Vibration Control in Bolt Action Rifles

Part II

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Introduction

In *Part I* of this article we discussed how vertical-plane transverse vibrations in a conventional rifle barrel (having no muzzle attachments) produce both a "launch angle" effect and a cross-track "kick velocity" effect on the bullet as it exits the barrel crown at the muzzle. We also showed how these two effects are combined into the single sinusoidal impact height variation that we normally see during barrel/ammo tuning. In *Part II* we will discuss our approach to controlling vibrations in the rifles that we build, the sources of the barrel vibrations that arise during firing, and how the accuracy-destroying effects of barrel vibrations can be minimized by proper rifle design and construction. Then, finally, we will discuss a couple of barrel tuning devices and how they work and share some thoughts on the likely effect of allowing barrel tuners in centerfire benchrest competition.

Vibration Control Approach

Based on our experiences, we have decided to take a three-fold approach to controlling the effects of barrel vibrations in building and firing the accurate rifle. The primary thing is to identify and to minimize all vibration sources as far as possible. While certain vibration sources can be eliminated completely and others can be reduced, we may have to be content with merely "regularizing" other vibration sources as to size and start timing during the firing cycle. The best example of a barrel vibration source that can be eliminated is the vertical-plane "slapping" motion of the back end of a sloppy-fitting, two-lug bolt body inside the oversize boltway of an action while it is trying to seat both top and bottom locking lugs evenly in response to the build-up of rearward bolt thrust during firing. Most common two-lug bolt actions have the locking lugs one above the other (in a vertical plane) when ready for firing "in battery." Thus, any bolt body movements involved in seating one or both lugs during firing are inherently vertical plane motions. This type of metal-to-metal impact during the firing cycle is particularly important to remove at its source because its effects on barrel vibrations are pernicious. The magnitude and timing of this vibration-driving force will tend to vary from shot to shot because bolt thrust varies tremendously depending on how well each particular brass cartridge case grips the chamber walls during firing. Also, this single energy source can excite many kinds of vibration modes throughout the rifle because of its broad frequency spectrum. A snug-fitting bolt body with fully engaged locking lugs eliminates completely this major source of transverse barrel vibrations.

The second approach is to absorb or to dampen out vibrations where possible in the rifle, or at least to construct the rifle so as to interfere with the propagation of vibrational energy from one part of the rifle to another. The use of poured Devcon-F aluminum-bearing epoxy pillars around each action screw as an action bedding technique in lieu of using turned metallic aluminum or stainless steel pillars is a practical effort to control vibrations by this second approach. The poured pillars of this material have long been thought to absorb more vibrational energy than would solid metal pillars ever since the subject was investigated by pioneering benchrest gunsmiths back in the dim, distant days of the 1950's and 1960's before "glue-in bedding" of benchrest actions came into widespread use. In fact, I recall a quote from a gunsmith of that era to the effect that "*There is something about Devcon that guns just seem to like*."

The third approach to controlling the effect of vibrations on rifle accuracy is to "tune" the reloaded ammunition to the remaining vibrations of the rifle barrel for best accuracy, or vice versa, to tune the rifle barrel to the use of fixed ammunition. When we develop a handload for best accuracy in a particular rifle, we are tuning the load to the vibrations of that rifle's barrel whether or not we realize quite what we are doing. In fact, the reason that we usually find best accuracy with our small caliber benchrest bullets seated well into the back of the rifling probably has more to do with getting the bullets to exit the muzzle after a more consistent barrel dwell-time and with initiating the barrel vibrations themselves more consistently than it has to do with achieving very uniform muzzle velocities or some other aspects of "cartridge accuracy," per se. [A speculative insight.] As explained in Part I for conventional rifle barrels, what we usually discover in our load-tuning efforts is that our rifle shoots most accurately with a given bullet and a given type of powder at either of two muzzle velocities: too slow or too fast.

If our target rifle is restricted to using fixed ammunition, we could perhaps tune the rifle to match the available ammunition, except that Browning Arms Company seems to have patented the concept of the adjustable tuner. Be that as it may, we sometimes get so involved with barrel tuning in building accurate rimfire (fixed ammo) rifles that we actually build them to produce larger amplitude barrel vibrations than might have been necessary (in apparent violation of our first two principles of vibration control just mentioned), exaggerating the vibrations in order to facilitate tuning the barrel to the ammunition. Successfully timing the bullet exit at the muzzle crown to occur at a precise point in the barrel vibration cycle requires the utmost consistency in the primer ignition process and in the related initiation of the barrel vibrations, themselves. [**N.B**. Finding the brand of rimfire match ammo with the quickest primer ignition characteristic will go a long way toward obtaining this timing consistency necessary for successfully tuning your rimfire barrel.]

Rifle Vibration Sources

The problems of sloppy bolt fit in the boltway and of unseated bolt lugs have already been mentioned as being among the worst sources of vibrational energy that rob accuracy and occur during the firing cycle. When most bolt actions are cocked, the sear pushes the rear of the bolt upward with about 20-pounds of force. This usually unseats the top lug. Once the sear support breaks to initiate firing, the forceful seating of this top bolt lug by the subsequent primer and powder pressures, and/or the impact of the bottom of the bolt on the inside of the boltway, produces a metallic "knocking" in the vertical plane within the receiver and sends waves of transverse vertical-plane vibrations of many high frequencies racing toward the muzzle at over 10,000 feet per second. [As a review of a topic that was covered in Part I, these high-frequency barrel vibrations are each the resonant frequency of a discrete high-order barrel vibration mode.] The best solution to these problems is to blueprint the factory action including the sleeving of the bolt body for a snug, perfectly aligned fit in the trued boltway. An integral part of this blueprinting operation is the machine truing of the rear faces of the bolt locking lugs and of the locking surfaces inside the receiver. It does not accomplish much vibration reduction merely to lap the bolt lugs into engagement at some particular bolt orientation as long as the bolt body has enough slop in its fit to be able to move around inside the receiver. The first article in this series (October 2003 Precision Shooting) described this action blueprinting process in detail.

Firing pin impact on the primer is another major source of broad-spectrum, high-frequency vibrational energy. Dry firing on a dummy "snap cap" round will demonstrate these vibrations in your rifle. Watch the scope reticle bounce with respect to the target image when you perform this dry-firing test just as you would fire the rifle in a match. Of course, igniting the primers electrically where it is practicable would eliminate this firing pin impact problem. Otherwise, we have always used G. David Tubb's light-weight Speedlock strikers and factory-strength, silicon-chrome firing pin springs in our blueprinted Remington Model 700's. The use of these Speedlock systems (1-806-323-9488) minimizes and regularizes the vibration effects of the firing pin impact. Table 1 shows a comparison of certain measured and computed firing pin impact parameters for a typical long action Remington Model 700. This Speedlock modification not only shortens the lock time by 1.0 msec (or by 35%, which is always worthwhile), but reduces the apparent vibrations of the rifle in dry firing (by a calculated 30% reduction in the driving force) while improving primer ignition energy availability (by 10% to 20%) and, thus, restoring primer ignition uniformity due to the high quality, full-strength spring. We believe that this Speedlock modification provides a significant and worthwhile improvement in the accuracy potential of any rifle using a Remington 700 bolt action. The factory-strength spring stores and releases the factory-specified energy content when the action is cocked at the factory-specified striker hold-back distance. Greg Tannel (Gre-Tan Rifles, 1-970-353-6176) has recently introduced an ultra-light bi-metallic striker with a reduced diameter low-drag spring that should offer these same advantages.

Table 1: Firing Pin Impact Comparison

	Remington 700 Long Action	**Tubb L/A**
Striker Weight	761.1 grains	317.1 grains
Spring Weight	202.8 grains	182.1 grains
Effective Weight	862.5 grains	408.2 grains
Spring Preload	22 pounds	24 pounds
Stored Energy	6.42 inch-pounds	7.01 inch-pounds
Acceleration	178.6 G's	411.6 G's
Impact Velocity	16.72 feet per second	25.4 feet per
Lock Time	2.911 milliseconds	1.917 milliseconds

Impact Momentum	1.025	ounce-seconds	0.737	ounce-
Impact Force	640.6	pounds	460.5	pounds

There are several smaller sources of bending moments which occur during the firing cycle and which can affect the front receiver ring and, thence, the barrel shoulder. These include the asymmetrical drilling and machining of the front ring itself, the partial collapsing under load of the weaker bottom lug seat in the receiver (weakened by the feed ramp cut in a repeating action), and the dynamic interactions between the front ring of the receiver and a one-piece scope base (or even, to a lesser extent, with the body of the scope itself when two-piece bases are used). When you get to the point where these effects are the largest remaining sources of accuracy-robbing barrel vibrations, you should sell that rifle and start over again with a fine custom single-shot benchrest action and build a proper benchrest competition-style rifle.

Assuming you are not shooting over the top of a fence post attached to a mile of taut barbed wire vibrating in the wind, the other (unavoidable) sources of rifle vibrations are generated by recoil forces and motions. The typical recoil lug at the front ring of the receiver directly generates a vertical plane bending moment on the rear of the barrel as it performs its task of transferring the recoil reaction force from the stock to the barreled action. The timing of the generation of this reaction force goes back to the timing of the acceleration of the bullet (and some of the powder gasses) by the high pressure gasses in the chamber. Figure 2-16 from Harold R. Vaughn's book, **Rifle Accuracy Facts**, shows some typical Chamber Pressure versus Time curves. The pressure peaks of the curves look something like the first half of a sine wave, and depending on what pressure level starts the bullet moving into the rifling, they span between as much as 1.0 msec and as little as about 0.4 msec (near the peak). Sure enough, this major energy source drives vibration frequencies between about 500 hertz and 1250 hertz. This is the primary source of the vibrations discussed back in Part I of this article. We should point out here that firing a lesser-recoiling round is the principal method of reducing this vibration source.

Recoil motions can and will affect barrel vibrations, especially if the rifle is fired over supports that are too hard. The traditional field support of firing over a rolled-up sleeping bag is just about ideal in this respect for any kind of accurate shooting. Of course, the barrel must be allowed to vibrate freely without coming into contact with anything else if real accuracy is to be obtained. If your front rest has a fore-end stop in front of its sandbag set-up, you must take pains never to allow this stop to contact your rifle barrel unless you do not mind placing last in your match. I have watched some benchrest competitors pounding their vestigial sandbag front rests to shape them exactly to their rifle's fore-end, apparently believing in the supreme importance of constraining the rifle to "track" straight rearward during recoil and to return "to battery" precisely on target. How-some-ever, this sandbag pounding also makes the rifle bounce off the now rockhard front rest when it is fired. The original (and still correct) idea of using a sandbag front rest was to absorb vibrations.

Also, it is always best for accuracy, whenever practicable, to allow the rifle to recoil freely for the first approximately one-eighth-inch of rearward motion. Firing “free recoil” significantly reduces recoil reaction-force vibration effects until after the rifle has been “caught” long after the bullet has departed. The “Flex-Joint” action mounting system developed by Harold Vaughn and shown in Figures 4-5 and 4-6 is an excellent example of how “free-recoil” firing can be designed into the rifle itself. This same recoil reaction-force reduction effect is also precisely why we should never add weight to the stock (and especially not to the butt-stock) of an accurate rifle. The lighter the weight of the stock, the less recoil reaction-force it would generate on the recoil lug if the rifle could be fired completely unsupported.

I once calculated the torque reactions of a typical rifle caused by spinning up a bullet of 308 (and smaller) calibers to typical stabilization spin rates. What I now recall is that the amounts of torque and rotational kinetic energy involved are truly miniscule and would **not** produce a measurable effect on rifle recoil motion.

Rifle Designs to Minimize Vibration Effects

> **Warning**. This section contains naked opinions and may not be suitable for sensitive readers.

First of all, select the lightest-recoiling cartridge that will do the job. Then, if the use of a conventional barrel is planned (i.e., no muzzle attachments allowed), select the heaviest profile, shortest length, highest quality barrel blank that is practicable for the rifle. [The selection of the optimum barrel blank for a conventional target rifle was discussed in detail in our article, “Precision Barrel Fitting,” published in the September 2004 issue of **Precision Shooting Magazine**.] We want the conventional target rifle barrel to be as stiff as possible so that the critical Mode 3, and higher, resonant frequencies will be raised out of the 500 hertz to 1250 hertz range excited by primary recoil forces. If the rifle is to utilize a barrel tuner, the barrel profile should taper quickly in front of the chamber swell to a somewhat smaller-diameter cylindrical shape extending on to the muzzle. The lighter barrel allows the addition of the barrel tuner without exceeding the weight budget, while the cylindrical shape facilitates attaching the tuner.

Select (in decreasing order of desirability and cost) a fine quality custom benchrest action, a blueprinted Remington Model 40X single-shot action, a blueprinted Remington Model 700 short or long action, or a blueprinted post-1964 Winchester Model 70 push-feed action. Solid-bottom actions that were designed as single-shot actions are potentially more accurate than those that were machined for magazine feeding. While the ultimate accuracy potential of a blueprinted Remington action can be slightly improved by sleeving the action, I do not recommend that technique as a practical or cost-effective approach.

Next, select the lightest, straightest, and strongest stock design that will work, and never add weight to the stock. As mentioned in the preceding paragraph, adding weight ahead of the butt-plate is particularly to be avoided because of the higher initial recoil moments it creates with every shot. The most accurate stocks will be quite stiff in the fore-end and wrist areas. Straighter stocks and stocks that are shallower top-to-bottom produce less initial muzzle rise in response to the recoil reaction-force from the firer's shoulder. The bolt action, scope and other parts should be as light as possible. As an ideal goal, we would wish to have all the rifle's weight budget allocated to the barrel itself.

Using Devcon 10610 Aluminum Putty (or 10760 Titanium epoxy) [available from MSC Industrial Supply, 1-800-645-7270] to pour pillars in wood or fiberglass stocks or to "skim bed" aluminum bedding-insert stocks may be providing some vibration absorbing characteristics as well as certainly utilizing excellent materials for the bedding job. The two main ideas in pillar-bedding a barreled action into just about any kind of stock for highest shooting accuracy are (1) to provide exactly three points of contact: around the two action screws and at the back (only) of the recoil lug, and (2) to induce no bending stress on the receiver as the two action screws are tightened snugly. As the name implies, the annular contact patches around the two action screws are the tops of two cast-in pillars that each run completely through the stock. Of course, the pillars themselves must be well secured into the stock. Also, the action screws must be safely clearanced inside the pillars so they will not become accidental recoil lugs. The rear face of the recoil lug is strongly bedded in this system, but we no longer find it beneficial to build up a pad of bedding material under the chamber end of the barrel.

The benchrest "glue-ins," the "barrel-block" bedding systems, and "skim-bedded" aluminum-insert systems are the only other practical bedding systems of which I am aware that are suitable for use in building really accurate stocked rifles. By "really accurate" I mean capable of consistently shooting small, round, one-hole groups of five shots at 100 yards and never throwing an unexplained "flyer" out of the group. The barrel, the middle of the action, the trigger, the safety, the bottom, sides and front of the recoil lug, and the bolt handle must not touch the stock, even under full recoil forces and vibrations. We must provide adequate clearance around all free-floated components. The fore-ends of most hunting rifle stocks are not strong enough to keep any reasonable-clearance barrel channel gap from collapsing into contact with the vibrating barrel during firing if the rifle is supported by a front rest under that fore-end. This barrel contact always destroys accuracy. I have never seen a "really accurate" rifle with **both** the barrel and the action bedded in the stock, even though this type of bedding is widely used for esthetic reasons, for economic reasons or for other practical reasons. To get the best accuracy with rifles using the more flexible hunting-type stocks (whether or not the fore-end is bedded), or with any rifle using a two-piece stock, the rifle should be supported for firing right below its center-of-mass using a soft-topped front rest. As the rifle interacts with this type of support, it bounces upward as a unit rather than whacking the front rest with the underside of its barrel through the fore-end.

The benchrest "glue-in" bedding system should be slightly more accurate than pillar bedding for low-recoiling rifles that can be fired "free-recoil." [An assertion.] This improvement comes about because, not only is it practically guaranteed that there will be no stress between the action and the stock with this system, but the whole action becomes one big recoil lug which keeps the rifle stock from imparting quite such a direct bending moment to the barrel shoulder in handling the initial recoil reaction-force. Combining the use of glue-in bedding with free-recoil firing works particularly well in low-recoiling benchrest rifles built on ultra-light, ultra-rigid benchrest stocks. The free-recoil firing and ultra-light stock both work to minimize primary recoil-reaction forces, while the glue-in bedding works to minimize the conversion of the remaining reaction forces into transverse barrel vibrations.

Properly designed, the barrel-block bedding system as shown in Figure 1 can produce the highest accuracy levels of any type of stocked rifle. [A bold assertion.] One key design feature of this system is to completely free-float both the barrel and the action. Another is to pillar bed the barrel-block into the stock. The bolt-action receiver must not contact the barrel block nor the stock. The barrel block should be long enough (about 6 to 8 inches) so that recoil reaction forces on the rear face of the block do not directly torque the barrel upward during firing (as is also accomplished with the benchrest glue-in above). As long as the barrel is held securely enough for accurate aiming, we do not need a massive nor a very stout barrel block for any vibration control purposes. We are not particularly counting on forcing the front portion of the barrel to vibrate as if it were a shorter, stiffer cantilevered rod. Another key design concept for vibration control is to mount the scope to a cantilevered scope base attached only to the barrel block and not allowed to contact the receiver. The idea here is to avoid combining the moments of inertia of the scope and the action (as would happen using receiver-mounted scope bases), which sum would more closely match the larger moment of the front part of the barrel. This combination would, thereby, allow the two ends of the barreled action assembly to vibrate in sympathy with each other right through the barrel block. The vibrational connection of the cantilevered scope to the barrel block is purposely made so weak that it cannot resonate with the much higher barrel vibration mode resonant frequencies. We attach a through-bored aluminum barrel block to the barrel using an epoxy adhesive so that there can be no stress in the attachment. In particular, since no clamping forces are utilized in the attachment, there is no possibility of distorting the bore inside the barrel. The minimum sidewall thickness of the glued-on aluminum block can be as little as about one-eighth-inch, so as not to require a really extra-wide stock fore-end, as most clamp-on block designs do seem to need.

Barrel Tuning

Devices can be attached to the muzzle end of a barrel to alter, or “tune,” the barrel vibrations to allow fixed match ammo to group more consistently on the target or for some other primary purpose (e.g., recoil reduction). These devices may be barrel masses, calibrated adjustable tuners, recoil compensators, muzzle brakes, sound suppressors, front sights, bloop tubes, or even military flash suppressors, bipods, or bayonets. Any of these devices will modify barrel vibrations and affect accuracy as well as the bullet’s expected point of impact. Also, any of these devices that are not **securely** attached to the barrel will play hell with accuracy. On the other hand, I do not know of any method for securely attaching a muzzle accessory to a conventional precision target barrel that will not distort the bore interior near the muzzle to some detectable extent. Threading or turning the muzzle causes the bore to expand by relieving residual hoop-stress around the bore, and clamping something around the barrel will always compress the bore inside the clamp. Perhaps a balanced method of both threaded (or turned cylindrical) barrel end and clamped attachment could be worked out. We will discuss the use of a barrel mass or a calibrated, adjustable barrel tuner to improve benchrest accuracy with a given lot of match ammo rather than comment more about inadvertent or haphazard barrel tuning with other devices.

The idea behind using a non-adjustable mass attached to the muzzle of your barrel as shown photographically in Figure 2 is pretty straightforward. If the added barrel mass weighs about the same as the bolt action at the back end of the barrel, the only transverse vibration modes in which the barrel can resonate will have a node at each end of the barrel. The barrel crown will be at, or quite near, this front-end vibration node for all modes of the barrel vibrations. A similar thing happens when we first attach an adjustable tuner to the muzzle of the barrel (before it has been "fine-tuned"). The basic design of the barrel tuner shown diagrammatically in Figure 3 and photographically in Figure 4 effectively moves the barrel crown back to the approximate location of the outermost transverse-vibration node when it is attached to the muzzle. This is not a really critical tuning operation, and will greatly reduce (if not completely eliminate) the cross-track "velocity kick" effect of barrel vibrations if the barrel crown is even just close to the location of the foremost barrel vibration node. To repeat for emphasis, the mere attachment of either a non-adjustable barrel mass or of an unadjusted barrel tuner minimizes or eliminates the "velocity kick" effect on bullet impact point.

The barrel **still vibrates**, however, even though the resonant frequencies and amplitudes are quite different after attaching the barrel mass or the adjustable tuner. The resonant frequency of any particular barrel vibration mode can only be **lowered** by attaching something to the muzzle that in effect "vibrationally" lengthens the barrel. The "launch angle" effect due to the Pos(t) function [See Part I of this article.] of the modified barrel vibration becomes the dominant effect by far on bullet trajectories by linking the bullet's departure angle to its time of clearing the barrel crown. But, why is the group position and group size on the target so strongly affected by changes in the adjustable tuner setting as small as .001-inch? The answer is that the **resonant frequency** for each barrel vibration mode is very sensitive to these small changes in effective mass distribution. By adjusting the barrel vibration frequency, we are causing the bullets from the same production lot of ammo to exit the barrel crown at different points in the adjusted dominant mode vibration cycle. In fact, you do not want to allow much of the excess bullet lube that is slung off a lead rimfire bullet after it exits the barrel crown to accumulate inside the tuner, or you may find yourself having to make a small tuner adjustment in the middle of a match. For this reason among others, I prefer to mount the tuner backwards (extending back over the barrel) when possible. Figure 5 shows a photo of what this looks like. The reversed tuner works almost as well as it does when conventionally installed, but allows easier bore cleaning, facilitates gun handling, and avoids most of the crud build-up problem. Also, Browning's attorneys probably would not believe they could say much about such an obviously different type of adjustable tuner.

Opinions differ as to the best tuning techniques to use, but I usually settle on a velocity where the groups are smallest just past (i.e., at a slightly higher velocity than) a maximum elevation on the target. One could have selected a minimum-elevation-producing muzzle velocity, I suppose, but you would need to stay at slightly lower velocities than where the minimum elevation occurred. In any case, you should fire some groups with mixed loads or lots of ammo (purposely varying the muzzle velocities slightly) in order to find a tuner setting where the old British idea of "compensation" works in your favor. This is where faster muzzle velocity bullets are expected to exit sooner and at a slightly lower launch angle than would average speed bullets, and where slower than average bullets are assumed to exit later and at a slightly more elevated angle. The hope and expectation would be that the trajectory differences of these different velocity bullets would tend to drop all the bullets into the same spot on the target. While this is really a long-range target shooting concept, it may be of some help even at ranges as short as 50-yards with .22LR match ammo, or 100-yards with 6mm PPC bullets. The reader is urged to try this for themselves. The above explanation of "compensation" was couched in terms of a "launch angle" variation with barrel dwell-time only because we were discussing the adjustment of an attached barrel tuner that has already minimized any cross-track velocity kick effect on the bullet by its mere attachment. "Compensation" also works with a conventional barrel where it is a **combination** of launch angle and velocity kick effects that is varied with bullet exit timing.

Some Thoughts on Allowing Tuners in Centerfire BR Competition

Let us assume for purposes of this discussion that a typical competitive centerfire benchrest rifle is currently capable of aggregating 0.100-inch groups at 100-yards under ideal practice conditions and, further, that actual match-winning aggregates average about 0.200-inches. These estimates are probably not too far off as figures of merit. The discrepancy between these figures, whatever they may be, is attributable to the performance degrading effects of real-world match weather conditions, match jitters, or other "operator errors." Since un-correlated (or independent) statistical errors combine by the Root-Sum-Square (RSS) method, the size of the residual error that would sum with the rifle figure of merit to yield the assumed average match aggregate would have to be 0.1732-inches. That is, if somehow our rifles were magically all capable of aggregating 0.000-inch groups, the average match-winning aggregate would be reduced only 0.1732-inch given the above assumptions. Hardly an earth-shaking event to the general public, but quite an improvement to us in the precision shooting field. If the rifle figure of merit is more realistically improved to 0.050-inch by judicious use of barrel tuners, the average match-winner would aggregate groups of 0.1803-inch according to the RSS rule. This potential improvement of 19.7 thousandths of an inch would likely be detectable in the published match results if one were to look closely. However, if the use of barrel tuners were to encourage or to require us to shoot quite a bit more for tuning our rifles, the average match-winning aggregates would improve more noticeably, but mostly because we would all shoot significantly better if we were to practice more.