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An Analysis of the Variables in the Torque Formula for Threaded Fasteners

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Abstract

The purpose of this study was to determine the relationship of the variables contained in the torque formula used by John Deere for threaded fasteners. The formula assumed the variables to be either constant or in a linear relationship. Since friction was a major factor in determining torque values for threaded fasteners and only a small amount of torque applied to the head of a cap screw resulted in clamp load, it seemed to be a big assumption that the torque coefficient for friction was a constant. By investigating this relationship, the industry may be able to gain a better understanding of the dynamics of torquing cap screws, and be able to provide a better product for the consumer.

AN ANALYSIS OF THE VARIABLES IN THE TORQUE

FORMULA FOR THREADED FASTENERS

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In Partial Fulfillment

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Master of Arts Degree

by

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CHAPTER 1

INTRODUCTION

Background of the Problem

The use of threaded fasteners had been a mainstay in the assembly of tractor transmissions and ensuring the fasteners do not come loose during use requires that the fasteners were tightened correctly. The desired result in tightening was that the fastener was actually stretched slightly during installation. The stretching of the fastener provided clamp load in the joint. Clamp load was the quantification, in pounds, of the force created by the stretching of a fastener. However, clamp load was very difficult to determine during the assembly process. Consequently, installation torque had been adopted as an indirect means for providing the desired clamp load. Torque tables had been developed to aid manufacturing engineers in the determination of the torque value for particular fasteners, but the tables were based on a formula which assumed all variables to be either constant or in a linear relationship.

Statement of Problem

The problem of this study was to investigate the relationship of the variables in the torque formula used by John Deere to develop the recommended torque tables for threaded fasteners provided by specification JDT904.

Statement of Purpose

The purpose of this study was to determine the relationship of the variables contained in the torque formula used by John Deere for threaded fasteners. The formula assumed the variables to be either constant or in a linear relationship. Since friction was a major factor in determining torque values for threaded fasteners and only a small amount of torque applied to the head of a cap screw resulted in clamp load, it seemed to be a big assumption that the torque coefficient for friction was a constant. By investigating this relationship, the industry may be able to gain a better understanding of the dynamics of torquing cap screws, and be able to provide a better product for the consumer.

Statement of Need

The need for the study was based on the following factors:

1. Clamp load was the desired result in tightening a threaded fastener.
2. Too little clamp load can result in loosening of the fastener.
3. Too much clamp load can result in permanent deformation and failure of the fastener.
4. Torque was an indirect means of providing adequate clamp load in a fastener.
5. Establishing process control of the tightening process requires an accurate interpretation of the actual fastener dynamics.

Statement of Hypothesis

It was hypothesized that the torque coefficient in the torque formula used by John Deere to develop the recommended torque tables for threaded fasteners provided by specification JDT904 was not a constant, but changed as the torque applied to the fastener increased.

Assumptions

The following assumptions were made in pursuit of this study:

1 That the recommended torque specifications conformed to industry standards for the size of cap screw.

2 That the torque and measurement equipment was accurate per the manufacturer specification.

3 That the cap screws conformed to the specifications and that the specifications were industry standards.

4 That the cast iron test bars and threaded holes were manufactured within specification.

Limitations

This study was conducted in view of the following limitations:

1 The size of cap screw used was ten millimeter with a pitch thread of one and one-half millimeter.

2. Only hard (non-gasketed) joints were included in the research. Gasketed joints were not included because of the variability inherent in different gasket materials.

3. The tested joints consisted of zinc plated steel cap screws threaded into cast iron material.

4. The clamp load during torquing of the cap screws was not available with the measurement equipment used.

Definition of Terms

The following terms are defined to clarify their use in the context of the study:

Clamp load: The force which a cap screw exerts on joint members being clamped together (Jensen, 1984).

Elastic region: The range of stress that can be placed on a material and still return to its original length upon release of the stress (Oberg, Jones, Horton, and Ryffel, 1989).

Torque coefficient: The measure of the lubricity of a bolt (Muraski, 1989).

Torque: The twisting force applied to a cap screw, which is the product of force and wrench length (Jensen, 1984).

CHAPTER 2

REVIEW OF THE LITERATURE

The main goal of an assembler in tightening fasteners was to achieve the correct preload in the joint; therefore, emphasis should be directed toward ensuring that adequate clamp load was achieved in all jointed assemblies (Bickford, 1990). Industry has attempted to achieve adequate clamp load by specifying installation torque; however, the torque specification of a fastener was an indirect means of identifying the desired clamp load of a particular joint and the tension produced in a fastener by applying torque to it was not the desired end result of an assembler in performing his task, but rather the clamp load that was placed on the joint after assembly (Bickford, 1987).

Bickford (1990) also states that the proper tightening of fasteners was an experimental science because of the number of variables involved, rather than based on rigorous theory or prediction. Derby (1989) agrees that accurately predicting clamp load of a fastener was difficult due to variables such as friction, variations in torque, and the determination of bolt tension. Derby goes on to state that only a small amount of torque applied to a fastener contributes to clamp load; most of the torque was absorbed in overcoming friction and because the amount of friction was variable, torque values alone are poor predictors of clamp load.

Despite the above concerns, industry has continued to use torque values to achieve clamp load in fasteners. The torque formula used by John Deere for development of the torque tables in specification JDT904 was:

$$T = D \times K \times F / 12$$

where:

T = Torque value in foot pounds

D = Nominal diameter of the fastener

K = Torque coefficient factor

F = Clamp load for the fastener in pounds

In the above formula, the nominal diameter of the fastener (D) was a constant, the torque coefficient factor (K) was constant, and clamp load for the fastener (F) was a constant based on the yield strength of the fastener material (Berns, 1984). Consequently, the determination of the torque table values was a direct calculation based on the fastener size and material.

However, rotation of the fastener creates clamp load and through the elastic region, clamp load was linear (Derby, 1989). This was corroborated by the elongation formula for steel shafts (Oberg, Jones, Horton, and Ryffel, 1989):

$$\text{Elongation} = \frac{(\text{Force})\ (\text{Length})}{(\text{Area})\ (\text{Modulus of Elasticity})}$$

Note that elongation was a linear relationship with force, given that the other variables are constant for a particular shaft.

Therefore, if clamp load was created by rotation of the fastener and clamp load was linear through the elastic region, then it follows that torque must be linear to rotation of the fastener, since the other variables of the torque formula were constant. But if the torque was shown to be not linear to rotation of the fastener, then the torque coefficient factor that was considered a constant, must be variable in relation to torque. The experiment was designed to investigate whether torque was linear to rotation of the fastener.

CHAPTER 3

METHODOLOGY

Materials and Parts Used in Experiment

The study was conducted using normal John Deere production threaded fasteners, washers, and test bars prepared on-site. The fasteners were new, zinc plated, ten millimeter cap screws with a pitch of one and one-half millimeters and were eighty millimeters long to accommodate the test fixture. The washers were also standard, zinc plated production parts. The test bars were cast iron, machined in-house using production type equipment to the same standards as the normal production parts.

Equipment for Experiment

The equipment for the experiment consisted of a DC electric torque tool, force transducer, and specially designed test fixture.

The DC electric torque tool was a recently purchased Georges Renault capable of torque accuracy of plus or minus three percent and angle capability of plus or minus one percent. The torque tool included a controller capable of storing data and providing graphs of torque and angle for each fastener tightening cycle..

A GSE model 500 force transducer connected to a digital display provided the ability to target the desired final clamp load.

The test fixture was specially designed to allow simulation of the actual joint conditions. It was designed to accommodate the force transducer within the joint simulation.

Procedure for Experiment

The study consisted of conducting a thirty-one piece sample of the torque to angle relationship for the ten millimeter cap screw. The initial targeting of the torque value was determined using the formula contained in the John Deere torque specification JDT904 to determine the ideal clamp load for the ten millimeter cap screw. A test piece was then run to establish the appropriate torque value for the experiment. This was necessary because the torque values in JDT904 are calculated for non-plated cap screws and the torque coefficient factor for zinc plated cap screws was lower.

The procedure for the experiment was as follows:

1. Indexed the cast iron test bar to a new threaded hole.
2. New cap screws were hand started and finish installed with the Georges Renault DC electric torque tool to a target torque of thirty-eight foot pounds.
3. Graphs were plotted comparing torque to angle after each tightening sequence.
4. The cap screw was removed and the procedure repeated.

CHAPTER 4

PRESENTATION AND ANALYSIS OF DATA

Information about the Data

This experiment gathered data on the relationship of torque and angle of the fastener as it was torqued to a target of thirty-eight foot pounds. The DC torque tool and controller was able to output the data in a graph format. Each graph was printed prior to beginning the next sample piece. The graphs were then analyzed for the amount of fastener rotation in degrees for given ranges of torque.

Analysis of Data

The data analyzed from the graphs was summarized in appendix B. The degrees were determined from the graphs (see appendix A) for each increase of ten newton meters(NM) of torque. The NM per degree was then calculated for each torque range. The mean of each torque range was then calculated. Analysis of the means was used to test the hypothesis. The results indicate that the torque increase per degree of fastener rotation was not linear to rotation through the entire torque range (see appendix B).

The bottom range represented the initial loading of the cap screw. This range had a calculated NM per degree of .327. Statistical analysis of the bottom range data revealed a standard deviation of .040 NM. Only one point in the sample fell outside three sigma of the mean.

The middle range represented approximately the desired final torque of the cap screw. This range had a calculated NM per degree of .421. Statistical analysis of the middle range data revealed a standard deviation of .047 NM. All points in the sample fell within three sigma of the mean.

The top range represented approximately the maximum torque of the cap screw. This range had a calculated NM per degree of ..533. Statistical analysis of the top range data revealed a standard deviation of .080 NM. All points in the sample fell within three sigma of the mean.

The top range had 27 percent more NM per degree than the middle range, and the bottom range was 22 percent less NM per degree than the middle range. This showed that the torque was not linear to rotation of the fastener, but increased as the fastener was tightened.

CHAPTER 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

The JDT904 specification used at John Deere for the determination of torque values for threaded fasteners uses a torque formula that assumes a constant torque coefficient factor and a linear relationship between clamp load and fastener torque. Authorities have been cited in the review of the literature supporting a linear relationship of clamp load to rotation of the fastener. Citations were also presented stating the high degree of the uncertainty regarding the torquing of fasteners. The experiment was designed to test the assumption of the torque coefficient factor as constant.

Conclusion

It was concluded that the hypothesis was supported by the data obtained from the experiment. The data reflected a significant change in the torque increase per degree within the torque ranges specified.

Recommendations

The need to conduct further research on the relationship between the torque coefficient factor and fastener torque was recommended by this experiment. This study documented a change occurs in the torque coefficient factor during torquing of the fastener, but the limitations of the equipment available for output data necessitates additional research into this relationship. Dynamic output of the clamp load during the tightening of the fastener and the analysis with relation to angle could provide more conclusive data in support of the hypothesis.

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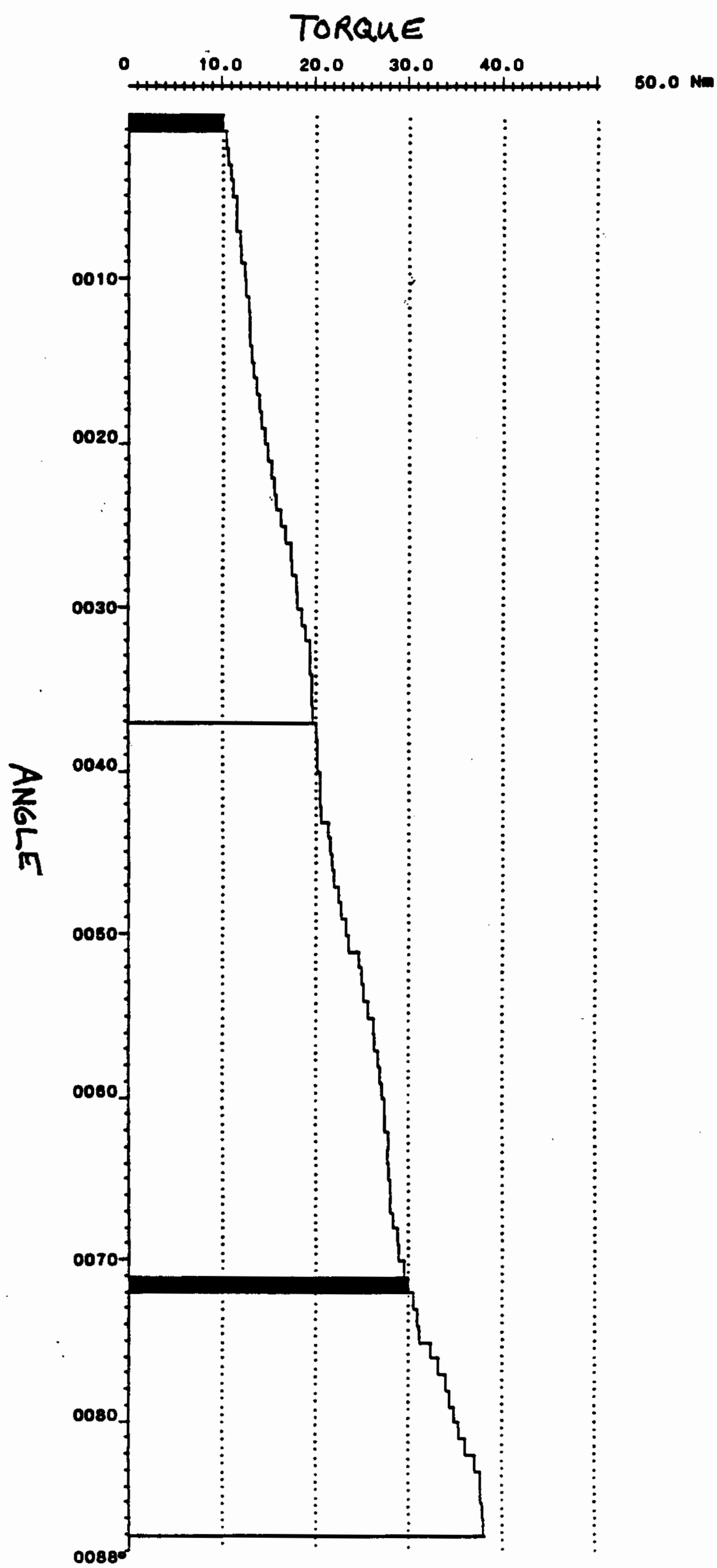
APPENDIX A

SAMPLE TORQUE TOOL GRAPH OUTPUT

Appendix A

Sample torque tool graph output



APPENDIX B

TORQUE AND ANGLE DATA

Appendix B

Torque and Angle Data

	Bottom of Range 10 - 20 NM		Middle of Range 20 - 30 NM		Top of Range 30 - 38 NM	
Sample Number	Degrees of Angle	NM per Degree	Degrees of Angle	NM per Degree	Degrees of Angle	NM per Degree
1	21	.476	20	.500	11	.727
2	30	.333	24	.417	13	.615
3	29	.345	23	.435	17	.471
4	31	.323	23	.435	17	.471
5	33	.303	19	.526	16	.500
6	38	.263	21	.476	15	.533
7	37	.270	34	.294	16	.500
8	34	.294	27	.370	18	.444
9	30	.333	24	.417	18	.444
10	30	.333	24	.417	15	.533
11	30	.333	24	.417	17	.471
12	30	.333	23	.435	17	.471
13	39	.256	23	.435	15	.533
14	32	.313	29	.345	16	.500
15	31	.323	27	.370	17	.471
16	31	.323	27	.370	17	.471
17	30	.333	25	.400	15	.533
18	30	.333	22	.455	12	.667
19	30	.333	23	.435	13	.615
20	36	.278	20	.500	12	.667
21	24	.417	20	.500	13	.615
22	32	.313	25	.400	19	.421
23	30	.333	23	.435	15	.533
24	30	.333	23	.435	18	.444
25	30	.333	27	.370	19	.421
26	29	.345	25	.400	13	.615
27	29	.345	25	.400	14	.571
28	34	.294	24	.417	17	.471
29	31	.323	24	.417	14	.571
30	29	.345	24	.417	13	.615
31	30	.333	25	.400	13	.615

Mean	**.327**	**.421**	**.533**
Standard Deviation	**.040**	**.047**	**.080**