# Shop Tech Talk January 2010

| Q. | Bolt Tightening on Machinery. When is tight,tight enough? |
|---|---|

**Seems like a simple enough question......just look up in a chart the size of the bolt and then use a torque wrench to tighten to the indicated value.**
**When we tighten a bolt what we are actually trying to do is increase the clamping force between the mating surfaces to a predetermined level. We achieve this in practice by putting tension on the bolt and stretching(preloading) it.**

***A properly tightened bolt is one that is stretched (preloaded)so it pulls mating surfaces without exceeding the design rating of the bolt or components.***

**The torque applied through the torque wrench is simply a measure of the energy required to spin the bolt along the threads, whereas tension is related to the stretch or elongation of the bolt that provides the clamping force of a joint. Friction forces alone under the nut face and in the threads account for a substantial percentage of the torque applied through the torque wrench.**

**So torque,as read on the torque wrench, is only a very indirect indication of tension in the bolt! Tension is what we really want to measure and is often called the bolt preload**

**There are very sophisticated ultrasonic/computer methods and other methods to do this but they are tools used by NASA and other organizations who must know exactly what the bolt tension is. For the average plant use we just need to be aware of the difficulties involved and create a proper bolt tightening procedure.**

**Below is such a procedure:**

1. **Know the bolt grade and type to be used**
2. **Reference a bolt torque table for target values**
3. **Determine the torque target value and special considerations such as whether you are working with dry or lubricated threads. Lubricated threads call for a lesser torque target value than dry threads. Torquing a lubricated bolt to a dry torque value may result in the failure of the bolt or bolt receiver.**
4. **Use a calibrated torque wrench for tightening only**
5. **Tighten the bolts in a balanced pattern when possible**

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****It is accepted that a bolt preloaded to a fixed value is safer than a bolt simply tightened to an arbitrary value. A preload of about 75% of the proof load of the bolt material is normally used.**

**For a bolt tightened with a torque wrench the torque required to provide an initial bolt tension may be approximated by the formula..**

$$T = K * D * P$$

**Where**

**K = Torque Coefficient (dimensionless)**
**D = nominal diameter of bolt (inches)**
**P = Preload or bolt clamp load(lbs)**

**<u>Typical K factors</u>**

| Bolt /Fastener Finish | K |
|---|---|
| Plain steel(dry) | 0.2+ |
| Zinc Plating(dry) | 0.21 to 0.33 |
| Cadmium Plating(dry) | 0.15 to 0.20 |
| Black Oxide Treatment(lightly oiled) | 0.16 to 0.19 |
| Moly-disulphide,white lead,wax | 0.10 to 0.15 |

**On the next few pages are 'Suggested Starting Torque Values for Different grades of Bolts'. This information is provided by Portland Bolt & Manufacturing Co. and is offered solely as a guide.**

**Also there is a page of explanations following the charts explaining various ASTM and SAE grades of bolts.**

**The last 2 pages show Hex head Bolt Markings**

**For much more detailed information on this subject of 'bolts tightening' please see:**
**http://www.boltscience.com/pages/faq.htm**
**http://www.surebolt.com/Bolt-Nut.htm**
**http://www.roymech.co.uk/Useful_Tables/Screws/Preloading.html**

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# Suggested Starting Torque Values

## ASTM A307

| Bolt Size | TPI | Proof Load (lbs) | Clamp Load (lbs) | Tightening Torque (ft lbs) | | |
|---|---|---|---|---|---|---|
| | | | | Waxed | Galv | Plain |
| 1/4 | 20 | 1145 | 859 | 2 | 4 | 4 |
| 5/16 | 18 | 1886 | 1415 | 4 | 9 | 7 |
| 3/8 | 16 | 2790 | 2093 | 7 | 16 | 13 |
| 7/16 | 14 | 3827 | 2870 | 10 | 26 | 21 |
| 1/2 | 13 | 5108 | 3831 | 16 | 40 | 32 |
| 9/16 | 12 | 6552 | 4914 | 23 | 58 | 46 |
| 5/8 | 11 | 8136 | 6102 | 32 | 79 | 64 |
| 3/4 | 10 | 12024 | 9018 | 56 | 141 | 113 |
| 7/8 | 9 | 15200 | 11400 | 83 | 208 | 166 |
| 1 | 8 | 20000 | 15000 | 125 | 313 | 250 |
| 1 1/8 | 7 | 25200 | 18900 | 177 | 443 | 354 |
| 1 1/4 | 7 | 32000 | 24000 | 250 | 625 | 500 |
| 1 3/8 | 6 | 38100 | 28575 | 327 | 819 | 655 |
| 1 1/2 | 6 | 46400 | 34800 | 435 | 1088 | 870 |
| 1 3/4 | 5 | 68400 | 51300 | 748 | 1870 | 1496 |
| 2 | 4½ | 90000 | 67500 | 1125 | 2813 | 2250 |
| 2 1/4 | 4½ | 117000 | 87750 | 1645 | 4113 | 3291 |
| 2 1/2 | 4 | 144000 | 108000 | 2250 | 5625 | 4500 |
| 2 3/4 | 4 | 177480 | 133110 | 3050 | 7626 | 6101 |
| 3 | 4 | 214920 | 161190 | 4030 | 10074 | 8060 |
| 3 1/4 | 4 | 255600 | 191700 | 5192 | 12980 | 10384 |
| 3 1/2 | 4 | 299880 | 224910 | 6560 | 16400 | 13120 |
| 3 3/4 | 4 | 347760 | 260820 | 8151 | 20377 | 16301 |
| 4 | 4 | 398880 | 299160 | 9972 | 24930 | 19944 |

## SAE Grade 2

| Bolt Size | TPI | Proof Load (lbs) | Clamp Load (lbs) | Tightening Torque (ft lbs) | | |
|---|---|---|---|---|---|---|
| | | | | Waxed | Galv | Plain |
| 1/4 | 20 | 1750 | 1313 | 3 | 7 | 5 |
| 5/16 | 18 | 2900 | 2175 | 6 | 14 | 11 |
| 3/8 | 16 | 4250 | 3188 | 10 | 25 | 20 |
| 7/16 | 14 | 5850 | 4388 | 16 | 40 | 32 |
| 1/2 | 13 | 7800 | 5850 | 24 | 61 | 49 |
| 9/16 | 12 | 10000 | 7500 | 35 | 88 | 70 |
| 5/8 | 11 | 12400 | 9300 | 48 | 121 | 97 |
| 3/4 | 10 | 18400 | 13800 | 86 | 216 | 173 |
| 7/8 | 9 | 15200 | 11400 | 83 | 208 | 166 |
| 1 | 8 | 20000 | 15000 | 125 | 313 | 250 |
| 1 1/8 | 7 | 25200 | 18900 | 177 | 443 | 354 |
| 1 1/4 | 7 | 32000 | 24000 | 250 | 625 | 500 |
| 1 3/8 | 6 | 38100 | 28575 | 327 | 819 | 655 |
| 1 1/2 | 6 | 46400 | 34800 | 435 | 1088 | 870 |

## ASTM A325 / ASTM A449 / SAE Grade 5

| Bolt Size | TPI | Proof Load (lbs) | Clamp Load (lbs) | Tightening Torque (ft lbs) | | |
|---|---|---|---|---|---|---|
| | | | | Waxed | Galv | Plain |
| 1/4 | 20 | 2700 | 2025 | 4 | 11 | 8 |
| 5/16 | 18 | 4450 | 3338 | 9 | 22 | 17 |
| 3/8 | 16 | 6600 | 4950 | 15 | 39 | 31 |
| 7/16 | 14 | 9050 | 6788 | 25 | 62 | 49 |
| 1/2 | 13 | 12050 | 9038 | 38 | 94 | 75 |
| 9/16 | 12 | 15450 | 11588 | 54 | 136 | 109 |
| 5/8 | 11 | 19200 | 14400 | 75 | 188 | 150 |
| 3/4 | 10 | 28400 | 21300 | 133 | 333 | 266 |
| 7/8 | 9 | 39250 | 29438 | 215 | 537 | 429 |
| 1 | 8 | 51500 | 38625 | 322 | 805 | 644 |
| 1 1/8 | 7 | 56450 | 42338 | 397 | 992 | 794 |
| 1 1/4 | 7 | 71700 | 53775 | 560 | 1400 | 1120 |
| 1 3/8 | 6 | 85450 | 64088 | 734 | 1836 | 1469 |
| 1 1/2 | 6 | 104000 | 78000 | 975 | 2438 | 1950 |
| 1 3/4 | 5 | 104500 | 78375 | 1143 | 2857 | 2286 |
| 2 | 4½ | 137500 | 103125 | 1719 | 4297 | 3438 |
| 2 1/4 | 4½ | 178750 | 134063 | 2514 | 6284 | 5027 |
| 2 1/2 | 4 | 220000 | 165000 | 3438 | 8594 | 6875 |
| 2 3/4 | 4 | 271150 | 203363 | 4660 | 11651 | 9321 |
| 3 | 4 | 328350 | 246263 | 6157 | 15391 | 12313 |

## ASTM A193 B7

| Bolt Size | TPI | Proof Load (lbs) | Clamp Load (lbs) | Tightening Torque (ft lbs) | | |
|---|---|---|---|---|---|---|
| | | | | Waxed | Galv | Plain |
| 1/4 | 20 | 3350 | 2513 | 5 | 13 | 10 |
| 5/16 | 18 | 5500 | 4125 | 11 | 27 | 21 |
| 3/8 | 16 | 8150 | 6113 | 19 | 48 | 38 |
| 7/16 | 14 | 11150 | 8363 | 30 | 76 | 61 |
| 1/2 | 13 | 14900 | 11175 | 47 | 116 | 93 |
| 9/16 | 12 | 19100 | 14325 | 67 | 168 | 134 |
| 5/8 | 11 | 23750 | 17813 | 93 | 232 | 186 |
| 3/4 | 10 | 35050 | 25288 | 164 | 411 | 329 |
| 7/8 | 9 | 48500 | 36375 | 265 | 663 | 530 |
| 1 | 8 | 63650 | 47738 | 398 | 995 | 796 |
| 1 1/8 | 7 | 80100 | 60075 | 563 | 1408 | 1126 |
| 1 1/4 | 7 | 101750 | 76313 | 795 | 1987 | 1590 |
| 1 3/8 | 6 | 121300 | 90975 | 1042 | 2606 | 2085 |
| 1 1/2 | 6 | 147550 | 110663 | 1383 | 3458 | 2767 |
| 1 3/4 | 5 | 199500 | 149625 | 2182 | 5455 | 4364 |
| 2 | 4½ | 262500 | 196875 | 3281 | 8203 | 6563 |
| 2 1/4 | 4½ | 341250 | 255938 | 4799 | 11997 | 9598 |
| 2 1/2 | 4 | 420000 | 315000 | 6563 | 16406 | 13125 |
| 2 3/4 | 4 | 468500 | 351263 | 8050 | 20124 | 16100 |
| 3 | 4 | 567150 | 425363 | 10634 | 26585 | 21268 |
| 3 1/4 | 4 | 674500 | 505875 | 13701 | 34252 | 27402 |
| 3 1/2 | 4 | 791350 | 593513 | 17311 | 43277 | 34622 |
| 3 3/4 | 4 | 917700 | 688275 | 21509 | 53771 | 43017 |
| 4 | 4 | 1052600 | 789450 | 26315 | 65788 | 52630 |

# ASTM A354-BD / ASTM A490 / SAE Grade 8

| Bolt Size | TPI | Proof Load (lbs) | Clamp Load (lbs) | Tightening Torque | |
|---|---|---|---|---|---|
| | | | | Waxed | Plain |
| 1/4 | 20 | 3800 | 2850 | 6 | 12 |
| 5/16 | 18 | 6300 | 4725 | 12 | 25 |
| 3/8 | 16 | 9300 | 6975 | 22 | 44 |
| 7/16 | 14 | 12750 | 9563 | 35 | 70 |
| 1/2 | 13 | 17050 | 12788 | 53 | 107 |
| 9/16 | 12 | 21850 | 16388 | 77 | 154 |
| 5/8 | 11 | 27100 | 20325 | 106 | 212 |
| 3/4 | 10 | 40100 | 30075 | 188 | 376 |
| 7/8 | 9 | 55450 | 41588 | 303 | 606 |
| 1 | 8 | 72700 | 54525 | 454 | 909 |
| 1 1/8 | 7 | 91550 | 68663 | 644 | 1287 |
| 1 1/4 | 7 | 120000 | 90000 | 938 | 1875 |
| 1 3/8 | 6 | 138600 | 103950 | 1191 | 2382 |
| 1 1/2 | 6 | 168600 | 126450 | 1581 | 3161 |
| 1 3/4 | 5 | 228000 | 171000 | 2494 | 4988 |
| 2 | 4½ | 300000 | 225000 | 3750 | 7500 |
| 2 1/4 | 4½ | 390000 | 292500 | 5484 | 10969 |
| 2 1/2 | 4 | 480000 | 360000 | 7500 | 15000 |
| 2 3/4 | 4 | 517650 | 388238 | 8897 | 17794 |
| 3 | 4 | 626850 | 470138 | 11753 | 23507 |
| 3 1/4 | 4 | 745500 | 559125 | 15143 | 30286 |
| 3 1/2 | 4 | 874650 | 655988 | 19133 | 38266 |
| 3 3/4 | 4 | 1014300 | 760725 | 23773 | 47545 |
| 4 | 4 | 1052600 | 789450 | 26315 | 52630 |

Notes:
1. Values calculated using industry accepted formula T = KDP where T = Torque, K = torque coefficient (dimensionless), D = nominal diameter (inches), P = bolt clamp load, lb.
2. K values: waxed (e.g. pressure wax as supplied on high strength nuts) = .10, hot dip galvanized = .25, and plain non-plated bolts (as received) = .20.
3. Torque has been converted into ft/lbs by dividing the result of the formula by 12
4. All calculation are for Coarse Thread Series (UNC).
5. Grade 2 calculations only cover fasteners 1/4"-3/4" in diameter up to 6" long; for longer fasteners the torque is reduced significantly.
6. Clamp loads are based on 75% of the minimum proof loads for each grade and size.
7. Proof load, stress area, yield strength, and other data is based on IFI 7th Edition (2003) Technical Data N-68, SAE J429, ASTM A307, A325, A354, A449, and A490.

The above estimated torque calculations are only offered as a guide. Use of its content by anyone is the sole responsibility of that person and they assume all risk. Due to many variables that affect the torque-tension relationship like, human error, surface texture, lubrication etc, the only way to determine the correct torque is through experimentation under actual joint and assembly conditions.

## Bolt Grade Explanations on Previous Charts

**ASTM A307:**

**The ASTM A307 specification covers carbon steel bolts and studs ranging from 1/4" through 4" diameter. This is your everyday, run of the mill bolt specification often manufactured using A36 round bar. There are three grades A, B, and C* which denote tensile strength, configuration, and application.**

**SAE Grade 2**

**The significant difference between SAE J429, Grade 2, and ASTM A307, Grade A, is the ultimate tensile strength rating for bolts between 1/4 inch and 3/4 inch diameters. SAE J429, Grade 2, has a tensile strength requirement of 74,000 PSI and the ASTM A307 Grade A only has a tensile strength requirement of 60,000 PSI. This means that SAE bolts have a 23% higher strength requirement than the ASTM bolts in the 1/4 through 3/4 diameter range.**

**ASTM A325 / ASTM A449 / SAE Grade 5**

**The ASTM A325 specification covers high strength heavy hex structural bolts from ½" diameter through 1-1/2" diameter. These bolts are intended for use in structural connections and therefore have shorter thread lengths than standard hex bolts.**

**ASTM A449 covers headed bolts, rods, and anchor bolts in diameters ranging from 1/4" through 3" inclusive. It is a medium strength bolt manufactured from a medium carbon or alloy steel that develops its mechanical values through a heat treating process. It is intended for general engineering applications.**

**ASTM A193 B7**

**Originally approved in 1936, this specification is heavily utilized in petroleum and chemical construction applications. The ASTM standard covers alloy steel and stainless steel bolting materials for high temperature service. This specification includes fasteners intended for use in pressure vessels, valves, flanges, and fittings. Although, this material is often available in national coarse (UNC) thread pitches, if being used in traditional applications, threads are specified 8 threads per inch (tpi) for diameters above one inch. B7 Alloy steel, AISI 4140/4142 quenched and tempered**

**ASTM A354-BD / ASTM A490 / SAE Grade 8**

**A354 grade BD bolts are higher in strength than A354 grade BC and equal in strength to ASTM A490 bolts. Unlike ASTM A490 however, the A354 BD specification is unrestricted in its configuration. Since A490 bolts are heavy hex structural bolts and do not exceed 1-1/2" diameter, specification A354 BD should be considered for anchor bolts, threaded rods, other styles of headed bolts, and bolts larger than 1-1/2" diameter where similar mechanical properties are desired. A354 grade BD does not require a magnetic particle test as is required by the A490 specification.**

**The ASTM A490 specification covers quenched and tempered, alloy steel, heavy hex structural bolts from ½" diameter through 1½" diameter with a minimum 150 ksi tensile. These bolts are intended for use in structural connections and therefore have shorter thread lengths than standard hex bolts. Refer to the Structural Bolts page of our site for thread lengths and other related dimensions. A490 bolts are similar in application and dimensions to A325 heavy hex structural bolts but are made from an alloy steel rather than a medium carbon steel, resulting in a higher strength fastener.**

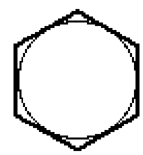
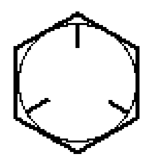
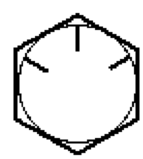
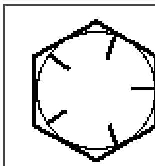
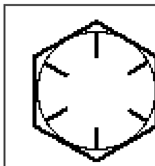
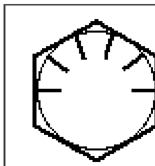
**SAE grade 8 bolts are made from a medium carbon alloy steel. Grade 8 bolts are significantly stronger than an A325. An ASTM specification with similar strength properties to grade 8 is ASTM A490.**

****SAE (Society of Automotive Engineers) establishes specifications covering fasteners intended for use in automotive, OEM, and equipment applications, while ASTM (American Society for Testing and Materials) provides specifications for construction fasteners.****

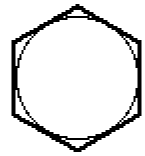
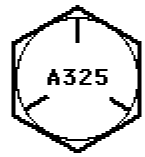
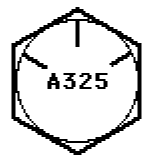
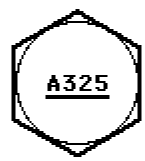
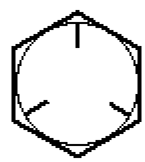
# Hex Head Bolt Markings

The strength and type of steel used in a bolt is supposed to be indicated by a raised mark on the head of the bolt. The type of mark depends on the standard to which the bolt was manufactured. Most often, bolts used in machinery are made to SAE standard J429, and bolts used in structures are made to various ASTM standards. The tables below give the head markings and some of the most commonly-needed information concerning the bolts. For further information, see the appropriate standard.

**SAE Bolt Designations**

| SAE Grade No. | Size range | Tensile strength, ksi | Material | Head marking |
|---|---|---|---|---|
| 1<br><br>2 | 1/4 thru 1-1/2<br><br>1/4 thru 3/4<br>7/8 thru 1-1/2 | 60<br><br>74<br>60 | Low or medium carbon steel |  |
| 5 | 1/4 thru 1<br>1-1/8 thru 1-1/2 | 120<br>105 | Medium carbon steel, quenched & tempered |  |
| 5.2 | 1/4 thru 1 | 120 | Low carbon martensite steel, quenched & tempered |  |
| 7 | 1/4 thru 1-1/2 | 133 | Medium carbon alloy steel, quenched & tempered |  |
| 8 | 1/4 thru 1-1/2 | 150 | Medium carbon alloy steel, quenched & tempered |  |
| 8.2 | 1/4 thru 1 | 150 | Low carbon martensite steel, quenched & tempered |  |

**ASTM Bolt Designations**

| ASTM standard | Size range | Tensile strength, ksi | Material | Head marking |
|---|---|---|---|---|
| A307 | 1/4 thru 4 | 60 | Low carbon steel |  |
| A325 Type 1 | 1/2 thru 1<br>1-1/8 thru 1-1/2 | 120<br>105 | Medium carbon steel, quenched & tempered |   |
| A325 Type 2 | 1/2 thru 1<br>1-1/8 thru 1-1/2 | 120<br>105 | Low carbon martensite steel, quenched & tempered |   |
| A325 Type 3 | 1/2 thru 1<br>1-1/8 thru 1-1/2 | 120<br>105 | Weathering steel, quenched & tempered |   |
| A449 | 1/4 thru 1<br>1-1/8 thru 1-1/2<br>1-3/4 thru 3 | 120<br>105<br>90 | Medium carbon steel, quenched & tempered |  |
| A490 Type 1 | 1/4 thru 1-1/2 | 150 | Alloy steel, quenched & tempered |   |
| A490 Type 3 | 1/4 thru 1-1/2 | 150 | Weathering steel, quenched & tempered |   |

Often one will find "extra" marks on a bolt head--marks in addition to those shown above. Usually these marks indicate the bolt's manufacturer.

ASTM A325 Type 2 bolts have been discontinued, but are included above because they can be found in existing structures. Their properties can be important in failure investigations.

While the bolts shown above are among the most common in the U.S., the list is far from exhaustive. In addition to the other bolts covered by the SAE and ASTM standards, there are a host of international standards, of which ISO is perhaps the most well known.