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An Investigation Into Dynamic Assembly and Static Inspection Threaded Fastener Torque Difference

Steven Carter Gray

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AN INVESTIGATION INTO DYNAMIC ASSEMBLY AND STATIC INSPECTION THREADED FASTENER TORQUE DIFFERENCE

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

by

Steven Carter Gray
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Approved by:

Dr. John T. Fecik, Advisor — Date: March 31, 1992

Dr. Rex W. Pershing, Graduate Faculty Member — Date: March 31, 1992

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CHAPTER I

INTRODUCTION

Dynamic threaded fastener torque, obtained during assembly, and static torque, obtained after dynamic torque, has been an ongoing concern to manufacturing personnel. When a torque tool is used to tighten a group of threaded fasteners it is not hard to identify nearly two hundred variables that will effect the preload and tension of the fastener. Because of these many changing variables it is very difficult to control and inspect threaded fastener torque after assembly (Bickford, 1988). Many assembly areas qualify dynamic assembly torque processes with static torque techniques. If dynamic and static torque is different incorrect decisions will be made.

Statement of the Problem

The problem of this study was to identify and explain the observable threaded fastener torque difference obtained during assembly installation (known as dynamic assembly torque) and the inspection torque obtained after assembly installation (known as static inspection torque). Casual observations between dynamic and static torque difference are subjective and contain individual bias. Quantitative methods must be utilized to insure that conclusions are well founded and that torque differences observed are justifiably compared. For this purpose: (a) Confidence levels must be established that determine the degree of risk that is undertaken for concluding an erroneous decision and (b) inferential statistics must interpret the facts to determine whether dynamic torque is different than static torque.

Statement of Purpose

Historically, postmortem threaded fastener torque inspection has been used by John Deere Waterloo Works to determine if the assembly torque process was within predetermined specifications. Inspection results, after process torquing, has resulted in much confusion. Often production time, money and corrective action inconsistencies have resulted because of differences between static inspection torque values and dynamic assembly torque values.

The purpose of this study was to prove that under selected conditions, dynamic assembly torque and static inspection torque were different. It was believed that if the variables that determine the difference between dynamic and static torque were constant then manufacturing static torque specifications could be developed. Acquired knowledge will be used to help develop a standard for threaded fastener torque inspection procedures at the John Deere Waterloo Works. A standard threaded fastener torque control procedure will (a) improve product reliability, (b) increase productivity and (c) decrease costs.

Confidence in the relationship between dynamic and static torque must be understood by all industries so that acceptable torque processes are developed and associated standard inspection techniques agreed upon.

Statement of Need

A no win situation develops if static torque is different than dynamic torque. The need for the study was based on the following factors:

1. Many assembly processes at the John Deere Waterloo Works require a torque tool that has been adjusted with a torque verifier. The method of establishing a torque setting is with a dynamic torque verifier. The assembler then installs and dynamically tightens fasteners during the assembly procedure. An audit inspector verifies threaded fastener torque from a static condition. Occasionally the fastener is found to be out of the allowable tolerance. The out of tolerance condition is recorded as a defect and assembly units are reclaimed based upon the audit inspector's findings. Occasionally the only error that can be discovered is the lack of understanding for the observable difference between dynamic assembly torque and static inspection torque. An urgent need is required by John Deere Waterloo Works to understand the relationship between dynamic assembly torque and static inspection torque.

2. Inspection audit personnel are extra expense that offer no value added to the end product. More often than not, inspectors unintentionally do more harm than good when reporting threaded fasteners that were beyond their torque specifications (Bergstrom, 1989).

3. Researchers have found that static torque measurement produced greater variation in torque measurements than dynamic torque measurements. (Munn, 1988). If torque can be controlled at the process, rather than by an inspector, product reliability will be improved.

4. New industry materials and engineering concepts will require tighter specifications on fastener torquing (Forgach, 1991). Tighter torque specifications will not be realized until a consistent measuring and assembly method is agreed upon.

5. Controlling threaded fastener friction is not easy. Friction depends on the smoothness of the contact surfaces, their hardness, flatness and lubrication (Assembly Engineering, 1988). If a threaded fastener is installed during assembly the dynamic method may (a) result in less friction than when a fastener is inspected statically, (b) result in more friction than when a fastener is inspected statically. If threaded fastener friction is difficult to control then dynamic and static torque inspection will very seldom be the same. It may be impractical to predict the

condition of one by viewing the other based upon the same specification parameters.

6. Studies have shown that the most useful torque reading from a hand torque audit occurs at a break point just prior to the turning motion of the fastener. This breakaway torque reading is valid only for fasteners with well lubricated threads and underhead areas (Shoberg, 1989). Of course not all assembly processes allow for well lubricated threads and underhead areas. It becomes apparent that a large portion of the torque tolerance is consumed by the inspection technique.

7. Laboratory tests of air powered tools, such as are commonly used in automotive assembly plants, have indicated that tools will repeatedly apply the preset torque within a spread of + or - 2% of the nominal value. However, tool output torque readings taken in an assembly plant, using a hand torque wrench to measure the residual torque on tightened fasteners, do not support the laboratory findings (Ellison, 1970). One of several beliefs must be accepted by industry: (a) Air tools do not hold + or - 2% of the nominal value, (b) Hand torque wrenches can not measure residual torque accurately enough to determine percent of tolerance held by air tools.

8. It is very difficult to control and inspect bolt tension in the field (Bickford, 1988). Since bolt tension has a direct relationship to torque it is important to

establish a standard procedure and practice for confirming threaded fastener torque installed by assembly.

9. Some companies monitor threaded fastener torques after the fact with torque inspection equipment. The torque is recorded on statistical process control charts (SPC) that aid in process adjustment and control. These companies increase costs by decreasing productivity (Production Engineering, 1987). If a real time torque monitoring practice can be formulated, costs would be reduced and reliability would increase.

10. Cummins Engine Co. saved time and improved accuracy with an automatic multiple spindle nut runner equipped with torque control transducers. The manual method prior to the automatic method had an accuracy of + or - 10% of the nominal torque value. The automatic method guarantees + or - 5% of the nominal torque value (Production Engineering, 1984). Using torque control devices, rather than manual feedback, to control threaded fastener torque will improve accuracy and guarantee assembly requirements.

11. Whether a product stays together, rattles, shorts out or fails in a short period of time often depends on proper assembly procedures and inspection methods (Leininger & Munn, 1988). To obtain proper threaded fastener torque, assembly procedures and inspection methods, a complete understanding of what is being inspected must be realized.

Once this is accomplish a correct torque verification practice can be agreed upon.

Statement of Hypotheses

Two factors, variation and target (mean), determine whether dynamic assembly and static inspection torque are different. The null hypothesis (Ho) for this study was that there is no statistical difference between dynamic assembly torque and static inspection torque. The null hypothesis was tested for variances (s^2) and means ($\bar{x}$) with three different types of threaded fasteners, under two different conditions (dry and lubricated). The null hypotheses for this study were:

Ho: s^2 of dynamic torque = s^2 of static torque

Ho: $\bar{x}$ of dynamic torque = $\bar{x}$ of static torque

Assumptions

From personal experiences and fastener torque related literature, specific assumptions were declared for torque measuring techniques. These assumptions were made to formulate a plan to compare dynamic assembly torque to static inspection torque.

The following assumptions were made in pursuit of this study:

1. Dynamic torque can be best measured with an in-line torque transducer. This is considered the state of the art

fastener torque verification method and is based on an accurate sensor with electronic measurement and control (Shoberg, 1989). An in-line torque transducer is a strain gage that responds to change in torque by outputting electric flow (amperes) or voltage change.

2. Static torque is best measured in the breakaway to continue tightening direction. Studies have shown that the most useful torque reading from a hand torque audit occurs at a break point just prior to turning motion of the fastener (Shoberg, 1989). Essentially this means that the threaded fastener has rotational force applied to its head, in the tightening direction. When the fastener threads move, torque is noted. This torque value noted is known as static torque.

Limitations

The many changing variables of assembly torque processes can be overwhelming when attempting to determined fixed relationships between dynamic and static threaded fastener torque. With few exceptions, every joint that is held together with threaded fasteners is unique and provides its own torque footprint, that over time may change. Awareness of the many variables associated with torque also provides caution for the confirmation of hard and fast relationships between dynamic and static fastener torques. There will always be exceptions to the basic rules when dealing with threaded fasteners. These exceptions exist because all joints are unique in one form or another.

Because of the many variables associated with threaded fastener torque this study was conducted in view of the following limitations:

1. The scope of this research paper prohibits the investigation of all known threaded fastener types and their corresponding joints. For this reason experiments included only three selected common size threaded fasteners, used at John Deere Waterloo Works.

2. Time between dynamic torque installation and static torque inspection has an infinite number of possibilities. To maintain experiment manageability and yet obtain practical information static torque was inspected immediately after dynamic torque installation.

3. There is a very large spectrum of possible threaded fastener coatings that will act as a lubricant or result in threaded fastener prevailing torque. This study was limited to (a) one type of threaded fastener that is plated, (b) fasteners with a light oil, (c) fasteners without any coating or oil (dry).

4. There is inherent variability between inspectors that verify dynamic torque with static torque techniques. A common practice is to use hand torque wrenches for auditing fastener tightness. The operator retorques the fastener in the tightening direction, applying tightening force until

thread movement is detected. The operator then stops and notes the torque value on the wrench's indicator. This technique is highly operator sensitive (Shoberg, 1989).

Conclusions from this paper were based upon one inspector that checked static torque immediately after dynamic torque. This limitation is required to focus upon the relationship between dynamic assembly torque and static inspection torque and not upon inspection variation. To insure experiment validity an experienced torque audit inspector was used.

5. Dynamic torque may be applied with a limited number of tools at an infinite number of installation tool revolutions per minute (RPM). If the joint's installation torque rate is higher than normal, the fastener may reach the required torque level but not the desired fastener tension (Munn, 1988).

For the purpose of this study, dynamic assembly torque was applied with either an impulse gun set at normal John Deere fastener installation RPM or an assembly torque wrench that dynamically tightens the threaded fastener under normal assembly operation conditions. These torque tools were chosen for each experiment condition based on their usage as a common torque application device and tooling availability.

6. Ultimate threaded fastener torque will react differently to the many varieties of materials that fasteners are threaded into. Such variables as material

density, hardness and surface finish will drastically effect dynamic and static torque relationships. To insure consistent and comparable experimental results female threads were fabricated from gray iron per John Deere Standard JDM B3.2 (1986), Specification for Gray (Flake Graphite) Cast Iron.

7. The threaded fasteners were assembled into common assembly components that are assembled at John Deere Waterloo Works. Results obtained from specific applications are subject to change under different conditions.

Expectations of Study

It was believed that as the threaded fastener size increased there would be a greater difference between (a) dynamic installation variance and static inspection variance, (b) dynamic installation average and static inspection average. If expectations were verified then the results would aid in logical torque verification procedures. The torque verification procedures could be used to establish manufacturing torque specifications when inspecting threaded fasteners by static inspection.

Definitions of Terms

Many terms in this paper are common to personnel that are actively involved in threaded fastener torques. Terms associated with a technical field are often misinterpreted by unacquainted readers and occasionally not agreed upon by knowledgeable persons. The following terms are defined to clarify their use in the context of this study.

Confidence interval: An interval estimate that is used to estimate the value of a population parameter with a specified level of confidence (Johnson, 1984).

Dynamic Torque: A torque (force X distance) that is measured when a fastener is continually tightened. Most often dynamic torque is experienced during the initial assembly of a joint.

F test: Used to determine the equality of two variances obtained from two populations (Johnson, 1984).

Fastener geometries: Those basic parts of a fastener that describe detailed thread and head characteristics. Example: pitch diameter, major diameter, surface finish.

Impulse gun: A tool that is used often in assembly departments to rapidly install threaded fasteners. Is different than an impact gun, that has a distinct mechanical pounding. Impulse guns have hydraulic power drives that deliver a dampened pounding when tightening a fastener.

Inferential statistics: The technique of interpreting the values of numerical data and then using them to make decisions (Johnson, 1984).

In-line torque transducer: A torque transducer that is installed between a torque tool and a fastener, to inspect dynamic or static torque. In torque related situations this transducer may be referred to as a in-line rotary torque transducer.

Null hypothesis: Generally a statement that a population parameter has a specified value. Often the phrase "there is no difference" is used in its interpretation (Johnson, 1984).

Observable torque difference: A comparative difference in torque values that may result in a concern with product reliability or process capability.

One-tailed test: Used in hypothesis testing to describe that the critical region may fall at only one end of a distribution (Johnson, 1984).

Postmortem: Used to describe events that have historically occurred. Does not provide continually active feedback.

Prevailing torque: Most often used to describe the dominate torque characteristic of threaded fasteners with nylon patches applied to the threads. Purpose of the nylon patch is to insure that the threaded fastener will not backout during product application.

Random: When each possible sample of a fixed size has an equal probability of being selected (Johnson, 1984).

Static torque: Torque that is obtained when tightening a fastener after dynamic torque applications. Generally, this torque will be greater than the actual dynamic torque.

Statistical significant difference: A condition where the result falls beyond a preconceived critical value. The critical value is obtained depending upon the degree of risk that a individual is willing to assume when rejecting an hypothesis when the hypothesis is true.

Threaded fastener: A fastener that is used to hold a joint together with a predetermined clamp force. The threads of the fastener obtain and hold the clamp force load (e.g. capscrews and bolts).

Torque transducer: Provides input voltage or excitation to a strain-gage bridge. The torque transducer reads the strain-gage output and may amplify the output and provide a digital readout (Herceg, 1976).

Torque wrench: Any tool type that is utilized to obtain the desired torque of a fastener. Most often production torque wrenches are equipped with a release mechanism that is activated when the desired torque is obtained.

Torque Nominal: The theoretical exact torque desired.

Two-Tail Test: Used in hypothesis testing to describe that the critical region may fall at either end of a distribution (Johnson, 1984).

Z test: Used in hypothesis testing when concerned with the difference between to independent means and when the variances are known. The Z test should not be used unless the subject data is normally distributed and sample data is equal or greater than n = 30 (Johnson, 1984).

CHAPTER II

LITERATURE REVIEW

Verification of threaded fastener torque has historically been a frustrating task. Duplication of assembly installation conditions can never be reproduced. The inspection of threaded fastener torque must be performed to insure that the joint has received the proper clamp load and to verify that the installation process is capable of continually obtaining the specified torque. Research and experimentation have developed means of verifying threaded fastener torque during the initial installation and after the torquing process. Well thought out plans verify torques during the installation process. Very little research attempts to deal with the appreciable difference found between dynamic assembly and static inspection torque.

An acousto-optic system developed by J. Maram and G. Kuhr of Rocketdyne Division, Rockwell International Corporation, combines laser beams and sound waves that measures the length of threaded fasteners before and after torquing (Machine Design, 1985). The lengths of loose and fully torqued bolts are compared and the difference is used to determine axial strain. The axial strain is then computed into the bolt's tension and torque. Maram and Kuhr's technique is to induce acoustic shock waves into a bolt with a pulsed laser. The shock waves travel from the bolt's head to its tip, that in turn will reflect waves back to the head. Surface distortions caused by the return shock waves deflect a continuous wave laser beam bounced off the bolthead to a light detector. The optical detector's position change output is fed to a timing circuitry for computing the interval between signals and thus determining a bolt's length.

The objective of torquing a threaded fastener is to obtain a static tension that will clamp components together. This task is best accomplished when the threaded fastener reaches its yield strength. The acousto-optic system tracks the bolt from its free state through elastic strain and to its yield point as torque is applied during the dynamic installation process.

The main benefit of the acousto-optic system is that all associated friction variables of the fastener are not a factor in determining final torque. In fact torque of the threaded fastener is not a factor. Beyond utilizing the acousto-optic system during initial assembly of the fastener the system may be used to inspect fasteners after assembly. This may be done by comparing the length of the fastener in a torqued condition to the length of the fastener after it is relieved of strain. Unfortunately, this process may become quit expensive and possible utilization is on a selected basis.

Bickford (1988) suggests that alternative bolts be used instead of attempting to control threaded fastener torque. Alternative bolts incorporate features that indicate or result in tension automatically.

An example of an alternative bolt is the twist off bolt. This bolt type is both held and tightened from the nut end. A splined section is connected to the bolt section by a reduced down section. The assembly tool holds the splined section as torque is applied to the nut. When the torque of the nut overcomes a predetermined force the reduced down section, with spline, breaks loose from the rest of the bolt. The bolt can easily be examined to determine if the minimum amount of torque has been supplied. Over torquing is not probable because of the characteristics of the reduced down section. A major short coming of the twist off bolt is that contamination may end up in the assembly. If the splined end of the bolt is not removed from the assembly such quality issues as bearing and gear failures will be unavoidable. Another short coming of the twist off bolt is that it labor intensive and not adaptable to normal assembly torque tools. Specially designed tooling would need to be designed to torque twist off bolts in a high speed production setting.

Another alternative bolt described by Bickford (1988) is the direct tension indicator washer (DTI). The DTI washer has five bumps on its upper surface. The other side of the

DTI washer is flat. The flat side of the DTI washer is placed against the work piece on the nut end. A regular washer and then nut is sequentially installed against the bump side of the DTI washer. As torque is applied to the threaded fastener the bumps partially yield and reduce in clearance between the regular washer. Torque of the threaded fastener continues until a feeler gage can not be inserted between the DTI and regular washers.

One major advantage of the DTI washer is that field inspection of the fastener's minimum torque can be accomplished without a torque wrench. Three disadvantages of the DTI washer are: (a) Maximum torque of the fastener must still be inspected with a torque wrench, (b) the DTI washer is additional hardware and results in higher production cost, (c) assemblers may remove the bumps on the DTI washer with a hammer or file to make it easier to tighten (Bickford, 1988).

Another alternative bolt is the DTI fastener manufactured by RB&W Corporation. The DTI fastener has a wavy flanged head. The fastener is tightened until the wavy flange is flattened against the upper surface of the joint. The advantages and disadvantages of the DTI fastener are basically the same as the DTI washer except that the DTI fastener does not require additional hardware. The DTI fastener can only be incorporated in applications where flanged fasteners are acceptable.

Alternative bolts provide immediate attribute information on whether the fastener obtained its minimum torque. In normal production settings this may not be enough. Verification that the treaded fastener did not exceed the maximum torque is required. Only variable data will provide information on the threaded fastener's target between maximum and minimum torque specifications.

Bickford (1983) explains some of the reasons why fastener preload changes. He states that the behavior of the joint in use will depend upon the bolt preload in use, not the preload obtained during installation. In other words, initial preload of the fastener during assembly can be different than the residual preload during use.

The five mechanisms identified that cause loss of preload are (a) fastener embedment relaxation, (b) gasket creep, (c) elastic interactions, (d) vibration, and (e) stress relaxation. Fastener embedment is the break down (creep) of high spots that are contacted during the initial tightening. High spots may be male to female thread joint surfaces or the bolt head that sinks down into the joint surface following the torque operation. Gasket creep is the result of relaxation in plastic or semi-plastic materials, that gaskets are comprised of. Elastic interactions depend upon such factors as stiffness of the joint members, the size of the joint, the distance between bolts and the sequence that bolts are tightened. Vibration, especially transverse vibration at right angles to the axis of the fastener, can eliminate all initial preload in a fastener. Stress relaxation occurs when fasteners are exposed to extreme temperatures and/or nuclear radiation. Under these conditions the atoms in a fastener will readjust over time to escape from high tensile stresses that they are exposed to during initial tightening.

Static inspection torque may be highly operator sensitive (Shoberg, 1989). After a threaded fastener has been assembled an inspector will attempt to verify torque with a torque wrench. The inspector will apply tightening force until the threaded fastener moves. The inspector will then stop and note the torque level on the wrench's indicator. Torque turn overshoot depends on how quickly the inspector responds and stops rotation after the threaded fastener turns. Shoberg (1989) states that studies have shown that the most useful torque reading from a hand torque inspection tool occurs at the break point just prior to the turning motion of the fastener.

Shoberg (1989) described the Fader/Shoberg Algorithm that calculates the breakaway point of a threaded fastener. The algorithm determines the maximum differential value between the torque-time curve and a mathematical line segment from the peak to some percentage of the peak. The breakaway point corresponds to the maximum difference between the two lines.

The Fader/Shoberg Algorithm may not produce results that are the same as those obtained when dynamically torquing a threaded fastener. The automatic method in which the torque tool calculates the break away point of the fastener may help correct the problem of static inspector variation.

CHAPTER III

METHODOLOGY

This was an experimental research study which collected and analyzed data from experiments. The purpose of each experiment was to verify or refute the null hypothesis. This chapter comprises a detailed description of the methodology used to prepare, conduct and analyze each experiment.

Population

Three different type threaded fasteners were chosen for the experiments. Each experiment consisted of inspecting dynamic installation and static inspection torque for a fastener type under two conditions (dry and oiled). The three different threaded fastener types and assembly component conditions for each experiment were:

1. Threaded fastener 1 1/16 inch-12 UN-2A with zinc (Zn) plating. The length of this fastener, measured from threaded end to under head, was .59 inch long and had no capscrew grade associated with it. This threaded fastener was torqued directly into a female thread, did not use a washer under its head and did not hold two components together.

2. Threaded fastener M16 X 2-6g with no plating. The length of this fastener was 5.12 inch long and was grade 10.9. This threaded fastener held two components together,

had a washer under its head and passed through approximately 3.94 inch of clearance material before engaging threads. This resulted in 1.18 inch of axial thread engagement.

3. Threaded fastener 1/2 inch 13 UNC-2A with no plating. The length of this fastener was 1.87 inch long and was grade 180. This threaded fastener held two components together, had no washer under its head and passed through approximately .5 inch of clearance material before engaging threads. This resulted in 1.37 inch of axial thread engagement.

Sample Selection and Verification

Threaded fasteners were randomly selected from storage material at John Deere Waterloo Works. Selected fasteners were inspected to verify that the population's thread form was within required specification limits and that contamination was not present. Thread form specification confirmation was accomplished by measuring the thread's major diameter and inspecting thread form with go and no-go thread ring gages.

Female threads, that normally assemble with the experiment's threaded fastener in assembly, were randomly selected from storage material at John Deere Waterloo Works. Selected female threads were inspected to insure that thread form was within required specification limits and that contamination was not present. Thread form specification confirmation was accomplished by measuring the thread's minor diameter and inspecting thread form with go and no-go threaded plug gages.

Equipment Used

Equipment used to perform the experiments was property of John Deere Waterloo Works. This equipment is normally used by John Deere employees in the production of John Deere components.

Torque Verifier

The torque verifier used for all experiments was a Digital Torque Meter, purchased from Skidmore-Wilhelm MFG Co., manufactured at Cleveland Ohio. This torque verifier is normally used by assembly and method set-up personnel at John Deere.

Inspection Torque Wrenches

Two different model static inspection torque wrenches were used for the experiments, both supplied by BelKnap, manufactured in Wixon, Michigan. The first type torque wrench, Computorq Model 6004CF, was used for experiments that had nominal torque values under 100 lb-ft (pound-feet). This model has a maximum torque limit of 250 lb-ft. The second type torque wrench, Computorq Model 2503CF, was used for experiments that had nominal torque values above 100 lb-ft. This model has a maximum torque limit of 300 lb-ft.

Assembly Torque Instruments

Two different model rotary in-line torque transducers were used for the experiments, both supplied by Crane Electronics LTD. Both torque transducer's output was input into a Universal Torque Analyzer, also supplied by Crane Electronics LTD. Torque transducer model VTA-135 was used for experiments that would not reach torques greater than 100 lb-ft. The maximum torque limit of this model is 100 lb-ft. Torque transducer model VTA-137 was used for torques greater than 100 lb-ft. The maximum torque limit of this model is 300 lb-ft.

Assembly Torque Tooling

Two different model impulse torque guns were used for the experiments. The first impulse gun type was a Uryu, Acra Pulse UX 1400. This impulse gun has a capacity rating from 75 to 120 lb-ft and free spins at 5250 RPM. The second impulse gun type was a Uryu, Acra Pulse UX 2000. This impulse gun has a capacity rating from 206 to 332 lb-ft and free spins at 4200 RPM.

A production torque wrench was used to dynamically assemble the 1 1/16 inch threaded fastener. This wrench had a release mechanism that activated when the desired torque was obtained.

Equipment Verification

For each experiment's thread size, target validation between the inspection torque wrench and in-line transducer was performed. This was done by connecting the torque wrench's male drive to the in-line transducer's female drive. In turn, the in-line transducer's male drive was connected to the torque verifier's female drive. Torque was applied to approximately the experiment's nominal torque value as viewed from the torque verifier's output. The experiment's nominal torque value was the nominal torque value target produced by the assembly equipment at John Deere that normally performed assembly of the components. Based upon a sample size of ten, the average difference between the transducer and the torque wrench was an offset that was adjusted from the experiment's in-line torque transducer data.

Data Collection Procedure

For each subject fastener, the in-line torque transducer was installed between the assembly installation tool and the drive socket. All fasteners were hand started into the joint's female threads. After hand starting the threaded fastener, each fastener was dynamically assembled by the experiment's torque tool. Adjustment of the installation tool's target was not performed. The adjustment was deemed unnecessary because of perceived close proximity to the fasteners nominal torque value from normal assembly activities at John Deere. The dynamic assembly torque displayed by the in-line transducer combined with the calculated offset was recorded. Immediately after each threaded fastener installation, static inspection was performed by torquing the threaded fastener in the break away to continue tightening direction. The static inspection torque displayed by the variable torque wrench was recorded for each fastener. Data collection was complete for an experiment when a sample size of 30 (n = 30) was obtained for each fastener size.

Analysis Procedure

Each experiment's static and dynamic threaded fastener data groups were first analyzed with the F test. The purpose of the F test was to determine if the variances of dynamic assembly and static inspection torque were statistically the same.

The formula used to calculate the F value was:

$$F = \frac{s_1^2}{s_2^2}$$

where: s_1^2 = larger variance of dynamic and static data

s_2^2 = smaller variance of dynamic and static data

The critical F value for 30-1 (n-1) degrees of freedom is 1.86. The critical F value is based upon a 95% confidence level, or a 5% level of significance. The critical region is about the equality of the variances for dynamic installation and static inspection torque data. The critical region is one-tailed and on the right based upon the larger variance as the numerator and the smaller variance as the denominator (Johnson, 1984). This test determined if the larger variance was statistically the same as the smaller variance.

Each threaded fastener data group was then analyzed with the Z test to determine if the means (or averages) of dynamic assembly and static inspection were statistically the same. The formula used to calculate the Z values was:

$$Z = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{(s_1^2/n_1) + (s_2^2/n_2)}}$$

where: $\bar{x}_1$ = sample size mean of static inspection torque

$\bar{x}_2$ = sample size mean of dynamic assembly torque

μ_1 = mean of static inspection torque population

μ_2 = mean of dynamic assembly torque population

s_1^2 = sample size standard deviation of static inspection torque

s_2^2 = sample size standard deviation of dynamic assembly torque

n_1 = static inspection torque sample size

n_2 = dynamic inspection torque sample size

The critical value for Z is + or - 1.96 for n = 30. The critical Z value is based upon a 95% confidence level, or a 5% level of significance. The critical region is about the equality of the sample averages for static inspection and dynamic assembly torque and is two-tailed. This interpretation results in a test to determine if dynamic assembly torque was statistically higher or lower than static inspection torque. Since the null hypothesis states that there is no difference in dynamic and inspection torque, $\mu_1 - \mu_2$ can be assumed as 0 (no difference).

Start and Completion Times of Events

Threaded fastener torque experiments were conducted in a relatively short period of time. This approach was undertaken so that inspection and installation factors could be controlled in a reasonable fashion. Installation factors consists of (a) transducer calibration, (b) variation of fastener properties, and (c) variation of joint properties. Inspection factors consists of: (a) variable torque wrench calibration and (b) consistency of inspector's torque values. Start and completion times of the experiment events are displayed in Table 1, p. 30.

TABLE 1

Experiment Completion Times

Threaded Fastener	Installation Tool	Start	Finish
1 1/16-12/Zn/dry	Torque Wrench	9 Nov 91	9 Nov 91
1 1/16-12/Zn/oiled	Torque Wrench	9 Nov 91	9 Nov 91
M16 X 2 dry	Impulse gun	8 Nov 91	8 Nov 91
M16 X 2 oiled	Impulse gun	6 Nov 91	6 Nov 91
1/2-13 dry	Impulse gun	11 Nov 91	11 Nov 91
1/2-13 oiled	Impulse gun	11 Nov 91	11 Nov 91

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

Following is data from the six experiments conducted. Displayed are dynamic assembly torque results when the threaded fastener was installed with an assembly torque tool and dynamic inspection results obtained from a variable torque wrench. Also displayed is the resultant of dynamic torque after static torque was subtracted. At the end of each table the mean and variance of each data set is calculated.

Presentation of Data

Experiment 1

Table 2, p. 32, displays the results of the 1 1/16-12 plated threaded fastener torque experiment. The required nominal torque was 75 lb-ft with a specification of + or - 15 lb-ft. The fastener's length was .59 inch and the fastener's surface was Zn (zinc) plated with no oil coating.

The average for dynamic torque was 74.7 lb-ft compared to 80.9 lb-ft for static torque. This resulted in an average difference of -6.2 lb-ft when comparing static to dynamic torque. The variance for dynamic torque was 1.582 lb-ft compared to 5.431 lb-ft for static torque. When comparing static to dynamic values, a variance of 5.716 lb-ft was obtained.

TABLE 2

1 1/16-12 UN Dry with Zn Plating

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
1.	75.2	86.2	-11.0
2.	75.6	82.6	- 7.0
3.	74.0	83.8	- 9.8
4.	75.8	80.4	- 4.6
5.	73.9	83.3	- 9.4
6.	75.0	81.7	- 6.7
7.	74.7	79.9	- 5.2
8.	72.6	80.6	- 8.0
9.	73.0	78.0	- 5.0
10.	75.2	80.1	- 4.9
11.	73.5	80.2	- 6.7
12.	76.7	83.5	- 6.8
13.	75.6	79.9	- 4.3
14.	74.8	82.5	- 7.7
15.	76.6	80.2	- 3.6
16.	74.7	84.8	-10.1
17.	74.0	83.4	- 9.4
18.	75.3	80.2	- 4.9
19.	74.9	77.8	- 2.9
20.	74.7	76.6	- 1.9

TABLE 2 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
21.	75.2	84.0	- 8.8
22.	76.0	78.6	- 2.4
23.	78.1	81.7	- 3.6
24.	73.2	79.8	- 6.6
25.	75.8	81.4	- 5.6
26.	73.7	80.4	- 6.7
27.	73.5	80.2	- 6.7
28.	73.6	81.0	- 7.4
29.	74.2	78.6	- 4.4
30.	72.9	76.8	- 3.9
Average	74.7	80.9	- 6.2
Variance	1.582	5.431	5.716

Experiment 2

Table 3, p. 34, displays the results of the 1 1/16-12 plated-oiled threaded fastener torque experiment. All conditions of this experiment were the same as experiment 1 except the entire threaded fastener was coated with a light oil.

The average for dynamic torque was 75 lb-ft compared to 77.6 lb-ft for static torque. This resulted in an average difference of -2.6 lb-ft when comparing static to dynamic torque. The variance for dynamic torque was 1.469 lb-ft compared to 6.698 lb-ft for static torque. When comparing static to dynamic values, a variance of 7.007 lb-ft was obtained.

TABLE 3

1 1/16-12 UN Oiled with Zn Plating

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
1.	77.3	79.2	- 1.9
2.	76.6	77.7	- 1.1
3.	76.1	79.0	- 2.9
4.	75.2	79.2	- 4.0
5.	75.2	77.0	- 1.8
6.	76.8	78.3	- 2.1
7.	76.2	78.1	- 1.9
8.	75.9	77.0	- 1.1
9.	73.0	72.9	0.1
10.	75.9	75.7	0.2
11.	76.1	73.0	3.0
12.	73.2	77.8	- 4.6

TABLE 3 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
13.	75.3	78.0	- 2.7
14.	74.9	73.2	1.7
15.	74.2	83.0	- 8.8
16.	73.0	73.4	- 0.4
17.	73.7	78.0	- 4.3
18.	73.0	77.8	- 4.8
19.	74.8	78.7	- 3.9
20.	74.5	80.0	- 5.5
21.	75.8	78.2	- 2.4
22.	73.9	76.5	- 2.6
23.	76.0	77.0	- 1.0
24.	74.3	82.0	- 7.7
25.	75.3	81.7	- 6.4
26.	75.6	78.9	- 3.3
27.	74.2	80.1	- 5.9
28.	73.7	75.3	- 1.6
29.	73.6	75.0	- 1.4
30.	75.1	74.9	0.2
Average	75.0	77.6	- 2.6
Variance	1.469	6.698	7.007

Experiment 3

Table 4, displays the results of the M16 X 2 dry threaded fastener torque experiment. The required nominal torque was 229 lb-ft with a specification of + or - 46 lb-ft. The fastener's length was 5.12 inch. The fasteners surface was nonplated and had no oil coating.

The average for dynamic torque was 232.6 lb-ft compared to 210.4 lb-ft for static torque. This resulted in an average difference of 22.2 lb-ft when comparing static to dynamic torque. The variance for dynamic torque was 92.723 lb-ft compared to 131.972 lb-ft for static torque. When comparing static to dynamic values, a variance of 57.013 lb-ft was obtained.

TABLE 4

M16 X 2 Dry and Non-plated

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
1.	232	195	37
2.	228	209	19
3.	229	201	28
4.	220	202	18
5.	234	223	11
6.	222	197	25

TABLE 4 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
7.	236	221	15
8.	238	209	29
9.	229	193	36
10.	227	192	35
11.	247	215	32
12.	240	216	24
13.	243	225	18
14.	247	217	30
15.	236	211	25
16.	221	204	17
17.	229	210	19
18.	226	216	10
19.	246	232	14
20.	240	227	13
21.	237	215	22
22.	245	224	21
23.	221	201	20
24.	246	219	27
25.	237	209	28
26.	234	220	14
27.	235	211	24

TABLE 4 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
28.	226	215	11
29.	218	194	24
30.	210	189	21
Average	232.6	210.4	22.2
Variance	92.723	131.972	57.013

Experiment 4

Table 5, p. 39, displays the results of the M16 X 2 oiled threaded fastener torque experiment. All conditions of this experiment were the same as experiment 3 except that the entire threaded fastener was coated with a light oil.

The average for dynamic torque was 220.5 lb-ft compared to 202.3 lb-ft for static torque. This resulted in an average difference of 18.2 lb-ft when comparing static to dynamic torque. The variance for dynamic torque was 72.671 lb-ft compared to 72.561 lb-ft for static torque. When comparing static to dynamic values, a variance of 43.909 lb-ft was obtained.

TABLE 5

M16 X 2 Oiled and Non-plated

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
1.	209	200	09
2.	219	198	21
3.	209	187	22
4.	223	209	14
5.	218	206	12
6.	225	218	07
7.	229	210	19
8.	227	207	20
9.	222	206	16
10.	222	194	28
11.	225	205	20
12.	219	207	12
13.	223	215	08
14.	222	202	20
15.	229	209	20
16.	225	201	24
17.	213	195	18
18.	234	206	28
19.	216	193	23
20.	210	206	04

TABLE 5 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
21.	206	197	09
22.	232	204	28
23.	218	199	19
24.	218	207	11
25.	218	193	25
26.	230	206	24
27.	237	214	23
28.	225	206	19
29.	201	181	20
30.	212	188	24
Average	220.5	202.3	18.2
Variance	72.671	72.561	43.909

<u>Experiment 5</u>

Table 6, p. 41, displays the results of the 1/2-13 UNC dry threaded fastener torque experiment. The required nominal torque was 75 lb-ft with a specification of + or - 15 lb-ft. The fastener's thread length was 1.87 inch. The fastener's surface was nonplated and dry.

The average for dynamic torque was 75.2 lb-ft compared to 74.2 lb-ft for static torque. This resulted in an average difference of 1 lb-ft when comparing static to dynamic torque. The variance for dynamic torque was 1.984 lb-ft compared to 4.316 lb-ft for static torque. When comparing static to dynamic values, a variance of 3.467 lb-ft was obtained.

TABLE 6

1/2-13 UNC-2A Non-plated and Dry

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
1.	74.2	76.0	- 1.8
2.	73.1	71.2	1.9
3.	75.1	74.0	1.1
4.	75.3	75.0	0.3
5.	76.2	79.1	- 2.9
6.	77.2	75.5	1.7
7.	76.9	73.9	3.0
8.	75.0	76.7	- 1.7
9.	74.5	74.1	0.4
10.	74.0	72.6	1.4
11.	74.7	71.0	3.7
12.	76.0	72.2	3.8

TABLE 6 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
13.	74.8	72.6	2.2
14.	76.4	74.6	1.8
15.	76.0	77.5	- 1.5
16.	77.7	78.6	- 0.9
17.	75.0	72.7	2.3
18.	75.0	72.6	2.4
19.	74.8	74.2	0.6
20.	76.4	74.3	2.1
21.	73.3	72.4	0.9
22.	75.1	71.2	3.9
23.	77.9	76.6	1.3
24.	76.9	75.0	1.9
25.	77.2	73.5	3.7
26.	74.8	72.6	2.2
27.	73.0	72.4	0.6
28.	73.7	74.5	- 0.8
29.	73.6	74.5	- 0.9
30.	73.3	74.9	- 1.6
Average	75.2	74.2	1.0
Variance	1.984	4.316	3.467

Experiment 6

Table 7 displays the results of the 1/2-13 UNC oiled threaded fastener torque experiment. All conditions of this experiment were the same as experiment 5 except the entire threaded fastener was coated with a light oil.

The average for dynamic torque was 74.8 lb-ft compared to 74.5 lb-ft for static torque. This resulted in an average difference of 0.3 lb-ft when comparing static to dynamic torque. The variance for dynamic torque was 2.204 lb-ft compared to 3.801 lb-ft for static torque. When comparing static to dynamic values, a variance of 2.563 lb-ft was obtained.

TABLE 7

1/2-13 UNC-2A Non-plated with Oil

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
1.	76.5	78.6	- 2.1
2.	76.1	77.2	- 1.1
3.	75.1	74.3	0.8
4.	72.8	73.7	- 0.9
5.	75.7	73.1	2.6
6.	75.0	74.7	0.3
7.	73.2	73.8	- 0.6

TABLE 7 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
8.	75.7	77.0	- 1.3
9.	74.5	75.4	- 0.9
10.	73.8	71.4	2.4
11.	76.0	74.2	1.8
12.	74.9	75.4	- 0.5
13.	73.0	71.8	1.2
14.	75.6	76.0	- 0.4
15.	75.2	73.0	2.2
16.	76.0	76.2	- 0.2
17.	71.7	73.0	- 1.3
18.	74.9	74.6	- 0.3
19.	76.1	74.6	1.5
20.	73.0	72.3	0.7
21.	76.6	78.8	- 2.2
22.	77.0	74.1	2.9
23.	74.1	72.2	1.9
24.	77.3	73.3	4.0
25.	75.5	77.8	- 2.3
26.	76.0	75.5	0.5
27.	71.9	72.5	- 0.6
28.	74.5	73.9	0.6

TABLE 7 continued

Data #	Dynamic Torque (Assem. Wrench) lb-ft	Static Torque (Insp. Wrench) lb-ft	Dynamic-Static lb-ft
29.	73.1	73.1	0.0
30.	74.2	74.3	- 0.1
Average	74.8	74.5	0.3
Variance	2.204	3.801	2.563

Analysis of Data

Each experiment's threaded fastener was analyzed with the F test and the Z test and in light of the null hypothesis, that no difference existed between dynamic assembly torque and static inspection torque. For both test statistics a significance level of 5% (.05) was used.

Table 8, p. 46, displays statistical information pertaining to all experiments. Included in Table 8 are the following statistics (a) dynamic torque average (D.AVG), (b) static torque average (S.Avg), (c) dynamic torque variance (D.Var), (d) static torque variance (S.Var), (e) F test, (f) Z test. The critical value (C.V.) for the F test was 1.86 and the C.V. for the Z test was + or - 1.96.

TABLE 8

Statistic Summary

Thread	Cond.	D.Avg lb-ft	S.Avg lb-ft	D.Var lb-ft	S.Var lb-ft	F C.V. 1.86	Z C.V. +,-1.96
1 1/16	Zn/dry	74.7	80.9	1.581	5.431	3.43*	12.8!
1 1/16	Zn/oil	74.9	77.5	1.469	6.698	4.55*	4.9!
M16	dry	232.6	210.4	92.723	131.97	1.42	-8.1!
M16	oiled	220.5	202.3	72.671	72.561	1.00	-8.2!
1/2	dry	75.2	74.2	1.984	4.315	2.17*	-2.2!
1/2	oiled	74.8	74.5	2.204	3.801	1.72	-0.7

Note. $^*p<.05$, one-tailed. $!p<.05$, two-tailed.

F Test Results

From Table 8, it was observed from the F test results that three of the six experiments resulted in a significant difference in variation. Both 1 1/16 thread experiments (Zn/dry, F = 3.43 and Zn/oil, F = 4.55) had F statistics that fell in the critical region, above the critical value of 1.86. The other experiment that fell in the critical region was the 1/2 dry experiment (F = 2.17). All other experiments conducted did not fall in the critical region with a 5% level of significance.

All experiments, except one, produced oiled threaded fasteners with a lower F statistic for the same size thread under dry conditions. The one experiment that did not produce a lower F statistic under oiled conditions was the 1 1/16 inch thread, where dry F = 3.43 and oiled = 4.55. The 1 1/16 inch thread was the largest size threaded fastener used for all experiments and was one of two experiments that did not use a washer under the fastener's head. This experiment did not clamp two components together but was torqued directly into the female thread.

Z Test Results

For all experiments, except the 1/2 fastener that was oiled, the Z statistic for static inspection and dynamic assembly torque fell beyond the critical value of + or - 1.96 (Table 8). The Z statistic for the 1/2 oiled experiment was -0.7. This indicates that the mean obtained from static inspection torque was not proven different than the mean obtained from dynamic inspection torque.

For all compared similar thread size experiments, except the M16 thread, the oiled thread had a lower absolute Z statistic than the dry thread. A lower oiled thread absolute Z statistic value means static inspection torque target was closer to the target obtain with dynamic assembly torque than dry threaded fasteners. The M16 oiled thread had a Z statistic of -8.2 or an absolute value of 8.2. This was greater than the absolute value of 8.1 for the M16 dry Z statistic of -8.1.

The Z statistic obtained for 1 1/16 Zn/dry was 2.61 times greater (12.8 / 4.9) than the Z statistic obtained for the 1 1/16 Zn/oil. The Z statistic obtained for the 1/2 dry was 3.14 times less (-2.2 / -0.7) than the Z statistic obtained for the 1/2 oiled.

For all experiments except the experiment that used 1 1/16 threaded fasteners, the Z statistic was negative. A negative Z statistic indicates that the mean for static inspection torque was lower than the mean for dynamic assembly torque.

CHAPTER V

SUMMARY, FINDINGS, DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Statement of the Problem

This study seeked to identify and explain the observable threaded fastener torque difference obtained during assembly installation (known as dynamic torque) and the inspection torque obtained after assembly installation (known as static torque). It accomplished this by conducting experiments in light of the null hypothesis that there was no statistical difference between dynamic assembly torque and static inspection torque.

Torque values observed may intuitively seem different in variation and target. This approach can not be recommended because of differences in individual biases. For this purpose, an observable torque difference between dynamic assembly and static inspection was broken down into statistical evaluations of variation (F test) and means (Z test). The confidence interval for each of these tests is subjective. This study took the conservative approach, using a 95% confidence interval, to insure that conclusions made would be largely accepted by others. The confidence interval was applied to a F test to determine if variances between dynamic assembly and static inspection torque were the same.

The confidence interval was also applied to a Z test to determine if means were the same.

Three of the six experiments indicated that the variances produced from dynamic assembly torque were different than static inspection torque. Five of the six experiments indicated that the means produced from dynamic assembly torque were different than static inspection torque. From observation of these results, it was concluded that dynamic assembly torque and static inspection torque may be different depending upon the assembly elements and method of inspecting torque.

The six experiments include many of the variables such as friction, assembly method, inspection method and threaded fastener type. It is now realized that there can be a countless array of factors that result in a difference between static and dynamic torques. There is also a countless array of factors that may result in conditions where dynamic assembly torque and static inspection torque can not be proven different.

Significance of the Study

The findings of this study add to the knowledge of design and production. The questions and thoughts of this paper can be utilized to help develop a sound torque inspection plan. This must be accomplished to improve product reliability and reduce costs.

Findings of the Study

The findings of the study were based upon the six experiment outcomes. All findings are the result of the experiment's F and Z test conclusions.

Based upon the experiment's outcomes it was concluded that dynamic assembly torque and static inspection torque will not always be the same. This finding refutes the null hypothesis that there was no difference between dynamic assembly and static inspection torque. Such factors as threaded fastener type, installation method, lubrication, joint type, inspector's influence result in a conclusion that assembly torque specifications can not be applied to static inspection torque.

Static inspection torques are not necessarily more variable than dynamic assembly torques. The degree of variability difference is influenced by all process and inspection elements included during each specific torque situation.

The mean (target) obtained from static inspection torque will not always be the same as the mean obtained from dynamic assembly torque. Once again the magnitude of this difference is the result of the method of assembly, method of inspection and factors specially associated with the components that are involved.

Discussion

This study has proven that dynamic assembly torque and static inspection torque are not always statistically the same. The results of this study are not consistent with Munn (1988) who stated that researchers found that static measurement produced greater variation in torque readings than dynamic assembly torque. Only under certain situations can static inspection torque be proven different than dynamic assembly torque.

The results of this study are consistent with Shoberg's (1989) findings that static inspection torque values are highly operator sensitive. It is believed than the conclusions of all experiments are a direct result of inspector's reactions and method of obtaining static inspection torque. A different inspector (or even the same inspector) under the same conditions could provide different results.

Certain assembly conditions and components result in lower static inspection torque values than dynamic assembly torque values. This event was proven with the M16 and 1/2 thread fastener experiments. This finding is inconsistent with Shoberg's (1989) findings that static inspection torque values are higher than dynamic inspection torque.

It is clear from observation that conclusions to any dynamic assembly verses static inspection torque experiment may be modified the next time the same experiment is conducted. This is likely to happen because one of the many variables that effected the experiment outcome on its first attempt may change on its second attempt. The challenge for industry is how to control and verify torque processes.

Conclusions

Based on the findings of this study the following conclusions can be made:

1. Dynamic assembly torque variation and static inspection torque variation will not always be the same. In only special situations will dynamic torque and static torque be the same. Even in these special assembly situations, a change in assembly components can result in a change in variation difference.

2. Static inspection torque variation will not necessarily be greater than assembly torque variation. This conclusion is subject to static inspection sensitivity and components of the torquing process.

3. Dynamic assembly torque target and static inspection torque target will not always be the same. This conclusion was based on the premise that the measuring instruments are calibrated the same and statistically produce the same average when verified against a standard.

4. Static inspection torque target will not necessarily always be greater than dynamic torque target. Static inspection torque tends to be greater than dynamic torque,

however, assembly methods and components may result in situations that result in a greater dynamic torque target than that obtained from static torque. An example of this condition was displayed by the M16 experiments. Table 8 shows that the M16 oiled static inspection torque average was 202.3 lb-ft. The dynamic assembly torque average was 220.5 lb-ft. This resulted in a Z statistic of -8.2, that fell beyond the critical value of -1.96. This outcome could be contributed to the fastener's characteristic of 5.12 inch in length. Approximately 3.94 inch of fastener shank was not used for threading into the female thread. This may have resulted in a shank twisting that absorbed some of the impulse gun's torque.

5. Since dynamic assembly torque and static inspection torque are not always the same, the specifications for static inspection torque can not be the same as specifications used for dynamic assembly torque.

Recommendations

The following recommendations are made:

1. Dynamic assembly torque targets be established with feedback from dynamic assembly torque values.

2. Offset specifications be developed for static inspection torques. The offset specifications will account for target difference and variation difference between

dynamic and inspection torques. The offset required must be developed from individual studies that are designed towards specific threaded fasteners and their assembly components.

3. A static inspection torque tool be used that reduces operator sensitivity. Shoberg (1989) describes one such principle, the Fader/Shoberg Algorithm, on which a static torque wrench could operate. If the Fader/Shoberg Algorithm was coupled with an automatic torque drive, that limited inspector influence, then variation between inspectors would be reduced.

REFERENCES

Assembly engineering. (1988, June). The trouble with torque. p. 50.

Bergstrom, R. P. (1989, September). Tightening down on joining. Production, pp. 90-92.

Bickford, J. H. (1983, October). That initial preload-what happens to it? Mechanical engineering, pp. 57-61.

Bickford, J. H. (1988, May). New twists in bolting. Mechanical engineering, pp. 30-34.

Ellison, H. W. (1970, January). Assembly plant torque control using a transducer computer (Report No. 700010). Detroit, MI: Society of Automotive Engineers.

Forgach, A. (1991, April). Better threadlocking demands consistent lubricity. Assembly, pp. 19-20.

Herceg, E. E. (1976). Handbook of measurement and control. Pennsauken, NJ: Schaevitz Engineering.

John Deere Standard JDM B3.2. (1986, June). Specification for gray (flake graphite) cast iron.

Johnson, R. (1984). Elementary statistics (4th ed.). Boston: Duxbury Press.

Leininger, E. & Munn, H. (1988, June). Applying plant wide spc of fastener assemblies. Automation, pp. 72-74.

Machine design. (1985, August). No-touch device deduces bolt torque. p. 50.

Munn, H. (1988, March). Torquing tutorial. Assembly engineering, pp. 38-41.

Production engineering. (1984, November). Tighten torque accuracy and cost control. pp. 22-23.

Production engineering. (1987, February). Torque monitoring system does more than tighten bolts. pp. 58-59.

Shoberg, R. S. (1989, November). Improved hand torque auditing. _Assembly_, pp. 34-36.