An experiment in proper torque

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I AM THE KIND OF PERSON THAT holds a grudge. I'm not proud of it, but it's part of my character nonetheless. There's a gas station I won't go to in Dale City, Va. because a clerk there insulted my girlfriend – in 1990. I didn't even marry that girl. Luckily they never have the lowest prices around.

Background

Given my ability and willingness to hold a grudge, it may not surprise you to learn that I'm still fuming a little bit over the rear wheel flange recall, especially the part where I feel like BMW Motorrad shifted the blame for the problem (assembly, rather than construction – but that's an exploration for another time) onto dealer technicians and BMW riders who perform their own maintenance.

To refresh your memory, here's a quote from the recall notification published by the National Highway Transportation Safety Administration (NHTSA): "In the affected motorcycles, the rear wheel mounting flange may crack if the rear wheel mounting bolts are over tightened." Maybe it's just me, but I find it just a little insulting that BMW assumes I can't use a torque wrench.

I did start thinking, however, that maybe they have a point. I'm sure no qualified technician would mount a rear wheel without properly torqueing the mounting bolts, but I have to admit that it's a lot easier to spin the bolts on "gudentite" when you're sitting on the floor of your garage (or on the side of the road) and the torque wrench is out of reach – or not even around.

Thesis

The hypothesis that emerged – one that would support BMW's assertion that the problem with the aluminum flanges is due to user/technician error rather than the engineering of the part or factory assembly – is that human beings cannot tighten a fastener to a given torque point without an actual torque wrench. I made the assumption – again to support BMW's position on this specific recall – that humans will over tighten fasteners if they don't use a torque wrench.

Testing

I gathered eight people for this experiment:

- Myself – 45-year-old male, 20 years of riding experience, and enough confidence, skills and tools to perform most regular maintenance tasks on my BMWs ('05 R 1200 GS and '98 K 1200 RS). However, I go to a mechanic for difficult things like replacing the rear wheel flange. I functioned as the "untightener" for this experiment, using a beam-type torque wrench to measure how much force (torque) it took to loosen the bolts we tested.
- Sunday – 42-year-old female that doesn't ride motorcycles, but has experience with fixing things around the house (including the use of power tools).
- Kurtis – 37-year-old male with 11 years of riding experience. He claims "minor" wrenching experience – oil changes and the like.
- Katie – 34-year-old female with three years of riding experience who does no wrenching at all. She is, however, an electrical engineer with a solid knowledge of mechanical matters.
- Dave – 46-year-old male with 25 years of riding experience. He's restored a vintage BMW and works on his own bikes regularly.
- Kermit – 52-year-old male who has been riding since age 5. He has his own motorcycle lift and a lifetime of practical mechanical experience that he's not afraid to use.
- George – 45-year-old male with 25 years of riding experience; he makes his living as an independent motorcycle mechanic and has worked as a master technician at motorcycle dealers as well.
- Greg – 50-year-old male with 25 years of riding experience who does "a little" routine maintenance.

I chose the settings to test, and George determined the best fasteners relevant to BMW riders to test them on. The valve cover bolts on a K 1200 RS engine should be tightened to 9 Newton-meters (Nm), but since we were using a blown engine, we tested it to 10 Nm. The front axle pinch bolt on an R 1100 RT goes to 22 Nm, so that was perfect to test 20 Nm. The front brake caliper mounting bolt on the same bike goes to 40 Nm. The rear wheel mounting bolt on an F 800 S goes to 60 Nm, and this is the same bolt and torque specified on many of the motorcycles affected by the recall. This specific motorcycle was built outside the recall range, so it has a steel flange already, but the torque spec is the same. Finally, the rear wheel mounting bolts on the RT go to 105 Nm, perfect to let us test 100 Nm.

We used a variety of standard hand tools (ratchets, Torx and hex sockets, standard sockets, breaker bar, etc.) for the testing. We used two types of Snap-On torque wrenches, one that is a typical "clicker" wrench that gives a physical indication (a click you can feel through the handle) when you reach the torque setting, and another with a split-beam mechanism that gives an audible click, but offers no physical feedback when you reach the torque setting. Both of those wrenches retail for about $300. The wrench used to test release torque was a CTA beam-type torque wrench that cost about $25.

The test procedure went as follows:

1. Each participant except Greg and George used a torque wrench to tighten the fastener to the appropriate torque to get an idea of what the appropriate torque feels like. I loosened the fastener after each test.
2. Each participant used a standard ratchet wrench (or breaker bar for 100 Nm test point only) to tighten the fastener to what he/she believed was the appropriate point.
3. I used the beam-type torque wrench to loosen the fastener, noting at what level the fastener started to come loose. The CTA torque wrench is calibrated in Kilogram-meters (1 kg-m = 9.80665 Nm), so I wasn't able to tell each participant how well they did as we went along.
4. We started at 10 Nm and proceeded to 20, 40, 60 and 100 Nm.
5. We rode to lunch – of course!

One thing we determined that we couldn't test or allow for is that it takes a little more torque to overcome a fastener's grip than the specified torque for tightening the fastener. For example, if a bolt is tightened to 100 Nm, it must take at least 100.1 Nm to loosen the fastener. We neither collectively knew nor was I able to find through research a formula to account for this, so our experiment must be taken with a grain of salt. By having just one person doing all the loosening, we at least minimized any variances in "break-free" torque that could have come from different strength levels or techniques had we used more than one person to loosen the fasteners.

The results for each target torque were as follows, in the same order as the participants are listed above:

- 10 Nm: 10, 8, 5, 5, 6, 5, 8
- 20 Nm: 15, 20, 13, 10, 10, 12, 18
- 40 Nm: 21, 20, 30, 28, 28, 40, 38
- 60 Nm: 60, 40, 44, 37, 47, 48, 41
- 100 Nm: 110, 96, 98, 103, 106, 118, 74

What is Torque?

When it comes to motorcycles, there's two ways we use the word torque, and they're both related to force.

The first way we talk about torque and motorcycles is usually relayed alongside horsepower. For example, my 2005 R 1200 GS left the factory with 100 horsepower (hp) when the engine runs at 7,000 revolutions per minute (rpm) as well as 115 Nm of torque at 5,500 rpm. Horsepower is actually a function of torque, but that's a discussion for another time.

The other way we talk about torque is when we need to know exactly how tight to go with a fastener.

No matter which way we're talking about torque, it's all about twisting force being applied to something. In the case of 115 Nm of torque at 5,500 rpm, it's the twisting force being laid out by the crankshaft – and thus applied to the driveshaft. In the case of the 60 Nm specification on the rear wheel mounting bolts on my GS, it's the point at which the engineers (and all the science behind what they do) say "this bolt is tight enough that, given the materials it is made of, passes through, and connects to, it can be expected to stay tight under nearly all circumstances."

Top to bottom: beam-type TR, split-beam TR, Snap-On click micrometer TR, Craftsman CM TR, 1/2" breaker bar (for perspective – it's 15" long)

George, our professional mechanic, and Greg, our "control," were the only two participants who didn't test each fastener with a torque wrench to get a feel for the appropriate tightness at each test point. Greg consistently under-torqued on his turn, just barely at lower levels, but far more significantly at the two highest points. George under-torqued three settings as well, but nailed 40 Nm and over torqued by nearly 20% at 100 Nm. Our most accurate participant was Sunday, who has never worked on a motorcycle in her life, but fixes anything and everything around the house; she hit 10 and 60 Nm exactly.

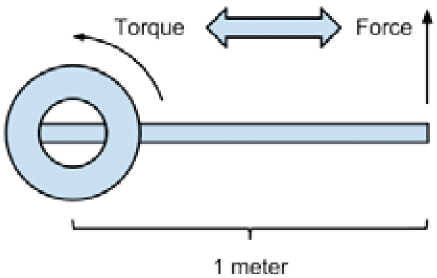
Forty Newton-meters seemed to be the most difficult to gauge, with five of our seven participants falling at least 25 percent under spec. Two of them were 50 percent under spec at this test point.

With the exception of the attempts at reaching 100 Nm without the aid of a torque wrench, nearly every participant under-torqued every fastener; only one participant hit torque marks precisely at 10, 20, 40 and 60 Nm. Nobody hit 100 Nm, but everybody was pretty close with the exception of George (20 percent over) and Greg (25 percent under).

Conclusion

In general, we humans were more likely to under-torque a fastener than we were to over-torque it, at least at lower specs. The only time the participants went over the specified torque at all was at the highest spec, 100 Nm.

My conclusion in this semi-scientific torque targeting experiment is exactly what I thought it would be when I set out on this path: It is always better to use a torque wrench when working on your motorcycle. The result that surprised me, though, was that the participants were more likely to under tighten a fastener than they were to overtighten it, something that seems to fly in the face of BMW's assertion that the flange cracks are somehow the fault of dealership technicians and shade-tree mechanics all over the entire world.



From a statistical standpoint, we measured 35 data points. Of those, only four resulted in torque values above the target point. This is a failure rate of 11 percent. Given that I have had two flange failures (a failure rate of 66 percent – two out of three), I find it disingenuous that BMW implies that it's my fault that my rear wheel flanges developed cracks. I also can't explain (yet) how over tightening the wheel bolts causes cracks where the brake disc mounts. I'm working on that, though, and hope to have a follow-up article about it soon.

We joked with George, our pro, that he would probably be the most accurate since he has spent over half his life working on motorcycles. He replied that he didn't need to go by feel because he always uses a torque wrench. This is sage advice well supported by this experiment. When you work on your motorcycle, always use a torque wrench. Quality torque wrenches can be had through many outlets, and don't be afraid of a beam-type torque wrench. Though they are low-tech feeling and looking, they never need calibrating and can be used both to tighten and loosen.

Once I had the data we needed, we tested a couple of other things. We discovered it took just 30 Nm of force to strip the K 1200 valve cover bolts (10 Nm spec). We also discovered that it's nearly impossible to get the rear wheel mounting bolt on an R 1100 bike to the proper torque spec (105 Nm) using just the BMW-supplied tool. We agreed that Greg was probably the strongest among us, and using just the lug wrench from the stock tool kit, he could only get those bolts to 78 Nm using all his strength and leverage. Using the extension tool supplied in the stock tool kit allowed most of the participants to torque those bolts to near the appropriate spec, though.

What the Hell is a Newton-Meter?

Science is hard, and a lot of that we can blame on Isaac Newton. After all, he invented both physics and calculus. He got this measurement of force named after him due to his Second Law of Motion, which states that Force equals Mass times Acceleration (F = ma).

When we're talking about crankshaft torque, a Newton is the measurement of how much force is required to accelerate one kilogram of some mass to a speed of one meter per second squared. In other words, 1 N = 1 kg * m/s2.

When we're using a torque wrench, however, we're not measuring speed, we're measuring rotational force. In that instance, picture an arm one meter long; a Newton-meter is the force of one Newton applied perpendicularly to the end of that arm. This is one of the reasons torque wrenches are different lengths – leverage affects force, so the length of the torque wrench has an effect on how that wrench measures torque.

Types of Torque Wrenches

The oldest, simplest and cheapest torque wrench is a beam-type one. There are no moving parts and it never needs calibrated. As long as you don't break it, it can last a lifetime. They require a little finesse to use and they're not the easiest to read; after all, it's just a pointer hovering over a scale. They don't ratchet, and they're usually long (for better leverage at high torque requirements), so they can be awkward to use. Another con of a beam-type torque wrench is that they're only as precise as the scale printed on them; they may go 10-20-30 Nm, requiring you to estimate where 22 Nm actually is.

The torque wrench that's probably most common among shade-tree mechanics is the click micrometer type. When you use the wrench and reach the desired torque, the force you're using overcomes an internal mechanism (under tension from a spring) and you feel and hear a "click!" as the wrench moves. There are many different types of click micrometer torque wrenches at all different price points, but they all have the same pros and cons.

The pros are that they're easy to use and generally accurate to within a few percentage points of the target torque. There are several cons, starting with your wrist getting tired from all the twisting – you always have to reset them to a low torque or you risk damaging the spring and thus ruining the wrench. Leaving them set to zero could potentially damage them as well. Click micrometer torque wrenches need to be treated with some care; a big drop can damage the internal mechanism, necessitating repair or replacement. Another con is that to change from a higher to a lower torque setting, you need to go below the lower torque setting, then crank back up to it. If you're doing a lot of different tasks, this gets tiring pretty quickly.

A split-beam torque wrench also gives you a "click" to let you know you've reached the torque set on the wrench, but it's an audible sound rather than a physical thing. These are easier to use than the click micrometer wrenches – you just spin a little dial to the correct setting, and then lock it in with a little cover that prevents the knob from spinning again. There's no heavy spring to twist against and you don't have to remember to release the tension when you're done using it. The main downside to split-beam wrenches is that they must periodically be calibrated.

There are also a variety of torque wrenches with digital readouts, but the digital readouts are built into either click micrometer wrenches or split-beam wrenches. Personally, I stay away from these, because the digital readout is another thing to worry about – it may not be waterproof, the battery could die, the screen could crack. They're also more expensive than their analog counterparts, sometimes by a factor of two or three. The advantage of a torque wrench with a digital screen is that you can use them in darker areas. Many of these digital torque wrenches can switch from inch- or foot-pounds to Newton-meters, relieving you of having to do math or squint at markings etched into the shaft of a wrench.

Other types of torque wrenches are dial type wrenches (not unlike the beam-type wrenches, but laid out with a dial instead of a linear scale) and torque angle wrenches. A torque specification that looks like 28 Nm + 45° requires that you first torque the fastener to 28 Nm, then use a torque angle wrench to turn the fastener another 45°. There are other types of torque wrenches unsuited for motor vehicle use, such as the hubless type used by plumbers.

In addition to the CTA beam-type wrench used in this experiment, I have two Craftsman click micrometer torque wrenches. Both are 3/8" drive and marked for both foot-pounds and Newton-meters; one ranges from about 10 to about 120 Nm, the other (shorter) one ranges from about 2 to about 30 Nm.

After this experiment, I went on eBay and bought a Snap-On split-beam torque wrench like the one George has. It's much easier (and faster) to use than the click micrometer wrenches that I couldn't resist. I paid $75 for it and will probably spend another $35-50 to get it calibrated. That is at least double what I paid for either of the Craftsman wrenches, but it will be worth it to not have to twist handles all the time.