Proper Barrel Tightening Torque

By James A. Boatright

Documenting a Serious Accuracy Problem

In Chapter 6, *Barrel-Receiver Threaded Joint Motion*, of his important book, ***Rifle Accuracy Facts***; *Precision Shooting, Incorporated*; 1998, Harold R. Vaughn used laboratory instrumentation to demonstrate conclusively that both the original barrel and a custom-fitted replacement barrel of his factory-produced hunting rifle would actually point out from his test rifle's receiver in measurably different directions after each shot was fired. Harold Vaughn showed how he could predict the impact point of the next shot by analyzing data from electronic strain gauges placed across the barrel-to-receiver joint of his bolt-action test rifle chambered in 270 Winchester. With our almost universal use nowadays of receiver-mounted telescopic sights, this barrel-pointing variation can produce a *displacement* of the bullet's impact point by up to about **one inch** on a 100-yard target for the next shot yet to be fired. We have no reason to believe that this **one minute-of-angle (MOA)** maximum shot displacement, measured by Harold Vaughn for his particular test rifle, would not be typical of this entire class of rifles using mass-produced, hunting-type bolt-actions. That the threaded barrel-to-receiver joint in a typical mass-produced hunting rifle can ***move about*** during the shot and that the factory-installed barrel can ***settle at varying orientations*** up to a rather surprising **one MOA** away from his rifle's nominal zero are indeed *rifle accuracy facts* that are well worth knowing. Harold Vaughn has discovered a commonly occurring and significant accuracy problem, and his book constitutes the first mention in print of this problem that I can recall. The rest of us probably failed to uncover this very real accuracy problem because:

1) It would not seem to be a likely type of problem to occur, and
2) It seems to cause accuracy problems only in mass-produced hunting rifles, but not in precision target rifles.

Harold Vaughn's Solution

Unfortunately, Mr. Vaughn reckoned the *cause* of this significant accuracy problem to be the *barrel-to-receiver joint motion* itself. He and his team of advisors then attacked this perceived problem "head-on"—attempting to *prevent joint motion entirely* by trying several innovative techniques for *radically increasing* the barrel-to-receiver *axial clamping force*, right up to the **20,000-pound** limit imposed by the use of conventional 60-degree V-threads and the yield strength of their **130,000 PSI** barrel steel. An axial clamping force of at least **24,000 pounds** was found to be necessary to "freeze" the threaded joint and prevent all barrel motion during the firing conditions tested. Mr. Vaughn went on to show that the maximum available axial clamping force could be increased to about **30,000 pounds** by completely redesigning the barrel-to-receiver joint or by using modified 60-degree V-threads. Any of several thread modifications discussed could allow production of this greater clamping force, basically by *spreading the stress loads more evenly* over the **eleven threads** of the barrel tenon used in the **1.0625-inch by 16 threads per inch** factory-design of the threaded joint. But up to **300**

foot-pounds of assembly torque would be required to obtain this much clamping force in the threaded joint, even when using the *slipperiest* thread and barrel shoulder lubricants they could find (Teflon tape and lanolin oil).

Problems Caused By This Approach

Regarding *proper barrel tightening torque*, Mr. Vaughn and his colleagues seem to have missed the point completely. This "brute force" approach to solving the barrel pointing problem identified in a typical hunting rifle would generate truly fearsome levels of built-in stress in the barreled action without reliably yielding much success. So, Chapter 6 of his book concludes by documenting several approaches that *should not be employed* in attacking this very real accuracy problem in mass-produced hunting rifles. Mr. Vaughn mentioned that the factory recoil lug failed during one barrel-tightening session and that he had some concern about the strength of the barrel shoulder itself. But, his factory-built hunting rifle was already accurate enough for its intended big-game hunting purposes, and over-torquing the barrel would hardly seem a suitable place to start in converting it into an accurate varmint or target rifle. In any event, *we just cannot recommend ever installing the threaded tenon of a custom-fitted match barrel using an assembly torque even approaching 300 foot-pounds.*

Applying even "mil-spec" barrel installation torque of **200 foot-pounds** to a 60-degree V-threaded barrel will *compress the chamber walls inwardly* by enough to cause the barreled action *falsely to gauge several thousandths short in headspace* for typical rimless bottlenecked cartridges. [Starting with the Model 1868 Allin-designed "Trap Door" Springfield rifle, the first regularly issued U. S. infantry rifle to utilize a separate barrel threaded into a receiver, the barrel tenons of our historic military rifles have always used *square threads* to lessen this chamber distortion problem.] Chamber and cartridge designs gauging headspace against *shallower* shoulder angles are the *more sensitive* to this compression-induced gauging error. With the **17.25-degree** shoulder angle of the .30-06 chamber, for example, each thousandth of an inch (mil) of radial compression produces **3.22 mils** of gauging error, falsely showing the compressed chamber to be too shallow in depth. In fact, this gauging error itself may be the principal reason behind the recommendations by different accuracy-seeking gunsmiths that *varying amounts* (**0.003 to 0.007 inch**) *of "pre-compensation"* be *added* to the headspace dimension in chambering in order to offset supposed "barrel stretch," "receiver crush," or "pull-up" effects in subsequent tightening of the custom-fitted barrel.

If *the receiver is known to be aligned with the axis of the barrel* and one really wanted to use these high installation torques for his barrel, the chambering of a replacement barrel for a rimless bottlenecked cartridge could be done in two separate steps:

> First, one could thread the barrel tenon using one of Mr. Vaughn's suggested modified V-threads, and chamber the new barrel normally, but without "pre-compensating" for headspace shrinkage, and then install the barrel into the receiver using as much torque as one desired.
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> Second, one could manually run-in the cleaned and re-lubricated chamber finishing reamer again, *carefully stopping at its previous depth,* by using a receiver-bushing-guided T-handle with the barrel still torqued into the receiver.

> As more and more running length of the reamer's cutting edges engage the inside surfaces of the chamber being restored, the reamer will become progressively more difficult to turn by hand. And the forward, cutting pressure should be gradually reduced while the reamer can still be turned.

In this second step, the same chamber reamer used in fitting the barrel will *shave* small amounts of metal from the areas of the chamber *distorted radially inward by compression,* after which the correct *diameter dimensions* will be restored so that the chamber headspace distance will again gauge properly. Perhaps one might wish to build an actual military "sniper rifle" in this way, as opposed to the "tactical-style target rifle" that I might prefer to build.

My Understanding of the Problem

We know from experience that, for whatever reasons, the free-floating barrels of our custom-made benchrest and target rifles having ordinary 60-degree V-threaded barrel tenons *do not* seem to suffer the pointing problems that Mr. Vaughn found with the bolt-action hunting rifle used in his tests. Furthermore, we know that the barrels of these benchrest and target rifles point with *outstanding repeatability* from one shot to the next. We experience no more than a **few thousandths of an inch** of increased group size on a 100-yard target attributable to *combined aiming and barrel pointing error,* even when these barrels were installed with little more than hand-tightening torque, a practice about which Mr. Vaughn expressed extreme skepticism.

My Solution to the Barrel Joint Problem

We use less than **35 foot-pounds** of barrel assembly torque with a blueprinted Remington 700 action, and the last **10 foot-pounds** of that torque is added simply to hold the non-pinned, trapped recoil lug better fixed in its desired orientation. The small "torque reaction" from spinning-up a bullet fired in my right-hand-twist barrel is basically working to ***tighten*** the right-hand-threaded barrel into its receiver. Using ordinary petroleum-based assembly lubricants, **35 foot-pounds** of barrel installation torque produces about **1500 pounds** of axial clamping force (or just **5 percent** of the force recommended by Mr. Vaughn), which is more than sufficient to hold both a five or six-pound barrel and its recoil lug in place. ***The key point here is that the axis of the threads in the front ring of the receiver and the front face of the receiver itself must be as perfectly square to each other as we can make them***.

If a separate recoil lug is to be clamped between the barrel shoulder and the trued receiver, the replacement lug ***must*** have had its faces *hand-lapped* into parallelism to within less than **0.0002-inch** maximum variation in thickness around its perimeter. ["Dead nuts" zero variation in thickness would be even better.] For many years we have successfully used David Tubb's three-eighths-inch thick stainless steel replacement recoil lugs. For most applications, we need to mill off about a quarter-inch of the excess height of these fine replacement lugs. We also bevel all of the under-the-stock-line square edges to prevent the shaving of bedding material during re-assembly. All available aftermarket replacement recoil lugs seem to have been *surface ground*, which, due to *differential thermal expansion with the heat of grinding*, always seems to result in the heavier bottom part of the lug remaining measurably thicker than the less massive (and quicker heating) upper portion of the ring. After being hand-lapped at room temperature, the lugs should "mic" evenly enough to be mounted into a face-clamping fixture for lathe-boring to match closely the oversize tenon diameter of our custom-fitted barrel.

I do not know of any good procedure for simply squaring-up the receiver face to these visibly crooked receiver threads, nor do we really want to solve the barrel joint problem in exactly that way, so instead, we always true each of these different aspects of the front receiver ring against the bolt-way axis (after it has been straightened and uniformed) as a reference. We actually *re-cut every critical surface* inside the receiver in a process we call "*blueprinting the action*." This essentially accomplishes the *finish machining* that, as Mike Walker once argued (unsuccessfully) with the "bean-counters" at Remington, should be done ***after*** heat-treatment of the roughed-out receivers. In *blueprinting* the mass-produced action from a hunting-type bolt-action rifle, we perform the following *ordered sequence* of operations, each designed to *remove the least possible amount of steel from the receiver*:

> First, we ream the boltway to produce a *straight cylindrical* inside surface with a slightly oversize inside diameter of **0.7050-inch,** by using a strongly three-way piloted hand-turned reamer and using *select-fitted pilot bushings* in either end of the boltway. [The third pilot is the surface behind the cutting edges of the hand-turned reamer.] We start reaming through the action from the after end because this is always the tighter end of the boltway. Then we switch to a pair of **0.7050-inch** bushings and hand turn the same reamer again through the receiver, starting from the opposite (front) end, to produce a smoother interior finish and to remove some of the trailing feather edges left from the first pass.
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> Second, we use a strongly two-way (**0.7050-inch**) piloted hand-turned reamer to re-cut the inside of the front ring of the receiver slightly oversize, but *coaxial* with the newly-straightened axis of the boltway and, at full reaming depth, to *square up* and *uniform* the lug seats in the receiver for the bolt-locking lugs.
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> Third, taking care to start "in-phase" with the remaining portion of the factory threads, we hand turn-in a strongly two-way piloted **0.010-inch** *oversize tap* (**1.0725x16**) to *re-cut the front receiver threads to be concentric with the boltway*. Mechanically, the axis of the new oversize threads ***must*** be coincident with the axis of the inside cylindrical surfaces of the re-bored boltway. Aside from doing a superb job of the thread-alignment task, the piloted tap always produces finished V-form threads of consistent, and known internal diameter. No tedious and time-consuming measuring of these internal threads, or subsequent adjusting of the tenon thread diameters, is ever required to match the varying receiver thread diameters that would result from using single-point machining to "straighten" these threads.
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> And fourth, using the fully run-in piloted tap as a precision mandril, we simply take a minimum facing cut in any available lathe *to square up the front face of the receiver accurately to the axis of the boltway, as well*.

This ordered, sequential procedure not only squares the receiver face and threads to each other (as required to resolve the barrel pointing problem identified by Mr. Vaughn), but also squares-up the entire front ring of the receiver to be co-axial with the re-bored boltway. Of course, the custom-fitted match barrel's oversize **1.0700-inch** tenon, set-back shoulder, and **0.010-inch** oversize threads should all be "essentially true," having been cut and threaded using single-point tooling in a well-maintained precision lathe. Of course, we *always* use a good *anti-seize lubricant* whenever we engage the receiver threads with the barrel threads, especially when *trial fitting* the threads. This long-lasting lubricant is also needed to reduce friction on the surfaces of the receiver face and the barrel shoulder during assembly and throughout the life of the barrel.

The bolt that will be used with this action is trued and fitted in a separate, more elaborate process. The lugs, face, and nose of the bolt and its added front and rear sleeves are all trued in a *single set-up* in a *dedicated lathe*. The surfaces of the front sleeve that do not bear inside the receiver rings when the bolt is in its locked position are hand-filed away to provide plenty of clearance for easy bolt cycling. The non-bearing sides of the rear sleeve need only slight relieving to allow for very easy bolt cycling. The remaining full diameter (**0.7050-inch**) lobed surfaces of the sleeves are "Borden Bumps," which serve to cam the bolt *precisely, repeatably*, and *squarely* into position in the receiver each time the bolt is locked. These lobes are lightly polished and high-concentration molybdenum disulfide grease is burnished into their surfaces as a friction modifier.

Why it Works

Even with no more than the nominal **50-percent** thread engagement of current American Standard Unified Screw Threads, the *lubricated* **30-degree** *sloping*, load-bearing faces of the matching *internal and external 60-degree V-threads* in the barrel joint will ***always*** *strongly re-center* the axis of the barrel tenon after each shot—even with only the **1500 pounds** of axial clamping force from using our preferred ultra-light assembly torque. At the same time the "sudden lock-up effect" of the square and lubricated barrel shoulder, as it contacts the "perfectly square" receiver face (or recoil lug) at each point *simultaneously all the way around* during installation, will always position the tenon of the free-hanging target barrel to essentially the *same pointing angle*, both upon *original assembly* and *after the disturbance of each shot* throughout the useful life of the barrel. When the threads are *square* with the face of the receiver, *both effects work together* to re-position the barrel properly after each disturbance. Any small displacement from the correct orientation produces a strong enough *restoring moment* to overcome dynamic (sliding) friction at the lubricated receiver face and barrel shoulders so as to return the barrel consistently to its proper pointing direction after each disturbance. If the weight of the barrel affects this "at rest" pointing direction, and it very well might, the effect of that side-loading moment should be consistent for all of our "flat firing" matches.

We use only a rather light-duty Davidson aluminum benchrest barrel vise, C-clamped to a workbench, and various light-duty internal and loading-port types of action wrenches, to install all V-threaded barrels into our bolt-action target rifles. We install benchrest competition barrels with about **25 foot-pounds** of torque which produces about **1000 pounds** of clamping force. No doubt, the competition benchrest barrel *really does move about* within the *lubricated* and *lightly assembled*, 60-degree V-threaded receiver joint during each firing. But in a properly fitted and properly assembled target rifle *the re-centering moments deriving from this clamping force, together with the un-avoidable* *side-loading moment due to the weight of the "free-floating" barrel, will return the barrel to its same "natural point of aim" after each and every shot as long as it is held nearly horizontal*. Not only must the barrel be "free-floating" for this *barrel alignment process* to work properly, but we must ***forego*** the obsolete practice of building a bedding "pad" to "support the underside of the chamber," and we must also take care ***not*** to bed the bottom or side surfaces of the recoil lug inadvertently.

[By the way, we can now understand exactly *why* we have always experienced such *disastrous accuracy loss* whenever we have allowed an over-length front action screw or front scope-base mounting screw merely to *contact* the threads of the barrel tenon within the front ring of any rifle's receiver.]

Back to Mr. Vaughn's Hunting Rifle

Having blueprinted several hundred factory-produced, hunting type bolt-action rifles from several different makers, we have a good idea just how true and square they really are when they leave the manufacturers. *The front threads in every single one of these actions that we have examined have been visibly misaligned.* The receiver threads in the actions made from forged steel billets appear always to have been *tapped crookedly* in manufacturing, even before subsequent heat-treatment *distorted* the entire receiver. Investment cast receivers usually seem to have been *warped* by uneven cooling, even before being *tapped crookedly*. It would seem that these consistently misaligned receiver threads could only have been installed using un-piloted, free-running taps. And, the front face of the receiver never seems to be particularly square to any possible reference surface—certainly not with the axis of the crooked receiver threads. One could even imagine some sort of conspiracy among the mass-producers of hunting-type bolt-action rifles. The industry would be shaken by change of geologic proportion if one maker's latest economy-model rifle started regularly shooting quarter-inch five-shot groups at 100 yards in all of its offered chamberings. Gun-writers would struggle to find new metaphors for "super accurate," and gun-controllers would solemnly warn of rifles "too accurate" for legitimate hunting use.

Mr. Vaughn makes no mention of having trued the receiver of his test rifle, but he does indicate that it retains the original factory thread diameter of **1.0625 inches**. I believe that the *un-trued and thus un-square receiver* of Mr. Vaughn's mass-produced bolt-action test rifle was almost certainly *causing* the tenon of his installed barrel to *hunt back and forth* during its settling process after each shot was fired, *around and between two distinctly different candidate barrel-pointing directions*:

1) The *axial direction of the internal receiver threads*, and
2) The *perpendicular to the unstressed receiver face*.

Summary

We prefer to resolve the *variable-barrel-pointing problem* first identified, measured and demonstrated so clearly by Harold Vaughn in his mass-produced, hunting-type, test rifle simply by *truing the front ring of the receiver* rather than by attempting to "freeze" the threaded joint via *over-torquing*. The choice between the two solutions is not difficult.