

TORQUING METHODS

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At some point in the late 1990's, BMW changed their method of tightening Oilhead cylinder heads from the traditional direct torque method to the angle method (and there are lots of other methods too). I think you are better off using the old method and have said so in chat groups. This has resulted in incredible nastiness being heaped on my head despite the obvious facts that (1) the old torque method is successfully used on every other bolt except the head studs and (2) nobody claims that one method is actually more accurate in the sense of average target force.

So this write-up is an effort to explain why the angle method should not be applied uncritically and under typical shade-tree conditions, the torque method is better. Again, I'm thinking only about home fixers who are "torquing" and "re-torquing" their heads — the incorrect (but revealing) name routinely used to mean, "tightening." How things are handled in factories or even shops that clean all threads with acetone before torquing is another matter.

While my experience with BMW boxers extends to 42 years, I am not trained in engineering. So, while the outlooks presented here are my authentic beliefs and practice, no one should take them as their practice without care. But as you will see, some of my reasoning is based on human factors¹ considerations (in which I am a specialist) and engineers tend to be very poor at understanding and properly addressing these (which should be pretty obvious). Likewise, I am concerned about the messy realities of men and women making decisions that could result in expensive mistakes while fixing old bikes of uncertain provenance².

What is tightening ("torquing") and what are the methods?

You need to clamp the cylinder head tightly on to the cylinder so that neither gases nor liquids escape the joint, even with a gasket in the joint or the gasket itself may destruct. But if you clamp the bolts too tight, they may break or worse, their place of attachment on the main engine body casting may break. BMW does not make the margin of safety between these two forces (between too loose versus "too bad") large enough because catastrophic breaks (as well as smaller failures) do occur now and then. But ignored in the discussion are the practical operational issues like the inadvisability of fooling too

¹ In the US, also known as "Engineering Psychology."

² I am talking about shade-tree mechanics (in urban settings, also known as curbside mechanics) and addressing cylinder/head studs. These are pesky and troublesome fellas that get loose from time to time due to the explosive pressures on them. There are other bolts that are spec'd to be tightened using the angle method. These include con-rod and other deep-inside stuff. The deep-inside bolts are not the ordinary world of shade-tree mechanics and are handled in sanitary, well lit, and otherwise controlled circumstances.

much with gasket and bolts and the risks faced each time you mess with a cylinder head. These risks, while not addressed in detail below, are a whole lot more of an issue with the angle method because you need to undo the bolts each time you pull 'em tight again.

The torque method

For perhaps 200 years, workers have been applying reasoning attributed to Archimedes to tighten two parts together to the desired clamping force. Ideally, you have a nut on a screw thread: that is essentially an inclined plane³. If the pitch of the plane is 1/200 of a foot for each 360-degree turn of the nut, when 35 foot-pounds are applied to the nut, there will be 7,000 pounds of clamping force. Simple and direct: you measure the torque specified by the manufacturer and you get the clamping force. That's it.

There is no shortcoming to that model except for determining the degree of friction. Therefore, manufacturers have to take friction into account; so they specify whether the torquing is to be done oiled or dry. The potential problem is not the presence or absence of friction (since you can specify torque either way just fine), but the degree of stability and predictability of that friction. Routinely, dry is specified. If the home repairer notes or feels any lubrication on the threads, they *must* tighten to a lower torque than specified to achieve the same clamping force if the torque was defined for a non-lubricated thread in a nice clean factory.

The angle method

The angle method is not based on anything as ancient as the Laws of Archimedes, but based on principles maybe just a few centuries old like Young's Modulus and Hooke's Law. It is based on the premise that when you stretch a metal stud a certain specified amount, it pulls back with a force you can establish by prior testing and/or look up in a handbook of metals. While not a force measure of clamping force like the torque method, never the less, the line of reasoning is unassailable if somewhat indirect and assumptive.

The angle method has two steps. First, you get the parts snuggled-up and establish a kind of base line for what follows. Exactly as with the torque method, you therefore tighten to a given spec say, 15 ft-lbs. Next, you follow directions like an automaton by tightening the nut the specified number of degrees, say 180-degrees. This stretches the stud the exact amount specified. As determined by the pitch of the thread, if you turn the nut 180-degrees, you will stretch the stud half a pitch or possibly 1/400 of an inch... which is a lot of you are stretching a 1 cm steel rod.

³ About precision micrometers, my trusty 1954 Starrett micrometer (and those since) does not use the angle method. Rather it uses the ancient torque method (albeit inversely by detecting break-away torque) on the friction thimble to ensure consistent readings.

There is no logical shortcoming to this model, provided all the assumptions are met. But let's say you are at home eyeballing the cylinder studs while sitting on your little work stool. A person could have some real questions about the angle method assumptions. Such as:

1. What is the condition of the stud? What heat has it been exposed to, times previously stretched or overstretched, condition of the threads or burrs, and other issues as to similarity to the original state of the metal and Young's Modulus today?
2. What is the state of the gasket and how many times has it been squashed, how long, and so on? For sure, the squishing it gets from the 15 ft-lbs and then the angle squeeze are very different than the thicknesses and squeezes in play when you re-torque the gasket already in the gap?
3. What lubrication is present on the threads? Did any speck of oil get in there while I worked or while any previous person worked... or did somebody loosen it enough to change the vertical slop on the valve lifter mechanism and let some oil in? And so on.
4. What influence does it make to do one stud at a time or pre-snug all first or do them 90 degrees then another 90 degrees or what?
5. And perhaps of greatest importance, when I try to establish that 15 ft-lb baseline, how much can I trust that I am on-target and not 15- or 20-degrees off the mark because that could be disastrous when cranking in the next 180-degrees?

There are a lot of unknowns there. Indeed, there are some "knowns" present that suggest you better modify the angle method for your particular instance. With the torque method, the means of adjustment for lubrication on the threads is pretty self-evident and you don't need an engineering degree and a handbook of metals to have good intuition about what to do.

However with the angle method, it isn't obvious at all how you should change the angle if the threads are a bit oily and so making the baseline 15 ft-lb setting, you torque wrench sailed past the usual baseline referent⁴. In that case, you have clamped extra tight (as with the torque method). But on the other hand, your torque wrench sailed past the spot where the dry factory torquing would have been. Should you add a few degrees or subtract them? Some of the assumptions are like those of the torque method because the initial snug-up is done using the torque method, but then there are *additional* assumptions (and hence, unknowns) on top of those.

⁴ Of course, you'd be completely clueless about all of this if you used a clicker, like an automaton, instead of a beam torque wrench that you have to eyeball all the time.

First, a joke from Mark Twain

They asked Mark Twain if he believed in Baptism. "Believe in it," he replied, "why I've seen it done."

Well, as far as the two methods go, you can *believe* in either because you can *see* either one done right on YouTube. With a clicker torque wrench and the little protractor device being sold to facilitate accurate angle torquing, you (or a robot) can do both steps of the angle method with your mind entirely disengaged (and that's a serious shortcoming of the method... outside of factories perhaps where no one's mind is engaged).

Occasionally and with either method, you ultimately know there's been some damage (if too tight) or some leaking or a blown head gasket (if too loose). But only a research lab would know if the clamping forces are correct. So there's no immediate feedback on your torquing performance unless a major break occurs.

What's deficient about the ancient torque method? What makes some people furious when asked about this long-recommended and intuitive procedure?

Over at Pelican Parts, the moderator⁵ thought it was insensitive of me to suggest the 200-year-old method might still be applicable. He provided the following characteristic invective: "... quit offering really really really really really really bad advice and uninformed truly spurious and baseless random musings." I would certainly be ashamed to offer fellow riders "really really really really really really bad advice," and so looked for some support. Or at least evidence that my point of view would not result in instant destruction of an engine.

Joe Dille, one of the most respected BMW wrenches, has a series of three articles on torque and fasteners. He prefers the angle method. He says in his reading on the subject that the ancient method is +/-25% accuracy (which he verified in some interesting home tests of his own) and the angle method +/-15%. Yes better, but few people would consider that a night-and-day difference when you get down to it. Maybe for others, 10% is equivalent to "really really really really really really bad advice." This is addressed below again⁶.

Remember, Joe is talking about a statistical variation, not a specific stud. Sometimes both methods will be precisely accurate. No one says the torque method doesn't hit the mark on average and is on-target most of the time. But sometimes, either will be off. The ancient method will be a more off and more often but the "central tendency," to use the

⁵ Why are there no distinguished wrenches on PP, Roger aside, possssibly? Many boards have lively contributions — even debates!!! — with famous wrenches. But on PP, only one Voice of Final Authority. Ummm, do I smell fish?

⁶ Actually, seems more of a psychiatric therapy issue. But I am just a human factors psychologist. Pity.

proper term used by statisticians, will be correct. It does not mean the wrench will always read 15% high or low or that the angle method will always be closer than the ancient method. It is just that readings will vary sometimes and they vary more with the torque method.

These findings arise from lab or even semi-realistic testing set-ups. While I have a lot of respect for the challenges of doing good research in realistic worlds (it is what I happen to do for a living), it may not be taking into account the particular realities you face sitting on your little stool facing the studs with an unknown history of stretching and with a pre-squashed gasket in the gap that you would really not like to loosen once again.

Color sidebar: Joe also did a bunch of tests on a dozen torque wrenches. Of those wrenches he borrowed from around his neighbourhood, the best clickers and the best beams were about as accurate; likewise for the worst about as inaccurate. On average, similar with a slight nod to the clickers. A friend with a recently calibrated clicker found that my old beat-up beam torque wrench was spot-on (that kind of test is pretty easy to do). However, all a clicker says to you is "click" while a torsion beam gives you a world of tactile information as you snug-up. As you can probably guess, as a human factors psychologist, I strongly favour beam wrenches for people who are sober and awake but clickers for those who aren't.

Back to a person sitting on their little work stool facing the old cylinder studs. What should he or she do? He could say, "Well, 15% accuracy seems a whole lot better than 25%." So he would undo all his studs and, hoping for the best, go to a fair amount of trouble and risk to apply the angle method. Remember, you can't do the angle method unless you undo all the studs. Right? Lotsa trouble and not something to be undertaken casually.

Or, he could simply put his beam torque wrench on each nut and advance up to say 35 ft-lbs. If any nuts start turning before 35 lbs, he can then just snug them up to 35 lbs while the torque wrench is still sitting on them (pretty easy, maybe lazy). Or he could decide at *that* point he really likes that extra 10% accuracy, and undo all the studs, etc., etc., etc.

Even if he uses the angle method, I suspect it would still be judicious of him to double-check that the studs aren't loose by seeing if they are at least, say, 30-35 ft-lbs. Can't hurt?

I don't agree with Joe about angle being better based on my experience applying it. When I snugged-up to the rather light 15 ft-lbs preparatory to using the angle method on my studs, I found my wrench was *way* all around the place, any place within an arc of maybe 60 degrees or more when it hit "15." But I sure wasn't stupid enough to crank another 180 degrees because I could be ending up at 240 degrees at the tightest or 120 degrees at the softest and I don't know if that includes the +/-15% tolerance and other errors of man or machine. That much potential error is enough to give a stud a terminal disease.

For sure, the angle method (and a whole bunch of newer and better methods used in factories and in robot fabrication) is better when the assumptions underlying that approach hold. If we are to believe Joe Dille, it is better but only because there is 10% less statistical variation not greater average accuracy-on-target (that's a loose way to

describe it, but OK for now). Not to mention 200 years experience of doing it the old way. Hardly the kind of trivial improvement proportional to the kind of vitriol I'm getting.

Some have suggested doing the angle method in several passes of upping the angle, just like the torque method. While this helps the angle method in avoiding putting all the force of clamping on the first and second bolts torqued, it does nothing to improve the accuracy or safety otherwise of the angle method. You are still mindlessly winding the nut ultimately to 180-degrees... unless you gained or lost a few degrees in the multi-stage stretching.

What's better about the ancient torque method?

Basically, the torque method is a direct application of force and so makes direct sense. But the angle method is more a matter of faith.

Many times I've done the old round-robin ancient torque method. You go to 15 ft-lbs all around, then 25, then to spec, each time noting how much tightening is needed on each stud, bolt, or nut, taking into account whether they are oily or not, is it a new gasket or already squashed, and other subtle factors. The important point is that your mind is engaged in what you are doing.

One important factor relating to human maintenance should be patently obvious: you can always be sure something is lubricated but not always sure it is clean and dry. Therefore, you can always adjust the torque method with some good judgment. But you will still be perplexed about what to do about the angle method since you have no way to know the relationship of the first 15-degree snug-up to the later stretch.

Likewise, my intuition is that when you are working with serious machinery and strong forces, tightening to a milquetoast 15 ft-lbs is pretty variable and unreliable, as I've noted above.

Like with digital speedometers that hide rather than reveal the passage of movement, the angle method removes the person from the process and substitutes a more automaton-like method. That's a dangerous way to work when fixing fine used machinery. Ever met anybody who likes digital speedometers?

If you use the angle method, be sure to turn that last angle using a beam torque wrench so that you'll have some idea what the torque reading is.

A person has to think about tightening heads statistically - that's the nature of variables of this sort. First, there is the average result. No one claims that the angle method produces more accurate results as far as average accuracy.

Second, there is variation in hitting the target. The angle method is better here than the torque method although if Joe Dille's write-up (cited in my write-up) is to be believed,

the difference is a mere 15% for the angle method and 25% for the torque method. Not the kind of difference that should generate the fierce name-calling seen in this thread.

The core problem is that BMW compromised (or felt pressured by the challenges of air-cooled design constraints to compromise) on the safety margin of the cylinder studs. It is a tricky design balance for all manufacturers and heads but less critical with water cooling. With a large safety margin and in the perfect world, there would be lots of room for tightening the gasket without ever stripping the studs.

That is why, I am guessing, the angle method has recently become the standard spec for the cylinder studs... and nowhere else among the dozens of other bolts on the bike (some being life-safety related). Because there is a bit less variance, there is less chance that an aberrant high torquing will strip the stud or engine casting because there are fewer high events.

All I am saying is that the angle method is fine, even superior often. But for a shade-tree mechanic, the bulk of judgment should favor using the torque method because it puts person and machine in better harmony.

BTW, there's a fifth head bolt, a short one, which clamps a corner of the head gasket near the timing chain hole. Funny, it has a torque spec, not an angle spec, eh? Ummm. What could that mean?

Even funnier, in that in the flood of invective from experts, nobody has mentioned that there happens to be no torque spec for the four cylinder studs! But BMW does have a generic spec for bolts of different sizes that could be applied to the studs.

Notes

1. A respected person posted on the Big List the view that many stripped threads resulted from the use of the old method and so BMW moved to the angle method.

There's not much different in operational practice between the two methods — at least not when it comes to the crucial aspects really. Let me try to characterize them so as to bring out the similarities and differences.

They start the same: you crank in 15 ft-lbs. With the angle method, you next crank in 180-degrees like an automaton (sometimes in two steps) and you are done. With the torque method, you may take another step or two, but you end at the chosen value, all the while working carefully with a beam torque wrench and noting conditions, as described previously.

The essential question is which method lives or dies fastest by failing to live with its assumptions. The angle method makes more assumptions. They share an assumption about oil vs. dry. If you are using the pay-attention-torque method, you are paying a lot of

your human attention to the state of the threads. But if you are using the automaton method.....

Yes, some inexperienced person who didn't know that you need to lower the torque criterion when the threads are oily (aren't they always?) will crank in 35 ft-lbs and SNAP. But what happens with the angle method? The inexperience and the experienced person will crank in 15 ft-lbs and then 180 degrees and then SNAP.

2. But we really got to stop speaking statistical gibberish. In my previous post, I tried to say that the angle method is "more accurate" but only in the sense of having less variation. I can't tell if Roger is now using "accurate" in that sense or not?

As a matter of fact, it is kind of gibberish to say that a defined method is "off target." A defined method is always on target on average. Both methods will always put you on target on average.

About variation, it matters. But it is gibberish to use terms like "+/- 15%." If you want to say something that actually says something, you must say something a little more complicated. You can say, "95% of the time, the clamping force will be within +/-15% of the desired value and 2.5% of the time it will be further higher." If you know what "two standard deviations" means, then you know what I am talking about.

3. The goal is to have good firmness — it is pretty essential to keep your wheels on if you plan to arrive alive. But you can achieve the same firmness dry or lubricated although you need a lower torque criterion if lubricated... as everybody knows. The difference is very much like the various reasons I give above for favouring the torque method. Plus one important consideration: some dark, wet night, you will want to remove that wheel if it goes flat. Don't phone me at that point and say, "The lug nuts won't come loose because I torqued them when without lubrication."

4. My thanks to Bernie and Steve O for taking time to react to this write-up. I will be laughing out loud when BMW starts using the superior *yield control tightening* method and people will be saying that advocates of the then ancient angle method are total fools.

5. I am less appreciative of the fellow who blasted me for aiming for correct spelling — he thinks that is falsely seductive and evil or something like that. I think correct spelling and careful editing shows respect for the reader.

Extra free footnote

In some respects, human factors psychology is worldview that influences practices whenever people and machines or computer systems mix it up together. To illustrate, think of the lug nuts that hold wheels to your car or in the case of single-sided rear swing-arms, on bikes too. The conventional wisdom is to torque them (good old standard torque method, eh) dry. Always dry. Universally recommended dry. Doesn't seem wise.