Understanding Nut And Bolt Specifications, version1.2

By R. G. Sparber

This article, written for those new to our hobby of metal working, attempts to discuss the various parameters that define nuts and bolts.

If you own a Machinery's Handbook, now would be a good time to get it out. If you don't own this repository of great metal working wisdom, maybe you can borrow one for now. It might also be helpful to read http://rick.sparber.org/spt.pdf which deals, in part, with the thread profile.

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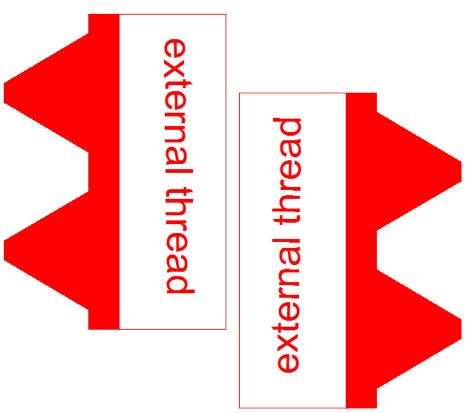
Bolt Thread Profile

There are many different thread profiles. I will deal with one of the most common: Unified Screw Threads.

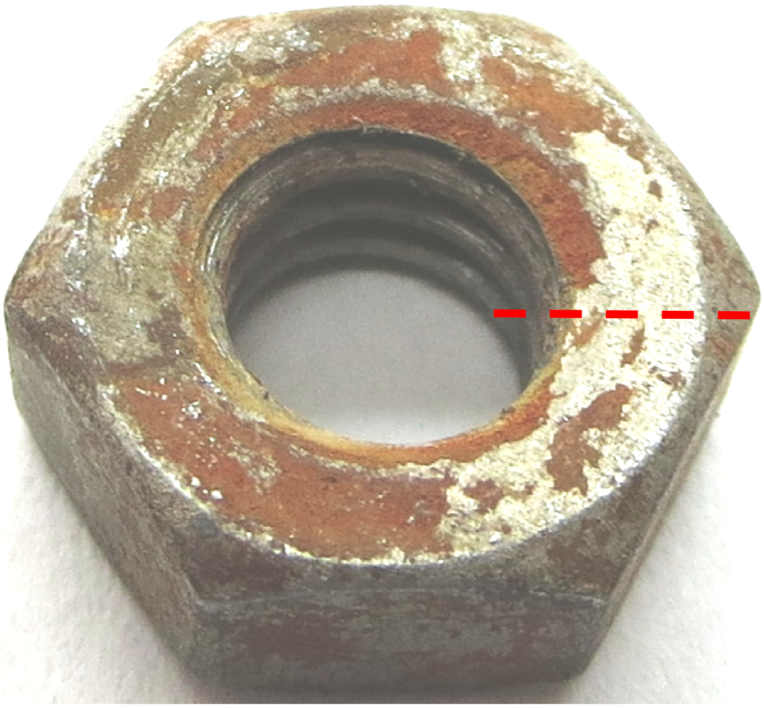
If you cut a bolt in half along its length, you will be able to see this profile. It is a repeating pattern so I show only a short length here.

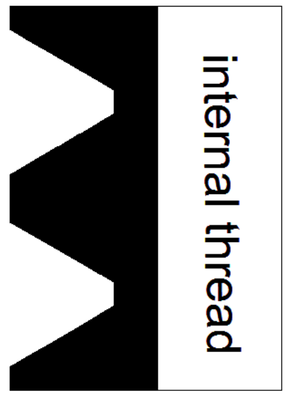
The sides or flanks of the profile are sloped. The outer most and inner most surfaces are flat. The flank symmetry means the clamping action is the same for both pulling towards the head of the bolt and pushing away from the head.



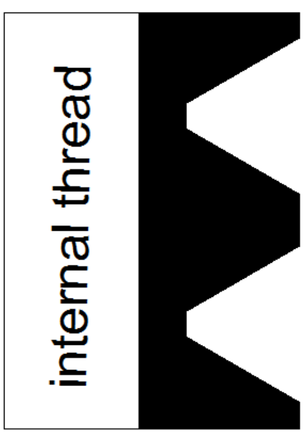
Next, take in the entire cross section of the bolt. Since this is a ramp wrapped around a cylinder, the right profile must be offset by half from the left profile. If they were lined up, the ramp would have no slope and it would be impossible to advance position as the bolt was turned.

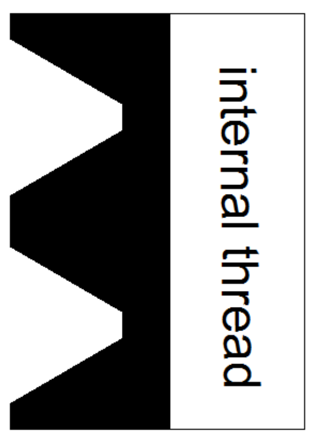
Nut Thread Profile





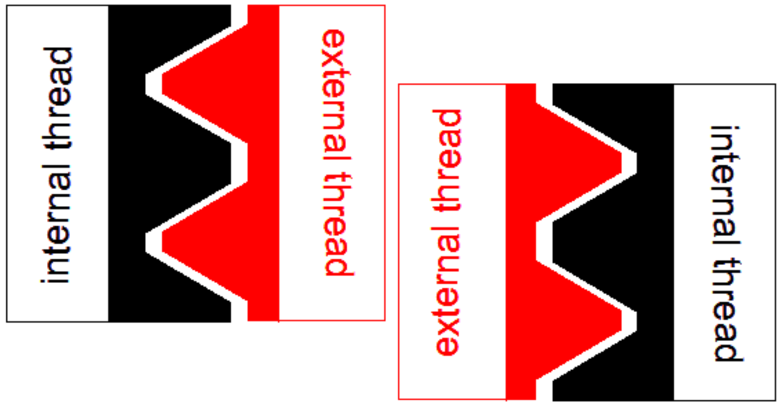
The internal thread profile found inside the nut is the mirror image of the external thread profile of the bolt. After all, the name of the game is that they fit together.





Sawing the nut in half across its face shows us the entire cross section. The right profile is offset by half from the left profile.

Nut on Bolt



Looking at a cut away picture, we can see how the bolt's external thread engages the nut's internal threads to create a working "system". Although I show white space separating the internal and external thread profiles, normally they touch at the top or bottom depending on the generated clamping force.

An essential aspect of this system is the ability to maintain functionality over a range of machining variations. Additionally, extra space may be desired between nut and bolt threads. All of this is related to ***thread class***.

The thread class is further subdivided into external and internal threads. The letter A follows the class number to indicate an external thread. The letter B goes with an internal thread. ***External: A*** ***Internal: B***

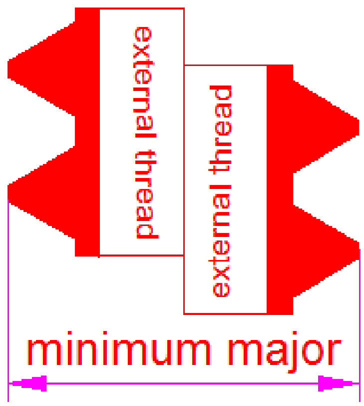
If you want the most generous machining tolerances, go for thread class 1A for bolts and 1B for nuts.

The most common thread class for a bolt is 2A along with the matching 2B nut. Most likely, this is what you buy at your local hardware store.

In some specialized applications, like aviation, there is a need for thread class 3A and 3B. The space between internal and external threads, in the worst case, is zero. No room for any crud on these threads! Tolerances on most parameters are tighter than the other thread classes.

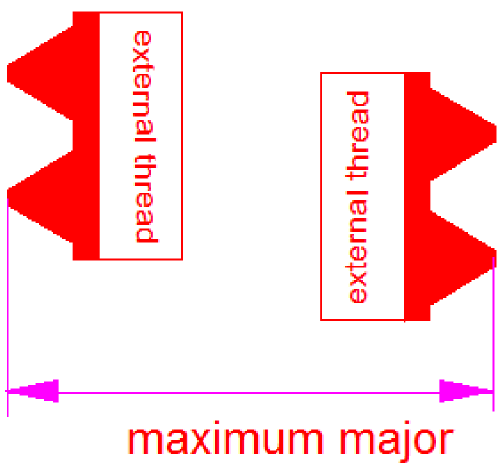
There are many tolerances associated with the nut and bolt. We will deal with them one at a time and then see how they work together as a system.

Bolt Thread Major Diameter Tolerance



The diameter of the bolt measured from outside flats is called the major diameter. There is a maximum and minimum major diameter specified.

If the bolt's major diameter exceeds the maximum, it might not fit through the nut.



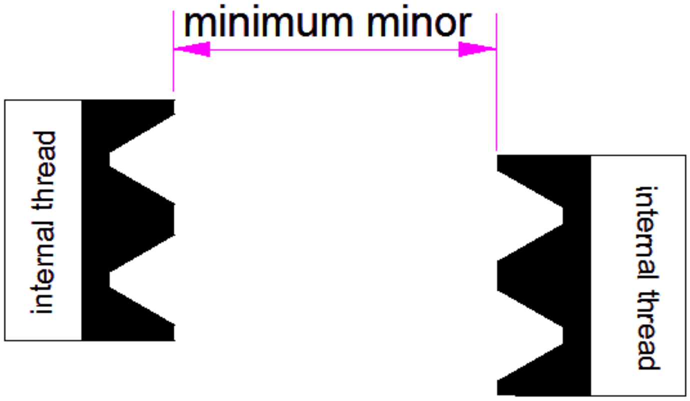
If it is smaller than the minimum, not enough thread will engage and the bolt may pull out of the nut when under axial load.

For a ¼-20 bolt with a 2A thread class[2], the major diameter must be between 0.2408" and 0.2489". This is a range of 0.0081".

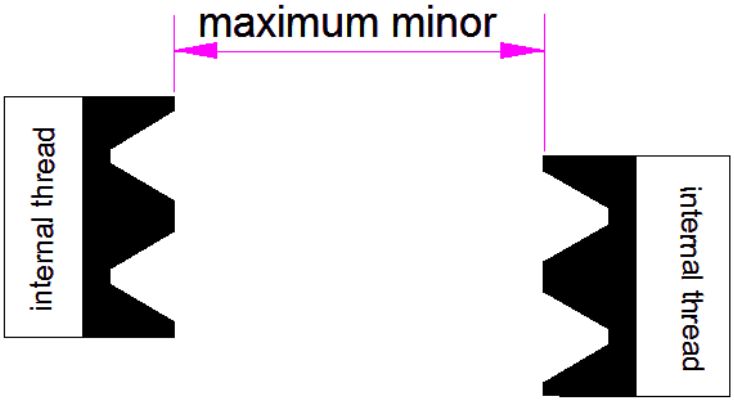
[2] Machinery's Handbook, 23 Revised Edition, page 1499.

Nut Thread Minor Diameter Tolerance

The diameter of the nut measured from inside flats is called the minor diameter. There is a maximum and minimum minor diameter specified.



If the minor diameter is smaller than the minimum, The nut might seize up on the bolt.

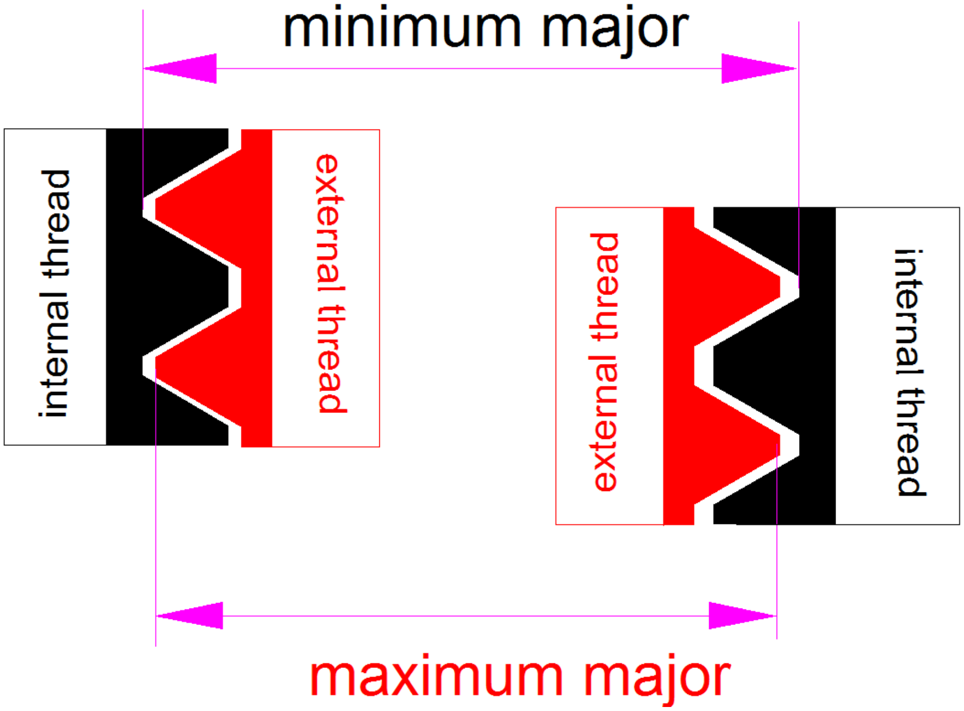


If the nut's minor diameter exceeds the maximum, it might not engage enough thread and the bolt may pull out of the nut when under axial load.

For a ¼-20 nut with a 2B thread class[3], the minimum major diameter is 0.2500". The maximum major diameter is indirectly specified using other parameters that will be presented later.

[3] ibid, page 1499.

Nut on Bolt - Worst Case Tight Fit at Major Diameters



Consider the case of a bolt that is at its maximum major diameter. It must fit into a nut with a minimum major diameter. Even in this worst case situation, it all has to fit and not bind up.

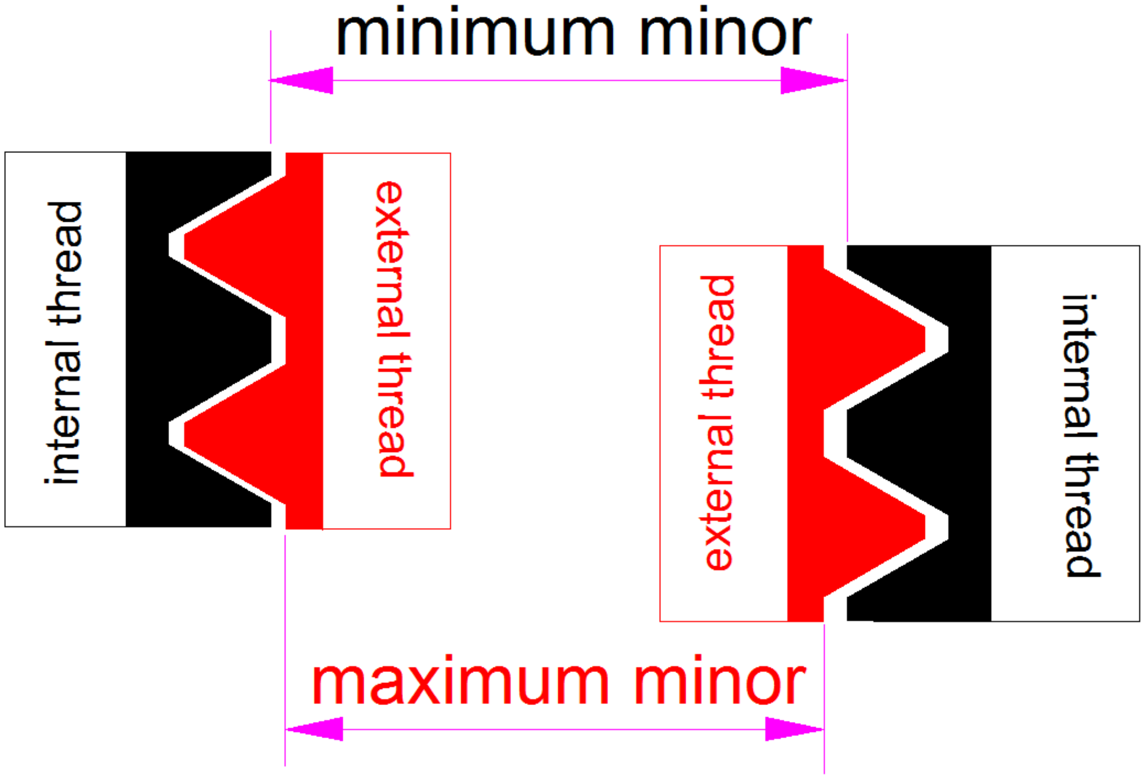
Note that there is still some white space between thread profiles.

For a ¼-20 nut of thread class 2B at minimum major diameter and a bolt of thread class 2A at maximum major diameter, the gap between threads is 0.2500" - 0.2489" = 0.0011". This is the space between nut and bolt derived from subtracting diameters. This difference is called the Allowance[4].

If you look in the Machinery's Handbook table, you will see that the allowance for a class 3A thread is always zero.

[4] Ibid, page 1475: "An allowance is the prescribed difference between the design (maximum material) size and the basic size." The minimum major diameter of the internal thread equals the basic size. The maximum material equals the maximum major diameter of the external thread.

Nut on Bolt - Worst Case Tight Fit at Minor Diameters



The previous case discussed the bolt jamming onto the nut because of interference at the major diameters. Now we will look at the possibility of jamming at the minor diameter.

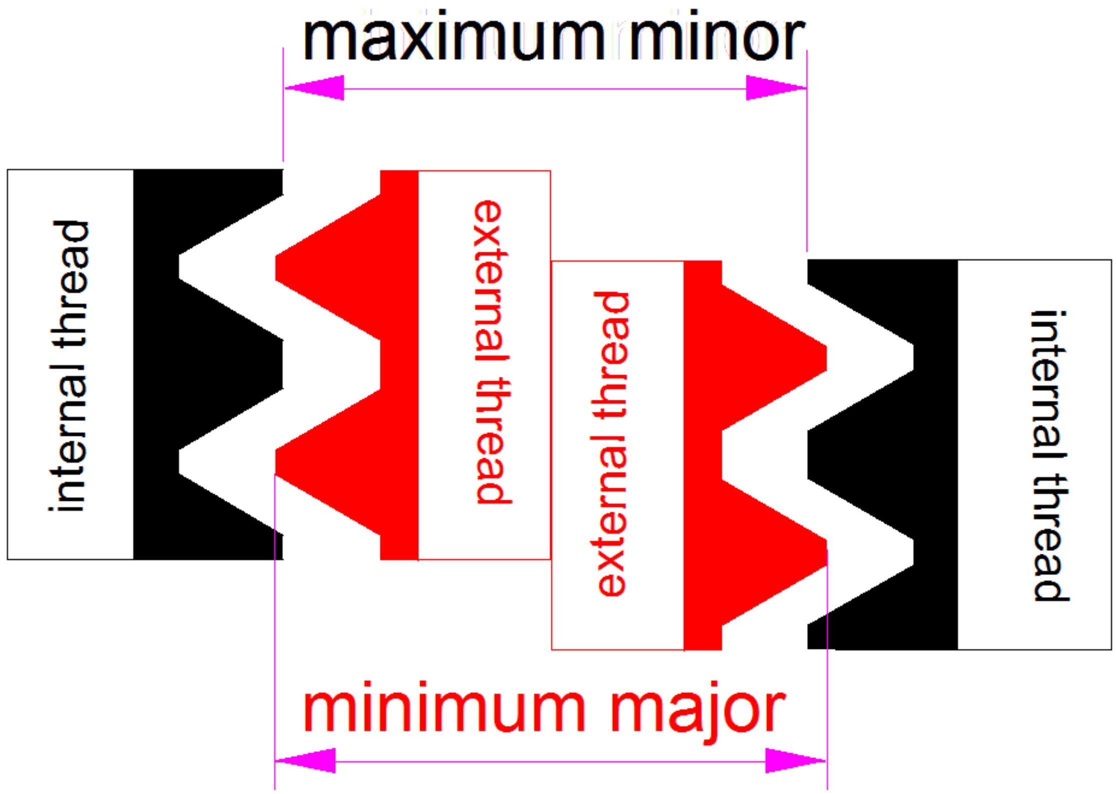
By design, the bolt and nut will not bind up even at these worst case diameters.

For a ¼-20 nut of thread class 2B at minimum minor diameter and a bolt of thread class 2A at maximum minor diameter, the gap is 0.196" - 0.1894" = 0.0066". This is the space between nut and bolt derived from subtracting diameters.

These last two examples demonstrated that in the worst case tight cases, the nut will not bind up on the bolt. So if you do find a 2A bolt that will not thread through a 2B nut of the same TPI, then one or both may be out of spec.

Nut on Bolt - Worst Case Loose Fit

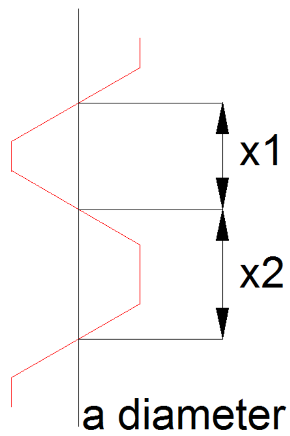
Here is the other extreme. The bolt is as skinny as it can be and still meet the requirements. The nut is as large as it can be. There still has to be enough thread engagement to provide the specified strength.



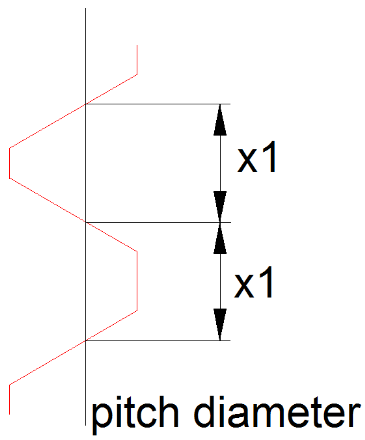
For a ¼-20 nut of thread class 2B at maximum minor diameter and a bolt of thread class 2A at minimum minor diameter, the engagement is 0.2500" - 0.196" = 0.054". This is the overlap between nut and bolt derived from subtracting diameters.

This demonstrates that in this worst case loose fit, there is still thread engagement. It is reasonable to assume that this is sufficient engagement to meet axial force requirements.

Bolt Thread Pitch Diameter Tolerance



Pitch diameter is a rather odd duck in my opinion. It is a diameter determined by measuring thread features.
Say this red line is the surface of an external thread. I measure the width of the groove or recessed part of the thread at a given diameter. Call this width x_1. Then I measure the width of the ridge at this same diameter. Call it x_2.



Adjust the diameter until x_1 equals x_2. Then the pitch diameter will have been found. If the pitch diameter of a bolt is too small, insufficient thread engagement will result. If the pitch diameter of a bolt is too large, it might bind up in the nut.

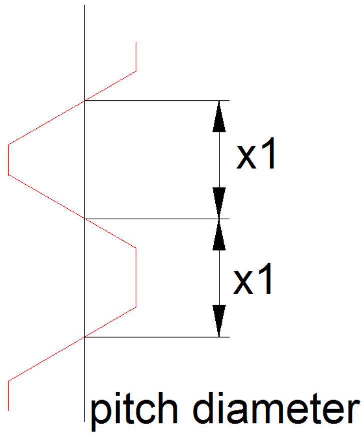
Specialized thread micrometers exist for performing this measurement. It can also be done using the 3 Wire Procedure.

The thread tables specify the minimum and maximum Pitch Diameter for external threads.

For a ¼-20 bolt of thread class 2A, the pitch diameter must be between 0.2127" and 0.2164".

Using the 3 wire method as described in http://littlemachineshop.com/instructions/ThreeWireMethod.pdf ,wires from Enco, and a Mitutoyo IP65 mic, I measured the threads on a high quality ¼-20 bolt. Since this bolt has 20 TPI, I used 0.029" wires. The wires were placed into the threads as per the procedure and the mic read 0.25870". Subtracting from this reading the constant associated with 0.029" wires, I got 0.25870" - 0.04370" = 0.2150". The spec is 0.2127" to 0.2164". So the bolt is in spec.

Nut Thread Pitch Diameter Tolerance



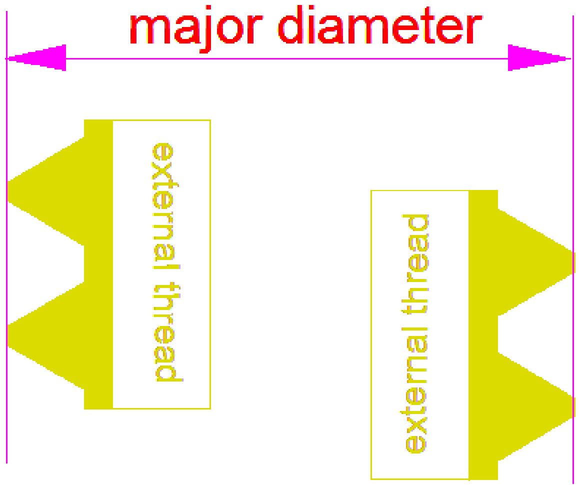
The internal thread is also defined partly by the pitch diameter. There is a minimum and maximum value.

I have seen internal thread micrometers that can measure this internal pitch diameter. A go/no go gage would be easier to use.

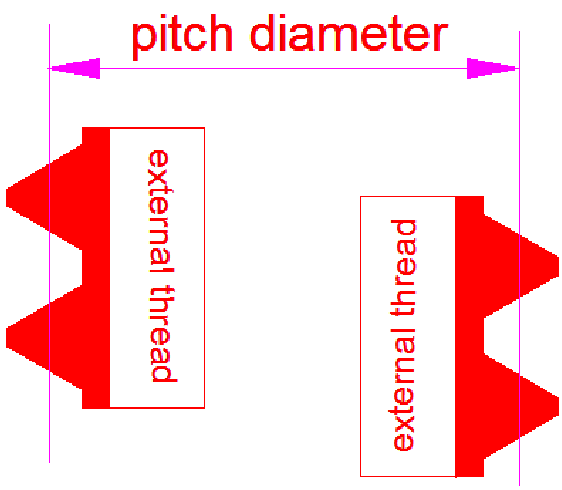
The thread tables specify the minimum and maximum Pitch Diameter for internal threads.

For a ¼-20 nut of thread class 2B, the pitch diameter must be between 0.2175" and 0.2224".

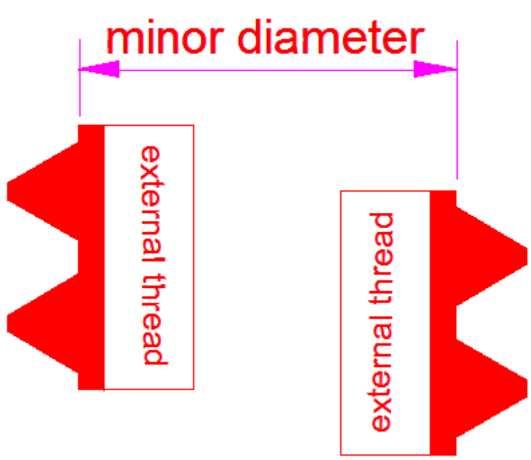
Bolt Threading Procedure



There are many ways[5] to single point cut a cylinder but the threading table implies to me that one should first turn the major diameter.



This should be followed by cutting the thread until the pitch diameter is in spec.



The final step is to verify and machine, if necessary, the minor diameter. If the cutter has the correct profile, there should not be a problem here.

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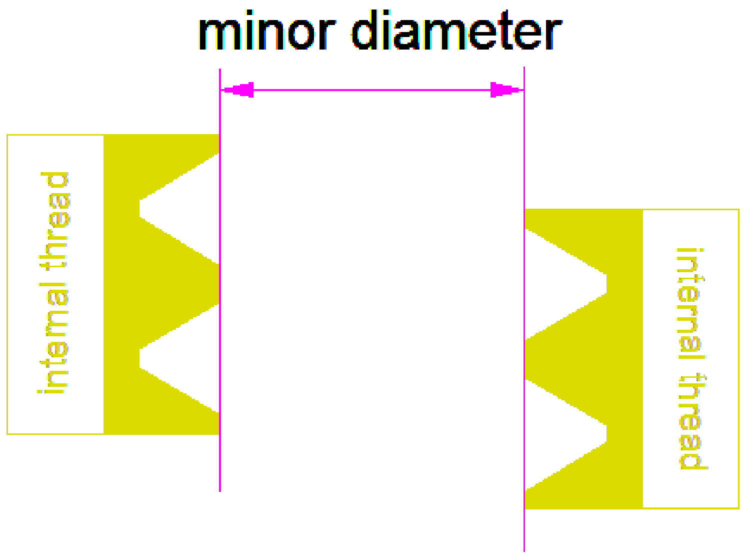
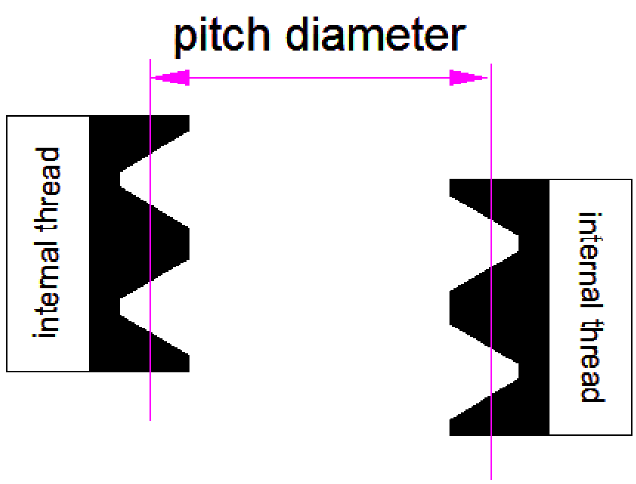
[5] For example, see http://rick.sparber.org/spt.pdf

Nut Threading Procedure

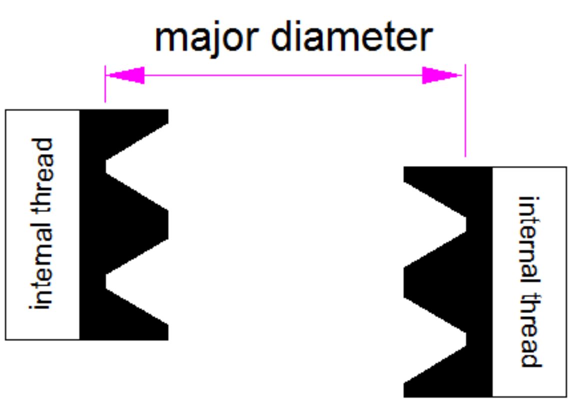


Again, following the threading table, I would start by drilling or boring the minor diameter.



This should be followed by cutting the thread until the pitch diameter is in spec.

Using a go/no go gage is probably the easiest way to do this measurement. You can't use the 3 wire method as far as I know.



The final step is to verify and machine, if necessary, the major diameter. If the cutter has the correct profile, there should not be a problem here.

Acknowledgements

Thanks to Andy Wander for encouraging me to dig deeper into this subject. Thanks to Mark Cason for exceptional technical assistance.

Thanks also to "doc" and Guenther Paul of the atlas_craftsman Yahoo group for their guidance and insights. Thanks to Ron Hamilton and Corey Renner of the Valley Metal club for their help. Of particular value was the suggestion of having a beer when the thread finally fits correctly.

Thanks to Little Machine Shop for their excellent write up on using the 3 wire method of measuring threads.

All photographs in this article were taken with my new camera, a Canon ELPH 330HS. Diagrams were rendered with my old DesignCAD Version 14.

I welcome your comments and questions.

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