Precision Barrel Fitting

By James A. Boatright

Introduction

In this article we undertake to discuss all aspects of rifle barrel fitting that impact the accuracy of the finished rifle, not just a sequence of machining steps. Inevitably, an article of this type entails putting down in black-and-white a hodge-podge of facts, ideas and opinions, some worthwhile, some possibly questionable, and some downright half-baked. No offense is intended, but if any toes are trod upon, please accept our apologies in advance and let us know how we have gone wrong. While there are many ways to accomplish the precision-fitting of match grade barrels, the procedures described here have resulted in rifles that shoot accurately.

Choosing the Barrel Blank

In our search for the finest barrel blanks to use for our rifles, we have decided, for now, to use only barrel blanks made of AISI 416R stainless steel as opposed to chrome-moly steel or other stainless alloys. Since most benchrest competition barrels at present are made of 416R stainless, these same manufacturers make most of the finest-quality custom barrels of that same steel. Also, we fear that some chrome-moly steel barrels may have been straightened by bending during manufacturing, and that would be anathema to those of us attempting to practice minimum stress gunsmithing. We have also observed quite a few inclusions of non-homogeneous materials in chrome-steel barrels and fear they might prematurely dull our chamber reamers as well as produce ugly bores and chambers.

We order the custom barrel blank to be supplied by the maker with the final outside profiling and any required barrel fluting already done. The finished barrel length and rifle chambering are also specified to the manufacturer. Ideally, the outside profiling of the barrel blank should be performed by the manufacturer after deep-hole drilling of the blank, but before final bore reaming, to avoid any tendency to develop a reverse taper in the bore during profiling to the desired outside contour. This could happen due to relieving selectively more of the residual remaining hoop-stress in the steel toward the smaller, muzzle end of the blank during the metal removal process for outside-profiling.

We try to work with the customer to define the longest, heaviest bullets he will be shooting so that we can order the barrel with the slowest twist rate that will do the job of stabilizing these bullets. We believe this allows the best barrel blank manufacturing quality, allows the completed rifle to shoot more accurately, and promotes quicker barrel break-in and eases later barrel cleaning due to less persistent copper fouling.

We also work with the customer to specify, within reason, the shortest finished barrel length and the heaviest, stiffest, barrel profile that will reasonably meet his requirements. If we can model the rifle barrel as a long, thin rod of uniform diameter, rigidly held horizontally at the breach end and supporting a weight at the muzzle, then the stiffness of this barrel increases with the *fourth power of its diameter* and varies inversely with the *cube of its length*. To put some numbers on this, consider the following two stainless steel barrel blanks, each weighing **6.9-pounds** before being gun-drilled for the bore, contoured externally or chambered. Barrel blank number one is **1.10-inches** in diameter and **26-inches** long, and it has a computed stiffness of **0.245-pounds per thousandth of an inch** of muzzle deflection. Barrel number two is **1.25-inches** in diameter, but only **20-inches** long, similar to a benchrest competition barrel. It has a computed stiffness of **0.899-pounds** of transverse force being necessary to produce the same thousandth of an inch deflection of the muzzle. While the two barrels weigh the same and are made of the same type of material, the shorter, larger diameter barrel is **3.67 times** as stiff.

The idea for scope-sighted target rifles is to use shorter, stiffer barrels to promote accuracy and benchrest shootability as long as neither excess muzzle blast nor reduced muzzle velocity becomes a problem. To achieve the highest absolute accuracy levels, the barrel of the contemporary short-range benchrest rifle is made very short and stiff. This exercise also indicates just how much gravity droop or stock fore-end pressure can affect the muzzle direction of rifle barrels. This very rigid barrel design goal minimizes barrel vibration problems in two separate ways. First, the stiffer barrel has the resonant frequencies for its more readily excited transverse barrel vibration modes well above one kilohertz and, thus, out of the frequency range of most of the spectrum (one kilohertz and below) of the excitation energy occurring during firing. Considering our two **6.9-pound** barrel blanks again, since the fundamental frequency of the transverse barrel vibrations varies with the *square root of the barrel's stiffness,* the shorter barrel vibrates at a frequency **1.92 times** higher than that of the longer barrel. You do not start a tuning fork vibrating by it exciting it using a driving frequency lower than its resonant frequency. Any vibrational energy transfer to the stiffer barrel will be relatively less efficient, and less barrel vibration is always better for accuracy. Second, in physics we find that wave energy of various kinds is directly proportional to the vibrational frequency of that wave. Looked at the other way around, if the same level of energy were somehow to be input into each of our two vibrating barrels, the stiffer one with the higher resonant frequency will vibrate with smaller amplitude (transverse deflection) being required to absorb that amount of energy. And, generally, smaller amplitude transverse, standing waves should result in somewhat less dispersion of the bullets at the target.

Equipment We Use in Barrel Fitting

We use a high-speed, geared-head, 13x40-inch tool-room-quality lathe that is dedicated solely to barrel work. This 2400-pound lathe is installed on six anti-vibration leveling feet that are set on a 6-inch thick, heavily reinforced concrete shop floor. The shop is temperature and humidity controlled at all times. The lathe bed ways are periodically checked for level both ways by using a very sensitive level. The lathe bed must never be allowed to twist due to improper support. The tailstock adjustment plate has been milled and shimmed, using stainless steel shim stock, for alignment with the spindle axis when it is locked at any location along the bed-ways. As with most factory lathes that had never been critically aligned, this one needed height adjustment at both left and right sides of the tailstock to achieve the alignment necessary for barrel work. Among the many useful instructional videos available from Greg Tannell of ***GTR Tooling*** is one on this very topic. Also, the tailstock set-over adjustment has been carefully zeroed and remains locked there. A matched set of two sensitive test indicators (reading 0.0040-inch half-scale) is handy in adjusting set-ups and in re-checking the tailstock alignment. This lathe has an inch-designated lead screw (instead of having a metric pitch) that is better suited to our barrel tenon threading work. This particular lathe is of the “high speed” type, which means that it has no back gear, and its slowest speed is 90 RPM. Using its rather small 8-inch diameter 3-jaw chuck, this lathe is well balanced enough to spin barrels that are, themselves, nice and straight at 1000 RPM comfortably for polishing out tool marks prior to buffing. We have observed that some barrel blanks are either not straight enough or not concentric enough in outside contour to spin at this speed without bowing in the middle and vibrating. We do not consider this an encouraging sign of high barrel quality.

Part of the reason we can chamber and thread at speeds of 90 RPM and above (usually at 228 RPM with tool steel reamers) is that we use a powerful through-the-bore coolant/lubricant pumping system that we also got from Greg Tannell and, under his advice, from ***MSC Industrial Supply Co.*** We use ***Rustlick Ultracut 255R*** (or equivalent) heavy-duty, chlorinated, water-soluble lubricant thinned 3:1 with water as the coolant. The coolant water evaporates over time and is checked and replenished weekly. A manual bypass valve is used to adjust the output pressure to about 150 PSI from the high-volume positive-displacement oil pump driven by a 1.5-horsepower, three-phase electric motor. The recycled coolant is routed through a high-pressure, micron-level filter before being delivered to the barrel muzzle to flow through the bore in order to cool and lubricate the reamer, and to carry away the chips during chamber reaming. We thread and chamber with the barrel driven from the muzzle end while being held in a 3-jaw chuck on the spindle. The barrel tenon is supported for threading by use of a quality tailstock-mounted live center engaging a precision re-cut 60-degree center installed in the big end of the barrel. During chamber cutting, the chamber end of the blank is running in the steady rest and the reamer holder is fitted into the tailstock ram. We use a # 3 Morse-taper ***JGS*** floating reamer holder, shown in Photo 1, to position and to drive the chamber reamer. We settled on this method after trying about every way of driving the reamer we had heard of, including using several different floating and adjustable reamer holders. The lathe apron is moved forward of the steady rest to remove it from the path of the high volume coolant flow returning to the chip tray.

Our lathes are equipped with BXA-size ***Dorian Tools*** quick-change toolposts with an assortment of tool holders for each machine. Most metal removal is accomplished using disposable, coated carbide inserts of various styles. In particular, we like the performance of ***Kennametal’s*** KC-730 grade “On-Edge” TNMC-32 triangular threading inserts held in ***Dorian’s #881*** tool holder for external threading of V-form threaded barrel tenons at 16 or 18 TPI.

Perhaps one of the more unusual techniques that we use in our barrel fitting procedure is to cut our chambers in one pass using only a finishing reamer. We use only sharp, live-piloted, finishing-type chambering reamers ground from M-2 or M-42 tool steel (*not* carbide) for all chamber cutting. We do this because we believe that a better chamber is cut when the reamer is closely piloted during the entire cutting operation. In other words, if a reamer can go off course in cutting metal, it will. If we were to use a roughing reamer or step-drilling for preliminary metal removal, we would later find it necessary to start the finish reaming cut without the benefit of the pilot bushing out there on the front of the reamer being engaged within the rifling of the barrel blank. For this reason, among others, we avoid re-chambering a previously chambered barrel. The bearing area of the extended nose of the reamer body that the live pilot runs on must be deeply grooved by the reamer maker to allow adequate coolant flow through the pilot bushing for use with our through-bore coolant system. We hand-file similar matching grooves into the head of the “bottomed out” machine screw used to hold the pilot bushing in place. We select the best-fitting pilot bushing from full sets of bushing diameters by **0.0001-inch** increments available for each caliber that we chamber (eight up and nine down from the nominal bore ID). A piloted tapered indicator rod makes a good handle for gauging the bore diameter (land to land) at the chamber end prior to reaming. We select for a slight drag on the pilot while moving it within the rifling.

If at all feasible, we prefer to have the final chamber neck diameter and throat ground into the chamber finishing reamer, but sometimes we hand-cut a throat deeper using Dave Kiff’s (***Pacific Tool and Gage***) Uni-Throater after the rifle is assembled. This tool is piloted in the installed chamber using an adjustable-stop sleeve, as well as in the bore using one of the afore-mentioned live pilot bushings, and very little torque is required to shave off the rifling lands, which is why we feel comfortable turning the throater by hand. When we know the boltway of the receiver is *concentric* with the chamber, we turn the throater using a T-handle running in a shop-made, close fitting acetyl plastic (***Delrin***) sleeve bushing in the receiver similar to the way a bore guide is used in barrel cleaning. The stop adjustment feature of this throater allows us readily to find the start of the existing throat by actually rotating the reamer backwards very gently, and then the calibrated stop is adjusted back by the amount the throat is to be moved forward so that the reamer’s forward cutting progress always comes up against a hard stop, which tends to make for a clean, smooth-finished cut with no chattering.

Since we mostly build target-type rifles, we usually specify very tight chambers that require the least possible movement of the brass during re-sizing in precision reloading the highest accuracy ammunition. For chamberings for which the best Scandinavian-made brass is available from ***Norma*** or ***Lapua***, we specify a chamber neck diameter that is between one and two thousandths larger than the loaded-round neck diameter without neck turning. In fact, we achieve benchrest levels of accuracy from this brass without any “case preparation” needed. For chamberings that will be using American-made brass, we usually specify a chamber neck diameter that will require at least some “clean-up” neck turning before a loaded round could enter the chamber. The neck length in the chamber can likewise be cut five to ten thousandths shorter than SAAMI/CIP maximum specification to better match the over-all-length (OAL) of available brass. Making either of these chamber design changes to an otherwise SAAMI or CIP specified chamber must be engraved on the left-hand side of the barrel. Also, the throat length cut by the chambering reamer can be specified to match a particular bullet when it is seated out properly for full powder capacity in the case and for best accuracy. Long bullets seated out for best hand-loading may not fit into the magazine, if so equipped, and may have to be single-loaded. We try to instruct our customers as to proper reloading equipment and techniques to get maximum performance from their new rifle without doing anything that could lead to the escape of high-pressure gasses into the action. We always discuss proper headspace control and the monitoring of case length between re-loadings.

There are a number of live-piloted cutting tools that we also use in barrel fitting: tapered indicator rods, 60-degree center cutters, and ***Remington Model 700*** bolt-nose recess cutters. We always order a matching GO chamber gage from the same manufacturer each time we order a new reamer. We also require a chamber print (dimensional drawing) for each reamer in our reamer file. We normally obtain these special-purpose reamers, as well as most of our live-piloted, finishing-type chamber reamers from Dave Kiff of ***Pacific Tool and Gage***.

Determining the Barrel Shank Dimensions

The barrel fitting example we will work through to illustrate the process here will be the fitting of a ***Krieger***-made, Remington Varmint/Sendero-weight 308 barrel blank with a 12-inch twist rate to a blueprinted Remington 700 short action using a trued and bored-out Tubb recoil-lug to produce a tactical rifle in 308 Winchester match chambering. We know before we start, and without measuring, that the required barrel tenon thread standard will be 60-degree V-form threads at **1.0725 inch** by **16TPI** because we used that size piloted tap to re-cut the threads concentric in the receiver front ring as part of blueprinting the action. The first step in preparing to fit the barrel is to make five measurements of the trued receiver, bolt, and recoil-lug using precision micrometers to make readings to ten-thousandth of an inch. The recoil-lug thickness is typically measured at **0.3680-inches** for a Tubb recoil-lug that we have ground and lapped parallel and bored to **1.0700-inches**. This is a good time to double-check that the recoil-lug actually measures the same within **0.0001-inch** all the way around at room temperature. The trued bolt-nose diameter is typically measured at **0.6900-inches**. These two readings are made using a high-quality ***Mitutoyo*** 1-inch digital micrometer. The remaining readings are made with a depth micrometer as shown in Photo 2. The bolt-nose to front of bolt-lugs measurement is **0.1550-inches**. The receiver-face to front of bolt-lugs is read as **0.7080-inches**, and the receiver-face to bolt-face measures **0.7070-inches**, both measured with the stripped bolt body locked into battery in the receiver and held to the rear. We record these measurements on a data sheet to be saved for this rifle along with a sketch of the barrel shank and its computed dimensions as described below.

The required tenon length (**1.0710-inch**) is found by adding together the recoil-lug thickness and the receiver-face to front of bolt-lugs measurements and then subtracting **0.0050-inch** for clearance. The trued bolt-nose diameter plus **0.0050-inch** clearance determines the diameter of the backbore recess (**0.6950-inch**) needed on Remington 700 barrels. The backbore depth will be just the bolt-nose to front of bolt-lugs measurement of **0.1550-inches** because the bolt-lugs will already clear the rear face of the barrel tenon by **0.0050-inch** after assembly. Next, we compute the distance we can expect in the assembled rifle from the receiver-face to the bottom of the backbore by taking the receiver-face to front of bolt-lugs measurement (**0.7080**) minus the sum of the backbore (**0.1550**) and the clearance (**0.0050**), or **0.5480-inch** in this case. Now the last dimension to compute is what headspace (**HS**) we should use when we cut the chamber. We will measure what we term "headspace" with a depth micrometer from across the back face of the GO headspace gage inserted into the trial-cut chamber down to the bottom of the backbore recess in the rear face of the barrel tenon, so we need to compute the proper distance from the plane of the bolt-face to the bottom surface of the backbore. The HS dimension is computed by subtracting the **0.5480-inch** distance that we just determined above from the receiver-face to bolt-face measurement of **0.7070-inch**, yielding a distance of **0.1590-inch** for headspace. However, experience has shown us that we need to cut the chamber **0.0010-inch** deeper than this computed dimension; that is, we should chamber to an adjusted headspace (**AHS**) dimension of **0.1580-inches** if we want the stripped bolt to close with just a slight drag on the GO gage when the barreled action is properly assembled. We have found that for best accuracy we must use a minimal torque of **25** to **35 foot-pounds** when installing the barrel into the receiver. If we used more torque, the headspace adjustment would have to be larger as well.

Preparing the Blank and Threading the Barrel Tenon

We have found that it works out best to machine and to thread the barrel tenon before cutting the chamber. We start by sawing off and facing each end of the barrel blank so that **0.75-inch** more than the required finished length remains, and that extra length is on the muzzle end. The chamber swell must extend at least well past the front of the planned chamber. We find that we must cut off at least **0.5-inch** from each end of many barrel blanks due to the way these blanks are hand-lapped. Some manufacturers trim one or both ends of the blank before shipment. The muzzle-end of some blanks is marked with a small saw cut to indicate the maximum usable length of the barrel bore. The bore diameter is gauged at each end of the blank using the set of live pilot bushings for this 308-caliber, and a new 60-degree center is cut in each end using the selected pilot bushing for that end on a center-cutting reamer held in the lathe tailstock just as a chambering reamer would be.

Next, with the chuck jaws opened up a bit, a dead center is installed in the spindle bore and a live center in the tailstock ram. The chamber end of the barrel blank is run on the dead center with a lathe dog driving the barrel off one chuck jaw. We set up to turn the muzzle end running on the live center, and check that the barrel spins true. Then, we turn down that extra **0.75-inch** left on the muzzle about **0.030-inch** in diameter to create a **0.75-inch** long cylinder with a good shoulder for chucking. The barrel blank is then reversed in the lathe and the muzzle end is chucked-up in the standard 3-jaw lathe chuck. The chuck jaws are snugly gripping a parallel cylinder section of the muzzle end that is long enough to avoid jaw flexing, and the jaws are run up against the shoulder to block any axial movement without requiring excessive gripping force. We lightly turn the outside of the chamber swell just enough to make sure it is concentric about the breach-end of the bore while the fresh 60-degree center is running on the live center of the tailstock.

Next, we layout the tenon length (**TL=1.0710-inch** in this case.) on the barrel stub, and start making turning cuts up to a shoulder stopping **0.020-inch** short of the **TL** mark. Rough out the tenon to a diameter of **1.090-inch**, or **0.020-inch** larger than the eventual outside thread shank "turn-to" diameter of **1.0700-inch**. Set up the steady rest on the oversize tenon, retract the tailstock, and cut the backbore to **0.6950-inch** inside diameter (ID) and to the previously measured depth of **0.1550-inch**. We normally use one of Dave Kiff's live-piloted specialty reamers to make this cut quickly and cleanly. Re-cut another new 60-degree center in the new end of the bore. Go back in with the live center and finish cutting the tenon (*simultaneously*) to both final diameter and length dimensions, using a well-radiused cutter bit insert, but otherwise leaving the barrel shoulder square. We use **1.0700-inches** for the tenon pre-threading diameter (instead of the nominal **1.0725-inch** major thread diameter) in order to leave a small flat on the tops of the threads.

We now thread the Tenon almost all the way to the barrel shoulder at **16 TPI**, using many small **0.002-inch** to **0.003-inch** threading cuts at the slowest speed our lathe can run (**90 RPM**). As shown in Photo 4, our outside threading insert holder allows cutting up to a left-hand shoulder. You have to practice threading up to a shoulder a bit to get the hang of it. We do not use a relief cut for a Remington barrel tenon because that would just weaken the chamber and obviate our close fitting of the bored-out recoil-lug. So, just as the threading bit reaches the left-hand end of the thread, the machinist's right hand has to disengage the lead screw half-nut lever while his left hand is backing out the cross slide control wheel a little over one full turn. The 60-degree threading bit is set accurately perpendicular to the axis of the lathe. The cutting edge is set accurately at the height of the spindle axis for smoothest cutting, and the compound slide is set at the customary **29.5-degree** angle off the perpendicular for cutting 60-degree V-form threads by advancing the compound between passes. When the flats on the tops of the threads look right, a last pass is made with the cross-feed set inward a half a thousandth (in diameter) for a cleanup cut. We now set up the steady rest on the barrel chamber swell, as shown in Photo 5, back out the tailstock and trial-fit the receiver and recoil lug on the tenon threads with a little *anti-seize* lubricant. We are looking for about an **H2-class** thread fit with no perceptible interference all the way up to a solid stop on the shoulder. A tight thread fit is not accuracy-producing. If any interference is felt, another cleanup pass is made on the threads.

Cutting the Chamber to Proper Headspace

The proper size pilot bushing is installed on the correct finishing-type chamber reamer, which is installed into the floating reamer holder in the tailstock ram. The lathe is run at 144 RPM, and the hand-lubricated reamer is run in a little way until the neck-cutting reamer flutes are well engaged in the barrel. At this point, we stop the lathe and set up the high-volume coolant pump. The conical, hollow neoprene fitting on the end of the coolant lance is passed through the headstock and carefully centered in the 60-degree center cut in the barrel muzzle that is being held in the 3-jaw lathe chuck and the lance is spring-loaded inward to make a good seal. The coolant lance has a rotary hydraulic joint on its outboard end. The pump bypass valve is fully opened (for ***no*** output pressure) and the three-phase pump motor is started. Start carefully closing the bypass valve to build up the pressure slowly while watching for leaks and checking that coolant flow is correct. Set the spindle speed up to 228 RPM, start up the lathe as shown in Photo 6, and continue watching for leaks. A small coolant leak at 150 PSI can get messy in a hurry. If everything is in order, run in the reamer and cut the chamber all the way to the "**0.020-inch** short" marks on the reamer flutes. Withdraw the reamer and stop everything. Clean and inspect the chamber. Install the GO headspace gauge, and make a headspace measurement from the back of the gauge to the bottom of the backbore recess with the depth micrometer. Subtract the previously calculated adjusted headspace (**AHS=0.1580-**

inch) from this reading and record this distance minus **0.002-inch**. Verify that we stopped about **0.020-inch** short. Restart the coolant and the lathe and advance the reamer to where you feel the reamer just beginning to cut, and then run the reamer inward for the recorded additional distance. Withdraw and recheck headspace, this time cutting to the precise adjusted headspace value. Withdraw and verify headspace is correct. We use a headspace tolerance of minus **0.0000-inch** to plus **0.0010-inch**. So, we are looking for an **AHS** reading of between **0.1570-inch** and **0.1580-inch**, with the later value preferred. Round over the sharp corner at the rear of the chamber using a sharp triangle scraper. Use a fresh piece of crocus cloth on a split wooden dowel to polish the chamber walls slightly. Clean and inspect a perfect chamber. Screw on and true up a shop-made sacrificial threaded sleeve to protect the Barrel Tenon threads and for use in subsequent work on the muzzle and in barrel polishing.

Crowning and Fitting Muzzle Brakes

There are many ways to go about finishing up the barrel from this point, depending on the types of finish and crown desired and on whether a muzzle brake is to be installed. Some rifles need a muzzle brake and some clearly do not, but they do not enhance accuracy, so we generally discourage their use in borderline cases. If it has been decided that a muzzle brake is to be installed, we reverse the barrel in the lathe again, chucking on the threaded sleeve we just installed to protect the tenon threads. We saw off almost all of the extra **0.75-inch** on the muzzle in a band saw and cut a new 60-degree center. Then we run in the live center and set up the lathe to cut the required muzzle brake threads using the same procedure described for cutting the tenon threads, except for leaving the muzzle about **0.100-inch** longer than required. When the brake fits the threads snugly, we bore or ream it to the correct larger-than-bullet-diameter ID and into true alignment with the bore of the barrel. Then we face the muzzle back to the correct tenon length (removing the 60-degree center), and break the front edges of the ends of the rifling lands with a medium-grit abrasive and a round-nosed brass crowning lap from ***Brownell's.*** After the barrel is installed, the muzzle brake will be indexed to vertical, if required, by facing-off the rear of the brake by the necessary calculated fraction of the thread pitch. Eventually, if the design of the muzzle brake permits adequate cleaning access, we prefer to semi-permanently attach the brake using either a ***Loctite*** product or with an epoxy adhesive. A loose muzzle brake is really bad for accuracy.

If the barrel is to be given a highly polished finish, we spin it in a lathe at up to 1000 RPM for polishing out the coarser grind marks using abrasive strips of medium grit, being careful not to "ripple" the contour of the barrel. The bed and other parts of the lathe are protected from contamination with abrasive particles during this operation. The muzzle is running on a live center with either the extra **0.75-inch** left on the muzzle or the muzzle brake protecting the rifling. As the barrel heats up and expands in length during polishing, the axial load build-up on the live center bearings must be checked and adjusted out frequently. Then the barrel is removed and held in a barrel spinner for buffing to the final finish. Then the barrel is returned to the lathe if it still needs to be crowned. With the muzzle indicating true within **0.0001-inch**, the desired type of crown is normally cut using a very sharp facing tool that is reserved just for crowning. We are also finding that crowns cut in the lathe using an 11-degree, profile-cutting, piloted, specialty reamer are good and quite accurate. We have also learned the trick of polishing the crown without damaging the ends of the rifling lands.

Finishing Touches

After the finished barrel has been torqued into the action with the recoil lug oriented properly, we need to mark the location to etch or engrave the chambering information where it will be readable above the stock line along the left-hand side of the barrel. For safety, any non-standard chamber information must also be marked. We also like to etch our shop logo over the chamber area. If impact marking is used, it should be limited to the side of the chamber swell to avoid any more damage to the barrel than necessary.

The barrel must be properly broken-in to perform at its best. The barrel should be seriously cleaned before its first firing to remove the last residual lapping abrasive before it gets ironed into the bore surface. We use and recommend a one-shot-and-clean barrel break-in procedure. Carbon fouling is cleaned using ***Shooter's Choice*** (or equivalent) and cleaning patches and a bronze bore brush. Then several applications of ***Sweet's 7.62*** (or equivalent) copper solvent are used with a ***Parker-Hale*** boar-bristle brush. The same PH cleaning rod and bristle brush are also used to apply ***Iosso*** bore paste whenever a mild, non-imbedding abrasive seems indicated. The boar bristles can be safely reversed in the barrel and will reach into the corners of the rifling grooves better than a patch-applied abrasive can. We do not leave an ammoniated copper solvent in the bore for more than ***15 minutes*** before patching it out and inspecting for copper with our ***Hawkeye Bore-Scope***, and we always neutralize the copper solvent by a final cleaning with ***Shooter's Choice***. We also patch out the bore to dry and thoroughly dry out the chamber before shooting the gun again or storing it. Some authorities recommend lightly oiling the bore before firing again, but we do not. We do not want some idiot overdoing it and firing a proof load in an oiled chamber. It should be emphasized that firing additional shots without completely removing the copper from the bore will not accomplish any further barrel break-in and might well damage the barrel. After a few cycles of one-shot-and-clean, the copper fouling should dramatically lessen as indicated by the color of the copper solvent as it is patched out and as verified with the bore-scope. At this point, try firing a three-shot group. If the third shot does not go into the same hole with the first two shots, the barrel is still not fully broken-in. If all three shots have gone in the same hole, clean the barrel again and shoot a five-shot, one-hole group for the record. Seeing this level of performance regularly and from a variety of rifles is what leads us to believe we are fitting barrels correctly.