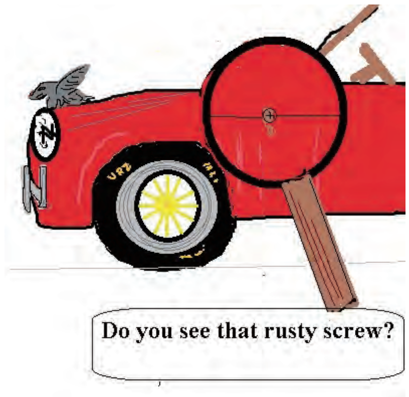
Undersizing

With every step forward there is a half-step back

by Thomas Doppke

With the steadily increasing importance of customer satisfaction and involvement in modern automobile design it became necessary to increase the corrosion resistance of many, formerly rusty components. Whereas before the customer took what was offered (Ford Motor Company's 'any color as long as it is black') the new generation wanted every part to be 'beautiful'! As the rest of the vehicle became better painted, rusty fasteners became more noticeable. Until the end of the second World War the available finishes for fasteners were limited to phosphate and oil, paint, or a few sintered zinc or galvanized coatings. One of the outcomes of the war was that the processes of electroplating that the Germans had developed were opened up to the rest of the world. Zinc electroplating became popular along with Cadmium and various dichromate treatments. However, with today's emphasis on long life and increased corrosion resistance these old platings do not perform well. The obvious solution of increasing the thickness to increase the corrosion resistance impacted dimensional fit.



Here we must digress a bit to talk about threads. It is an inescapable truth that nothing can be made to an exact dimension repeatedly. That is, the finished parts will vary due to machining tolerances, variation in tools and setup, stock properties and size, and so on. While it is possible to control these properties a bit, an allowance has to be made for manufacturing variation. A look at any dimensional table will show the maximum and minimum dimensions for standard thread pitches.

A problem then arose about "fit". Would a maximum external thread fit into a minimum/internal thread? How to control the manufacture of such? How to live and control a multitude of various parts with conflicting dimensions? The solution was that only an allowance for coatings and other significant variations would be permitted on external threads, and internal threads would not have any allowance although there were maximum and minimum dimensions listed to account for normal machining variation (although the loosest fits were allowed some leeway).

Repeating to clarify: there is a dimensional range which accounts for machining variation plus, for external threads only, an allowance for fit, coatings, etc. Since there are various joint conditions, three classes of fit tolerances were developed: a loose fit for parts that require lots of clearance space, as in military hardware and components which may be contaminated with dust or sand; a regular set of tolerances for most normal use parts; and a third class for very tight joints which cannot function with any appreciable looseness such as in adjustments in precision components. In the Inch system these were labeled 1A, 2A, and 3A for bolts, 1a, 2a and, 3a for nuts (capital letters for external and lower case for internal threads). Metric parts were given another set of definitions. A letter (lower case g, h, etc. for external, capitals for internal (i.e., G, H) to denote a tolerance class and a numeral to denote the tolerance grade. The standard usage bolts are denoted as 6g. Refer to any metric thread standard for a more detailed explanation of this system.

ALLOWANCE CHART for METRIC THREADS

	EXTERNAL THREAD				INTERNAL THREAD	
Class>	g	e	f	h	H	G
Pitch	Standard	Loosest Fit	LooserFit	Tight Fit	Standard	Loose Fit
0.2	-0.017	-	-	0	0	+0.017
0.25	-0.018	-	-	0	0	+0.018
0.3	-0.018	-	-	0	0	+0.018
0.35	-0.019	-	-0.034	0	0	+0.019
0.4	-0.019	-	-0.034	0	0	+0.019
0.45	-0.020	-	-0.035	0	0	+0.020
0.5	-0.020	-0.050	-0.036	0	0	+0.020
0.6	-0.021	-0.053	-0.036	0	0	+0.021
0.7	-0.022	-0.056	-0.038	0	0	+0.022
0.75	-0.022	-0.056	-0.038	0	0	+0.022
0.8	-0.024	-0.060	-0.038	0	0	+0.024
1.0	-0.026	-0.060	-0.040	0	0	+0.026
1.25	-0.028	-0.063	-0.042	0	0	+0.028
1.5	-0.032	-0.067	-0.045	0	0	+0.032
1.75	-0.034	-0.071	-0.048	0	0	+0.034
2.0	-0.038	-0.071	-0.052	0	0	+0.038
2.5	-0.042	-0.080	-0.058	0	0	+0.042
3.0	-0.048	-0.085	-0.063	0	0	+0.048

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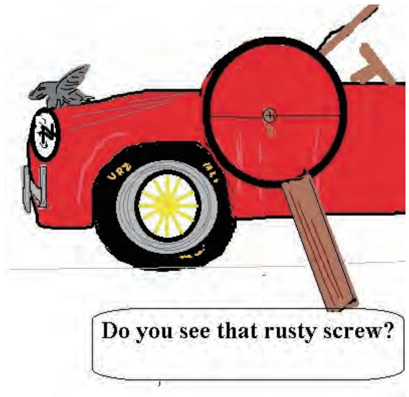

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0.45	-0.020	-	-0.035	0	0	+0.020
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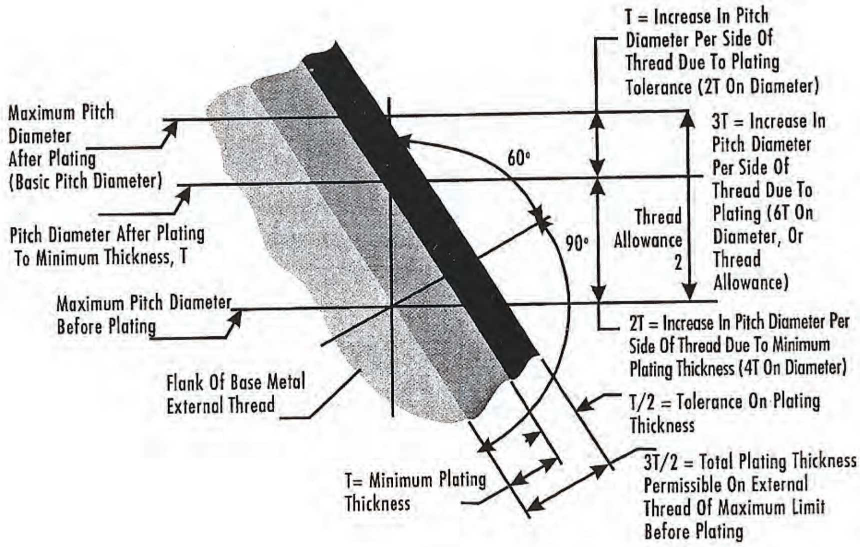
The standard class for 90+ % of fasteners is 2A (inch) and 6g (metric). The standards read "For Class 2A threads with coating (plating) the maximum is increased by the allowance, to the basic size. This is the same value as Class 3A". Per ASME B1.1 "Only in class 2A threads is the allowance available to accommodate coatings. …size limits for standard external thread Class 2A apply prior to coating. The external thread allowance may thus be used to accommodate the coating thickness on coated parts provided that the maximum coating thickness is no more than one-fourth of the allowance."

So what have we learned? Thread dimensions have a range. Standard classes of bolts are allowed an extra bit of space to accommodate coating thickness. Nuts also have a plus and minus dimension but they don't get any extra room. The coating/plating can only be one-fourth of the allowance.

Now what does this have to do with Undersizing? Most standard platings, zinc electroplate, cadmium electroplate, dichromate treatment, phosphate and oil, some paints and dyes all fit into this allowance restriction. That is, the old standard platings. These, unfortunately, did not hold up to the required corrosion resistance requirements. Increasing the thickness of coatings for increased corrosion resistance pulls their thickness into interference fit ranges (remember, only ¼ of allowance can be used for coating!)

To meet today's requirements many of the high corrosion resistant coating are based upon a formulation of a metallic paint (usually zinc or aluminum dust or flake) and various topcoats and additives. The coating is applied, simply, by dipping a bucket full of parts into the paint solution and spinning the excess metallic paint off at high speed. Then the parts go into an oven bake. A second coat or a top coat may be added, depending upon the corrosion life specified. While the coater is required by the customer to coat the part with xx mm of coating to meet yy hours of salt spray or other specified test there is no way that the exact thickness can be met or even tested consistently. The coater will coat the parts but will disavow any certification as to maximum thickness. Although the OEM (customer) knows this they really don't wish to change anything and end up playing the coater against the plant complaints of poor and tight fits, recess fill, threads filled with excess metal, inspection documents, etc.

Added to the problems is the fact that there is no allowance for coating on the internal threads. Since both parts are being coated with a thick coating the allowance is easily used up by the bolt threads alone. The "Rule of Six" explains the stack up dilemma.



Since the thickness of the coating deposited on the flanks of the thread results in a flank diametral displacement equal to four times the plating thickness (the thickness is added to north, south, east, and west sides of the part) it seems that the thickness that could be added is limited to a maximum of ¼ of the alliance (remember above the comment in standards about one-fourth of allowance for coating). However, the coating thickness must allow for a working tolerance for the plater to ensure that the maximum thickness does not exceed the limit. A tolerance of 50% of the thickness has been determined as reasonable. Using this yields a permissible total plating thickness of 1.5 times the minimum or "3T/2" as shown in the illustration above. This means that the coating should not be more than 1/6 of the allowance.

How thick are these modern coatings? Who knows? To avoid rejects in the corrosion cabinets the plater will put on a thicker thickness than specified to avoid the possibly of a reject. The short table below shows the maximum thickness (allowance added) that a thread pitch can accommodate. Thicker than this is an interference fit (and plant jams, low torque potential lose parts, and so on and so on). And remember this is only on the bolt. Where is the clearance for the nut? (not here!)

Thread Pitch Per Inch	Metric Thread (Approx.)	Maximum Thickness (Inch)	Metric Thickness (Approx.)
32 or less	0.6	0.00015	0.0008mm
30 to 13	0.8 to 2.0	0.00020	0.0050
10 to 5	2.5 to 5	0.00030	0.0080
Greater than 5	Greater than 5	0.00050	0.0130

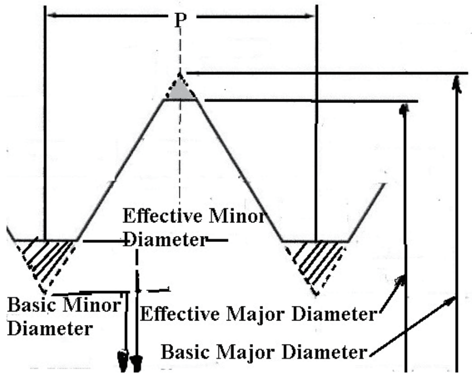
Most zinc based dip/spin applied coatings are not controllable to any fine degree and specifications for these types of coatings list the thickness as a "typical" value (usually about 0.001" or 25 microns. The actual thickness can vary from as thin as 12 microns in some areas to as much as 60 in others (0.0005" to 0.0025").

Many engineering plating specifications have a statement embedded somewhere that says that the parts may be produced undersized/oversized (before coating) to accommodate the coating thickness providing the finished product (after coating) meets all the specified properties. Since no one can tell at what point the strength of the part is compromised by what amount of undersizing/oversizing, most manufacturers just ignore this point. The manufacturers do not wish to get involved much with several identical parts with the varying dimensions, the plants will certainly mix up identical size parts, and there is no effective way to gage parts with the thick paint metallic coatings. One way that is used is to make the parts to the low end the dimensional range and hope that the parts will fit together. Plant tooling will force them together but it worries the engineers that torque is lost in overcoming the friction of the parts mating that should have gone into tensioning the joint. The tooling will either force them together or will peel off part of the coating, losing the reason for its existence in the first place. If the maker would manufacture the bolt to a "e" fit (0.063 external from chart above) and the mating nut to a "G" fit (0.028) there is a chance that the parts could possibly fit together better. However, coordinating two different makers and getting agreement to make a non-standard thread class is very slim.

Is this all hypothetical? Let's take a M8 x 1.25 bolt as an example. The "typical" coating thickness is 25 microns thick (assuming that they actually did coat it to that value). We are allowed 0.028mm for coating allowance. Rule of Six- the coating will increase the diameter by 6 times this amount (4 x 0.025mm = 0.100mm thick, 6 = 0.150mm). The nut will also have some thickness so these parts will not assemble easily, if at all, on the assembly line.

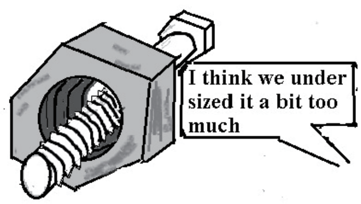
Since the thicker coatings are now a 'done deal' today what are the negatives to downsizing? First is the question of loss of strength. Using a M8 x 1.25 Grade 8.8 bolt for an example- the yield strength value is 18.75 kN (TSA x Stress [MPa]). If the part is undersized the 'typical' 25 microns and using the Rule of 6 for coating thickness here we get 17.83 kN minimum yield strength[1]. How much the loss of a kN would mean in a joint is uncertain. However, today's requirements for weight savings has led the designers to use smaller bolts, tightened to higher preloads (that is, tightened to nearer the yield point than before). Maybe that one kN is important!

Secondly, manufacturers do not like having to make and handle different classes of the same part. While they may be making the same size bolt for several customers, the problem of mixing, cross contamination, plating company mix-ups (most makers send their parts out for coating), and excessive time and cost to set up a different class fit on the thread formers (it takes about one hour to take down and about 6-8 to set up a new part) is addressed by ignoring the requirements and either 'no quoting' or stating that the parts will be to standard dimensions. Also, the customer often will not allow any cost increase for the special fit specification.



Thirdly, the plants may mix-up the parts, especially if there is little difference between standard parts and the special coatings. Another common occurrence is that in cases of part shortages on the assembly line the plant will use whatever fits the hole, regardless of finish.

In summary, oversizing has been the outcome of the demand for better corrosion resistance on fasteners. Like the opening statement, one step forward often entails a half step back, as usual. It seems that every advancement in producing a better or safer product usually leads to new difficulties. The solutions tried so far by the industry do not seem to have been very effective. Many of the new specifications have a statement embedded somewhere saying that the parts may be produced undersized/oversized (before coating) to accommodate the coating thickness, provided the finished product (after coating) meets all specified properties. Since no one can tell at what point the strength of the part is compromised by the undersizing/oversizing, most makers just leave this point alone. Another 'save your neck' phrase often found is "must meet 6g after plating".



The final point that has been mentioned before is that there is no allowance for the matching internal threads. If the coated bolt thread exceeds the allowable tolerance and will cause hard assembly or even jamming, what will happen if it is mated with a nut with the same or similar finish? Since many of the new finishes are applied by the dip/spin process it can be imagined that the amount of coating that nestles in the internal threads spaces would be greater than the amount on an external surface, harder to spin off, and settles back into the valleys (roots) to form fused chunks. The baking process will make these into metallic, fused chunks welded to the thread.

Maybe we should consider the Rule of 6 to be changed into a Rule of 12 for mating part joining!

This means that the allowance for our M8, from above 0.028, could only be used for platings 0.0023 thick. AND that is only if the parts are really 'typically' 25 microns thick. Since the plating thickness is usually measured on the flat of the part, the actual amount of thickness on the threads, tips, roots, etc. is up to anyone's guess. And we haven't even considered recess fill and its impact on driving.

The final answer? Since the requirement for increased corrosion resistance is here to stay and undersizing does not seem to work well with the current crop of coatings, a search for a thinner coating with high corrosion resistance seem to be the direction that current users are taking. Various combinations of zinc nickel and cobalt nickel electroplates have done well without excessive thickness. Let's all cross our fingers and hope for the best.

[1] We used the effective major diameter (7.188 minus) in our calculations. The basic diameter is for a full thread profile which does not exist in the real world. Once again the tables are wrong.