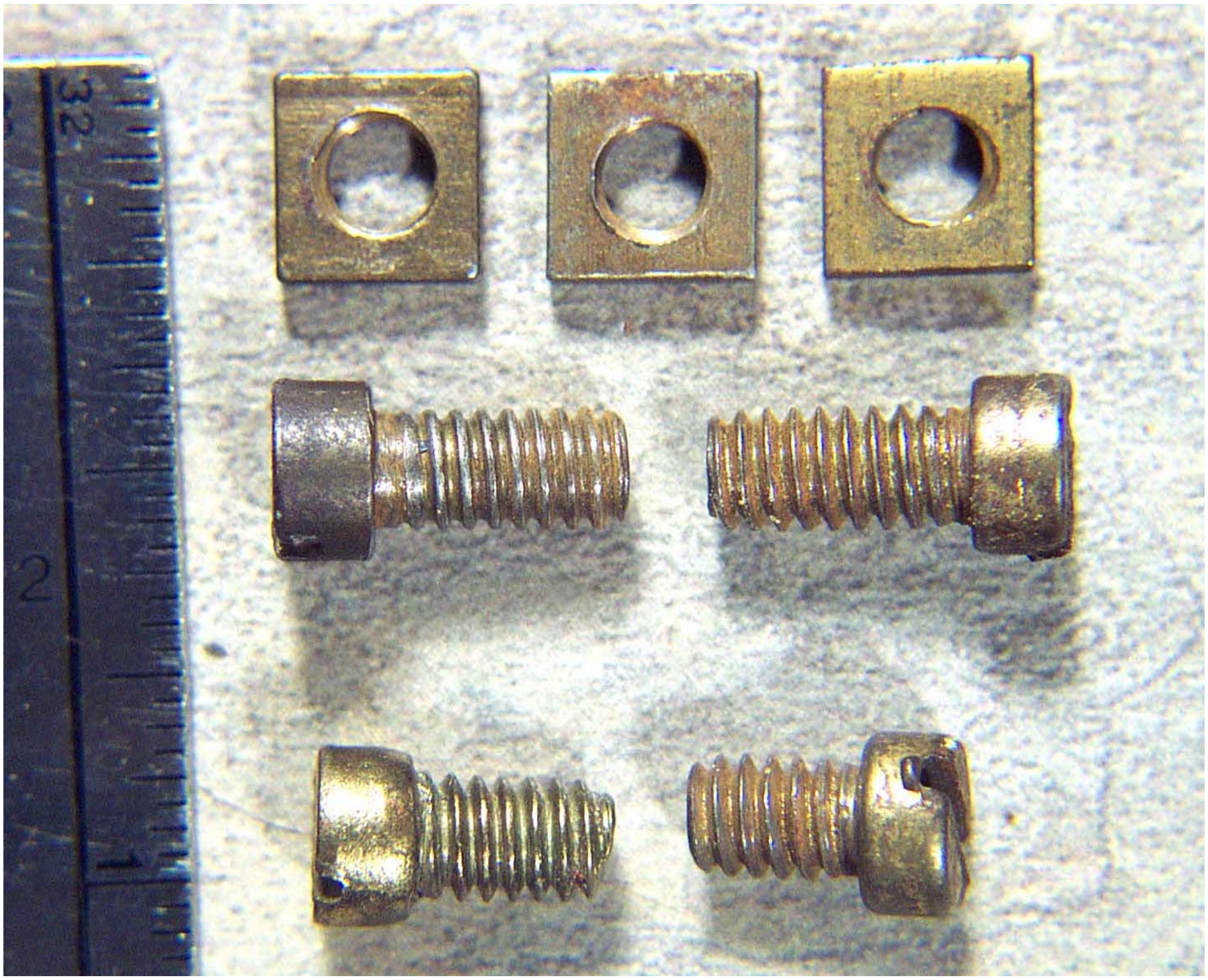
Meccano Bolt Sizes



By
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“New” Meccano Bolt Size

The Basics

This story started with a newly acquired 1929 US Meccano No. 50 outfit. In examining the contents (which is another story!), I tried to fit the set screw from the 2” Pulley into the boss of a ¾” Flanged Wheel – and it did not fit! (Don’t ask why I did this – I’m not really sure!) Looking at a listing of screw sizes, the suspicion arose that perhaps another size screw was being used. Knowing a (dangerously) little about machining and measuring, I ordered a set of thread measuring wires.

Before continuing with the story, it would be in order to briefly discuss screw threads and their measurement. Because this will get technical, some definitions are included at the end of this document. There are several dimensions required to define a screw thread. The obvious ones, and those which are very commonly used, are the outside diameter and the threads per inch. Thus, a (US) screw would be described as #8-32 NC - #8 screw diameter, and 32 threads per inch. The “NC” describes the thread shape as a National Coarse: 60 degree angle between the sides of the thread, and a defined flat at the top and bottom of the “V”. Unfortunately, the outside diameter is a nominal figure, and for a screw is actually the maximum diameter. Practical screws are always smaller (unless you are dealing with a precision fit). A more important diameter is the “pitch diameter”, measured half way up the sloped sides. (To be a bit more precise, the pitch diameter is measured at the line shown on the drawing, where the distance between the slopes is just one half of the pitch.) If you picture an even mountain range, the tops of the mountains could easily be shaved off to make the overall landscape lower, but the sides of the mountains do not move. Thus, a method is needed to measure partway down the “slopes” of the screw. A common, and well documented, method uses three wires of small diameter which fit in the threads. Two wires are fit into adjacent threads on one side of the screw, and the third wire is placed in the thread on the opposite side. A micrometer is then used to measure the distance over the wires, and a formula applied to convert the measurement. This formula is dependent on the pitch, or threads per inch, the angle of the slope, and the diameter of the wires.

The screw sizes in question here are a British standard, and an American standard. Meccano uses the 5/32 BSW thread (for nearly all purposes). This is 5/32 inch diameter (nominal, or 0.1563 inches) British Standard Whitworth: 32 threads per inch, a 55 degree angle, and rounded top and root. (Inch measurements are given throughout, because all of the data I have is in inches.) This thread is not a common size (at least today in the USA), and many references do not list BSW data for the 5/32” diameter. The American thread is a #7-32, or a #7 (nominal) diameter (0.151”) and 32 threads per inch (also an uncommon size today). This uses the US Standard (or A. S. M. E. Standard) thread shape, which is a 60 degree angle and a truncated (flat) top and root. From these dimensions, it might appear that measuring the outside diameter could resolve what the screw size is, but tolerances make this quite inaccurate. The diameter of the US screw is only 0.0053” smaller than the BSW screw. The basic dimensions are given below, for easy comparison, along with #6-32 and #8-32.

	Outside diameter (max) inches (mm)	Threads per Inch	Pitch diameter (max) inches (mm)	Angle degrees
#8-32	0.1640 (4.166 mm)	32	0.1437 (3.741 mm)	60
5/32 BSW	0.1563 (3.970 mm)	32	0.1362 (3.459 mm)	55
#7-32	0.151 (3.835 mm)	32	0.1307 (3.320 mm)	60
#6-32	0.1380 (3.505 mm)	32	0.1177 (2.990 mm)	60

One further technicality: I have so far referred only to "screws". When discussing threads, the term is always "screw thread". When referring to the physical object which has a male screw thread, it could be either a "screw" or a "bolt". A bolt is used with a nut, while a screw threads into another part – hence "set screw" and "nut and bolt". In Meccanoland, a bolt can magically turn into a screw when it is inserted into a coupling, for example. For consistency, though, I will call it a bolt.

Returning to the story, I set up a holder for the wires. I used wires 0.0195" diameter. Each bolt was placed between the wires, and measured with a digital micrometer reading to 0.00005". As mentioned above, there are simple formulas to convert the measurement over the wires to the pitch diameter. While the pitch of the two threads are the same (32 threads per inch), the thread angles are different and so the formulas are different. I elected to measure everything 'over the wires', and convert the nominal pitch diameters to the 'over the wire' measurements. An egg carton was marked with sizes in 0.001" increments, and the bolts placed in the appropriate 'bin' after measurement. As each group of bolts was completed, the number in each bin was recorded. The graph below shows the distribution of sizes found. One would expect a bell shaped curve showing the statistical distribution of sizes (see the section on Statistics). The curve actually shows two distinct groupings, a clear indication that there are two standards present. I have shown the pitch diameters converted to 'over the wires' measurements on the same graph. The square is the converted size of the #7-32 screw, and the triangle is for the 5/32 BSW. I measured over 100 bolts from different sources (outfits and odd parts bin), and verified that the US Meccano outfits from at least 1922 on used the #7-32 thread. I have a few outfits from before 1922 which contain #7-32 bolts, but the dates are not certain. U.S. outfits from 1916 have 5/32 BSW bolts.

So much for the bolts – what about the nuts? Unfortunately, it is very difficult to measure inside threads, and especially so for the sizes we are interested in. The commonly accepted method is a plug gage – an accurately ground "screw" (actually, usually a "go –no go" pair) to verify a particular thread. Such plug gages are expensive for the hobbyist, and in these instances they would have to be custom made because these threads are so unusual. I elected to select three bolts from those measured as described above. One is the maximum size BSW bolt, one a near-minimum BSW, and a "typical" #7-32 bolt. I sorted a pile of nuts from my loose parts bin into three groups. The largest would fit on the maximum 5/32 BSW bolt, and can be assumed to be of British manufacture. The next size down would not fit on the maximum bolt, but will fit on the minimum 5/32 BSW bolt. These might be British 5/32 BSW, but most are probably US #7-32, based on the proportions of BSW and #7-32 bolts in the parts bin. The smallest nuts would not fit on either of the BSW bolts, but will fit on the #7-32 bolt; these are almost certainly of US manufacture.

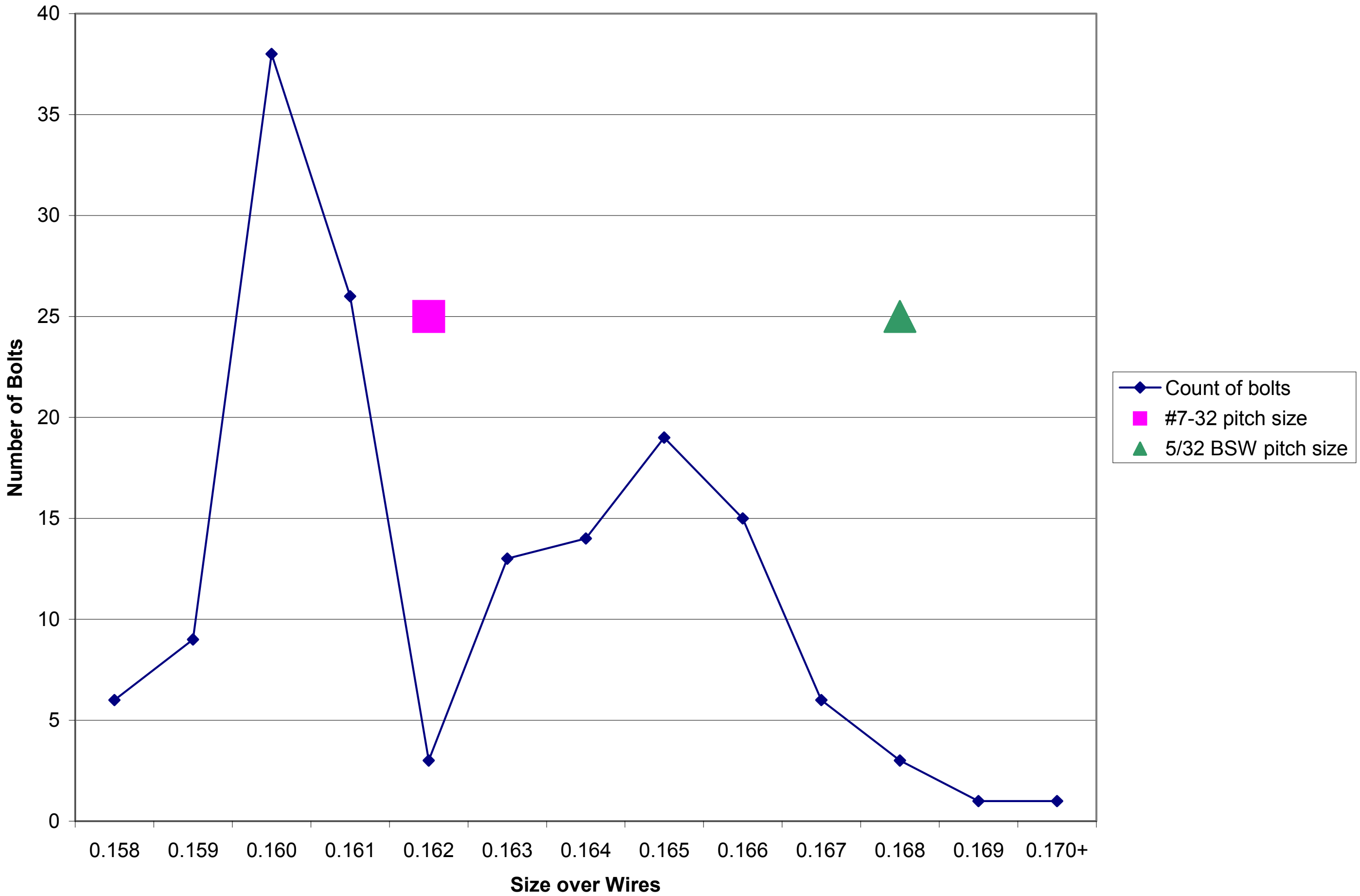
To summarize, see the close-up picture of four bolts and three nuts. The two bolts closest to the scale (that is a one inch mark visible!) are 5/32 BSW, and the other two are #7-32. The outside diameters of the four bolts are all within about .001” of each other – and the supposedly larger 5/32 BSW bolts are actually smaller than the #7-32! The more rounded threads of the 5/32 BSW bolts is visible. The nut closest to the scale fits on a near-maximum 5/32 BSW bolt, and is most likely a 5/32 BSW nut. The nut farthest from the scale is #7-32. The one in the middle is probably a #7-32 nut. It is apparent how difficult it is to distinguish these by visual inspection.

The #7-32 nuts and bolts were used to the end of the US Meccano Company; that is, until the nuts and bolts were replaced with the #8-32 Erector nuts and bolts. The 1929 #50 outfit which prompted this investigation contains #7-32 bolts. When this size started in use is a more difficult question. 1916 US outfits contain 5/32 BSW nuts and bolts. Two later (circa 1917 – 1921) outfits contain #7-32 nuts and bolts, but the exact dates of these outfits are not known.. It does appear that the #7-32 size was used well before the US Meccano factory opened in Elizabeth, NJ in 1922. Is it possible that shipping was disrupted in World War One to the extent that these parts had to be made in the US? What other parts were made in the US before the Elizabeth factory opened (the early electric motors are known to be of US manufacture)?

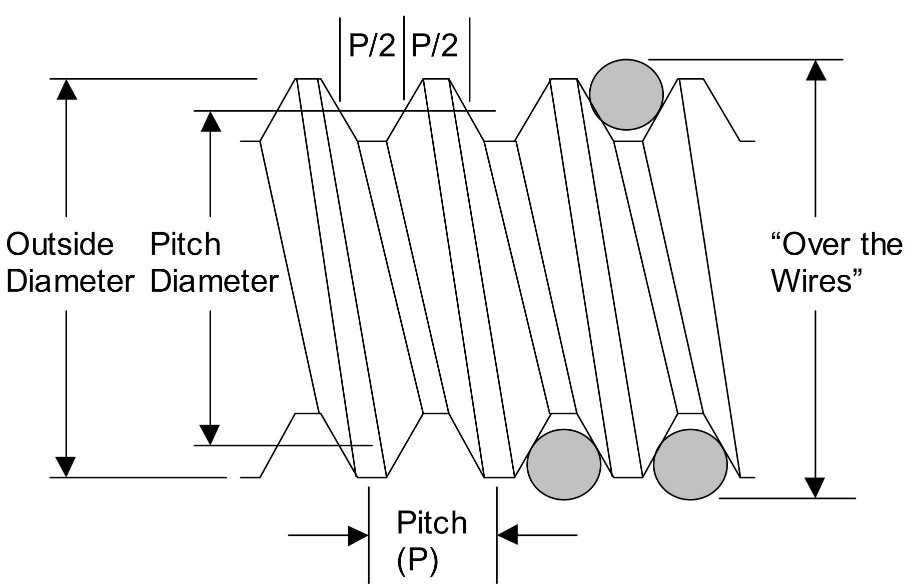
This is all rather arcane – who cares what size screws were used?? Indeed, this is a pretty esoteric discussion. A few people, however, might find this useful. It is now possible to identify tapped parts which were made in the United States, by trying a known (and carefully selected!) 5/32 BSW bolt in the boss. If it fits, it may have been made on either side of the Atlantic, and if it doesn’t fit, it is most likely an American part.

A further point must be made. It must be remembered that Meccano (and other similar systems) were, and still are, toys. It must not be assumed that precision industrial practices would be applied to the manufacture of toys. Such practices can become too expensive for the ultimate goal – to produce a child’s plaything in (hopefully large) quantity. Certainly, if the nuts and bolts will not fit together, word will get around that the toy does not work, and sales will suffer. But, as Lou Boselli has pointed out, these are still toys.

Distribution of Bolt Sizes



Screw Thread Dimensions and Three Wire Measurement



This is a view of the way I measured the bolts. The three wires are mounted in a holder made from two Flat Girders (tin plated, and so made in USA) and a 1” Threaded Rod. The holder is supported in a small vice. A bolt is shown supported by the wires, ready for a measurement. The egg carton, with the sized marked, is in the backgound.

Tolerances

Tolerances (and allowances) have varied over the years, both in magnitude and clarity of definition. For example, modern standards call for an allowance for a class 2 fit. The 9th Edition *Machinery's Handbook* (1937) lists the same tolerances on machine screws as the 13th edition, but does not include tolerances on nuts. In the 1920 edition, nut tolerances are not given, but tap tolerances are given (it is easier to measure the tap than the hole it makes). As for BSW threads, none of my books give tolerances for 5/32 bolts. Tony Knowles found a formula for the tolerance (*T*):

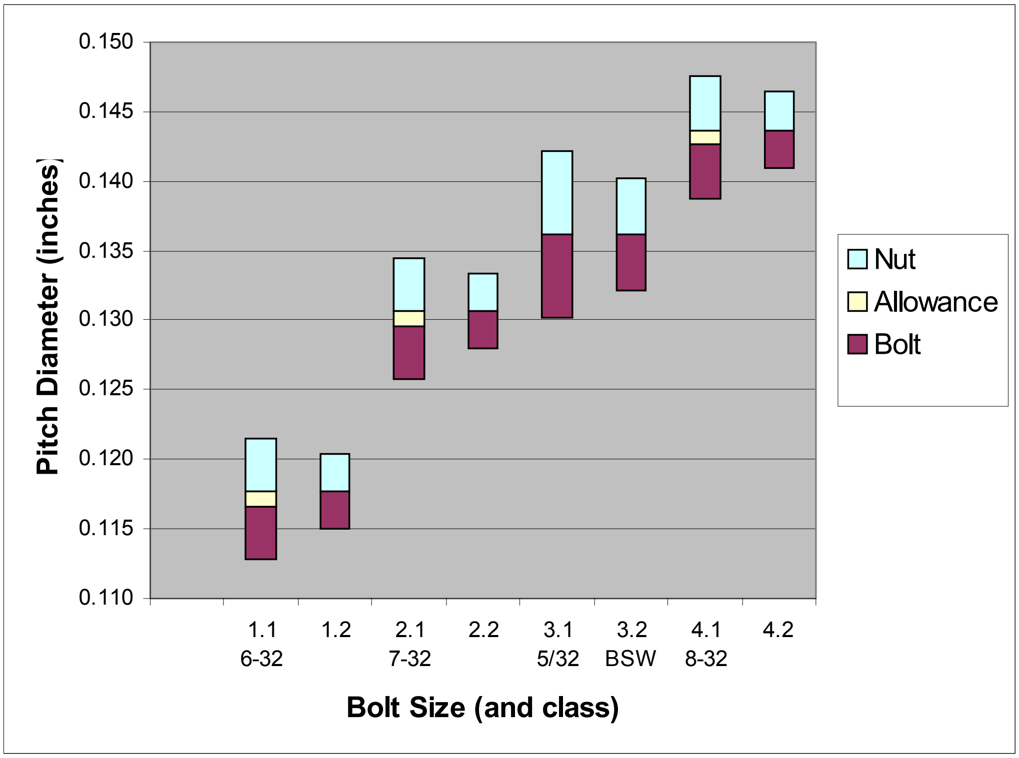
$$T = 0.002 \times \sqrt[3]{D} + 0.003 \times \sqrt{L} + 0.005 \times \sqrt{P}$$

where *D* = nominal diameter, *L* = length of engagement, and *P* = pitch (all in inches). Using a length of engagement of 1/8", the tolerance for 5/32 BSW is 0.003"; for a "loose or free" fit (1.5 times the standard tolerance), it is 0.0045". Neither number approaches the roughly 0.006" tolerance found by actual measurement. The 9th Edition *Machinery's Handbook* (1937) does list tolerances for screws from ¼ BSW and larger; extrapolating these to 5/32 BSW yields tolerances on the order of those found by measurement of Meccano bolts.

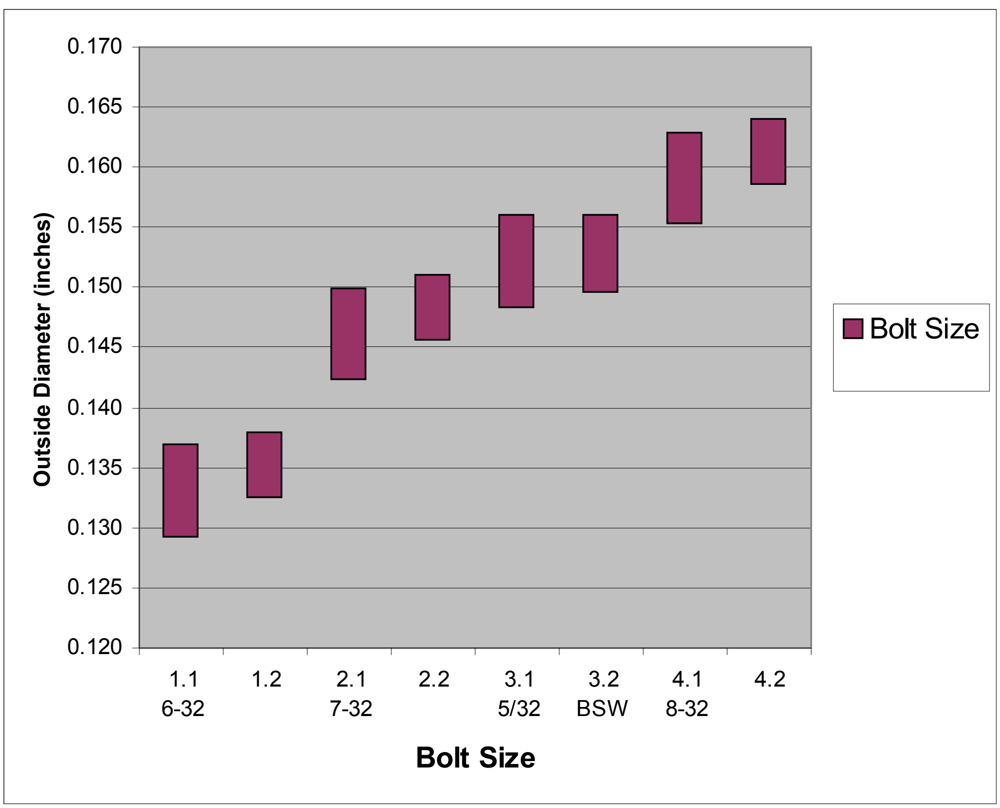
The chart below illustrates the tolerances and relative sizes, based on pitch diameter, of the nuts and bolts of interest. Based on my measurements, the tolerance on BSW bolts (as Meccano produced them) is significantly larger than that for the #7-32 bolts. The largest 5/32 BSW nuts will indeed fit an 8-32 screw, as borne out by experience. Some 5/32 BSW bolts will fit #7-32 nuts, also confirmed by tests. These BSW tolerances are estimates, based on extrapolated and measured data. They do not seem to be grossly out of line, however; the (single) depth of thread for 32 pitch is 0.020", or the double depth (which would apply to a diameter) is 0.040", so these tolerances are less than the depth of thread.

Remember that these are all based on pitch diameter. The outside diameter of a bolt has a larger tolerance than the pitch diameter. The outside diameters (with tolerances) of these bolts (except the #6-32) will overlap. The second chart below illustrates the outside diameters of the various size bolts.

Pitch Diameter and Tolerance



Outside Diameter with Tolerance



Definitions:

Outside Diameter: the overall diameter of the bolt, measured over the peaks of the thread.

Pitch: the spacing of the threads. The pitch can be specified as the actual spacing of the threads (for example, 0.5mm), or in threads per inch (for example, 32 tpi). Strictly speaking, the pitch should be the spacing of the threads, so the second example should be specified as 0.03125" (1/32 inch). For US threads, however, the threads per inch is nearly always used.

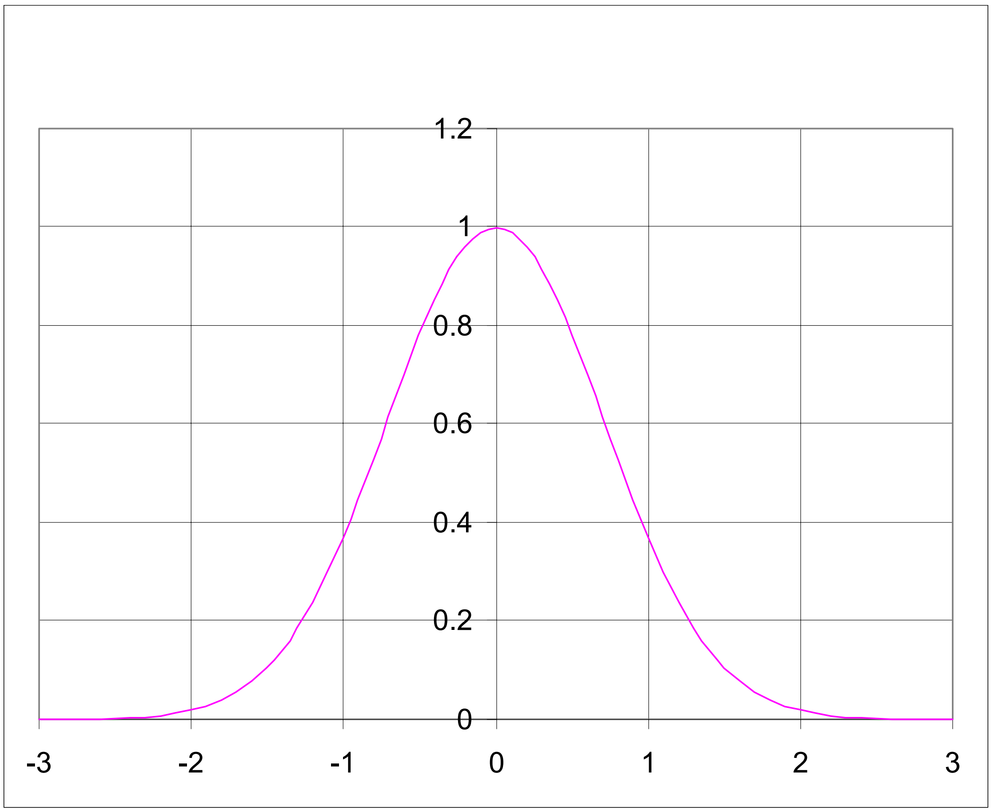
Pitch Diameter: The diameter of a bolt measured at the pitch line. The pitch line intersects the threads at a distance from the axis of the bolt such that the intersections with the sloped faces are one half the pitch apart.

Tolerance: The permissible variation in a measurement. On a base dimension, tolerance can be one way only (2", +0, -0.005", for example, for a shaft to fit in a bearing), or it can be in both directions (2" +/- 0.0025", for example; the total tolerance in this case is the same as the previous example). In the case of screws/bolts and nuts, the tolerance is usually specified in one direction only. Usually, the nominal dimension is the base. Tolerances on screw diameters are minus; that is, the screw can be smaller than the nominal dimension, but "never" larger ("never" in quotes, because there are screws out of tolerance, and certain classes of interference fit). Tolerances on nuts are plus; the hole in a nut can be larger than the nominal, but not smaller. There are classes of fit, which define the tolerances. For UNC (and UNF) threads, the classes are 1, 2, 3, 4 and 5. Class 1 is a loose fit; more on this under "allowance". Class 2 is the common fit; this is what you would expect on practically any nut and bolt you buy at a hardware store. Class 3 is a precision fit; class 4 is a selective assembly fit; and class 5 is for studs which require force to assemble (light drive fit). Only classes 1 and 2 are of interest here. (These classes are from the *Machinery's Handbook*, 13th Edition, 1948, pp. 1085 – 1088.)

Allowance: An intentional minimum clearance when fitting two parts together. In the case of nuts and bolts, the common fit lets a maximum size bolt to fit into a minimum size nut with no clearance (at least in 1948); that is, they are (theoretically) a perfect fit. There is no allowance. For a Class 1 UNC fit, the maximum bolt size is defined as 0.0011" less than the nominal size. The nut has no allowance, but it does have a tolerance. This means that there is a minimum clearance between the nut and bolt. The class 1 fit is intended for hand assembly, where disassembly is required (sounds familiar!).

An Aside on Statistics and Normal Distribution

The discussion on tolerances simply indicated the maximum and minimum measurements. While tolerances allow the size to vary between these limits, the natural variations will (usually) not result in an even distribution throughout the range. If we measure a large enough sample, we will find that most parts fall near an 'average' size, with few near the maximum and minimum sizes. This is called the "Normal Distribution", and the formula for the "ideal" curve has been determined (often attributed to the mathematician Gauss, but actually developed before his time).

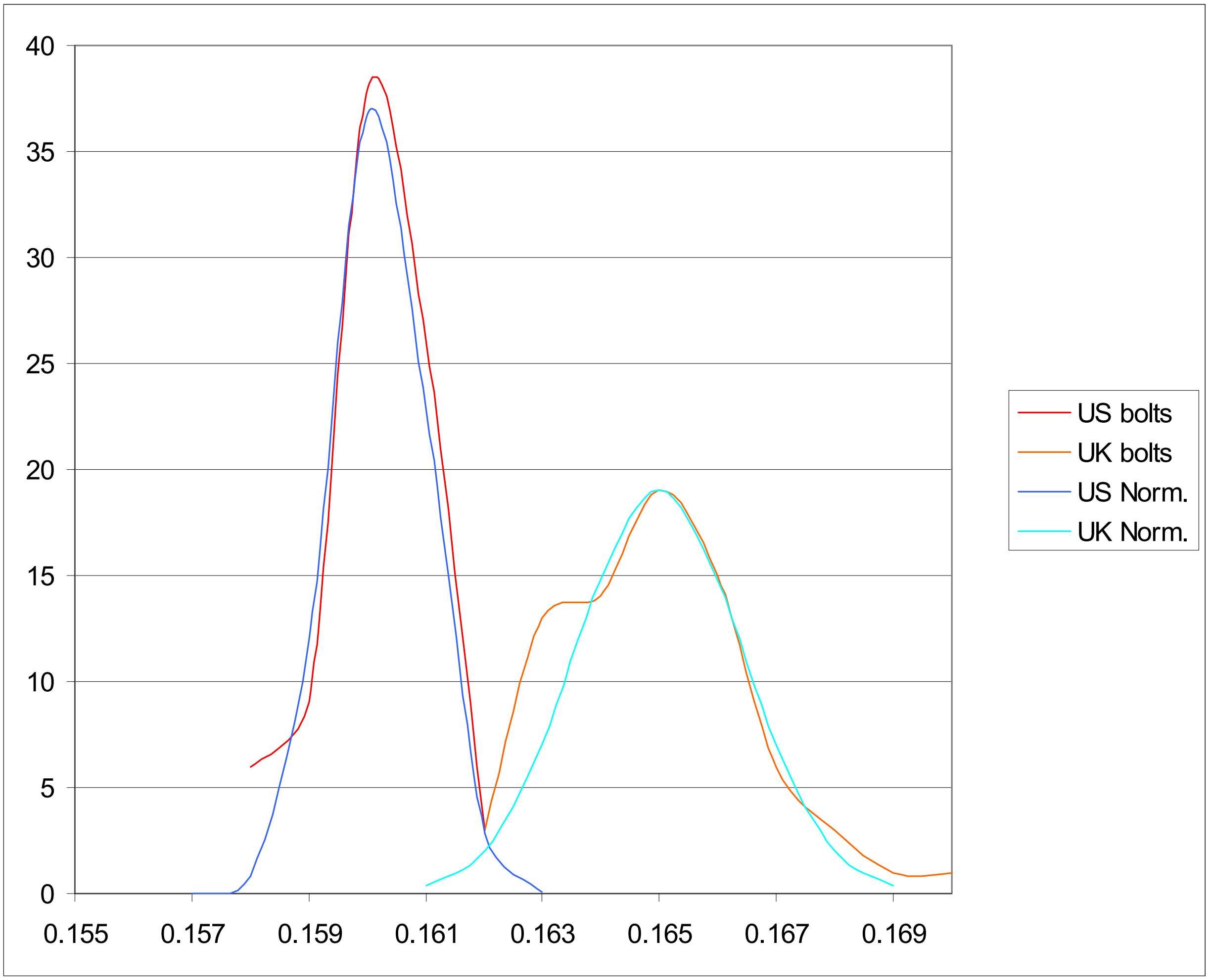


This is an example normal distribution curve, where the average is zero and the maximum is one. This curve can be adjusted in height, average, and width (which is usually measured by a term called "standard deviation"). An interesting feature of this curve is that it never actually reaches zero, even for extremely large values along the horizontal axis. However, for all practical purposes, the curve can be considered to reach zero at values of three or four. The formula for this curve is expressed as:

$$y = A \times e^{-B(x-C)^2}$$

where A is a constant representing the maximum value, B is a constant representing the "width" of the curve, and C represents the average value. e is the constant 2.718281828459045. For this example, A and B are 1; C is 0. This is a great simplification; the basic curve of most interest to statistics has an area under the curve of one, and the constants are themselves too complex for this discussion.

I thought that it might be interesting to compare the curve of bolt size distribution to normal distribution curves. I plotted the bolt size distribution, and smoothed the resulting curve. Since there are two bolt sizes, they were plotted as separate curves, so the “corner” at the bottom joining the two would not become smoothed. I then adjusted the constants in the formula for the Normal Distribution to produce two curves approximating the measured values. The result is shown below:



The two blue curves are the adjusted Normal Distribution curves.