Transverse Vibration Loosening Characteristics of High-Strength Fastened Joints using Direct Tension Indicators (DTIs)

July 1998

SPS Contract Research
Jenkintown, PA

Transverse Vibration Testing of M16 Class 10.9 Fastener Sets

Comparison of fastener sets with and without Direct Tension Indicators (DTIs)

Introduction:

In recent years, Direct Tension Indicators (DTIs) designed for use with hex head cap screws and other fasteners in the automotive, off-highway, and industrial equipment markets have been introduced. Although DTIs have been used on structural bolts for over 35 years in dynamically loaded structural applications such as bridges, buildings, power-plants, and cranes, research is warranted for evaluation of service-related performance characteristics of the specific DTI types used in these new markets.

The "Junker's" transverse vibration-loosening test provides a simplified method for broad scale testing and inspection of the transverse vibration (loosening) properties of fasteners. The test machine is able to generate relative motion in the clamped parts perpendicular to the axis of the fasteners. The Junkers method provides quantitative results relating the variables of clamp-load, number of cycles, and amplitude. Figure 1. depicts a standard configuration for the Junker's transverse vibration-loosening apparatus.

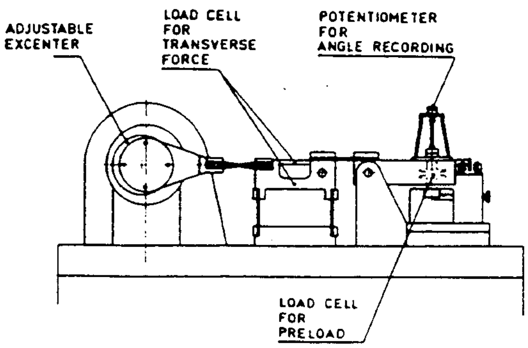

Figure 1. Junker's Transverse Vibration-Loosening Apparatus

The Junkers test is considered a 'severe' test of the loosening characteristics of fasteners, particularly when compared to previously introduced test methods which rely on axial dynamic loading to induce loosening. Junker largely established the viability of the current method in a paper entitled, 'Investigations of the Mechanism of Self-Loosening and Optimal Locking of Bolted Connections'.

Background:

This test program was undertaken, in part, to address questions raised by Original Equipment Manufacturers (OEMs) of over-the-road trucks, who have expressed interest in research data about the potential for vibration loosening of fastened joints with and without DTIs.

A comparison transverse vibration test is designed to expose two or more fastener sets to the same test parameters to determine the effects of the differences. The present research compared nut-bolt-washer assemblies with nut-bolt-DTI assemblies. To better understand vibration-loosening, Junker's provides us with models of bolted joints under static conditions and under transverse vibration. (See Figure 2a and 2b.)

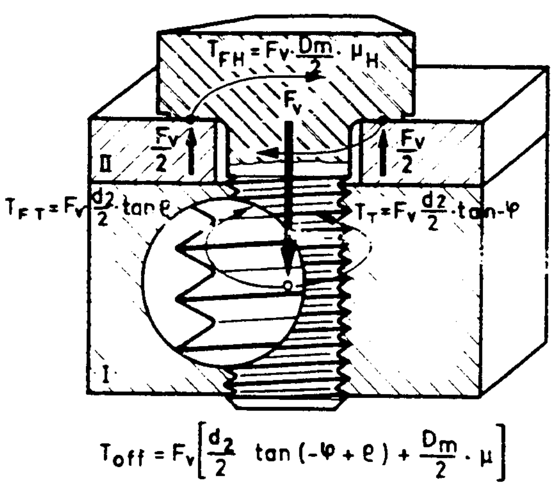

Figure 2a
Bolted Joint under static conditions

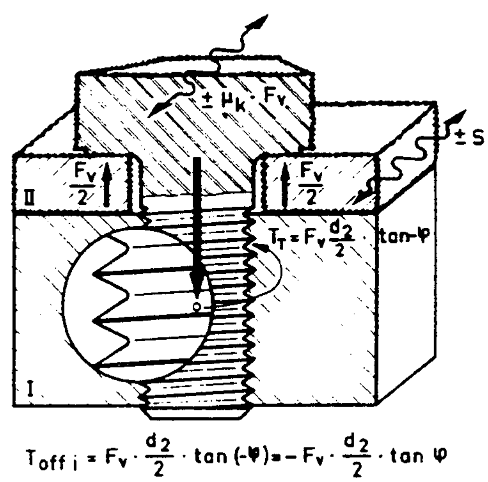

Figure 2b
Bolted Joint under transverse vibration

Results of transverse vibration-loosening tests are useful for deployment of bolting strategies which reduce or prevent the risk of vibration loosening in service, or mitigate its effects where it can not be avoided entirely. According to Gerhard H. Junker, originator of this test, "(I)t is well established that a dynamically loaded joint fails in most cases either by fatigue failure or by rotation loosening of the fastener. Even the fatigue failure is often initiated by partial loosening."[1]

Test Procedure:

Specimens of plain finish M16-2.0 X 85mm Class 10.9 Hex Head Cap Screws with matching zinc plated Class 10 Nylon Insert Lock Nuts, and zinc/yellow plated Hardened Washers were provided by a major manufacturer of over-the-road trucks. All tests were conducted on fastener sets in the 'as-received' condition, without the use of supplemental lubricants. Matching plain finish Class 10.9 M16 Direct Tension Indicators were provided by J&M Turner, Inc.of Langhorne, PA.

All tests were conducted at SPS Contract Research Laboratories in Jenkintown, PA. Each fastener set was tested on the 1" capacity SPS Tranverse Vibration Machine, which is capable of recording clamp-loads of up to 30,000 lbs. (133 kN).

Steel coupons were fabricated and used to ensure a consistent bearing surface for each of the tests. Tests were conducted 'nut up', with a hardened washer (or the DTI, when one was used,) placed under the nut. The effective grip length of the fastener sets was ~ 54mm.

Clamping force was generated for each test by turning of the nut until each fastener set was preloaded to 23,400 lbs., (104 kN), irrespective of the torque required to tighten the standard sets or the flatness of the DTI sets. For information purposes, some torque readings were recorded in order to quantify variation in the nut factor 'K' of the fastener sets. The preload at which the testing started represents the OEM's stated target tension, equal to 80% of proof load.

The amplitude of the transverse displacement was set at 10%. ($\pm$ 0.063") of nominal fastener diameter at a no-load condition. Each fastener set was tested at a speed of 750 CPM for 80 seconds in order to complete 1,000 transverse-vibration cycles.

A chart recorder is used to plot clamp-load vs. vibration cycles during each test, thereby permitting more detailed analysis of the results. Charts of the clamp-load vs. vibration curves from the subject test program are attached to this report as "Appendix A". Cycles are plotted along the X-axis and the clamp load of the fastener set is plotted along the Y-axis.

Results:

Vibration loosening of the fastener sets which did not include DTIs was clearly evident. Retained clamp load after 1,000 cycles ranged from a high of 21,000 lbs. to a low of 4,200 lbs. Expressed as a percent, clamp load loss was between 10% and 82%, averaging 63%. The mean clamp load after 1,000 cycles was 8,660 lbs., or almost a third of the initial preload. Only one sample from the group without DTIs retained more than 50% of its initial clamp load after 1,000 cycles. Exclusive of this one specimen, the remaining fastener sets required an average (mean) of 473 cycles to reduce clamp force by 50%.

Vibration loosening of the fasteners sets which did include DTIs was noticeably less than those without. The difference is clearly notable when one compares the results graphically portrayed by the chart recorder. Retained clamp load after 1,000 cycles ranged from a high of 22,750 lbs. to a low of 20,900 lbs. Expressed as a percent, clamp load loss was between 3% and 11%, averaging 8%. The mean clamp load after 1,000 cycles was 21,590 lbs. All of the samples from this group retained more than (88%) of initial clamp load after 1,000 cycles.

Conclusion:

Under the conditions of the subject test, there was a significant difference in the loss of clamp load between fastener sets with and without DTIs. Fastener sets without DTIs lost an average of 63% of their initial clamp force after 1,000 cycles, contrasted with an average loss of only 8% in the fastener sets in which DTIs were present. Under the test parameters and conditions of the study, DTIs appear to provide improved resistance to vibration-loosening.

The primary function of DTIs is, of course, to ensure that proper clamp force is attained in bolted connections. The scope of this study did not include determining the precise mechanism whereby the DTI connections also appeared to demonstrate superior vibration-loosening characteristics.

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[1] New Criteria for Self-Loosening of Fasteners Under Vibration, Gerhard H. Junker, European Research & Engineering, Standard Press Steel Co., Unbrako Koblenz, 1973

Summary of Data from Transverse Vibration Tests

Tests on sets with **no DTI**

sample #	starting clampload	clampload after 1000 cycles	number of cycles to 50% original clampload	total clampload lost (%)
1	23,400	4,200	615	82%
2	23,400	5,000	545	79%
3	23,400	5,000	255	79%
4	23,400	21,000	Not Applic.	10%
5	23,400	8,100	475	65%
mean =	23,400	8,660	473	63%

Tests on sets **with DTI**

sample #	starting clampload	clampload after 1000 cycles	number of cycles to 50% original clampload	total clampload lost (%)
1	23,400	21,400	Not Applic.	8%
2	23,400	22,750	Not Applic.	3%
3	23,400	21,400	Not Applic.	8%
4	23,400	20,900	Not Applic.	11%
5	23,400	21,500	Not Applic.	8%
mean =	23,400	21,590	Not Applic.	8%

SPS TECHNOLOGIES

Test Certification

SPS Laboratories

TO:

J&M Turner Inc.
340 E. Maple Avenue
Suite 303
Langhorne, PA 19047

Attn: David Sharp

Date: July 23, 1998

CERTIFICATION NO. 980301

P.O. NO: 21

Transverse vibration tests of M16-2.0 x 85mm, Class 10.9, plain finish hex head cap screws with zinc-plated Class 10 nylon-insert locknuts and zinc-plated washers supplied by PACCAR. Plain finish, Class 10.9, size M16 Direct Tension Indicators and plain finish nonlocking hex nuts were provided by customer.

Test Parameters:

Test Machine: One inch diameter, 30,000 lbs. capacity, Junkers test machine
Joint orientation: "Nut-up", washer (or DTI) located under nut
Grip Length: 45 mm
Bearing Surface under Bolt head: mild steel
Machine frequency: 750 cycles per minute
Seating Torque: various as specifed
Test Duration: 1000 cycles
Test Amplitude: various as specified
Lubricant: Parts tested "as-received"

Test Program:

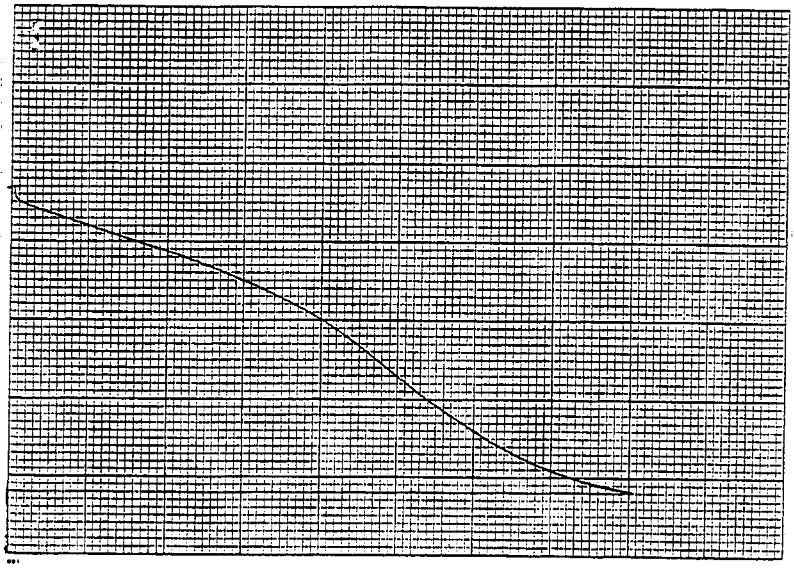
The following tests were performed based on authorization of Mr. David Sharp. Clampload vs. test cycle plots furnished under separate cover.

TESTED BY Robert H. Strunk
Subscribed and sworn to before me this 24 day of July, 1998
Michael A. Coladonato

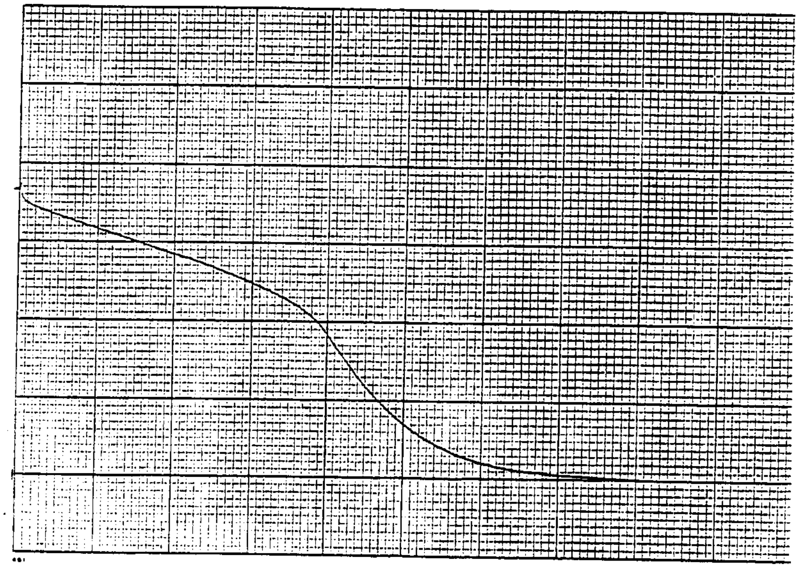
Notarial Seal
Michael A. Coladonato, Notary Public
Abington Twp., Montgomery County
My Commission Expires April 29, 2000

Highland Avenue
Jenkintown
Pennsylvania 19046
(215) 572-3000
Fax (215) 572-3193
Telex: 83-4254

Test #1
No DTI

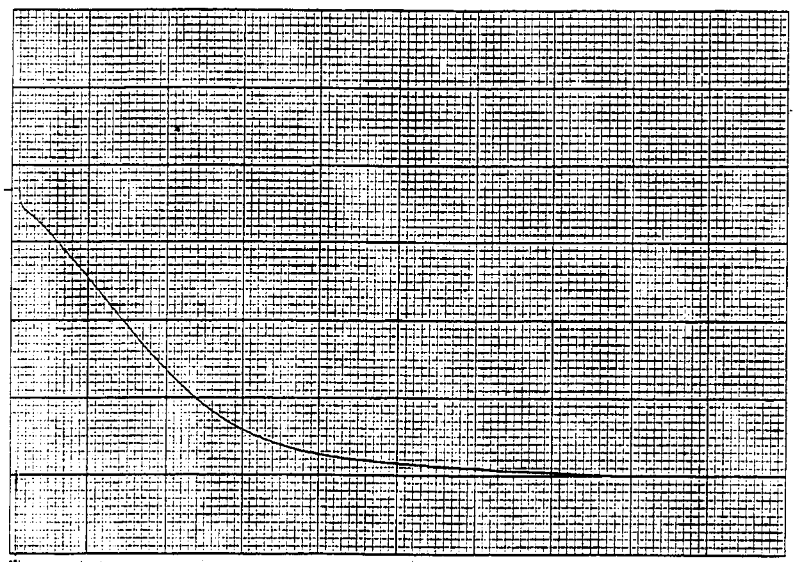


Test #3
No DTI

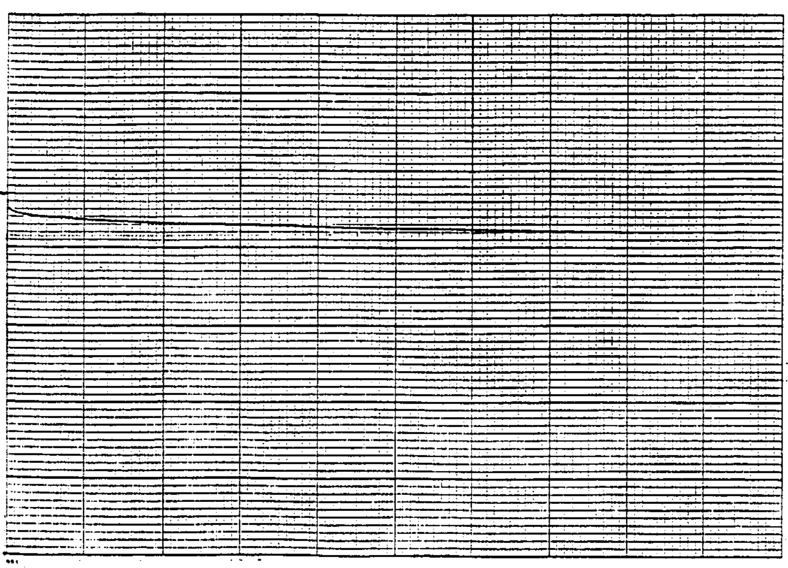


No DTI

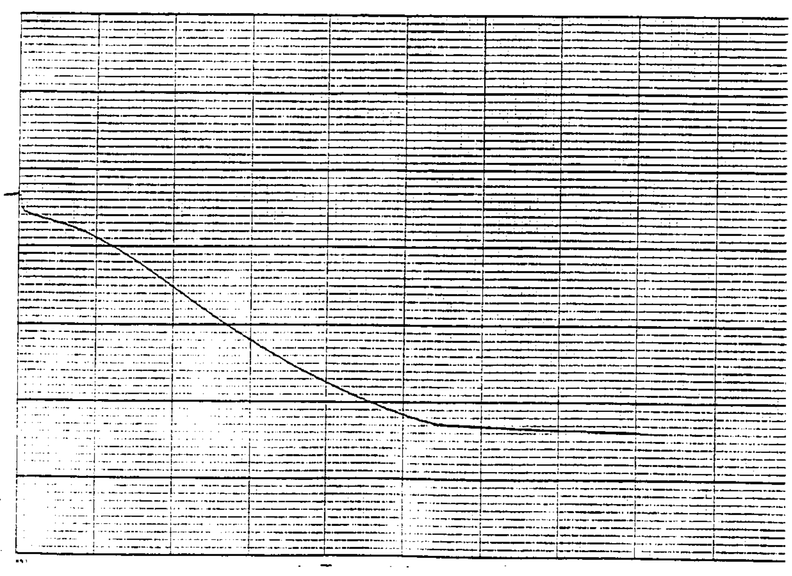
Test #5
No DTI



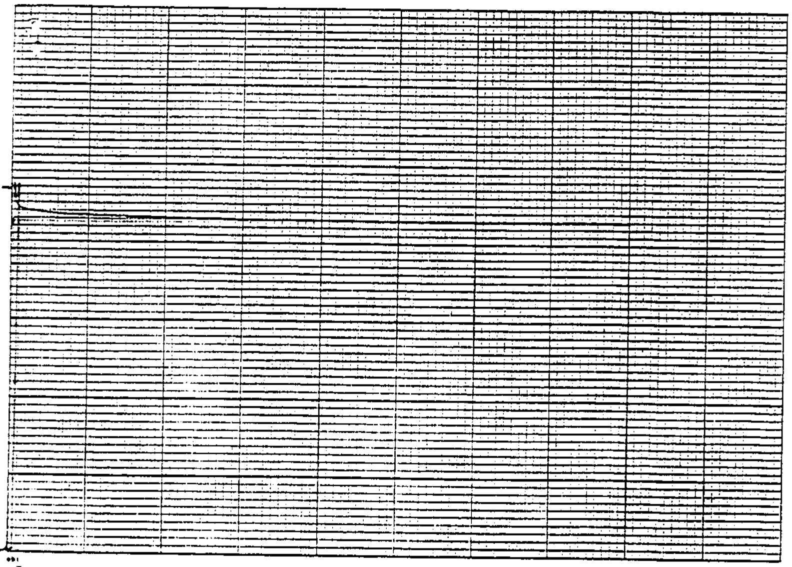
Test #7
No DTI



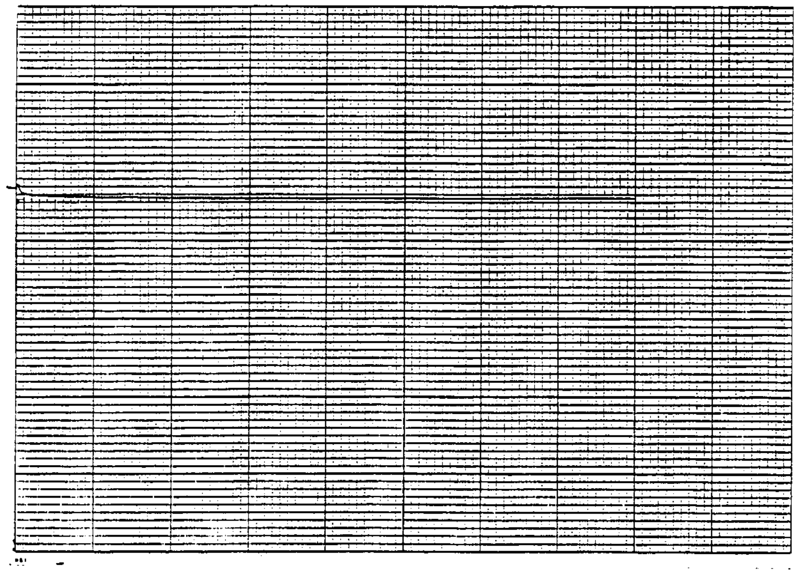
Test #9
No DTI



Test #2
DTI under nut

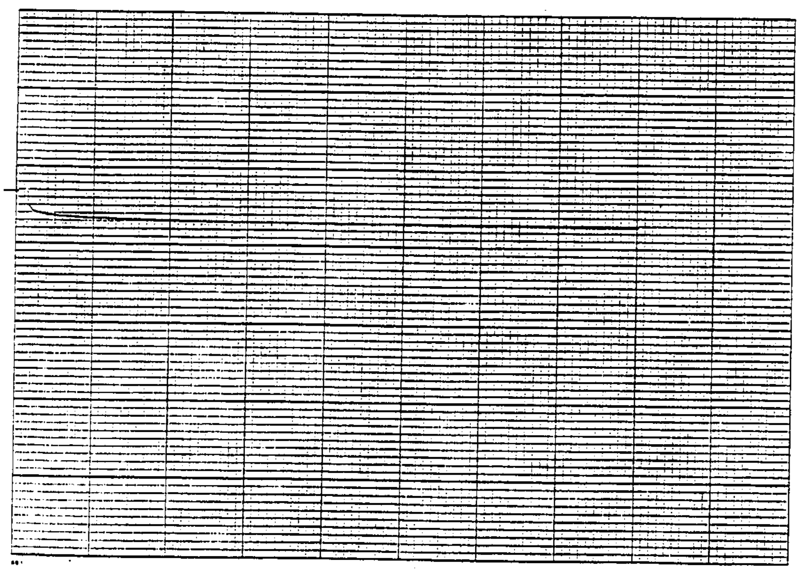


Test #4
DTI under nut

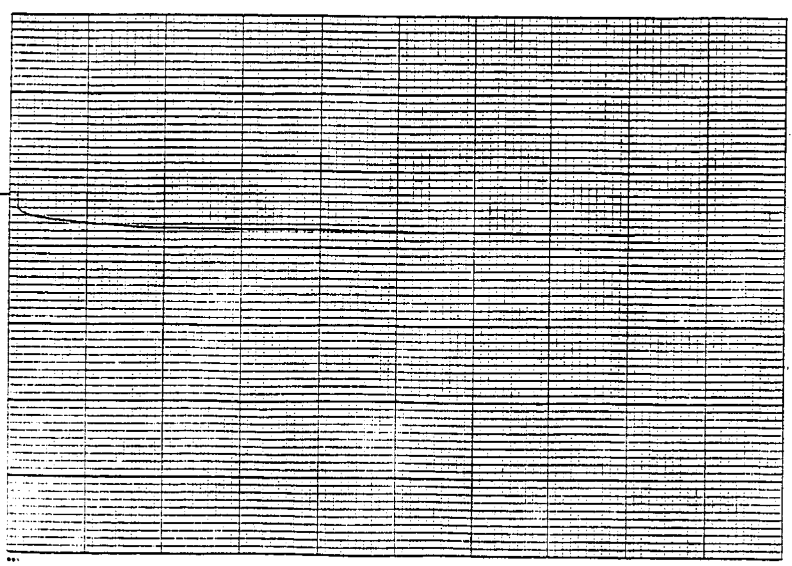


With DTI

Test #6
DTI under nut



Test #8
DTI under nut



Test #10
DTI under nut