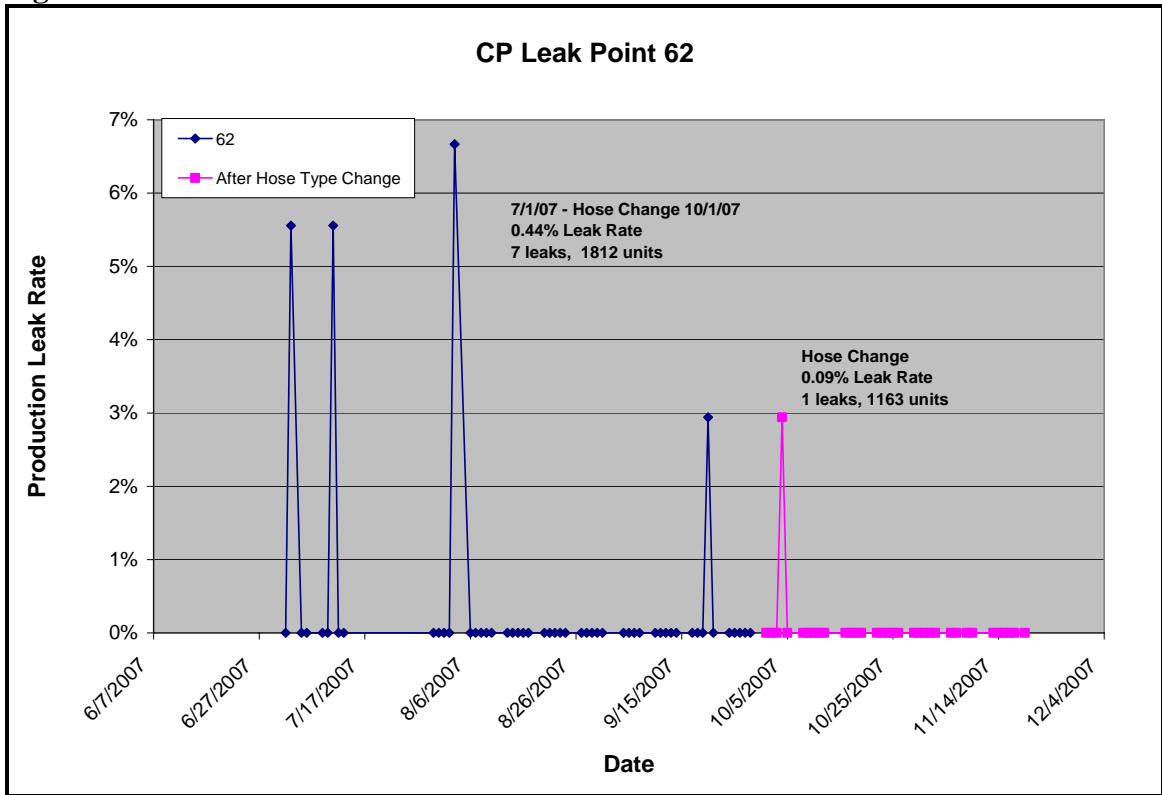
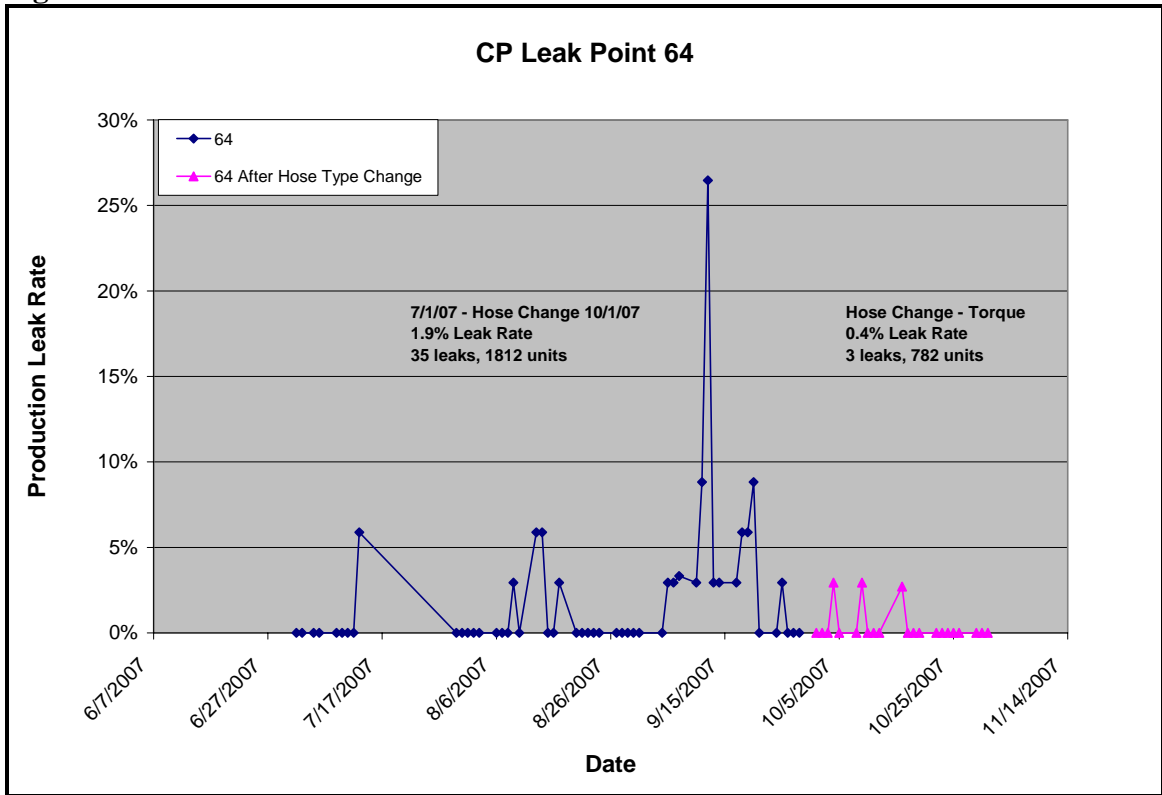
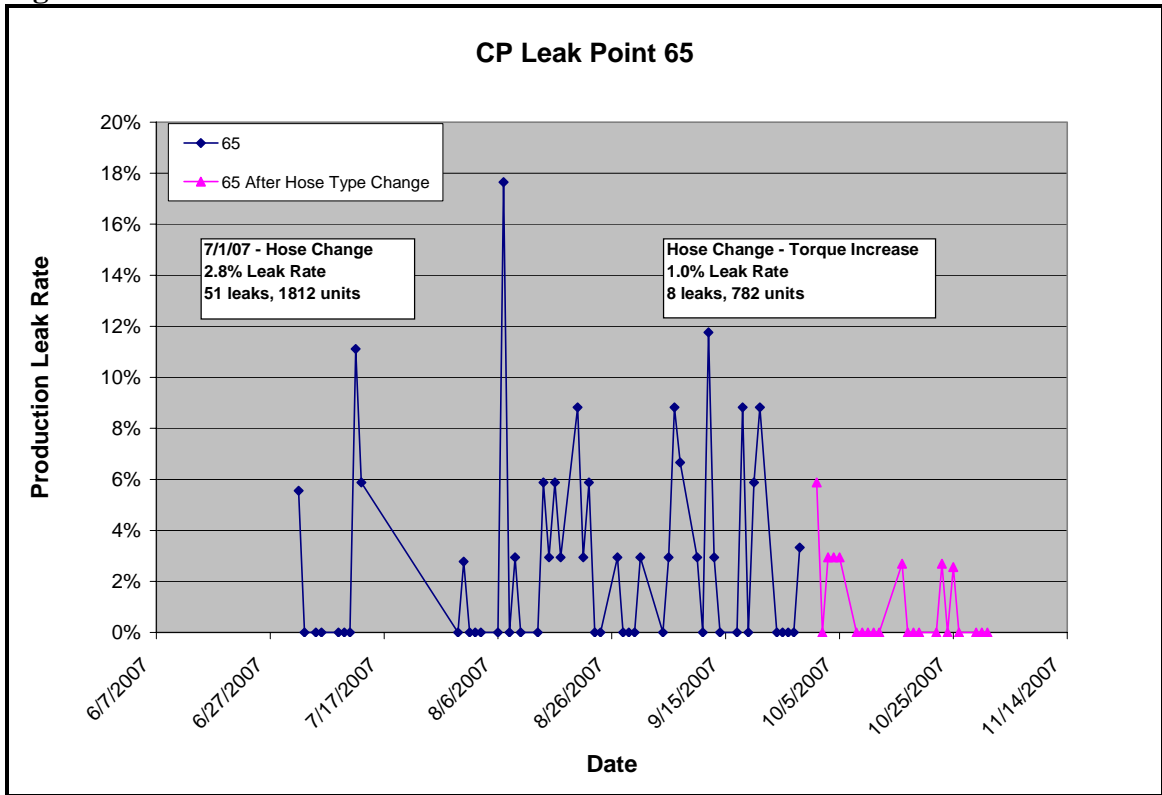


Figure 3.28 Leak Rate of LP 64



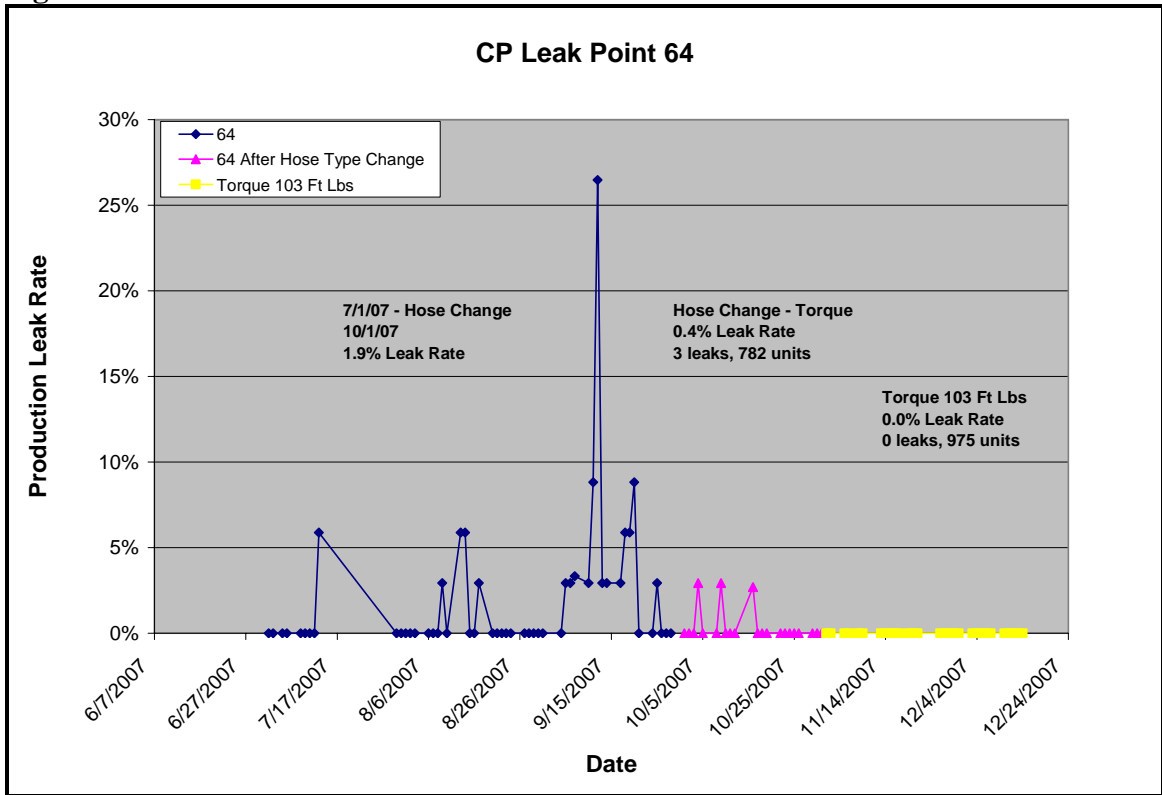
**Figure 3.29 Leak Rate of LP 65**



The leak rate went down significantly on all 4 LP's with the hose type change. The leak rate went from 2.8 percent to 1.0 percent on LP 61, 0.44 percent to 0.09 percent on LP 62, 1.9 percent to 0.4 percent on LP 64, and 2.8 percent to 1.0 percent on LP 65. The p-values from the two proportions tests are respectively, 0.038, 0.038, 0.00, and 0.00. All are below the 0.05 limit to reject the null hypothesis, meaning all are statistically lower than the original leak rates.

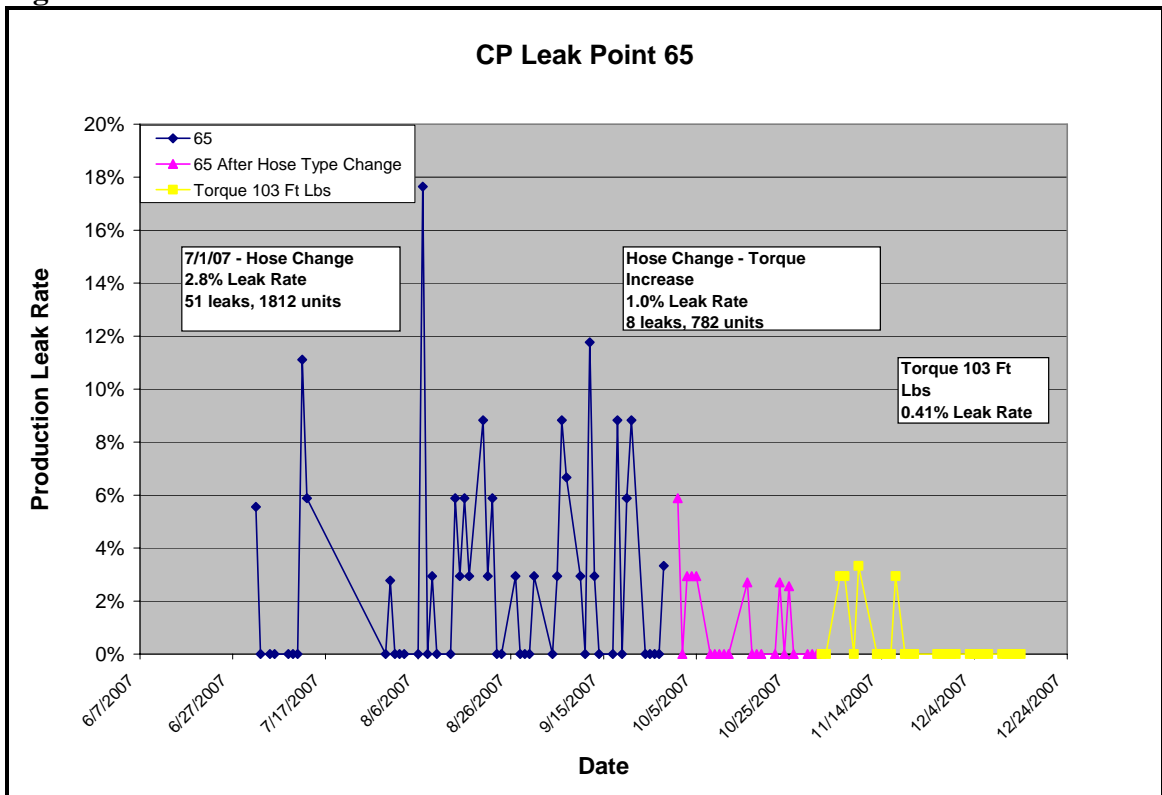
The leak team then discussed and decided to increase the torque on these 4 LP's by 20 percent and would monitor the resulting leak rate. The torque was increased from 86 ft lbs to 103 ft lbs. The left hand side of the machine, LP's 64 and 65, was changed first, and was implemented on Nov 1<sup>st</sup>. Figure 3.30 and 3.31 show the leak rate results.

**Figure 3.30 Leak Rate of LP 64**



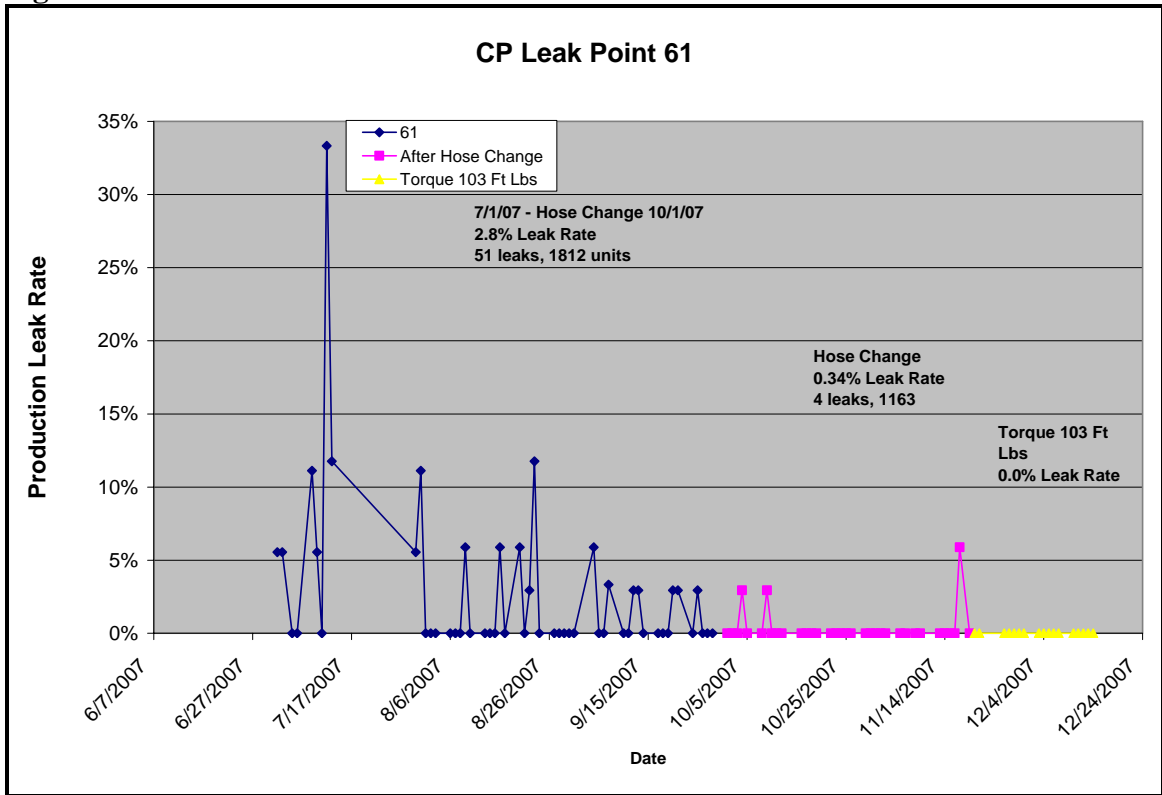


**Figure 3.31 Leak Rate of LP 65**

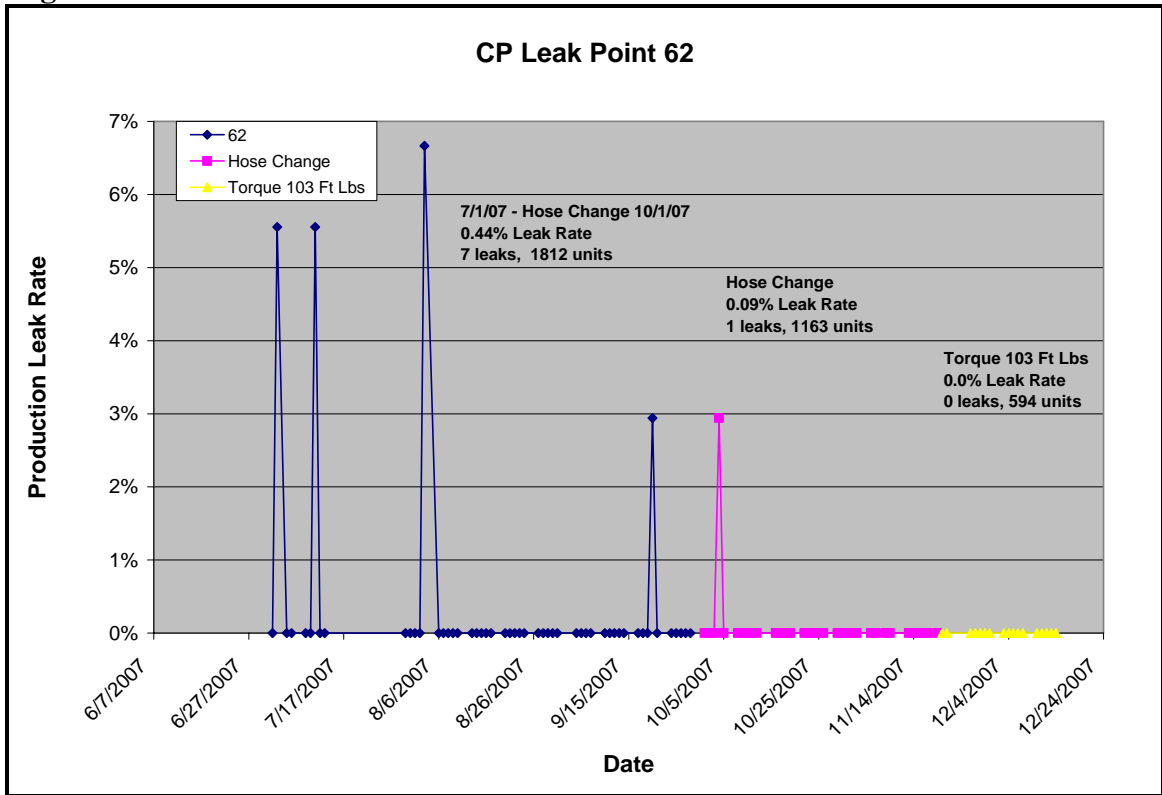


The increased torque on LP's 64 and 65 reduced the leak rate to 0.0 percent and 0.41 percent from 0.4 percent and 1.0 percent, respectively. The p-values with this change are 0.041 and 0.069, respectively. The p-value of 0.041 for LP 64 is below the 0.05 limit, the p-value of 0.069 for LP 65 is not below the 0.05 limit. The results were viewed positive, so the torque was also increased on LP's 61 and 62. The leak rate results for LP 61 and 62 are shown in Figures 3.32 and 3.33.

**Figure 3.32 Leak Rate of LP 61**



**Figure 3.33 Leak Rate of LP 62**



The increased torque on LP's 61 and 62 reduced the leak rate to 0.0 percent on both joints. The p-value for this change is 0.023 and 0.159, respectively. The LP 61 leak rate change is statistically significant, while the LP 62 leak rate change is not statistically significant. The rate is at 0.0 percent, so the only way to reduce the p-value is to run more units in order to increase the number of opportunities and for the leak rate to remain at 0.0 percent.

## CHAPTER IV: ECONOMIC IMPACT

The best solution for the ground drive loop hose joints, 61, 62, 64, and 65, was to change the hose type to a more flexible material to allow better alignment of the JIC connects. The assembly torque applied to the joint with a click torque wrench was also increased by 20 percent. This increase in torque increases the compression forces on the JIC faces of the male and female fittings. All of these joints are -12 size joints which are more tolerant to higher torque than smaller joints.

The leak rate of the ground drive loop hoses was reduced by an average of 96 percent after changing these 2 variables. The percent reduction for the joints 61, 62 and 64 was 100 percent. The percent reduction on the remaining joint, 65 was 85 percent. Table 4.1 shows the overall change with the ground drive loop hoses. The average time to fix was calculated from ALSTAR repair time. The repair cost per hour was provided by the CNH Wichita Plant Manufacturing Engineering Group. The leak rate before was the leak rate in the middle of 2007, after the detection method in the plant was somewhat stable. The leak rate after was the rate after the tests were done and the process was stable. The percent reduction is calculated by the equation =  $[100 \text{ percent} - (\text{leak rate after})/(\text{leak rate before})]$ . The annual volume of units is from the WPC 2007 Annual Forecast. The savings per leak point was calculated as =  $[\text{average time to fix} * \text{repair cost per hour} * (\text{leak rate before} - \text{leak rate after}) * \text{annual volume}]$ . Table 4.1 shows the results from the ground drive loop hose connections.

**Table 4.1 Ground Drive Loop Hose LP's Results**

LP	Average Time to Fix (Hrs)	Repair Cost Per Hour	Leak Rate Before	Leak Rate After	Leak Rate Difference	Percent Reduction	Annual Volume of Units	Savings
61	0.391	\$ 53.83	2.80 %	0.00 %	2.80 %	100 %	7509	\$ 4,426.98
62	0.273	\$ 53.83	0.44 %	0.00 %	0.44 %	100 %	7509	\$ 484.65
64	0.281	\$ 53.83	1.90 %	0.00 %	1.90 %	100 %	7509	\$ 2,156.19
65	0.296	\$ 53.83	2.80 %	0.41 %	2.39 %	85 %	7509	\$ 2,858.87
						96 %		\$ 9,926.68

The loader arm leak points were LP's 210 and 222. The two variables that were changed with respect to these joints were the assembly process torque and whether or not to use Loctite 545 during the assembly process. Loctite 545 was already part of the assembly before this study started. The assembly torque was the first variable to be changed in the study. It was increased by 20 percent from 40 ft lbs to 47 ft lbs. The results were not the same between the two leak points. The leak rate for 222 was reduced slightly, but the leak rate for 210 increased significantly. The LP 222 is a forged fitting and LP 210 is a brazed fitting, therefore the results are in line with expectations. Brazed fittings are known to be constructed of softer material and this higher torque deforms the joint more and creates a higher leak rate. Both of these loader arm circuit joints are -8 size components.

It was determined that the higher torque was not a good solution; therefore it was reduced back to the original value of 40 ft lbs. The Loctite 545 was then removed from the assembly process. The leak rate after this process change was the best from the study. The leak rate is not 0 percent, but the percent reduction is 41 percent and 89 percent for LP's 210 and 222 respectively. Table 4.2 shows the overall results for these leak points.

**Table 4.2 Loader Arm LP's 210 and 222 Results**

LP	Average Time to Fix (Hrs)	Repair Cost Per Hour	Leak Rate Before	Leak Rate After	Leak Rate Difference	Percent Reduction	Annual Volume of Units	Savings
210	0.241	\$ 53.83	2.30 %	1.35 %	0.95 %	41 %	7509	\$ 926.40
222	0.237	\$ 53.83	4.50 %	0.51 %	3.99 %	89 %	7509	\$ 3,824.50
						65 %		\$ 4,750.89

The correct assembly torque was discussed a number of times with suppliers in the hydraulic components industry. Each supplier has their own recommendations. The leak team was told by a number of different suppliers that the larger fittings are more forgiving of higher torque than the smaller fittings. The leak team was told that -8 was the change over size between large and small. Therefore, the higher torque is only recommended for -10 size joints and higher.

Table 4.3 shows the results for all six leak points from the project. The average percent reduction for all six joints is 86 percent. The calculated savings is for internal WPC rework. This internal savings is only part of the benefit to the company. Some of the other benefits are oil loss reduction, warranty reduction, and customer satisfaction improvement.

**Table 4.3 Total LP's Results**

LP	Average Time to Fix (Hrs)	Repair Cost Per Hour	Leak Rate Before	Leak Rate After	Leak Rate Difference	Percent Reduction	Annual Volume of Units	Savings
61	0.391	\$ 53.83	2.80 %	0.00 %	2.80 %	100 %	7509	\$ 4,426.98
62	0.273	\$ 53.83	0.44 %	0.00 %	0.44 %	100 %	7509	\$ 484.65
64	0.281	\$ 53.83	1.90 %	0.00 %	1.90 %	100 %	7509	\$ 2,156.19
65	0.296	\$ 53.83	2.80 %	0.41 %	2.39 %	85 %	7509	\$ 2,858.87
210	0.241	\$ 53.83	2.30 %	1.35 %	0.95 %	41 %	7509	\$ 926.40
222	0.237	\$ 53.83	4.50 %	0.51 %	3.99 %	89 %	7509	\$ 3,824.50
						86 %		\$14,677.57

The first phase of this project was to improve the leak rate of current product SSL's manufactured at the WPC Plant. The six joints analyzed have been greatly improved. The next step is applying the lessons learned to other problem joints in the WPC Plant. The increased torque on larger fittings will have to be analyzed to determine if it reduces the leak rates verses causing an increase in leak rate. The use of Loctite 545 will need to be analyzed joint by joint too. It has proven to be a benefit from previous testing, but the use of it depends on the joint and particular circumstances of that connection.

## CHAPTER V: CONCLUSIONS

There were only six joints analyzed in this study, but the results from these six were very promising to help resolve the leak problem at the CNH Wichita Plant. These six joints were selected because of their chronic leak problem. The variables that were changed depended on the particular joint and circumstances that pertain to it.

The first phase of this project was to improve the leak rate of current product SSL's manufactured at the WPC Plant. The six joints analyzed have been greatly improved. The next step is applying the lessons learned to other problem joints in the WPC Plant. The increased torque on larger fittings will have to be analyzed to determine if it reduces the leak rates verses causing an increase in leak rate. The use of Loctite 545 will need to be analyzed joint by joint too. It has proven to be a benefit from previous testing, but the use of it depends on the joint and particular circumstances of that connection.

The second phase of this project was to give direction to future products at the WPC Plant. The first recommendation from the study would be to investigate the use of o-ring face seal connections in the ground drive loop hose joints. The JIC connections that are currently being used are not designed for the working pressure that is be applied to joints. The -12 JIC connections are designed for 3500 psi or less and most of the loop hoses on SSL's are 3500 psi or more, some up to 5250 psi. The second recommendation is to reduce the number of joints in SSL's where possible. The average SSL has 300 joints that have to be made in the assembly process. There a number of ways to reduce the number of joints: use tube-hose combination, use more brazed tubes, and use more tubes where possible.



Overall, this project has provided good analysis of leak data. The end result is to continue to use the information collected in this project to help reduce rework associated with leak within the WPC's manufacturing process and also to reduce the number of leaks that make it to the end customer.

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