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Department of Technology Research Paper

Abstract
The purpose of this research is to identify the issues with forward breakaway and show why forward breakaway cannot be used to determine a Cpk value and thus determine capability. The need for this research is industry must find a way to prove a torque input tool that is not able to be used with an inline transducer without using Cpk as the capability determiner.

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Department of Technology
Research Paper

A Research Proposal for Presentation
to the Graduate Faculty of
the Department of Technology
University of Northern Iowa

In Partial Fulfillment of the Requirements for
The Non-Thesis Master of Science Degree

By
Jeremy Thede
December 17, 2014

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Shahram Varzavand ______________________ 12/17/2014

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Signature of Second Faculty Professor Date

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Introduction to Study

In manufacturing two piece of material are often held together by bolts. Design engineers will determine a specific clamp load that the joint needs to have to ensure that the joints will stay together. Design engineers give specification to manufacturing engineers not in terms of clamp load, but in terms of torque. The manufacturing engineers will then determine the correct tool to use to achieve the torque the design engineers have called out.

There must be ongoing monitoring of torque values to ensure that proper clamp load is being achieved. Many of the joints that are being held together by a bolt are considered to be structural joints. The joints are the ones that if there is a failure, the structural integrity of the widget will be compromised and often safety will be compromised. Other joints are considered to be critical to the operation of a particular widget. If the bolt does not continue to hold clamp load, the widget will fail. Some joints are not as important. These particular joints, if they fail, will result in potential customer downtime, but no real catastrophic failure will result from it.

In a manufacturing setting, joints are set up based on a certain risk that they pose to the widget if they fail as well as the ability for the process to detect a problem with the joint. The number associated with this is then used to determine a strategy to use to ensure that the joint has the proper clamp load (by way of torque). This can include using different types of tool to install the bolt, as well as using audits to ensure that the bolts are being torqued to the value that design engineering has put forth.

One key activity that must be performed when installing a tool that will be used to torque bolts is verifying the tool is currently, and will continue to produce values that are within the specifications given to manufacturing engineers by design engineers. Depending on the tool this is accomplished in many different ways. Inline transducers and forward breakaways may be used to accomplish this. Also depending on the tool, there may need to be capability studies performed to ensure that the tool will and will continue to perform as required.

Statement of Problem

There are two problems associated with this. First, not all tools can use the preferred method, inline transducers. Second, there are inherent problems associated with using forward breakaway. The manufacturing engineers must use the cheapest tool possible, while the quality engineers must ensure that the tool will operate as intended by design engineers so that there is no risk to the customer. This task must be accomplished prior to using the tool for production due to the possibility of impact to the customer if suspect joints were allowed to be sent to the customer.

Statement of Purpose

The purpose of this research is to identify the issues with forward breakaway and show why forward breakaway cannot be used to determine a Cpk value and thus determine capability. The need for this research is industry must find a way to prove a torque input tool that is not able to be used with an inline transducer without using Cpk as the capability determiner.

Statement of Need

Manufacturing in today's environment means that every product must be produced with the upmost in quality. There are many joints that are fastened together by process of applying torque to a fastener. If the device that is applying that torque is not capable of producing the torque needed every day, there will be quality issues. If there are quality issues, there will often be a decrease in customer satisfaction. When customer satisfaction decreases so do profits by way of fewer customers purchasing units. The need for this study comes from the fact that without a robust process to determine capability there is an increased likelihood that customer satisfaction will decrease because the manufacturer may be using subpar equipment.

Research Question

The research question to be answered is can capability be proved on a tool that cannot use an inline transducer given the effect of human error?

Literature Review

In attempting to answer the research question it was quickly realized that there was going to need to be research, significant research to understand all the factors that may be at play.

Scope

The literature that was reviewed was limited to no older than 10 years old scholarly journals. The scope did not include referring websites such as *Wikipedia* as it has been found that they are often not correct in information that they convey. Scope was also limited to determining capability, and the factors of torque in assembly. The factors that affect torque not only being those forces and reactions in a physical sense, but also the reasons that torque is used when clamp load is actually what is being achieved.

Torque

It is extremely important that fasteners be installed correctly. Not only can product quality suffer due to loose fasteners, but also safety concerns. Miller (2007) found that fasteners can account for nearly 50% of a bill of materials when building assemblies. The large percent of fasteners in an assembly means that it is very important for the fasteners to be installed correctly to ensure good quality and efficient manufacturing. Torque has been used as the most practical method to determine the correct assembly of a bolted joint. It is relatively easy to measure the amount of torque present in a joint either by measuring it in a dynamic fashion during installation, or after in a static fashion by performing a forward breakaway on the joint.

One question that many people have is why do we measure torque? If the actual force that we are looking to achieve is clamp force, why would torque be the force that we choose to measure? Dirago (2014) found that in heavy equipment applications, design engineers have used torque as the standard for long-term durability and vibration resistance. The philosophy behind using torque has been based upon the idea that higher torque on a bolt results in a more secure and higher clamp load on a joint. This idea was found to be false; in fact the higher torque does not necessarily mean that a joint will be more secure.

The torque value that manufacturing and quality engineers must ensure the joint is being torqued to come from the design of the assembly. Hwang (2013) says that in vehicle design the torque that the bolt is to be installed at is mainly determined on hardware tests. The preferred method that is used today is using numerical simulation by means of one of the many failure effect analysis programs that are available on the market. Often the study will develop the installation torque that is based upon torque by using angle curves. Prior to the use of failure effect analysis this was set in a more manual way through destructive testing. The use of fasteners in an assembly is mainly driven by ease and cost. Fasteners can be brought to torque by simple tools; the caveat is that in order for the fastener to be effective the manufacturer must be confident that the correct torque is consistently achieved.

Clamp is defined by Dirago as “the load on the joint brought about by the drawing together of the fastener components.” Dirago goes on to say that clamp is not related to torque, in fact studies have shown that when torqueing same assemblies the actual clamp value will vary more than 30 percent. Clamp is the true measure of durability in a joint. If the clamp load is insufficient the bolt can become the fuse in the assembly, thus subjecting it to the forces that the entire joint would normally see. This can result in a fracture on the bolt across the cross-section. Eventually the bolt will be unable to support the load of the assembly and fail.

There are many factors at work when using torque as the definition as the force to calculate clamp load. Milenkovich (2013) found that the assembly of a bolted joint with a nut works the same as a joint that uses a bolt going into a threaded hole. In the case of a joint with a nut, the nut is tightened on a bolt to fasten an assembly, the nut then tightens against the surface of an assembly member, thus placing the head of the bolt on the opposite side of the assembly. The body of the actual bolt is put under strain pulling apart as the torque of the bolt increases.

According to Milenkovich (2013) the normal assembly process is an assembler is given a specification torque to install a bolt at, typically in newton meters. A torque wrench is then used to ensure that the bolt is installed at the correct torque. The clamp load that is achieved only counts for about 10% of the total torque applied. The rest of the torque is used up on under head friction and friction resistance in the threads. It can then be seen why when a lubricated bolt is used, often times the bolt will break. The actual stretch that is happening to the bolt is much greater because of the lubrication. After maximum torque for the bolt is achieved there will be a loss in torque as the fastener continues to be turned. When the decrease is torque is realized, often what has happened is the bolt is now much looser and the bolt has been yielded. Upon the bolt being snugged, each rotation of the bolt will increase the torque to turn the bolt, thus increasing the stretch of the bolt similar to that of a rubber band. This phenomenon creates the clamp load that is the intended purpose of torqueing the bolt.

Milenkovich (2013) stated that a load has two different states that it can be in; static or dynamic. Static is when the load is sitting at rest, dynamic is when the load is moving or in service. The design engineer should design a bolted joint so that when it is tightened it will exceed the expected load that the joint may see when the assembly is put together. The joint should also be designed so that when the bolt is installed the main part of the load is realized in the actual assembly itself, rather than in the bolt. The load should not be on the actual mating part. Milenkovich (2013) gives a great analogy for this. The basic concept of load distribution on an assembly is seen when a person is attempting to lift a load. Unless the person possesses enough strength they will either drop the load, or not be able to pick the load up. The same principle applies when a bolted joint is attempting to bear the load.

Katsis (2005) found that while the original solutions to install fasteners in an assembly at a predetermined torque were to use preset torque wrenches, a problem with this solution was quickly realized. A large amount of audit data needed to be collected to for data acquisition to ensure that the torque wrench was used correctly.

Katsis (2005) said that about two decades ago the first digital torque wrenches came on the market. Digital torque wrenches were limited in the fact that; data measurement was nonexistent, torque tools were very fragile, as well as being sensitive to adverse conditions that may be present in a manufacturing environment. Nearly fifteen years ago the first non-digital torque wrench that was able to communicate came to the market.

The original torque wrenches were a clicker type of torque wrench, where upon reaching a preset torque the tool would click. This would activate a switch when the tool was clicked. The switch was in a normally open position, when clicked the switch would then go closed. Upon release of pressure on the tool, the switch would move back to its normally open position, thus allowing the system to reset. During the time that the switch was closed the circuit was then able to count the amount of time that it was in the closed state according to Katsis (2005).

This allowed a system where the same wrench would need to be used to tighten four joints. The system would know if each of the four joints were tightened by counting the amount of times that it moved from the open to closed state as well as ensuring that the correct duration of time while in the closed state. The shortcoming of this system was the only data that was collected was that of attribute data, basically only answering the question did the wrench click four times, yes or no? This would still enable PLC programs that would halt further progress in the manufacturing assembly if the correct number of clicks and correct duration of click were not seen.

One of the setbacks of the initial offering of attribute data collecting torque wrenches was there was a need for the wrench to be connected to a computer via a cable, thus providing a hindrance and potential safety issue for the employees conducting assembly operations. Nearly years after the first attribute torque wrenches were introduced, a company came up with a solution; radio frequency (RF) enabled torque wrenches. This allowed the torque wrench to be moved without the hindrance of a cable. Today's digital torque wrenches offer many of the same features that power tool with an in-line transducer do. The portable torque wrench still holds the advantage in two areas: remote assembly where the tool moves to the product rather than the product moving to the tool and in torque auditing.

Torque Auditing

While torque auditing is a commonly accepted practice within the manufacturing industry, there are many shortcomings with the process. Camillo (2013) said that a torque audit measures the residual torque, which is the amount of tension that remains in the joint after it has been tightened to the assembly. Torque auditing prevents over-or-under torqueing fasteners and detects missing fasteners. It also serves a purpose of validating the manufacturing process, the input tool, the design of the assembly, and the materials that are used in completing the assembly.

Takasaki (2011) found that in-line torque auditing is accomplished by placing a torque transducer between the socket and the driver of the tool applying torque while the tool is applying the torque. There are a couple tests for torque to turn tests, first breakaway torque and secondly running torque. Breakaway torque is defined as how much force is needed to restart a fastener from a static state to a dynamic state. Running torque is basically what the inline transducer uses, where it is the amount of torque required to continue turning a fastener.

There are other methods to determine a static torque value other than breakaway. Camillo (2013) said that there are three ways to perform a static torque audits. The standard method is known as breakaway. Using analog or digital torque tools and auditor will slowly apply pressure in the tightening direction until the first movement of the fastener is noted. Some digital torque tools have a setting that allows the auditor to put in a degree of movement that the torque tool will then give the peak torque at the angle that the tool was set to. The drawback to this setup is it requires data on each joint that is to be checked to be collected to determine what that umber of degrees should be. The auditor would then need to manually change the degree for each joint that they check.

An example of breakaway torque is an engine in an automobile. Specifically, breakaway torque would be the amount of torque that is required to start an engine. This is the amount of torque that is necessary to overcome all the static friction that is evident in an engine. In the winter it is much harder to start an engine, not only because of the cold effects on the battery but also the cold effect on engine oil. Oil's job is to protect the friction surfaces of an engine. As it gets colder the oil will thicken increasing its viscosity. The thickness causes increased drag on all associated parts, thus increasing the breakaway torque needed to overcome all things affecting the engine running. An automotive mechanic can measure the amount of torque required to turn the flywheel in an automotive engine to determine if there are other things at play causing the engine to not want to start. Determining the actual root cause may be more involved than that, but it will provide a quick answer. Running torque can be characterized by the same example. This is the amount of torque required to keep the flywheel in an engine turning once it has started. This will decrease in our example over time as the engine warms up and thus heats up the engine oil reducing the viscosity.

Camillo (2013) stated that the next method that is used to perform a static audit is the loosening test. This method uses the same principle as the forward breakaway, instead of going in the tightening direction; the pressure is applied in the loosening direction. The torque value that is recorded is close to the approximate torque that was applied to the joint. The issue with this type of inspection is the potential for loosened fasteners making it through the process and on to the customer. The final method is the mark and return. This method uses a line marked on the head of the bolt and on the surface that the bolt is snugged up to. The bolt is then loosened and tightened to that mark recording the value at the exact point that the line. The issue with using this method is once again loosening a bolt as well as finding the exact point that the two surfaces were aligned. Depending on the thickness of the marker being used, there may be considerable difference in the torque value recorded.

With all the shortcomings of checking torque Hagiwara, Mano, Nunogami, Ozeki, & Ito (2009) had a goal to develop a new testing machine that would be used for the torque and or clamp force tests to be used in accordance with ISO 16047. The study was framed around using a piezoelectric force sensor to detect the torque and clamp forces that are present in a bolted joint. The study went on to say that that the clamp force that the threaded assemblies needed to be must be controlled to increase the reliability of the completed assemblies. The problem with measuring clamp load is that with current tools it is difficult to measure, thus the method used to measure clamp load in manufacturing is torque. ISO 16047 frames the various characteristics that are at play when using torque as the measuring force down to an accuracy of ±2%. It was found that it was possible to develop a system that combined a load cell and torque measuring cell complete with piezoelectric sensors.

Determining Capability

Determining the capability of process can be a challenge. In some cases it is simple, simple take data, and perform statistical rigor on that data to determine if the process is in control and will not drift out. In the case of joining two parts tougher performing capability analysis can be much more difficult. Often times the only criteria that is given is to verify that the process is capable. In many cases of joining parts the standard response of Cpk is not a viable option.

Jeang (2010) found that Process capability analysis is used to measure the level of quality in a production environment. Some of the problems with this type of capability is it has a difficult time finding a difference between alternatives for process selection. Due to this problem there is a drive to find a capability expression that can be used to evaluate alternatives. Frequently used Process Capability Indices include Cp and Cpk.

The ASTM Standard E2281-08a (2012) defines process capability as the natural or inherent behavior of a stable process that is in a state of statistical control. It goes on to say that a state of statistical control is achieved when the process exhibits no detectable patterns or trends, such that the variation seen in the data is believed to be random and inherent to the process.

Khodaygan & Movahhedy (2012) stated that process capability indices (PCI) are extensively used to determine whether or not a process is capable of producing objects within specified limits. The first CPI what was identified was Cp. Cp considers the overall process variability relative to the tolerance given by manufacturing tolerance. The weakness of these indices is that it measures the overall spread of the measurements and not the specification mean spread. Cpk was developed to take into effect the spread of the process mean in addition to the measures that Cp takes into effect. Cpk gives the user an ability to know where the process is running in relation to the mean of the specification. This will allow the user to know if there is a good chance that the process will drift outside of the specification limits. The generally accepted value for Cpk is 1.33.

The ASTM Standard states that Cpk is a process capability index that considers the mean against a specification limit. Meanwhile Cp is used in situations where the variation is looked at within the parts where a specification limit is not able to be used. The ASTM Standard says that

Cpk can be equal to but never larger than Cp. Cp and Cpk are equal only when the process is centered on the specification. If Cp is larger than Cpk, then the process is not centered. If both Cp and Cpk are greater than 1 the process is performing able to and actually performing within specifications. The converse is true if both Cp and Cpk are below 1. If Cp is greater than 1 and Cpk is less than one the process is capable, but not centered and performing within the specifications given.

Khodaygan defines Cp as $C_p = \frac{USL-LSL}{6\sigma}$. Whereas USL is the upper specification limit given by engineering, LSL is the lower specification limit given by engineering, and σ represents process standard deviation. As can be seen from the equation, Cp cannot present an assessment of the process mean.

Khodaygan defines Cpk as $C_{pk} = \frac{d-|\mu-m|}{6\sigma}$ where σ is once again the process standard deviation, μ is the mean value. *d= (USL-LSL)/2* which equates to the half of the specification width. *m= (USL+LSL)/2* is the mid speciation range related to the manufacturing tolerance set by manufacturing engineers.

As above often times a process will be compared with the specifications that either the customer or engineering has given then use a proportion of the actual process to the product specifications. It is from these indices that management and engineering make decisions on actions that need to take place to ensure that the customer is always protected. The ASTM standard section 4.4 gives guidance on Process Performance indices. When a process is not in a state of control special cause variation will appear. Special cause can lead to many unwanted effects including spikes in the process mean and long term mean shifts.

The issue with measuring Cpk in a situation such as torque in a static state is the true value is not known. Due to the fact that there are human errors, specifically with a human using their intuition to determine when a bolt moves, it is nearly impossible to determine a Cpk value when attempting to determine the capability of a torque tool. It is relatively easy when determining the Cpk value for a tool that allows the use of an in-line transducer because it completely overrides any human influence on the process.

Research Method

Given that the issue was determining capability of a particular torque tool, the first step was to use a joint that the torque tool would actually be used on. Below is a picture of the joint that was used.

Figure 1. Threaded holes that cap is inserted into.

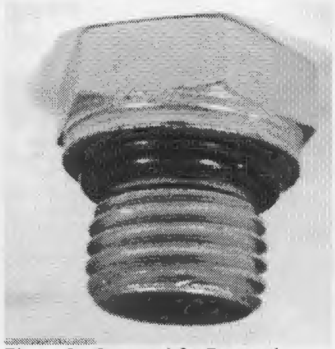

Figure 2. Cap used for Research

This is a joint where the bolt on the left side of the screen uses an O-ring, yet the joint is still defined as a hard joint. Each of the letters represents a location for the bolt that was used for the study. During the study the bolts will be used one time only, as well as the manifolds. This way the exact same conditions exist during the study, as do during the actual installation on the assembly line.

Three methods for installation were utilized. A DC gun complete with inline transducer, an SR click wrench, and the tool that is being verified. The DC gun was verified and certified capable; the SR click wrench also underwent verification to ensure that it was capable or repeating.

Currently in the industry that this study was performed the preferred method of determining capability is Cpk. The Cpk value that is accepted as representing a stable process that is centered is a value of 1.33. Due to this need one of the steps in the process was to contact the manufacturer of the inline transducers that are currently owned by the company. The inline transducer company did not recommend and in strongly suggested that we do not use an inline transducer with the particular tool that was in question. Due to the way that the inline transducer is assembled and the actual action of the tool that was in question, the company that produced the inline transducer said that the transducer may give erroneous values. Furthermore, the tool may actually damage the transducer.

Given the information that was given by the inline transducer manufacturer an alternative method was needed to determine the torque value present in each joint. It was decided that a few of the methods found in the literature review would be used. Forward breakaway, mark for torque, and a standard 3 degree audit setting on the torque wrench. The study also utilized two experienced employees that conducted their torque collection in a complete random order without having the knowledge of each value, nor the value that each employee had.

Below is a picture of the torque wrench that was used to perform the forward breakaways. It is a Crane IQWrench 75 Nm. The reason that this particular wrench was used is because of its ability to read in not only peak, but also what Crane calls audit mode. Audit mode is simply a preset value that the wrench will allow the bolt to turn prior to giving a torque reading. The perceived advantage to this is the human error will be minimalized.

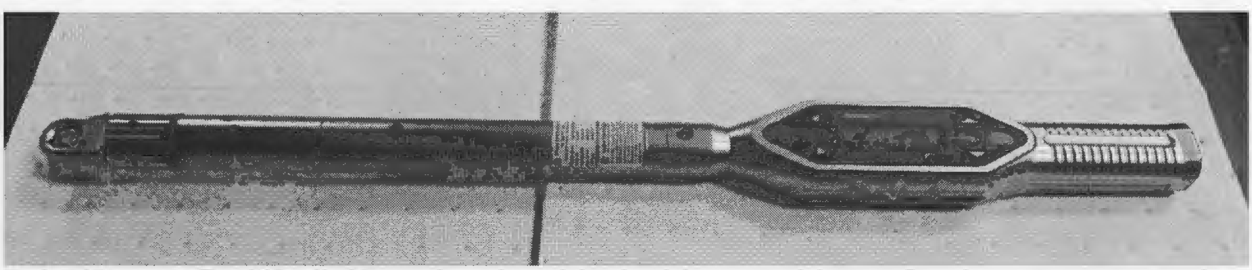

Figure 3. Torque wrench used for research

Data Analysis

The first step in analyzing the data was to ascertain if the data was normal. This was verified by performing a normal probability plot along with a Shapiro-Wilk test for significance.

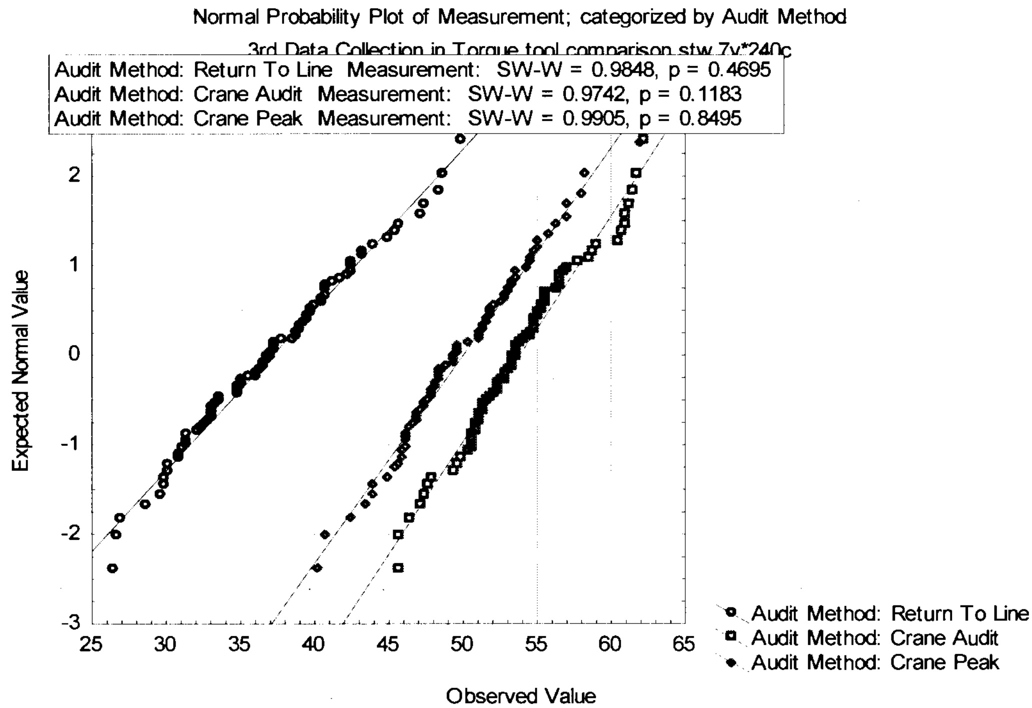

Figure 4. Normal Probability Plot by Audit Method created in Statistica©

Given the graph above with the data from the study, the normal probability plot shows that there is a normal distribution on the data when grouping the data into categories of audit method. Due to the fact that the data is normal the study progressed into the next phase.

The next thing that was looked at was the means plot for audit method. We wanted to see if there was a true discernable difference in the three different methods used to conduct the study. The reason that this was significant was the inability to use an inline transducer limited how we would use the Cp and or Cpk value that we would get. We needed to ensure that the audit data was going to be the best possible data that we could use with the least amount of human variation influencing the data. The first step was to see if we could even see a difference in the data.

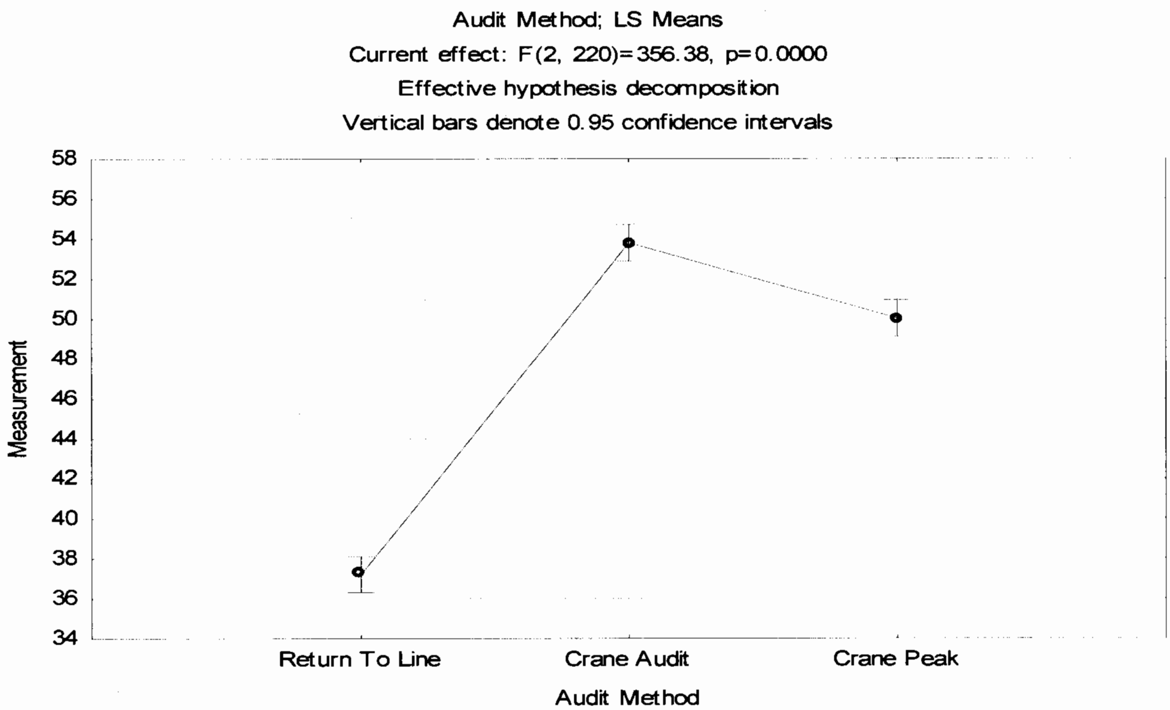

Figure 5. Means Plot by Audit Method created in Statistica©

As can be seen from the above graph there is a difference between the three different audit methods. As expected the return to line (mark for torque) method produced the smallest over all mean value. The graph also shows that given the 95% confidence intervals there is a statistical difference between the peak method and the audit (3 degree of movement).

The next step was to see if there was a difference in the mean values collected for each input variable. This would take into consideration all three audit methods and look at them in a means plot way to see if a difference can be seen. What we are attempting to do is see if any one audit method is better than another. From the means plot above we are able to see that there is a difference between each audit method. The next question that needed to be answered was what means plot is the best one? The solution that was found was to use the means plot of the DC gun. The DC gun has the highest capability to being correctly installed. The SR click wrench has the ability for the assembler to over torque the joint, the input gun that is in question would not be able to be used, and therefore by process of elimination the DC gun values were used.

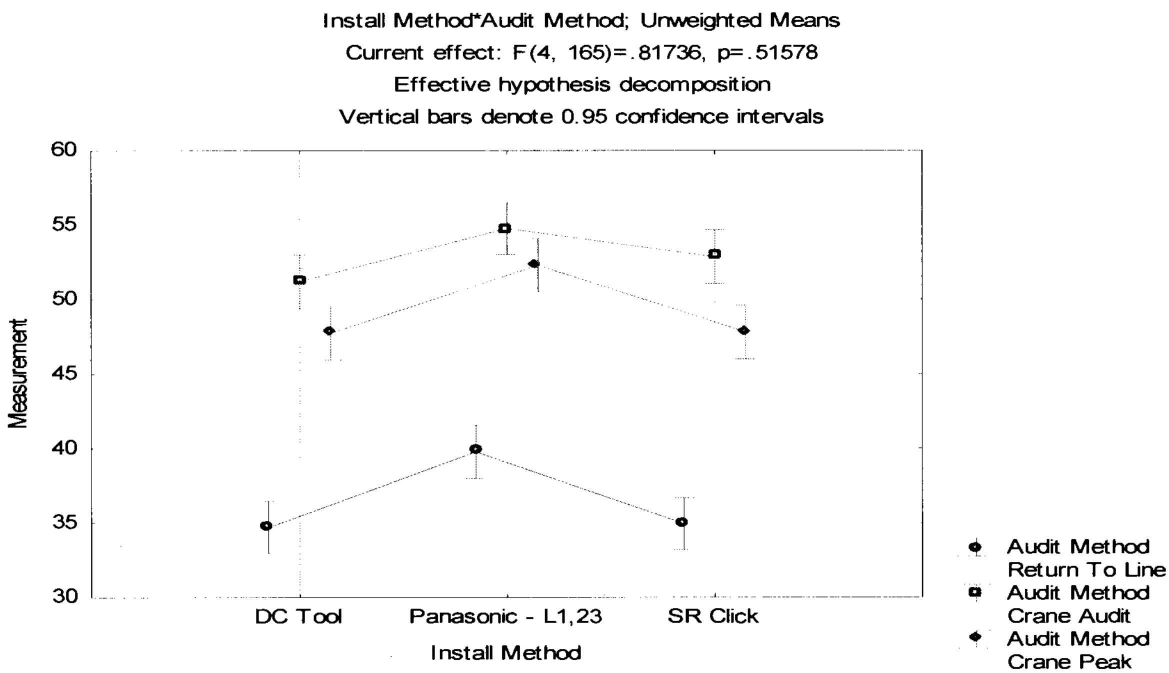

Figure 6. Means Plot by Install Method created in Statistica©

As can be seen from the above chart the means plot of the 3 degree audit as well as the one for peak mode is overlapping, meaning that I cannot tell a difference between the two values. Due to the fact that the peak mode was the closest to the actual input torque (40 Nm) as well as keeping the same mean variation between the DC tool and SR click wrench, it was chosen that the peak mode would be used to assess capability of the input tool in question.

Next a capability study was run on each input method. The DC tool is the first one that was performed.

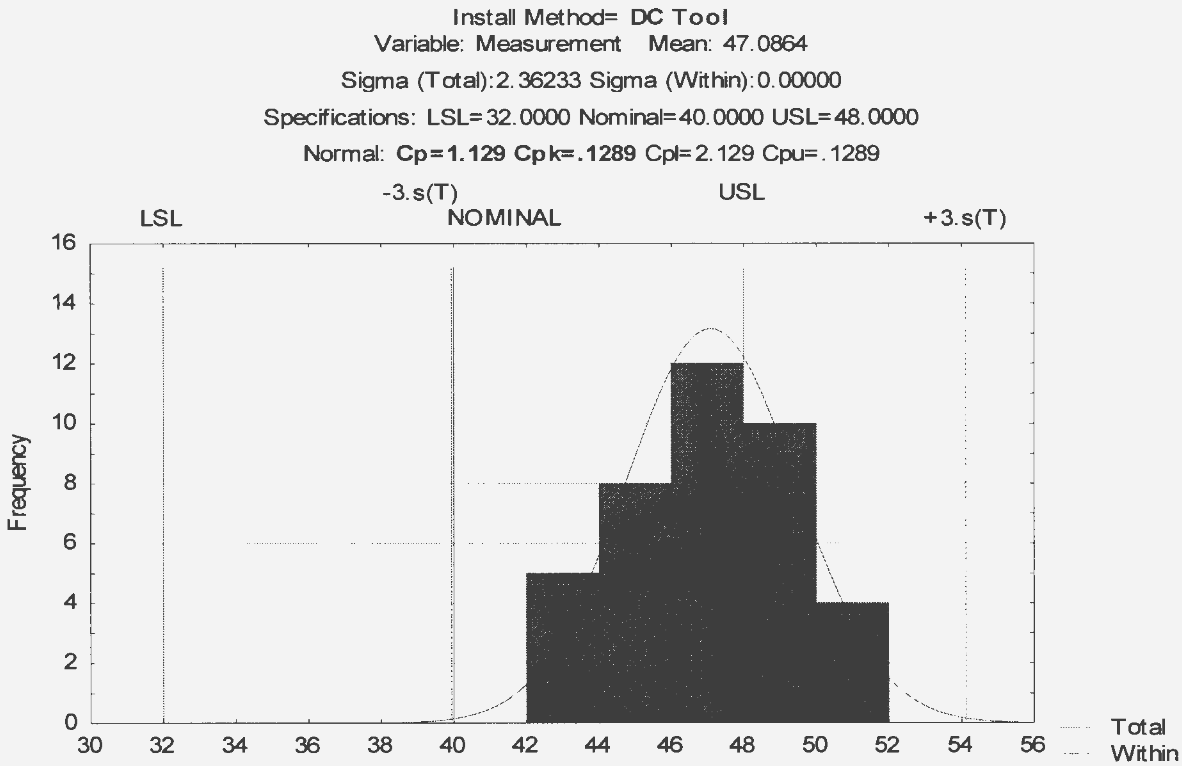

Figure 7. Capability Histogram using DC Install Method created in Statistica©

The Cpk value for using forward breakaway was obviously well below the industry standard of 1.33. This would be expected due to the fact that the specification that it is being compared to is an input torque specification. Due to the transfer function of static torque as well as the lack of a true specification to use, this would not be a viable option to use. Therefore we turn our attention to the Cp value. For the Dc tool, regarded as the most stable process that is being used, a Cp value of 1.129 was achieved.

Next we turn our attention to the SR Click wrench to gain some additional data on Cp.

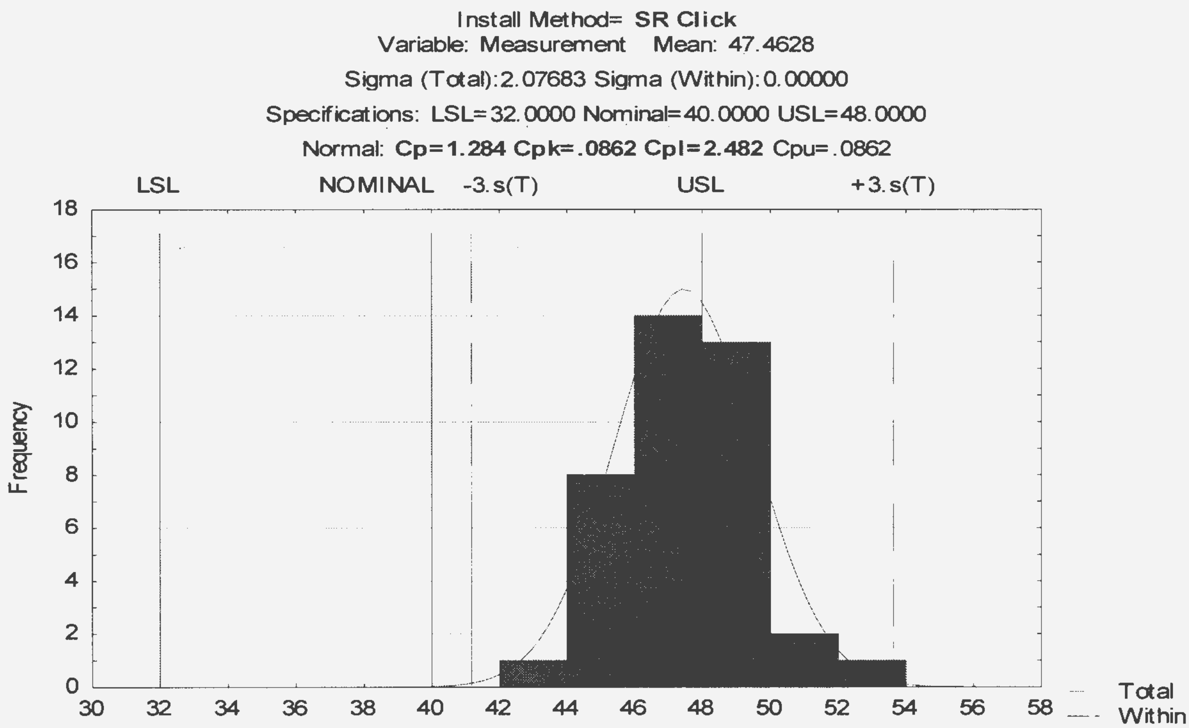

Figure 8. Capability Histogram using SR click Wrench Install Method created in Statistica©

In the case of the Cp for an SR click wrench a value of 1.284 was given. What this tells us is our two most reliable tools that this particular company uses have a Cp value when using peak forward breakaway of 1.129 and 1.284 respectively.

Next we turn our attention to the values that were gained from the tool that is in question.

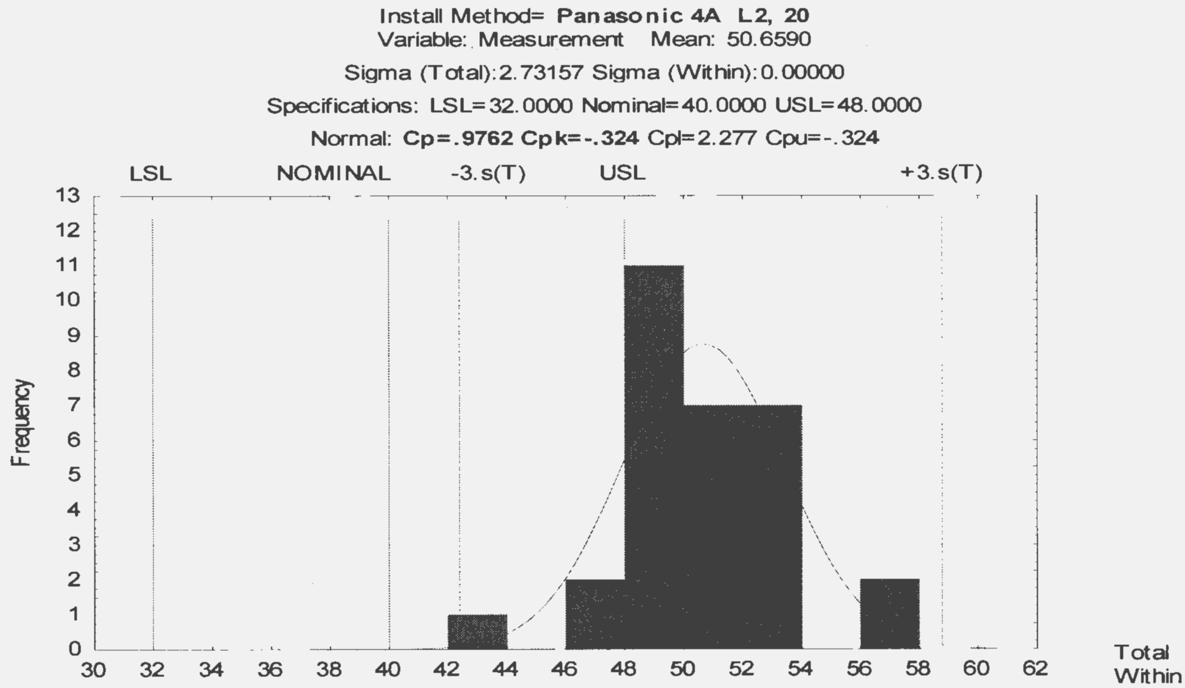

Figure 9. Capability Histogram using Panasonic Tool Install Method created in Statistica©

The capability value from above shows that the tool that is in question has a Cp value of .9762. While this value is lower than the two other input tools, this is to be expected. The amount of the Cp that should be considered acceptable is the issue that must be answered.

Conclusion

In conclusion the method that would be applied to determine the capability of this torque tool would be Cp. The value that should be used to determine capability would be an average of the two Cp values that have been determined to have an acceptable Cpk. Further inspection would need to continue to ensure that the values that the forward breakaway is getting are actually what the engineering specification is. While this is not the preferred method, there is not at this time a better method to ensure that the torque tool is going to consistently operate at the torque level that is requested.

Another method would involve using bolts with strain gages on them, or instrumented washers. The problem with using them is they are calculating the amount of clamp load that the joint is actually seeing. If one were to use those two methods there would need to be a substantial investment of time and money to change the way that we look at engineering specifications. The additional cost and time is not something that the business is willing to take on at this time.

Another option would be to get rid of the torque tools that do not allow the use of inline transducers to verify their capability. This would result in a substantial cost that the business is not willing to take on at this time.

The final result of the study was that the acceptable Cp value going forward will be 1.0 on tool that are only able to have capability determined by using forward breakaway. Given that the value of 1.0 is the pass/fail criteria, the tool that was the subject of the testing was found to not meet the particular company's quality standards. This meant a systematic removal of the tools with replacements.

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