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The Effect of Zinc Plating on Torque Coefficient

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Abstract

The purpose of this study will be to investigate the effects of three variables: Zinc plating, Flange head hex bolt, and washers on the torque coefficient of the respective bolts. The problem first surfaced when zinc plated bolts with washers started stretching and breaking at the recommended torque. This problem never surfaced when the bolts were steel ; It was therefore concluded that the coefficient of friction must be different for zinc plated with washers than steel bolts with washers. An experiment will be devised in which the torque coefficient of the three types of bolts are investigated. Material has been ordered and a budget has been approved for this experiment.

The Effect of Zinc Plating on Torque Coefficient

A Research Paper

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By

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Chapter 1
INTRODUCTION

JDT 904 has been used as a torque standard now since 1953. Generally, it has been widely accepted as a basis for torque settings within John Deere. A recent event, however, caused quality engineering to question its validity regarding cast iron and plated bolts and washers. This research paper reports on the findings of an experiment planned to test the effects of three variables on torque coefficient or "K" factor. Torque coefficient has been investigated by several groups but investigation into the subject matter failed to yield the proper information for the special circumstances involved in the incident.

Statement of Problem

The problem that needs to be investigated is " Should John Deere torque standards be changed for zinc plated bolts?"

This problem statement can be broken down into several sub problems that need to be investigated:

1. Is there a statistical difference between the torque coefficient of zinc plated bolts vs carbon steel bolts?

2. Is there a statistical difference between the torque coefficient of zinc plated washers vs steel washers ?

3. Is there a statistical difference between the torque coefficient of a hex head flange bolt and that of a nut washer arrangement?

4. Is there a difference in clamping load between the 1st and 2nd installation of a bolt?

What is refereed to as coefficient of friction is actually torque coefficient or "K" factor. Torque coefficient is also made up of thread interference, smoothness of surface finish, and nicks in the threads. "K" factor is the slope of the regression line in the torque tension relationship. Torque is the independent variable and tension is the dependant variable. A relationship is calculated in the form of a linear regression line (a + bx): b is the slope of the line and referred to in this study as torque coefficient or "K" factor. John Deere Standard 904 assumes a K K factor or .2. If our experiment shows the actual K factor to be significantly different than .2, John Deere standards should be changed to reflect this fact.

Statement of Purpose

The purpose of this study is to explore the questions raised in section II. These questions should be answered in order to revise the John Deere Torque standard to accurately reflect true "K" factors. The more accurate "K" factors are in preparing torque guidelines, the more accurate clamping loads will be on the joint. Inaccurate "K" factors will lead to stripped threads, leaky joints, or inadequate clamp loads on a joint.

Statement of Need

At a large midwestern agriculture manufacturing firm, an incident occurred that set off an investigation into the validity of JDT 904 torque standard. The steering arm of the mechanical front wheel drive unit of a tractor is a very important mechanical device. If this unit fails, it could cause loss of steering and possible injury or death to the operator. The arm is held in place by 4 M16 x 2 x 50 mm bolts. For several years, these bolts and washers were made of plain carbon steel : The failure rate was 0% at the recommended torque. A decision was published which authorized the change to yellow dichromate zinc plated bolts and washers. The first day of production, 2% of the new zinc plated bolts failed- either they stretched beyond their yield point or they broke completely. Obviously, something was different about the zinc plated bolts vs the carbon steel bolts. The torque applied to the bolts was the same so something must be causing the bolts to stretch more under the same load. The most obvious difference between the two situations was that the coefficient of friction must be different for zinc plated bolts as opposed to carbon steel. If this is true, however, why didn't the torque standard reflect this fact? The observation of broken bolts in a steering arm assembly pointed to a larger problem of inaccurate torque guidelines. The formula for induced tension in a bolt is T=KDF where T=tightening torque, K=Torque coefficient, D=nominal screw diameter, and F=tension induced in the screw. For example, suppose an analysis determines we need 7000 lbs of clamp load and we have a .5 diameter cap screw. The formula would indicate a recommended torque of 58 ft lbs. If the K factor changes to .15, the recommended torque of 58 ft-lbs would produce 10,523 lbs of clamp load. It is possible this much clamp load would yield or fail the bolt. Accurate K factors are very important in determining the proper clamping load on a joint. The need for this study was demonstrated by the failure rate of zinc plated bolts in the steering arm assembly. Clearly, more information need to be gathered on the effect of washers and galvanized plating on the torque coefficient of bolts.

Jack Trilling, Director of Engineering at Holo Kron Company states

Because induced tension can vary considerably from one type of assembly to another for any given torque, the data tabulated in this article should be used with caution-particularity in applications where

> control of preload is critical and must be obtained by the torque-wrench method. For some applications, the relationship between torque and induced tension should be determined experimentally for the actual part lubrication practice involved.

Howard T. Griffin, chief engineer at Flexallow Inc. states

> Although tabulated torque tension values will be based on the commonly accepted equation T=KDW, values so computed are intended only as starting point guidelines for fastener users. Values will be based on assumed torque coefficient (K). In actual service, the K values could, and most likely will, differ from our selected K levels. Where bolt clamping load is critical to assembly, it is the responsibly of the installer to determine proper assembly torque by acceptable instrumentation.

Based on the quotes given, it can be ascertained that exact torque coefficients are largely unknown since 90 % of applied torque may be wasted in overcoming friction. It has been determined that there are 75 variables that affect torque coefficients (Smith, 1975). The experiment attempts to determine the effect of 3 variables- zinc plating, hardened washers, and flange head bolts on torque coefficient.

The Skidmore Wilhelm Mfg Co. reported finding variations in K factors ranging from .3 for lubricated plain steel parts to .15 for non lubricated stainless steel parts. Clearly, accurate K factors are essential in determining proper preload of a fastener.

In an experiment done on bolted joint torque factors by the University of Michigan, the K factor for 21 configurations of bolt, nut, and washers were investigated. The stated purpose of the study was to:

1. Determine if there are any substantial differences in performance with different coated bolts.

2. Define a torque coefficient by using the formula T=KDF where T is the torque, K is the torque coefficient, and F is the tensile load in the bolt.

An experiment done by Brian Ogle, an engineer at John Deere waterloo works, experimentally determined the K factor for wax and non wax coated bolts using aluminum as the thread material and aluminum as the clamping material. His paper concluded:

> "JDT 904 needs to be rewritten to address other materials, like aluminum and also need to address the different friction conditions that exist throughout out product like oil, epoxy, loctite, and plating vs washer."

Clearly, there is a need for accurate K factors in the industry. This issue needs to be addressed in a manner acceptable to the scientific and industrial community.

Statement of Hypothesis

In Inferential statistics, the T test and the F test are used to determine if there is a statistical difference between 2 groups; the T test is a test for means and the F test is a test for variances. Because this study attempts to answer several questions concerning variables which affect torque coefficient, several null hypothesis are advanced:

T test

μ (1) of K factor of zinc plated bolts = μ(2) of K factor of steel bolts

μ (1) of K factor of flange head bolts = μ(2) of K factor of plated bolts

μ (1) of K factor of 1st installation = μ(2) of K factor of 3rd installation

F test

S (1) of K factor of zinc plated bolts = S (2) of K factor of steel bolts

S (1) of K factor of flange head bolts = S (2) of K factor of plated bolts

S (1) of K factor of 1st installation = S (2) of K factor of 2nd installation

Assumptions

The following assumptions are made in pursuit of this study:

1. The pitch diameter of all bolts tested are the same and are within specifications for the industry.

2. There are no nicks or imperfections in the threads of all tested bolts.

3. The cleanliness of all classes of bolts are similar.

4. The most accurate way of measuring K factor is with a fixture that negates the torque of the bolt and measures only clamping load.

5. The K factors are normally distributed.

6. The number of applications in torquing successive bolts to the sample of cast iron will not appreciably change the K factor during the experiment.

7. The sample of bolts used in the experiment is representative of the general population of zinc plated and steel bolts.

8.The effects of variation within the bolts can be neutralized with random selection.

9. The friction coefficient of cast iron is similar to nodular iron.

10. The bolts tested meet ANSI std 242 for mechanical strength and chemical composition of metric fasteners.

11. The inside pitch diameter for tapped holes of the test material does not vary out of the specification for an M16 x 2 hole.

12. The data gathered from an M16 tapped hole is representative of the population of metric fasteners.

Limitations

This study is limited by the following factors:

1. A simple random sample of M16 x 2 x 90 bolts will be used to test all three hypothesizes.

2. A single torque value of 310 Nm will be used to test K factor clamping load.

3. A Nova model 32 digital torque wrench will be used to check torque values.

4. The test block for tapped holes will be B215 Gray Iron poured by John Deere Waterloo works.

5. The test block for the clamp test will be B215 Gray Iron poured by John Deere Waterloo works.

6. All bolts will be washed to remove oil and other impurities.

7. The study includes only electroplated galvanized zinc plated bolts.

8. This study is limited to a random sample of 32 pieces of each group of parts. From this sample, conclusions will be drawn about the general population.

9. Only 6 classes of bolts will be used:

1. zinc plated bolts.
2. plain carbon steel bolts.
3. zinc plated bolts with washers.
4. plain steel bolts with washers.
5. zinc plated flange head hex bolts.
6. plain steel flange head hex bolts.

Definition of Terms

The following term definitions were taken from:

1. Mechanical Engineering Design by J.E. Shigley ,1977

2. Machinerys Handbook published by The Industrial Press , 1982

3. Strength of Materials by S Timoshenko , 1988

Torque- A measure of the tendency of the force to rotate the body upon which it acts about an axis. The magnitude of the moment due to a force acting in a plane perpendicular to some axis is obtained by multiplying the force by the perpendicular distance for the axis to the line of force. Torque is commonly expressed in foot-pounds, inch-pounds, and Newton-Meters.

Pre-load- The amount of tensile load applied to a bolt when it is installed.

Coefficient of friction- The ratio of the limiting friction to the normal reaction between the sliding surfaces. The ratio is constant for a given pair of surfaces under normal conditions.

Torque Tightening- The tightening of screw and nuts to a given value or torque to produce a desired pre-load.

Friction- The universal force between surfaces that opposes sliding motion.

Coating- The application of some material such as metal or organic compound to the surface of a fastener.

Inferential statistics- The technique of analysizing the values of numerical data and then using them to make decisions.

Random- The conditions in which each member of a sample has an equal chance of being selected.

Torque wrench- Any tool that is utilized to obtain the desired torque of a fastener.

Chapter 2

Review of Literature

Since man first invented the bolt and stressed joint, many ideas have been tried to measure the bolt preload. The most accurate method to date has been to measure bolt elongation with a micrometer. This method is expensive and time consuming. Bolts with built in elongation measures have been tried but have proven to be very costly. The tried and true method that has stood the test of time is through torque applied to the bolt measured with a torque wrench. This method is the simplest but is apt to be inaccurate due to the effects of friction on the bolt threads.

Much research has been done on the effect of variables on torque coefficient. It has been determined there are 75 variables that affect torque coefficient and thus bolt preload. Torque coefficient is directly related to coefficient of friction between the threads and the washer face. Coefficient of friction is correlated with Columbs friction law which states:

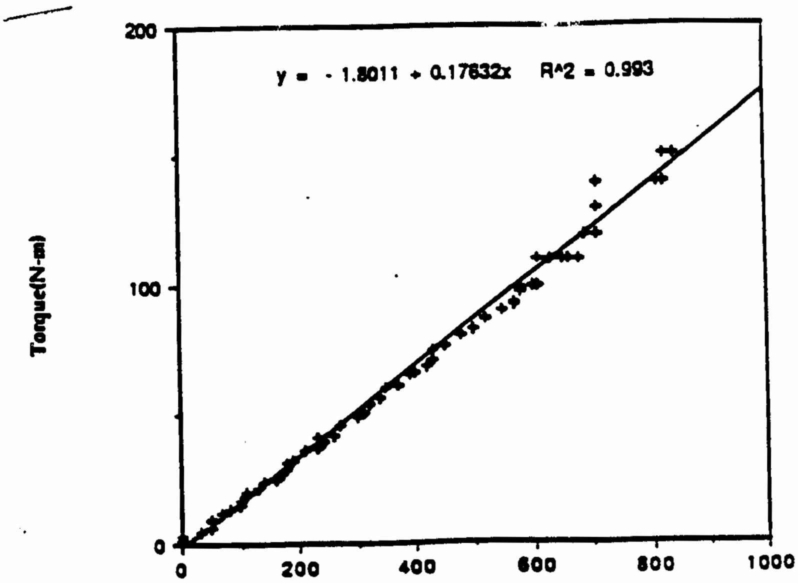
> The frictional force is proportional to the normal force and is independent of the contact area and speed of sliding. The ratio of the tangential force to the normal force during sliding is called the coefficient of friction and depends on the nature of the two surfaces. (Grolier ,1991)

The John Deere handbook #3 on torque states that K Factor (Torque coefficient) consists of :

1. The slope of the regression line of the torque tension curve.
2. The thread friction factor and washer face friction factor.

Table 1 illustrates how K factor is derived as the slope of the torque tension regression line.

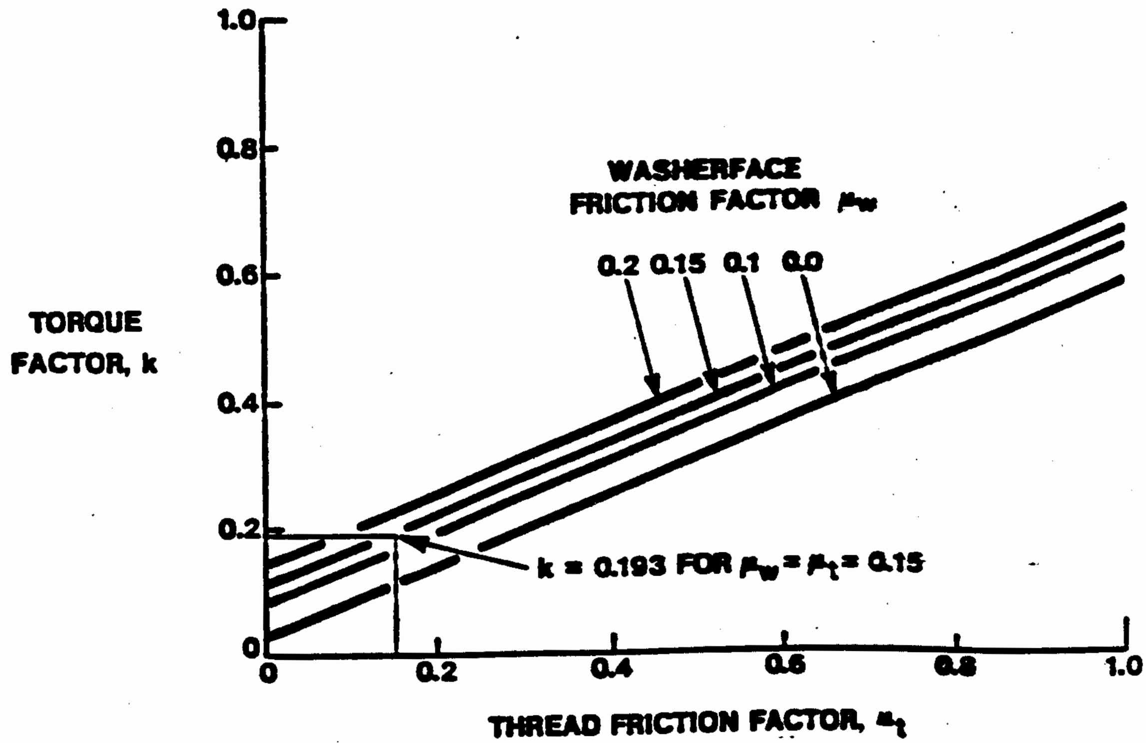
Figure 1. Torque Tension regression line of steel bolt



Note: From John Deere Handbook #3, H.D. Berns Author. Reprinted by permission

Figure 2 shows that K factor consists of the thread friction factor and washer face friction factor. 40% of the torque is taken up by the thread friction factor, 50% of the torque is taken up by the washer face friction factor while 10% of the torque goes into bolt preload. Thread friction factor and washer face friction factor refer to the coefficient of friction for the respective areas of concern. The coefficient of friction is that ratio of the frictional force to the tangential force or torque acting upon the bolt. It is a precise mathematical measurement which requires precise measurement equipment. The table illustrates that a thread friction factor of .17 will interact with a washerface friction factor of .15 to form a torque factor of .19 .

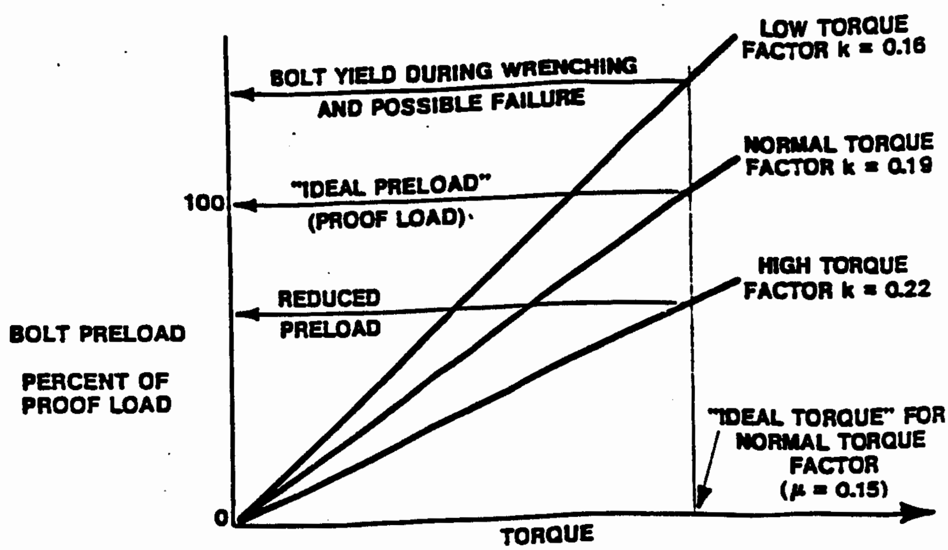
Figure 2. Interaction between thread friction factor and washerface friction factor to yield torque factor



Note: Reprinted from John Deere Handbook #3, H.D. Berns Author, 1982. Reprinted by permission

Figure 3 illustrates the effect of different K factors on bolt preload. If an ideal bolt preload is achieved when K=.19. a smaller bolt preload is achieved when K=.22 while a larger bolt preload is achieved when K factor is .15. The need of an accurate K factor is reflected by the graph as inaccurate bolt preload will be a result of inaccurate K factors. If a table or formula assumes a K factor of .2 (as does JDT 904), any variation from this proper K factor will result in improper clamp load.

Figure 3. Effect of K factor on Bolt preload



Note: Torque Tensioning (p 12), Cleveland Ohio, Howard Griffin. Adapted by permission.

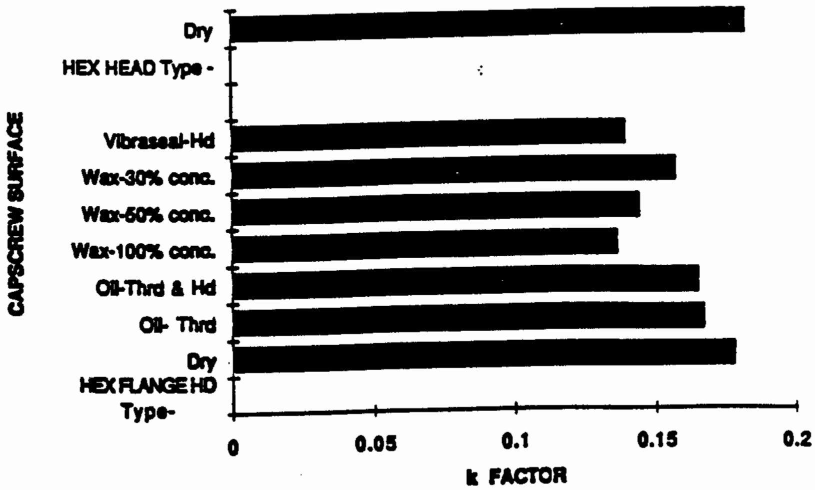
In a study done by the John Deere Product Engineering Center in December 1992, the effect of hex head dry and flange head dry were calculated. The results indicate a K factor of approximately .17 can be expected. However,this study fails to compare the results of zinc plated vs steel plated bolts.

Figure 4. K Factor as a result of various combinations of capscrew treatment

Capscrew Surface Treatment	k Factor	Example of Torque Requirement at upper limit Nm (1)	at +/- 10%control Nm (2)	at +/-20%control Nm (2)
HEX FLANGE HD Type-				
Dry	0.178	45.70	41.55	38.08
Oil- Thrd	0.167	42.88	38.98	35.73
Oil- Thrd & Hd	0.165	42.36	38.51	35.30
Wax-100% conc.	0.136	34.92	31.74	29.10
Wax- 50% conc.	0.144	36.97	33.61	30.81
Wax- 30% conc.	0.157	40.31	36.65	33.59
Vibraseal-Hd	0.139	35.69	32.44	29.74
HEX HEAD Type -				
Dry	0.182	46.73	42.48	38.94

Note: Torque/Friction coefficient of capscrews (p. 34) by Vern Holman, 1982. Adapted by permission.

Figure 5. K factor as a result of wax concentrations and various treatments



Note: Bolted Joint Torque Factors (p23) by Vern Holman, 1982. Adapted by permission

In his conclusion, Vern Holman writes:

> Results at this time should be viewed as general comparison only, that is, each critical application should be tested when accuracy in clamp load is required due to the variables.

The University of Michigan performed a study on how bolted torque factor varies when the corrosion protection on zinc plated hardware changed from a clear to a yellow chromate. In this study, 21 separate variables were investigated ranging from sample 1 (yellow chromate flanged nut with hardened washer) to sample 21 (six month storage yellow flanged nut in nodular iron lubed in 6 in 1 oil. Table 6 shows the results of this investigation.

Table 6. K factors as a result of different configurations of bolts, nuts, washers and lubricant

	Sample Configuration for the bolt, nut, washer, and lubricant	Mean Value of Torque Factor	Standard Dev. of Torque Factor	Number of Samples
#1	As received yellow flanged bolt and nut with as received plain washer	0.181	0.015	10
#2	As received clear flanged bolt and nut with as received plain washer	0.187	0.023	10
#3	Yellow flanged bolt and nut oiled with 30w motor oil with as received plain washer	0.081	0.015	5
#4	Clear flanged bolt and nut oiled with 30w motor oil with as received plain washer	0.094	0.006	5
#5	Yellow flanged bolt, nut, and plain washer all cleaned in isopropyl alcohol	0.132	0.004	5
#6	Clear flanged bolt, nut, and plain washer all cleaned in isopropyl alcohol	0.174	0.005	5
#7	As received and 6 month storage yellow flanged bolt and nut with as received plain washer	0.162	0.018	7
#8	As received and 6 month storage clear flanged bolt and nut with as received plain washer	0.138	0.014	7
#9	As received (second shipment) yellow flanged bolt and nut with as received plain washer	0.172	0.005	5
#10	Yellow flanged bolt and nut with plain washer all solvent cleaned by John Deere	0.224	0.045	9
#11	Clear flanged bolt and nut with plain washer all solvent cleaned by John Deere	0.189	0.031	9
#12	As received (6 month storage) yellow flanged bolt and regular hex nut with plain washer	0.196	0.042	10
#13	Waxed yellow flanged bolt and nut with plain as received washer	0.097	0.008	6
#14	Waxed yellow flanged bolt and nut with green painted washer	0.077	0.006	4
#15	As received and 6 month storage yellow flanged bolt and nut with green painted washer	0.252	0.048	5
#16	As received (second shipment) yellow flanged bolt and nut with green painted washer	0.228	0.014	5
#17	Yellow flanged bolt & nut, plain washer all solvent cleaned by John Deere, lubed with 6 in 1 oil	0.163	0.0175	5
#18	Clear flanged bolt & nut, plain washer all solvent cleaned by John Deere, lubed with 6 in 1 oil	0.154	0.0172	5
#19	As received (second shipment) yellow flanged bolt, as received nodular iron block with taped holes	0.142	0.005	5
#20	As received (second shipment) yellow flanged bolt, nodular iron taped holes, lubed with 6 in 1 oil	0.113	0.007	5

Note: Bolted Joint Torque Factors (p11) D.L. Carolan (1992). Adapted by permission

Torque coefficients of between .113 and .252 were reported for various combinations of coatings and bolt washer configurations in this study.

A study performed by Brian Ogle in November 1991 showed torque coefficients varying from .111 to .175 depending on lubrication and plating.

Table 7. K factor using cast iron without oil as substrata and torque values of 50 to 70 Nm

CAST IRON WITHOUT OIL
(Table 5)

EXPERIMENT	50Nm Zn Plain			70Nm Zn Plain			50Nm Zn w/ Wax			70Nm Zn w/ Wax		
Sample	Nm	Lbs.	K	Nm	Lbs.	K	Nm	Lbs.	K	Nm	Lbs.	K
1	50.0	6900	0.163	70.5	9500	0.167	50.0	10300	0.109	69.9	13700	0.115
2	50.0	6900	0.163	70.1	7800	0.202	49.9	10200	0.110	70.0	13800	0.114
3	51.0	6500	0.176	71.2	8200	0.195	50.4	10100	0.112	70.0	13200	0.119
4	50.4	5700	0.198	70.4	8300	0.190	50.2	9600	0.117	69.9	13600	0.115
5	50.1	6600	0.170	70.4	8000	0.198	50.7	10800	0.105	69.9	13600	0.115
6	50.7	7500	0.152	70.3	9800	0.161	49.9	9800	0.114	70.3	13600	0.116
7	50.4	5900	0.192	70.6	9400	0.169	50.1	10100	0.111	69.7	14000	0.112
8	50.5	6300	0.160	69.9	8300	0.169						
9	50.9	6300	0.160	69.9	8900	0.176						
10	51.3	6100	0.189	70.4	10300	0.153						
AVERAGE	50.5	6470	0.176	70.4	8950	0.178	50.2	10129	0.111	70.0	13643	0.115
STD DEV	0.424	533	0.015	0.377	842	0.017	0.293	382	0.004	0.181	244	0.002
MAX - MIN	1.3	1800	0.047	1.3	2500	0.048	0.8	1200	0.012	0.6	800	0.007

Note: Results of study of torque vs clamp load (p3) by Brian Ogle, 1991. Adapted by permission

In developing a suggestion assembly torque guideline , a target clamping load was used equal to 75% of the proof load values listed in ASTM F568-87 for length measurement. Howard Griffin (1992) states that:

> Under controlled conditions when uniform conditions such as hardware is present, it may be safe to aim for 80% of proof clamping load. Any torque table must be careful to use appropriate torque coefficients, as this has a very large effect on the clamp load.

The type of plating investigated in this paper is zinc plating. Zinc plating consists of the galvanizing process. There are three types of galvanizing processes- hot-dipped, electroplating, and mechanical plating. Hot dipped plating is a process of immersing the parts to be coated into a bath of molten metal. Electroplating is a process of coating metal by electrolysis of dissimilar metals. Mechanical coatings is the process of depositing powdered zinc onto the base metal resin using cold welding and mechanical means. All zinc plated bolts used in this study will be electroplated as this is the standard for the industry (Fisher, 1974)

The effect of washers on K factor is difficult to predict. Originally, washers were thought to serve the following purposes:

1. To protect the outer surface of the connecting material from the effects of galling.

2. To assist in maintaining a high clamping force in the bolt assembly.

3. To provide surfaces of consistent harness so the variation in the torque tension relationship can be maintained.The effect of a washer on K factor cannot be estimated.

SInce this experiment investigates the effect of plating, washers, and hex head on K factor, it is imperative that the research has not been done before. There is no evidence that this type of research has been performed previously.

Chapter 3

Statement of Methodology

The methodology used in this experiment is designed to test the null hypothesis set forth in the statement of hypothesis section. The test procedure set forth is designed to test whether there is a statistical difference between the means and variances of 3 sets of populations:

1. Zinc plated bolts vs carbon steel bolts.
2. Hex head vs flange head bolts.
3. Hex head and washer arrangement vs plain hex head bolts.

Population and sample selection

The populations used in the experiment consist of 3 types of bolts:

1. 2 sets of 32 pieces of M16 x 2 x 90 mm zinc plated hex head bolts (with and without washers) .
2. 2 sets of 32 pieces on M16 x 2 x 60 mm plain carbon steel bolts (with or without washers).
3. 2 sets if 32 pieces of M16 x 2 x 60 mm flange hex bolts (zinc plated and plain carbon steel).

All samples will be randomly divided into 2 subgroups. Each bolt will have an equal chance of being put into one category or the next.

Instrument development and validation

A test fixture designed by Brian Ogle, an engineer at John Deere Waterloo Works, will be used in the experiment. The test fixture is designed to accept a 1.5" x 1.5" x 18" block of metal in which holes of appropriate sizes are drilled. Each hole is designed to be used only once since repeated use of the same hole may polish the threads and change the K factor. The head of the bolt clamps against a circular block of metal chosen to match that of the desired material. In this case, both the substrata and clamping material will be cast iron. The fixture is designed to negate the effects of the torque on the bolt and therefore should provide a more accurate reading than that of a load cell under the head of the bolt.

The output data from the load cell will be sent to a portable PC via the SAMAT data analyzer. The SOMAT analyzer displays the clamp load as digital format in thousands of pounds of clamp load. The clamp load is then plugged into the formula T=KDF. Knowing the torque applied to the bolt and the clamp load, the K factor can be calculated. Since K factor, however, is the slope of the Torque-Tension regression line, the question can be asked "Is K factor at 310 Nm the same as K factor throughout the torque tension regression line? It is for this reason , an entire torque tension regression line will be plotted as part of this experiment.

In this portion of the experiment, readings will be taken at 10 Nm increments and tension recorded for each increment. This information will be plotted on a scatter plot and the regression line will be calculated. The value of this line will be compared to the value calculated for individual readings to see if there is a significant difference.

The data gathered in this experiment will be presented in the form of a 2 x 3 data table with values given at each intersection: The table would have hex head, hex head with washer, and flange head as columns with zinc and steel as rows. The proper statistical tool to use in this case is ANOVA- Two factor without replication. ANOVA will compare all the means of the table by row and by column and test for statistical difference. An F test and T test would not be adequate in this case since these tests can only test 2 means and 2 variances at a time. The results of a 2 X 3 table would be confusing and inconclusive. Since ANOVA assumes normal distribution and equal variances, these tests will have to be performed first before ANOVA is used.

Budget

Substrata test bars-machining-15 hours at $15.00/hour=	$225.00
material	$ 85.0
Top clamping block-machining- 5 hours at $15.00/hour=	$ 75.00
material	$ 65.00
	$450.00

Time Line

Completion of test block and top clamping block	-	25 Jan 1993
Completion of experiment	-	10 Feb 1993
Compilation of results	-	25 Feb 1993
Report of findings and completion of experiment	-	10 Mar 1993

Chapter 4

Analysis of the Data

The experiment was performed on February 19-20 1993 in Z-1 Inspection station. The experiment took 10 1/2 hours to perform. This procedure actually involves 2 separate experiments which will be referred to as experiment 1 and experiment 2. Experiment 1 attempts to answer the following questions:

1. Is there a difference between the K factor of zinc plated bolts vs steel bolts?

2. Is there a difference between the K factor of flange head bolts vs plain hex head?

3. Is there a difference between the K factor of hex head bolts vs hex head with washer?

Experiment 2 attempts to answer the following question:

1. Is there a statistical difference between 1st installation and 2nd installation of a bolt?

Table 8 shows the results of clamping load at 228 ft lbs on various combinations of head and washer arrangements. In table 8, the mean represents the mean clamp load at 228 Nm. The results are reported as the PDDTK statistical software package reports them. The mean clamp load is the most important data in this table as this is the information used to calculate K factor.

Table 8. Raw results of torque-tension experiment using 228 Nm of torque

General Statistics for zinc bolts-no washer

# of points	Mean	Standard Deviation	Range	Maximum	Minimum
32	20572	0.9352	3300	22000	18700

General Statistics for zinc bolts-with washer

# of points	Mean	Standard Deviation	Range	Maximum	Minimum
32	22609	1.9352	7100	26300	19200

General Statistics for Flange Head-ZInc Screws

# of points	Mean	Standard Deviation	Range	Maximum	Minimum
32	16712	1.84	7300	20500	13200

General Statistics for Flange Head-Zinc Screws

# of points	Mean	Standard Deviation	Range	Maximum	Minimum
32	18630	1.6713	5900	21600	15700

General Statistics for steel hex head-no washer

# of points	Mean	Standard Deviation	Range	Maximum	Minimum
25	18992	1.98	7200	22800	15600

General Statistics for plain steel-with washer

# of points	Mean	Standard Deviation	Range	Maximum	Minimum
25	22756	1.03	3900	24700	20800

Note: All data was analyzed using PDDTK package

While table 8 represents the raw data gathered in this experiment., It should be noted the wide variation in clamp loads reported for each configuration. Clamp load is plugged into the formula T-KDF to figure K factor.Table 9 shows the final results of the 2 x 3 table. In an effort to analyze the results statistically- ANOVA single factor and ANOVA 2 factor without replication was used. Analysis of Variance is a statistical tool to determine what the P is value that a particular combination of means generates as a result of random chance or variation. Table 10 shows ANOVA-single factor. Results of the table indicate a P value of 5.5% which means there is a 5.5% chance that the variation can occur as a result of random variation.

Table 9

K Factors by Configuration and plating

	hex head	hex head w/washer	flange head
steel	.231 (K factor)	.192 (K factor)	.235 (K Factor)
zinc	.213 (K factor)	.194 (K factor)	.262 (K Factor)

These figures differ from Brian Ogles figures at 50-70 Nm of torque. It is known , however, that Brian used a different configuration of bolts than I tried. In general, these figures are similar to the University of Michigan obtained using waxed and zinc plated bolts. They are also in the same range as Vern Holmans experiment. The K factors derived in this experiment are similar to past studies.

Table 10

ANOVA-Single factor Analysis

Anova: Single-Factor					
Summary					
Groups	*Count*	*Sum*	*Average*	*Variance*	
Column 1	2	0.444	0.222	0.000162	
Column 2	2	0.386	0.193	2E-06	
Column 3	2	0.497	0.2485	0.0003645	
ANOVA					
Source of Variation					
	SS	*df*	*MS*	*F*	*P-value*
Between Group	0.00308233	2	0.00154117	8.74834437	0.05599591
Within Groups	0.0005285	3	0.00017617		
Total	0.00361083	5			

Table 11 examines the results in ANOVA-two factor without replication. In this analysis, the columns have a P value of 14% while the rows have a P value of 80%.. F critical values are 18.5 and 19 respectively. Neither rows or columns reach the critical 5% level.

Table 11.

ANOVA-Two Factor without replication Analysis

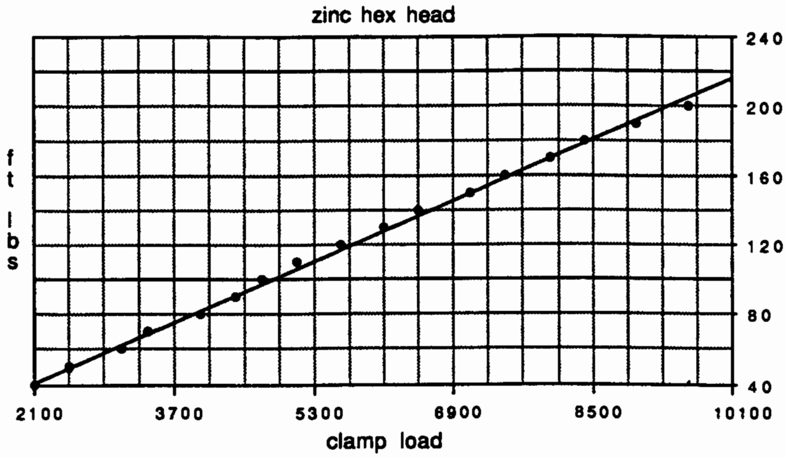
Anova: Two-Factor Without Replication						
Summary	*Count*	*Sum*	*Average*	*Variance*		
Row 1	3	0.658	0.21933333	0.00056433		
Row 2	3	0.669	0.223	0.001231		
Column 1	2	0.444	0.222	0.000162		
Column 2	2	0.386	0.193	2E-06		
Column 3	2	0.497	0.2485	0.0003645		
ANOVA						
rce of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2.0167E-05	1	2.0167E-05	0.07934426	0.80465848	18.5127647
Columns	0.00308233	2	0.00154117	6.06360656	0.14157074	19.0000264
Error	0.00050833	2	0.00025417			
Total	0.00361083	5				

Two factor without replication divides the probability into Rows and columns and analyzes them separately. It is a more accurate picture of the effects of independent variables than ANOVA-single factor. Without replication refers to the fact the experiment was done only once and was not repeated.

In an effort to verify the validity of the research technique, a regression formula was calculated to zinc head-no washer. Table 12 shows the results of the regression formula. In this table, the regression formula shows a slope of 21.7%. The experimental technique is therefore verified and the result of experiment 1 can be accepted as true and valid.

Table 12

Regression Analysis of Zinc-Hex Head bolts with no washer



Report Created: 4:20:24 AM

Linear Best Fit Curve
Pts Plotted = 17 Offscale Pts = 0

Regression Equation:
Y = 2.17752E-02 X + (-4.37462)

Correlation Coefficient = .999014
Std. Error about Regression Line = 2.31574
t Statistic (Hypothesis: Slope=0) = 87.1387

Experiment 2

In this portion of the experiment, 1st installation clamp load was compared with 2nd installation clamp load. The bolts were installed in the same holes for the 2nd time and the clamp load was once again figured using the standard tightening torque formula. Figure 12 shows the results of experiment 2.

Table 12

Comparison of K Factors 1st and 2nd installation- steel no washer

1st Installation	2nd Installation
.231 (K Factor)	.347 (K Factor)

The T test and F test are the proper statistical procedures for analyzing the results of this portion of the experiment. Table 13 and 14 show the results of the T test and F test respectively. The T test shows conclusively there is a significant difference between the means with a P value of .0000026%.

Table 13

T Test--Paired two sample for means

22.8	11			
22.3	11.2			
21	11.1			
20.9	10.9			
21.4	9.4			
17.7	12.3			
17.5	13.2			
18.5	14.5			
19.3	11.6			
18.4	10.7			
20.1	10.3			
20.1	14.8			
19.2	15.2			
20.9	13.8			
19.8	14.6			
18.2	14.5			
16.8	12.6			
19.3	14.6			
19.1	12.8			
20	12.6			
17.3	14			
15.9	13.1			
16.7	14.7			
16	13.9			
15.6	10.7			
		t-Test: Paired Two-Sample for Means		
			Variable 1	*Variable 2*
		Mean	18.992	12.724
		Variance	3.95743333	2.92023333
		Observations	25	25
		Pearson Correl	-0.3433736	
		Pooled Varianc	-1.1673	
		Hypothesized I	0	
		df	24	
		t	10.3256106	
		P(T<=t) one-ta	1.3097E-10	
		t Critical one-ta	1.71088232	
		P(T<=t) two-ta	2.6194E-10	
		t Critical two-ta	2.06389814	

The test results prove conclusively there is a statistical difference in the means. The mean of the K factor of the first installation is 18.9 while the mean of the second installation is 12.72.As mentioned above, the probability of this occuring by chance is .00000026%.

Table 14

F Test-Paired two sample comparison of Variance

22.8	11			
22.3	11.2			
21	11.1			
20.9	10.9			
21.4	9.4			
17.7	12.3			
17.5	13.2			
18.5	14.5			
19.3	11.6			
18.4	10.7			
20.1	10.3			
20.1	14.8			
19.2	15.2			
20.9	13.8			
19.8	14.6			
18.2	14.5			
16.8	12.6			
19.3	14.6			
19.1	12.8			
20	12.6			
17.3	14			
15.9	13.1			
16.7	14.7			
16	13.9			
15.6	10.7			
		F-Test: Two-Sample for Variances		
			Variable 1	*Variable 2*
		Mean	18.992	12.724
		Variance	3.95743333	2.92023333
		Observations	25	25
		df	24	24
		F	1.3551771	
		P(F<=f) one-ta	0.23105692	
		F Critical one-t	1.98375716	

While it was demonstrated that there is a statistical difference in the means, the F test did not find a statistical difference in the variance. There was a 23% that the variation which occured in the samples were a result of random variation. This is significantly above the critical 5%level and is therefore not critical.

Chapter 5

Statement of study

In October of 1992, the groundwork was laid for this study when the failure rate went from 0 to 2% on the first day of production involving zinc plated bolts and washers. This observation led to the hypothesis that the coefficient of friction was different for zinc plated bolts vs steel bolts.

A scientific test was developed to test 4 hypothesis relating to various questions asked by the industrial community. The test was designed to be completed in 2 stages. The 1st stage involved the formulation of a 2 x 3 table: Zinc and steel were the rows while hex head, hex head w/washer, and flange head were the columns. The second stage of the test involved a comparison of K factors for 1st and 2nd installation of steel bolts into a cast iron hole.

Experiment 1 & 2 were analyzed using different techniques. ANOVA-single factor and ANOVA-two factor without replication were the statistical tools used for investigation for experiment 1. A standard T & F test were used for experiment 2. Both experimental results were analyzed on EXCEL version 4.0.

Both experiments used a scientific test fixture designed by Brian Ogle of the John Deere Waterloo Works. The fixture was designed to negate the effects of torque on the load cell. In the first experiment, 6 samples of 32 readings were extracted using the 6 combinations of platings and configurations. K factors were induced from the formula T=KDP where T= tightening torque, K=torque coefficient, D=nominal screw diameter and P=tension induced in the screw. The load cell measured tension induced in the screw and that figure was plugged into the above named formula. K factor was then calculated for each combination of the 2 x 3 table. In the second experiment, clamp loads of 1st installation was compared with clamp loads of 2nd installation using the same bolts and substra. Both experiments yielded surprizing results.

Summary of findings

Experiment 1

1. ANOVA single factor failed to reach the critical 5% level of significance. ANOVA single factor showed a P value of 5.5%.
2. ANOVA Two factor without replication shows a P value of 14% for columns and 80% for rows.
3. The regression analysis of a torque tensions relationship validates the static formula t=KDF. The static results of experiment 1 is therefore taken as being valid and true.

Experiment 2

1. The T test for clamp load on 1st installation vs the clamp load for 2nd installation shows a P value of .00000026%.

Conclusions

1. It is concluded that because the null hypothesis is accepted for both single factor and 2 factor: There is no significant difference between the following combinations:

    a. ZInc vs steel

    b. Flange head vs hex head

    c. Hex head vs hex head with washer

2. It is concluded there is a statistical difference between the 1st installation and 2nd installation of a bolt.

Recommendations

The following recommendations are made as a result of this study:

1. JDT 904 (John Deere Torque standard) remain intact in relation to the recommended K factor of .2.

2. Service bulletins change the recommended torque for 2nd installation bolts to reflect an increase in torque coefficient.

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