SAE International® SURFACE VEHICLE STANDARD

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Tension Indicating Washer Tightening Method for Fasteners

RATIONALE

J2486 has been reaffirmed to comply with the SAE five-year review policy.

Foreword—The fundamental function of mechanical fasteners is to create and maintain a prescribed tension (also known as clamping force or preload) in bolted joints. Bolted joints, which in practice attain the prescribed levels of tension after tightening (or tensioning) of the fasteners, are described as properly tensioned or preloaded. Original Equipment Manufacturers (OEMs) choose from a number of different assembly techniques to attain the tension that the responsible engineers expect or need for a given application. Such techniques provide tension to meet requirements that can be divided into three general categories:

a. A requirement that the tension be above a minimum prescribed level.
b. A requirement that the tension be above a minimum prescribed level and below a maximum prescribed level.
c. A requirement that the tension be within permissible limits of a prescribed target, wherein demonstrated control and statistical measures of dispersion from the target (or proximity to permissible limits) are used to determine acceptance.

Design engineers typically choose from among these three options depending upon the nature of the application, the service environment, production capabilities, installation costs, and other factors. Engineers will then specify procedures for installation of fasteners so, that required levels of tension are achieved. Success in achieving required tension depends upon the methods chosen and how well the manufacturer controls the extraneous variables which may impact the chosen method.

Attainment of at least a minimum level of tension is needed to resist vibration loosening, fatigue, joint slip into bearing, and other conditions which are potential forms of joint failure. Thus, the majority of mechanically fastened applications are intended to attain tensions above a prescribed minimum level. When properly designed and tensioned, a fastened joint is capable of withstanding anticipated service loads throughout the life-cycle of the finished product.

1. Scope

1.1 This SAE Recommended Practice covers installation and inspection methods for fasteners which are tensioned using Tension Indicating Washers (TIWs) as a means to ensure that adequate tension is developed in mechanically fastened joints. Figure 1 depicts a typical TIW, and Figure 2 depicts a fastener assembly with a TIW before and after tensioning.

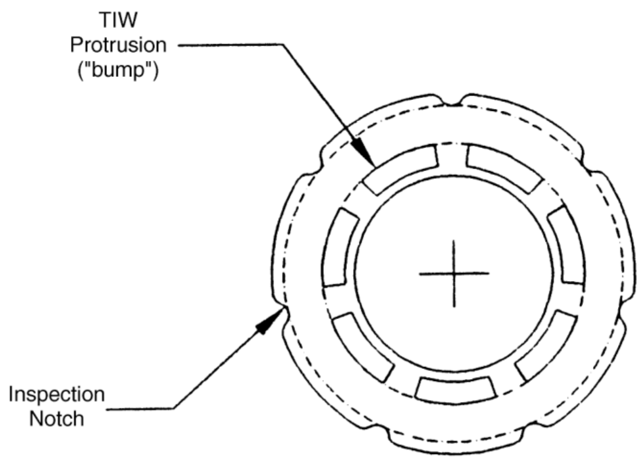


FIGURE 1—TENSION INDICATING WASHER (TIW)

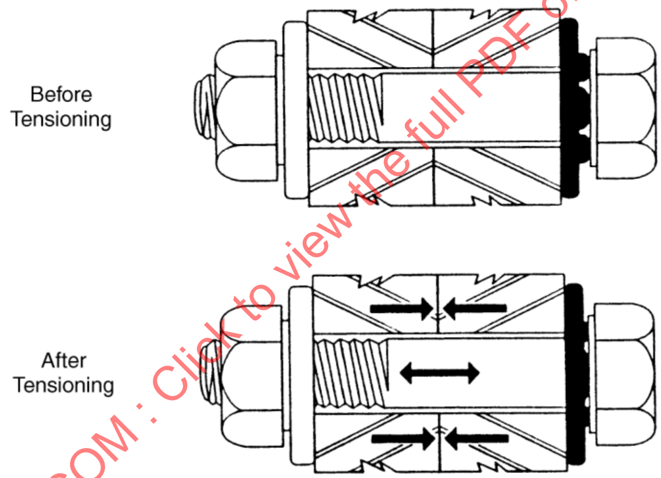


FIGURE 2—ASSEMBLY BEFORE AND AFTER TENSIONING

1.2 This document describes practices for the use of TIWs which are typically produced for use with SAE J429 Grade 5 and Grade 8 fasteners or their metric counterparts, although the same principals hold true for bolted joints using other fasteners. Users are advised to contact a manufacturer for advice on use of these products before using them with special fasteners or applications.

1.3 This document defines and illustrates preferred installation and inspection methodologies. The contents of this document are presented as accurately as possible; however, responsibility for its application lies with the user.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J174—Torque-Tension Test Procedure for Steel Threaded Fasteners—Inch Series
SAE J174M—Torque-Tension Test Procedure for Steel Threaded Fasteners—Metric Series
SAE J429—Mechanical and Material Requirements for Externally Threaded Fasteners
SAE J1701—Torque-Tension Tightening for Inch Series Fasteners
SAE J1701M—Torque-Tension Tightening for Metric Series Fasteners

2.1.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 4—Practices for Force Verification in Testing Machines
ASTM F 959—Standard Specification for Compressible-Washer-Type Direct Tension Indicators for Use with Structural Fasteners

2.1.3 IFI PUBLICATION—Available from Industrial Fasteners Institute, 1717 East 9th Street, Suite 1105, Cleveland, OH 44114-2879.

IFI Technical Data—Fastener Standards, 6th Edition

3. *Definitions*

3.1 Tension Indicating Washer (TIW)—A steel washer-shaped mechanical load cell with protrusions projecting from one face and corresponding pockets on the opposite face. It is used as a direct method to confirm a tension load in a fastener or bolted joint. Also known as a Direct Tension Indicator (DTI).

3.2 Torque—The product of force times lever arm length. With respect to fasteners, it is the moment resistance of the fastener and its components to turning, and is expressed as in-ozs, in-lbs, and ft-lbs, or newton-meters (Nm).

3.3 Tension—The force transmitted by fasteners into assembled parts after tightening. Also known as clamp load, clamping force, preload, or pretension. Expressed in pounds (lbs), thousands of pounds (kips), or kilonewtons (kN).

3.4 Tighten (Tightening)—The action of taking a fastener assembly into tension, usually by turning or torquing a bolt head or a nut. The action intended to induce tension, although efforts to attain tension are not synonymous or directly correlated with actually generating tension.

3.5 Snug—The condition of a mechanically fastened joint in which all of the mating materials are drawn into firm and near-continuous contact by application of some initial clamping force.

4. *Tensioning Methods Overview*

4.1 The design of mechanically fastened joints follows generally accepted engineering principals supported by empirical evidence. Installation or tensioning methods, play a significant role in determining whether design assumptions concerning required tension are met. There are two categories of tensioning methods: (a) indirect, and (2) direct.

4.2 An indirect method is one which relies on the correlation between tension and a related variable. The most common indirect method is torque, or more specifically, the control of input torque as a means to estimate attained tension. The torque method is indirect because torque is not a property of a tensioned fastener. Greater detail on torque-tensioning methods can be found in SAE J174/J174M and SAE J1701/J1701M.

4.3 A direct method is one which relies on changes in fastener properties as evidence that tension is present. Fastener elongation or joint compression are properties which are direct evidence of fastener tension.

4.4 Although tension can be measured by direct methods such as load cells or strain gauges, these methods are usually not practical on a production line. The most practical methods of achieving control of joint clamp load involve torque control, tightening angle control, combinations of torque and angle, and use of Tension Indicating Washers. More information on indirect and direct tensioning methods can be found in the technical data section of The Industrial Fastener Institute's book Fastener Standards.

5. Recommended Control Practices

5.1 **Handling and Storage of Fasteners—**Particularly when torque measurement is to be used to control tightening, it is imperative that fasteners be protected from shop dust, direct, moisture, and other environmental factors. It is recommended that fasteners remain in protective storage until their imminent use. Both plain finish and coated fasteners are susceptible to surface corrosion, even when exposure is limited to conditions inside a typical warehouse.

5.2 **Fastener Surface Condition—**Dry or rusty threads and bearing surfaces significantly increase the amount of torque required to tighten fasteners to a prescribed tension. Failure to protect fasteners from environmental factors may lead to inability to properly tension the fasteners, or torsional failures during attempts to properly tension them. The necessity for adequate lubricant to achieve the desired level of bolt pretension cannot be over-emphasized—particularly in applications reliant upon higher clamping forces.

5.3 **TIW Surface Condition—**Unlike nuts or bolts, TIWs themselves are not generally affected by the presence of lubricants, dust, or surface corrosion. This permits the TIW to indicate whether the chosen assembly method (usually torque) was able to attain the required clamping force. The TIW will not flatten if the surface condition of the fasteners is such that it prevents adequate tightening (e.g., seizing, galling, severe corrosion, etc.).

5.4 **TIWs and Torque—**The purpose of the TIW is to indicate the adequacy of whatever level of torque has been applied. For example, fasteners which lack sufficient lubricity to enable generation of the required tension are identified as those on which the TIWs are not adequately compressed.

5.5 **Lubrication—**Use of fasteners in varying states of lubricity is possible with the TIW method. Fasteners which accumulate rust or dirt from shop or job site conditions can be cleaned and lubricated prior to installation without adversely impacting the ability of the TIW to indicate clamp force. However, necessary precautions for "field lubricating" may need to be considered in order to avoid introduction of any unacceptable factor.

5.6 **Bolt Holes—**Users are advised to specify and control the acceptable characteristics of bolt holes. Such practice requires the establishment of accepted limits on bolt hole location, minimum and maximum permissible size, permissible limits on out-of-round, alignment, burrs, finish, and other variables. In order for fasteners (including TIWs) to function properly, control of these elements is necessary.

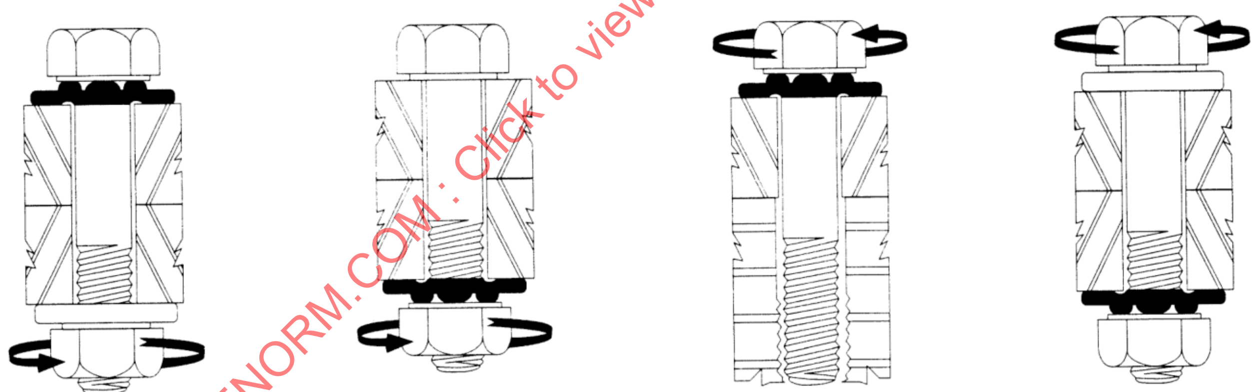
5.7 **Bolt Lengths—**Although rare, in some cases, the use of TIWs will require the use of slightly longer bolts due to the added thickness of the TIW within the grip of the joint. Bolts should project through nuts far enough such that at least one full and complete thread is "exposed" beyond the nut face. This maximizes the contact area between the mating surfaces of the nut and the bolt. A maximum of three full threads projecting beyond the nut face is often established to ensure that a sufficient number of threads remain in the "grip" of the joint, thus stabilizing performance and mechanical characteristics. Alternately, one can specify a minimum number of threads which must remain within the grip after tensioning.

6. Installation Methods for TIWs—This document recognizes four permissible methods for installation of fasteners using TIWs. When a particular method is not specified, selection shall be made by the party responsible for installation and tightening of the fasteners. Unless specified otherwise, the "normal" inspection method shall apply.

6.1 Method 1—Torque Tensioning/TIW Inspection—The most common method for the use of TIWs involves retaining the use of the OEM's current torque-tensioning practices and uses the TIW as an inspection device to point out those applications, occurrences, or pieces of installation equipment which for one reason or another did not attain the required tension. The following is a step-by-step procedure for using this method:

6.1.1 TIW-TORQUE TIGHTENING

a. Use normal specified and calibrated "torque-controlled" installation equipment.
b. There are four basic assembly configurations compatible with use of TIWs. (See Figure 3.) Fasteners are to be assembled in the normal manner, and whenever possible, TIWs are located under the head of each cap screw or bolt with the protrusions ("bumps") facing the head.
c. Set the equipment to operate at the specified or calibrated torque settings and operate it as normally required. Follow procedures for "snugging" or "stepping up" the level of torque in increments before final tensioning. For joints with fasteners in close proximity, follow normally prescribed tightening patterns.
d. Whenever possible, tightening shall be done from the end opposite from the TIWs. This enables inspection to verify that clamping force has been generated throughout the full length of the fasteners.
e. Continue tightening until the specified torque is applied, or on tools so equipped, until the torque-controlled shut-off occurs.
f. Follow tensioning with an appropriate inspection protocol selected from Section 8.



TIW under head, turn nut to tighten, bolt head held. | TIW under nut, turn nut to tighten, bolt head held. | TIW under head, turn head to tighten into a tapped hole. | TIW under nut, turn head to tighten, nut held.

FIGURE 3—BASIC ASSEMBLY CONFIGURATION WITH TIWs

6.2 Method 2—Modified Turn-of-Nut/TIW Inspection—It is well established by research that the geometric method known as "turn-of-the-nut" can be used under controlled circumstances to reliably attain required clamping force. The method relies on attainment of a proper snug condition, followed by match-marking and a prescribed degree of turn thereafter.

6.2.1 TIW-Turn-of-Nut Tightening

a. Use normal specified installation equipment.
b. Fasteners are to be assembled in the normal manner, and whenever possible, TIWs shall be located under the head of each cap screw or bolt with the protrusions ("bumps") facing the head.
c. Set the equipment to operate at the specified or calibrated torque settings and operate it as normally required for any torque controlled "snugging" or "stepping up" operations prior to final tensioning. For joints with fasteners in close proximity, follow normally prescribed tightening patterns.
d. Whenever possible, tightening shall be done from the end opposite from the TIWs. This enables inspection to verify that clamping force has been generated throughout the full length of the fasteners.
e. Previously published "degrees of turn" can not be used when TIWs are used, as it takes more "turn" when TIWs are present due to the compression of the TIW bumps during the turning (tightening) operation. Figure 4 depicts a comparison between the turn-tension relationship on 3/4 in SAE Grade 8 fasteners with and without TIWs. Appropriate "degree of turn" must be determined experimentally in the actual application using TIWs.

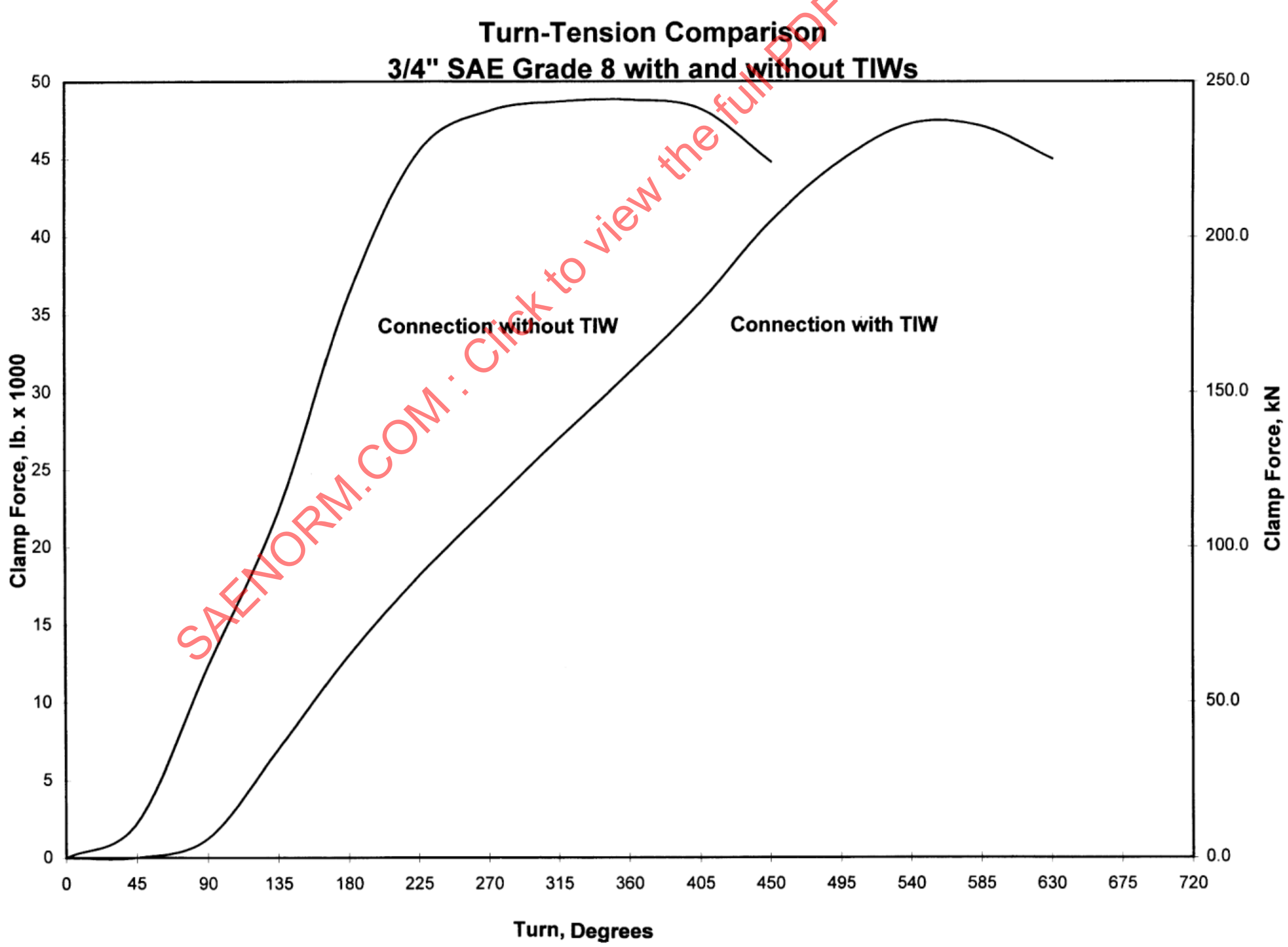


FIGURE 4—TENSION-TURN RELATIONSHIPS WITH AND WITHOUT TIWs

f. To determine an appropriate "degree of turn" experimentally, start by selecting an appropriate sample size for tests. Next, establish the "degree of turn' beyond the snug condition which is required to sufficiently flatten the TIWs such that the appropriate "no-go" feeler-gage can not be inserted. (See 7.1.) Add to the experimentally derived "degree of turn" a plus (+) tolerance to allow for practical limitations of equipment and operators.

g. Confirm that the experimentally derived "degree of turn" is satisfactory to meet the inspection requirements outlined in Section 8 in actual practice. Use of TIWs with the "turn-of-nut" method typically reduces the variation in clamp load normally attributed to the use of the "turn-of-nut" method alone. This is because TIWs change the slope of the "turn-tension" curve.

6.3 Method 3—Modified Torque-Angle/TIW Inspection—Among the most sophisticated installation methods known is "Torque-Angle" Tensioning. This method is based upon empirical evidence which correlates controllable indirect factors of torque and angle with known material responses to alignment, elastic tensioning, and yielding. Recent variants of this method store electronic "signatures" of how these variables interact, and provides control of the installation based on the information provided in these signatures.

6.3.1 TIW-TORQUE-ANGLE TIGHTENING

a. Use normal specified installation equipment.

b. Fasteners are to be assembled in the normal manner, and whenever possible, TIWs shall be located under the head of each cap screw or bolt with the protrusions ("bumps") facing the head.

c. Set the equipment to operate at the specified or calibrated torque settings and operate it as normally required for any torque controlled "snugging" or "stepping up" operations prior to final tensioning. For joints with fasteners in close proximity, follow normally prescribed tightening patterns.

d. Whenever possible, tightening shall be done from the end opposite from the TIWs. This enables inspection to verify that clamping force has been generated throughout the full length of the fasteners.

e. Previously prescribed "signatures" can not be used when TIWs are used, as the torque-turn/joint response relationship is different when TIWs are present due to the compression of the TIW bumps during the turning (tightening) operation. Appropriate "degree of turn" must be determined experimentally in the actual application using TIWs.

f. To create appropriate "signatures" experimentally, refer to the instructions provided by the manufacturer of the installation equipment.

g. Confirm that the experimentally derived "signature" is satisfactory to meet the inspection requirements outlined in Section 8.

6.4 Method 4—Visual Control/TIW Inspection—A common method for the use of TIWs in maintenance or repair involves using readily available box or socket wrenches with simultaneous visual inspection of TIW compression. This method is used for example when OEM torque guidelines are not available, when calibrated torque wrenches are not available, when field conditions undermine the relied upon torque-tension relationship, or when normally prescribed tightening tools are obstructed from access to the bolted connection. The following is a typical step-by-step procedure for using this method.

6.4.1 VISUAL-TIW TIGHTENING

a. Use any appropriate wrench or driver of capable strength, (i.e., capable of delivering normally required levels of torque).

b. Fasteners are to be assembled in the normal manner, and whenever possible, TIWs shall be located under the head of each cap screw or bolt with the protrusions ("bumps") facing the head.

c. Follow normally prescribed tightening patterns. If none exist, start at the center or most rigid part of the connection, and continue to the outside or free edges.

d. Follow normal procedures for "snugging" or "stepping up" the tension in increments. The snug condition is attained in joints constructed with TIWs when initial partial flattening of the TIW protrusions has occurred. (See Figure 5.) This is sometimes called "flat-topping" the TIW, because the top of the normally convex protrusions just begin to flatten.

e. Whenever possible, tightening shall be done from the end opposite from the TIWs. This enables inspection to verify that clamping force has been generated throughout the full length of the fasteners.
f. Continue tightening until the gap between the TIW and the bolt or cap screw head is virtually flattened as judged by eye.
g. Follow tensioning with an appropriate inspection method selected from Section 8 to confirm visual judgment.

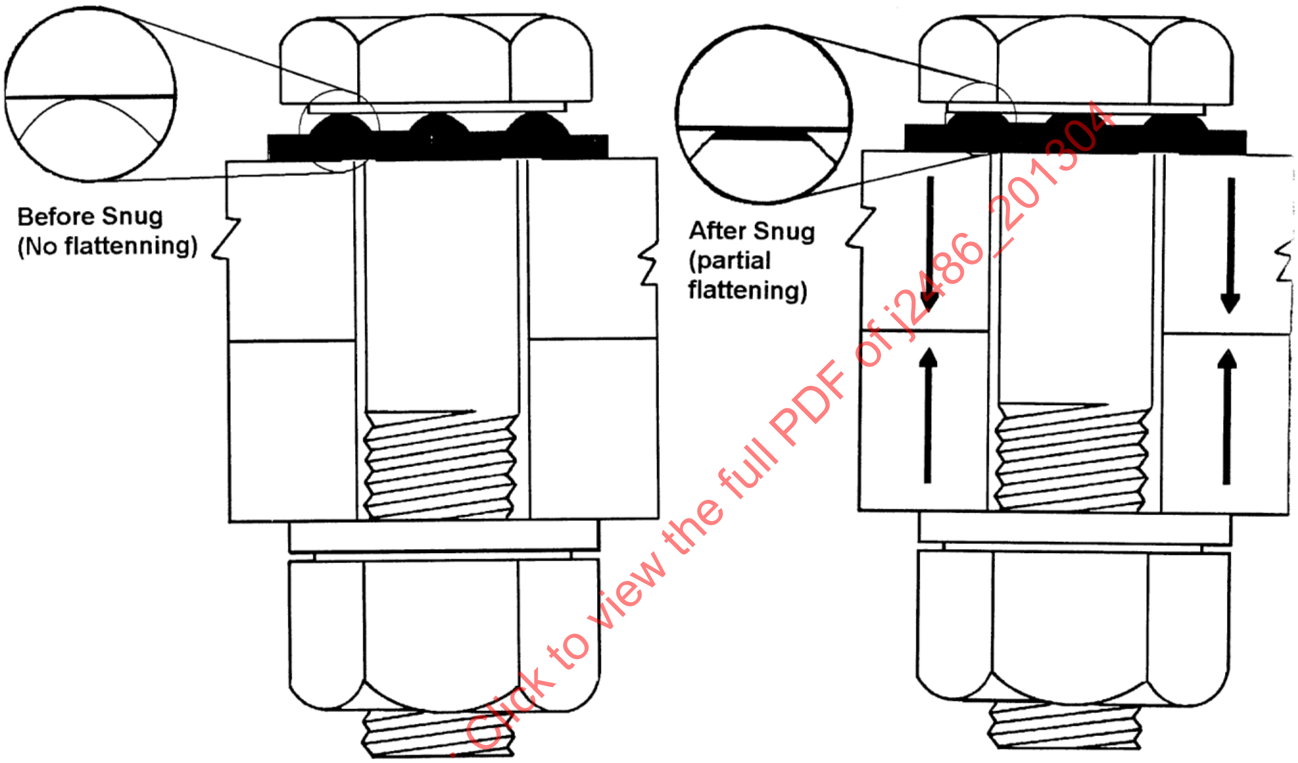


FIGURE 5—TIW PROTRUSIONS BEFORE AND AFTER "SNUG"

7. *Value of Inspection*

7.1 Inspection Philosophy—Inspection of fasteners for tension performs two roles. First, inspection affirms that specified processes and stated procedures achieve desired results under a diversity of normal assembly conditions. Second, inspection identifies opportunities for improvement in processes or procedures, providing feed-back which can be used for continuous improvement.

7.2 Inspection Cost/Value-Added Inspection Processes—Quality Cost Systems categorize inspection as either a value-added operation or a non-value-added cost. Classification of the inspection method is largely determined by whether or not the inspection method directly ensures that a characteristic meets requirements (i.e., tension). If it does, the inspection is a "value-added" operation. If it does not, the inspection is a "cost." Regardless of the method chosen, OEMs and others balance the benefits offered by inspection methods with their associated costs, and choose methods accordingly.

7.3 Torque Inspection—Inspection by torque measurement subsequent to installation and tightening of a joint fastener with TIWs is not recommended. Torque inspection is subject to significant uncertainty, as numerous factors impede the ability of torque to be reliably correlated to tension.

7.4 TIW Inspection—Inspection of a fastened joint to verify that TIW protrusions are flattened is direct evidence of tension. Such inspection may take place at any time subsequent to installation without reducing the validity of the inspection. Undertensioned fasteners can be identified by unflattened TIWs, which can be further tightened subsequent to installation to ensure that required tension is generated.

8. Inspection Methods

8.1 Method 1—Mandatory 100% Inspection—This is usually reserved for critical applications, previously identified troublesome applications, and for special purposes.

8.1.1 Provide the inspector with an appropriate feeler-gage, (e.g., 0.25 mm for metric product, 0.010 in for inch product.)

8.1.2 Inspection of each fastener is accomplished by trying to insert the feeler-gage in the space between the protrusions on each TIW. (See Figure 1.) Note that there are “Inspection Notches” around the periphery of each TIW to help indicate where insertion of the feeler-gage is to be attempted.

8.1.3 In order to “pass” an inspection, the applicable feeler-gage shall be able to be inserted between the protrusions and contact the bolt body in less than half of the entry spaces. That is, the feeler-gage shall be “refused” in more than half of the spaces around the periphery of a TIW.

8.1.4 If the feeler-gage is able to be inserted in half or more of the entry spaces, then the particular fastener is undertensioned and must be further tightened until a sufficient number of feeler-gage “refusals” can be attained.

8.1.5 Adequate clamping force has been generated if the feeler-gage is refused in more than half of the entry spaces between the protrusions.

8.2 Method 2—Normal Inspection—This is the most common method of inspection. It is used on a variety of applications and is chosen for its balance between cost and value-added. Normal Inspection entails inspection of a stated percentage of fasteners using a feeler-gage (usually 10%), followed by an overview visual inspection confirming that all other fasteners appear to be similarly flattened.

8.2.1 Provide the inspector with an appropriate feeler-gage, (e.g., 0.25 mm for metric product, 0.010 in for inch product.)

8.2.2 Inspection of the specified number of fasteners (i.e., 10%) is accomplished by trying to insert the feeler-gage in the space between the protrusions on each TIW. (See Figure 1.) “Inspection Notches” around the periphery of each TIW help indicate where insertion of the feeler-gage is to be attempted.

8.2.3 In order to “pass” an inspection, the applicable feeler-gage shall be able to be inserted between the protrusions and contact the bolt body in less than half of the entry spaces. That is, the feeler-gage shall be “refused” in more than half of the spaces around the periphery of a TIW.

8.2.4 If the feeler-gage is able to be inserted in half or more of the entry spaces, then the particular fastener is undertensioned and must be further tightened until a sufficient number of feeler-gage “refusals” can be attained.

8.2.5 Adequate clamping force has been generated if the feeler-gage is refused in more than half of the entry spaces between the protrusions.

8.2.6 The remaining fasteners (i.e., 90%) are visually inspected to ensure that they also appear to be sufficiently flattened to indicate attainment of required clamping force.