

Notes on Hammer Forged Barrels

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Background

Hammer forging barrels has always been a mysterious process to the American shooting community. In the article “Hammer Forged Barrels” (*Precision Shooting*, November 2005, pages 22-29) we attempted to remove the mystery by describing the hammer forging process in detail. Later, in “Experiments with Rimfire Hammer Forged Barrels” (*Precision Shooting*, March, 2006, pages 88-97), we discussed the performance of these barrels in rimfire applications. Since those articles were published, a number of topics related to hammer forging have come up, and we feel they may be of interest to the shooting community. This article considers forging machines, integral chambers, rifling form, rifling errors, forging force, and standard rifling specifications along with some history where known.

Type of Forging Machines

Our first article explained the hammer forging process based on the GFM machinery used by Sturm, Ruger & Co. These machines are known as radial forgers because the hammers move in linear, radial lines as shown in Figure 1. This forging technology was developed in Germany prior to World War II and continued after the war by GFM of Steyr, Austria. GFM produced their first machine to commercially forge barrels about 1950.¹

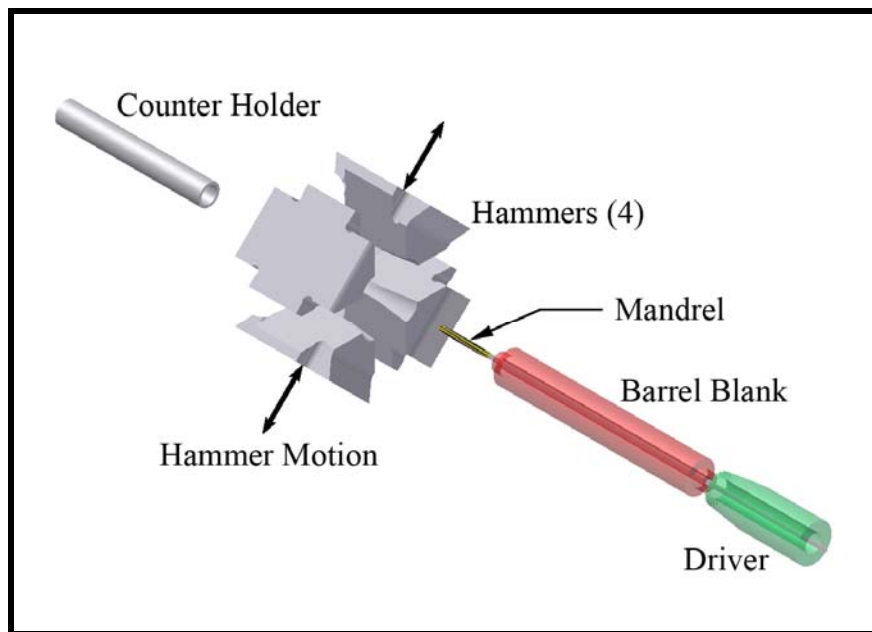


Figure 1 – Layout of the radial forging process. The two hammers move in the direction shown by the double arrows. The other two hammers move perpendicularly to their back face, too, but the arrows don't show in the figure. The driver and counter holder move the barrel blank over the mandrel and into the reciprocating hammers.

Before continuing, let's define the term forging diameter as the diameter of the barrel resulting from the hammers closing down on the barrel blank. With that in mind, we'll explain that the hammers on GFM radial machines actually have two types of motion. The first, a mechanical eccentric similar to a punch press, rapidly opens and closes the hammers about 2mm to 5mm (0.080" and 0.200") between 1000 and 1600 times per minute (the actual stroke and rate depend on the specific machine). The second, a computer numerical control (CNC) system similar to that on CNC lathes, precisely controls the position of the mechanical system and the resulting forging diameter. Hence, a radial machine can change its forging diameter to any size within the machine's range during the forging process under computer control. (For the record, older machines built prior to CNC technology used a tracing cam.) This degree of control becomes very important when forging chambers as we'll discuss shortly.

The other method of forging barrels is called rotary swaging (or rotary forging, depending on the equipment manufacturer) because all the hammers rotate as a group in addition to moving radially. Torrington Machinery appears to have originated the rotary swaging process more than 100 years ago (see their website at www.torrington-machinery.com). Barrels may have been made using this process prior to the 1960's, but it was Winchester who developed this technology in the USA. As part of Winchester's new manufacturing processes introduced in 1964, rotary swaging was chosen as the method to manufacture barrels. Winchester used machines made by the Cincinnati Milling Machine Company with dies made by Champion Tool and Die of McKeesport, PA.²

Notice from Figure 2 that a barrel blank is pushed over a mandrel while forging takes place in a manner similar to radial forging. However, in rotary swaging, fixed rollers attached to a stationary housing push the hammers in as they rotate and centrifugal force pulls the hammers out between rollers as shown in Figure 3. The forging diameter can be changed by spacing the dies out during machine setup, but this cannot be done dynamically while forging a barrel. Hence, barrel blank size becomes very important to rifling quality on a rotary machine.

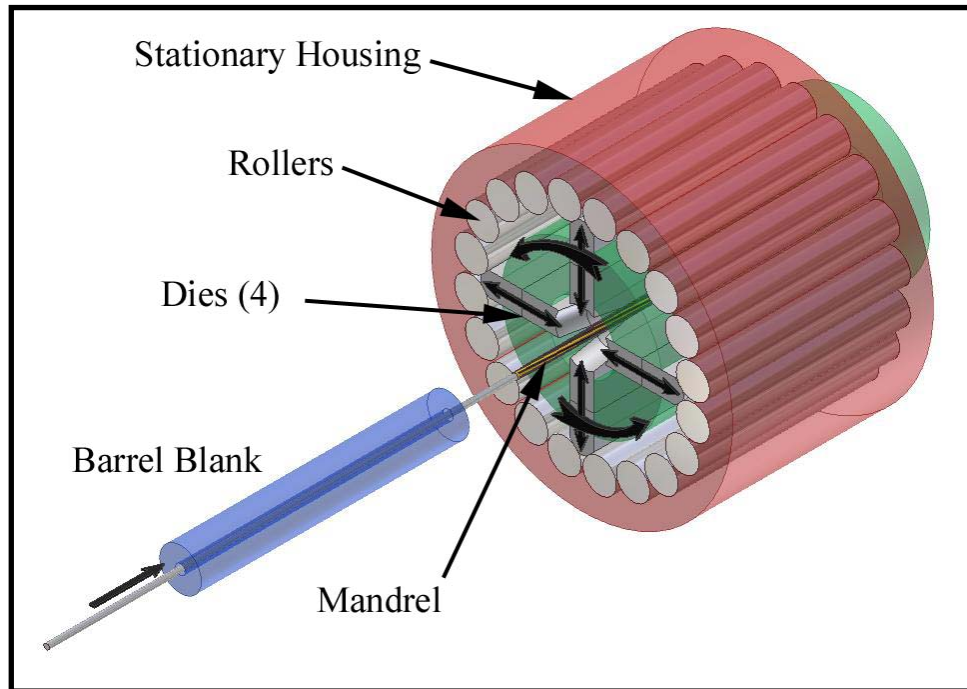


Figure 2 – Layout of the rotary swaging process. The dies rotate as a group inside of the stationary housing as the barrel blank is pushed over the mandrel and into the dies.

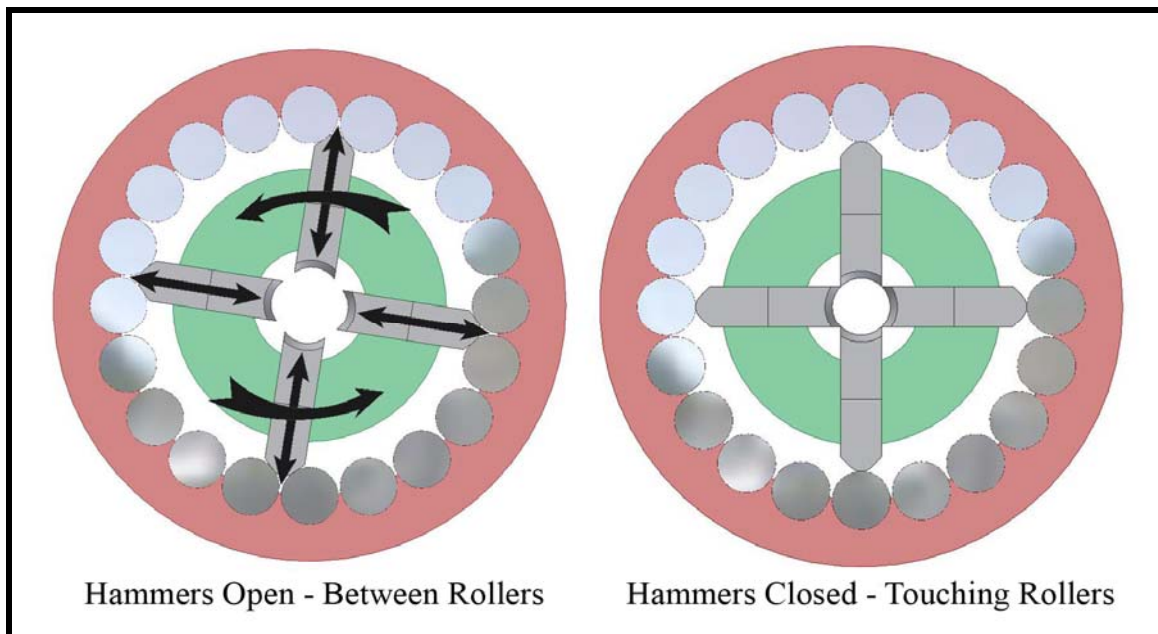


Figure 3 – End view of the rotary swaging process showing how the dies rotate within the rollers. The dies retract through centrifugal force when they are between the rollers (left picture) and they close as they touch the rollers' high points (right picture).

Both methods can make accurate barrels. Winchester used the rotary swaging process to manufacture barrels for Model 70 varmint rifles, including the new .225 Winchester introduced with the Post-64 Model 70 in 1964. While this cartridge was never accepted commercially, contemporary reports show at least some of these rifles were very accurate. A portion of the Post-64 Winchester Model 52 and Model 70 target rifles used forged barrels as well, and they have an excellent accuracy record.³ We don't know if the target rifle barrels were manufactured on rotary swagers or GFM radial forgers. While Winchester initially chose the rotary swaging process, by 1972 they had installed at least one GFM radial forger.⁴

Radial machines have become more popular than rotary machines for manufacturing rifle barrels, largely due to more inherent process control, but also because of the research and improvements by GFM. GFM is the largest supplier of hammer forging machines worldwide with equipment dating back to 1946 (www.agfm.com). Other manufacturers build forging machines, but GFM has more installations than any other company, possibly more than all others combined. However, barrel manufacturing is only one small application for both radial and rotary forging machines. Most machines of both types are busy worldwide producing many types of automotive, aerospace, and medical components.

Forging Chambers

Mr. Werner Augustin was employed for 30 years by GFM as an engineer and cold forging specialist. In 1993, Mr. Augustin founded Augustin GmbH based in Steyr, Austria. The company specializes in tungsten-carbide tooling sales and also consults in cold forging processes. Hence, he has vast experience in the tooling and processes used to cold forge rifle barrels. In 1995 Mr. Augustin wrote a short book titled *Cold Forging of Rifle Barrels with and without Cartridge Chamber on Cold Forging Machines type GFM SHK und SKK 06*. This might be the only technical book ever written on the subject, but only a few copies were photocopied and distributed to GFM customers. Mr. Augustin gave permission for the authors to place his book on the Internet. You may download a copy of this book in Adobe PDF format from:

<http://technology.calumet.purdue.edu/met/higley/index.htm>

The table of contents includes the following topics, each illustrated with a number of drawings:

- 1.) Material employment when cold forging barrels
- 2.) General information on cold forging techniques
 - 2.1. Barrel blank
 - 2.2. Machine adjustment
 - 2.3. Hammer shapes and their influences
- 3.) Layout of barrel forging form and of barrel blank
- 4.) Forging sequence during cold forging of barrels
- 5.) Various pictures of cartridge chambers, defects and their elimination

- 6.) Layout of forging mandrels for barrels with and without cartridge chamber
- 7.) Hammer layout for barrels with and without cartridge chamber

The most prominent item listed in the title is “with and without cartridge chamber.” GFM developed the technology needed to forge the chamber along with the rifling in the 1960’s, and this remains a key advantage of radial forging machines when producing large quantities of identical barrels.¹ Figure 4 shows a sketch of a forging mandrel with a chamber.

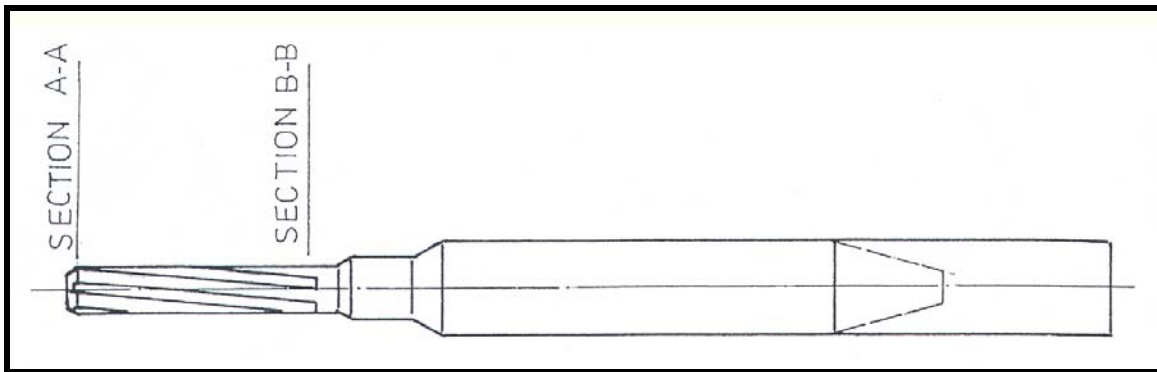


Figure 4 – Sketch of a forging mandrel including the chamber (from page 20 of *Cold Forging ...*).

As the machine forges a barrel, the machine controller adjusts both forging diameter and mandrel position to forge the chamber portion of the barrel. Figure 5 shows this operation just after the shoulder has been formed.

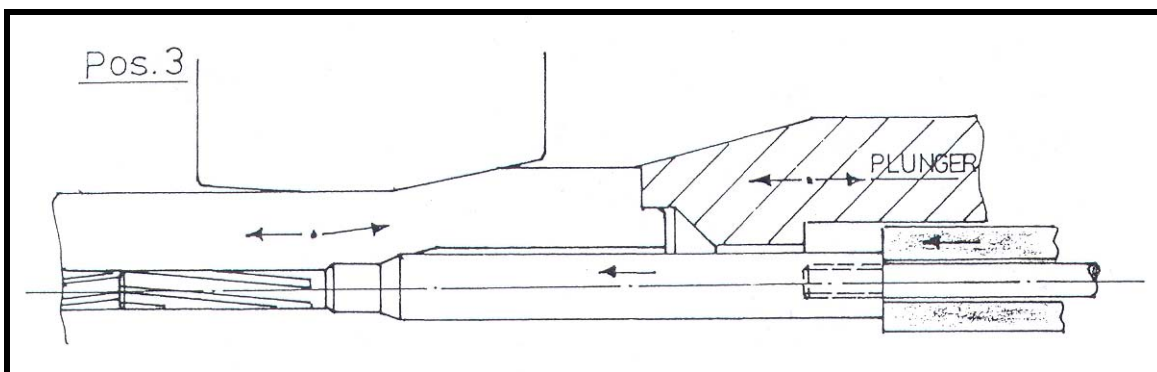


Figure 5 – Sketch of chamber forging (from page 16 of *Cold Forging ...*).

Very precise controls are needed to properly form the throat, neck, and shoulder area. As described earlier, the GFM machines have a fixed mechanical hammer stroke, but the stroke position and resulting forging diameter along with mandrel position are controlled by a computer. Hence, the machines are programmed to adjust the forging diameter and

mandrel position, so straight round blanks may be used to forge barrels with integral chambers.

In contrast, the rotary process cannot adjust its forging diameter during the forging process resulting in a constant diameter along the finished barrel blank. However, chambers can still be forged on rotary swaging machines, but the raw blanks must be turned with a smaller outer diameter over the chamber area to account for the different internal dimensions. The size and location of the step requires considerable experimentation to achieve acceptable results.

With either method, forging a barrel with the chamber requires a barrel blank with a hole about 0.020" larger than the base of the cartridge versus one where only the rifling is forged and the hole need only be slightly larger than groove diameter. The drastic change in size has an effect on rifling form and quality which we will discuss next. For this reason, some barrel manufacturers prefer to forge only the rifling and then cut the chamber separately. At Sturm, Ruger & Co., for instance, CNC lathes quickly and accurately thread the barrel shanks and cut the chambers. Ruger feels they have better control of both the rifling and the chambering process this way.

Rifling Form

Many different rifling forms have been tried over the centuries. For the most part, barrel makers have settled on parallel sided grooves as shown in the left side of Figure 6. The parallel sides come from cut rifling where toolmakers find it easiest to grind the hook cutters with parallel sides. When button rifling was developed in WWII, the same parallel sides were carried over.

The squared corners of parallel rifling tend to collect fouling, and bullets do not seal well in the sharp corner. These problems have been known since muzzle loading days, and some manufacturers cut grooves with angled sides, considerably complicating the tool grinding process. Our research has turned up some surprisingly old barrels with this form including original Stevens and Ballard barrels. However, the oldest barrel we have seen with these angled sides is from a Danish rolling block of about 47 caliber dating back to the late 1860's.⁵ More recently, Obermyer R form rifling and Broughton C form rifling have these angled sides.

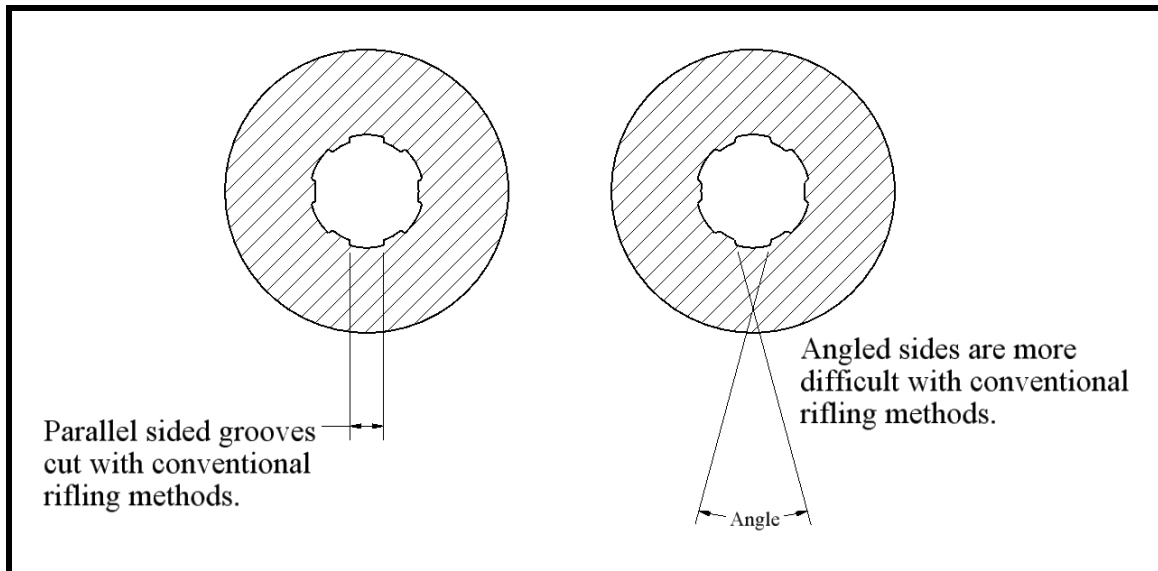


Figure 6 – Cross section of a barrel with parallel sided lands.

We can see from a historical perspective that even early barrel makers recognized the advantages of angled sides, and now many match barrel makers charge extra for the angled sides. Not commonly known, however, is that hammer forging requires these angled sides for the process to work properly. All forged barrels have at least one side angled 5 degrees or more, an unusual circumstance where a manufacturing requirement actually produces a better product. We tried to trace the history of the angled sides back to the beginnings of hammer forging in the 1930's without much luck. We believe late 1930's era German machine gun barrels will show rifling with angled sides, and we hope to examine some of these barrels to find out for sure.

We have been able to trace the origins of asymmetrical forged rifling as shown in Figure 7 (also see page 19 of *Cold Forging ...*). GFM delivered a forging machine to Rock Island Arsenal in 1972 where considerable development work was done forging barrels similar to M16 barrels. During testing, they found that the trailing edge of the rifling (the 30 degree side in Figure 7) was difficult to fill out when forging fast twists (1-7"), especially when forging with the chamber. Opening the trailing angle solved the problem without affecting shooting quality or barrel life since the other side of the rifling actually imparts spin to the bullet as it passes through the barrel. At this point, the status of these barrels is unknown. GFM does not know if these barrels were actually used on M16s or if these were experimental barrels for some other purpose.¹

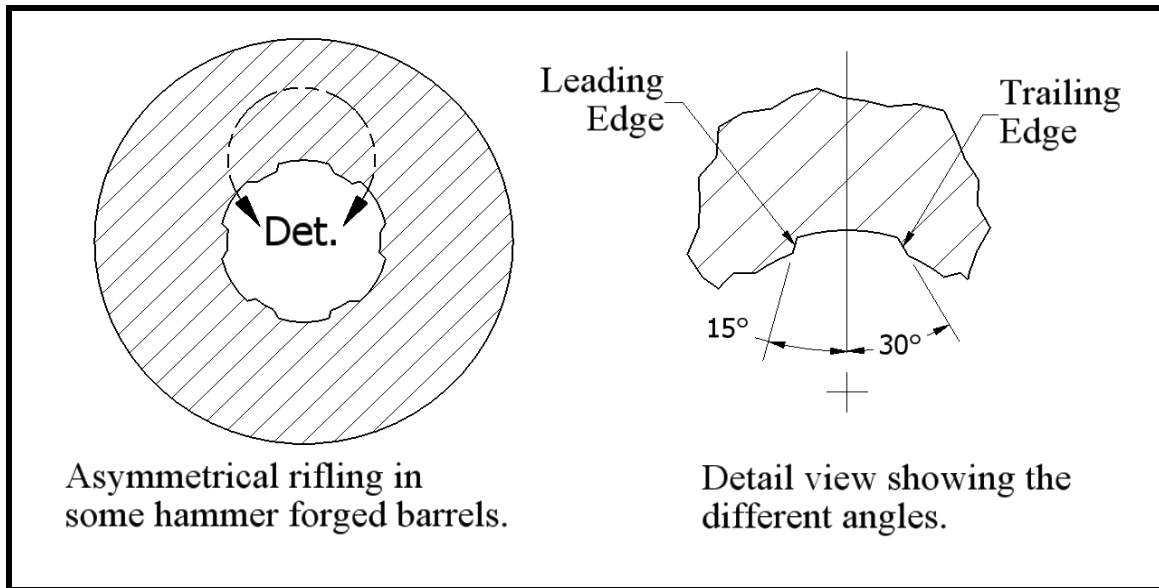


Figure 7 – Asymmetrical form of some hammer forged barrels.

There are many other rifling forms that lend themselves to forging. An interesting one was used by the Russians on AK-74 barrels. Rather than having unequal angles, they simply opened the angle up wide and added large radii in the corners (see Figure 8).¹ This form looks very much like polygonal rifling. It would be interesting to fit a barrel of this form to a target rifle and compare it with more conventional rifling.

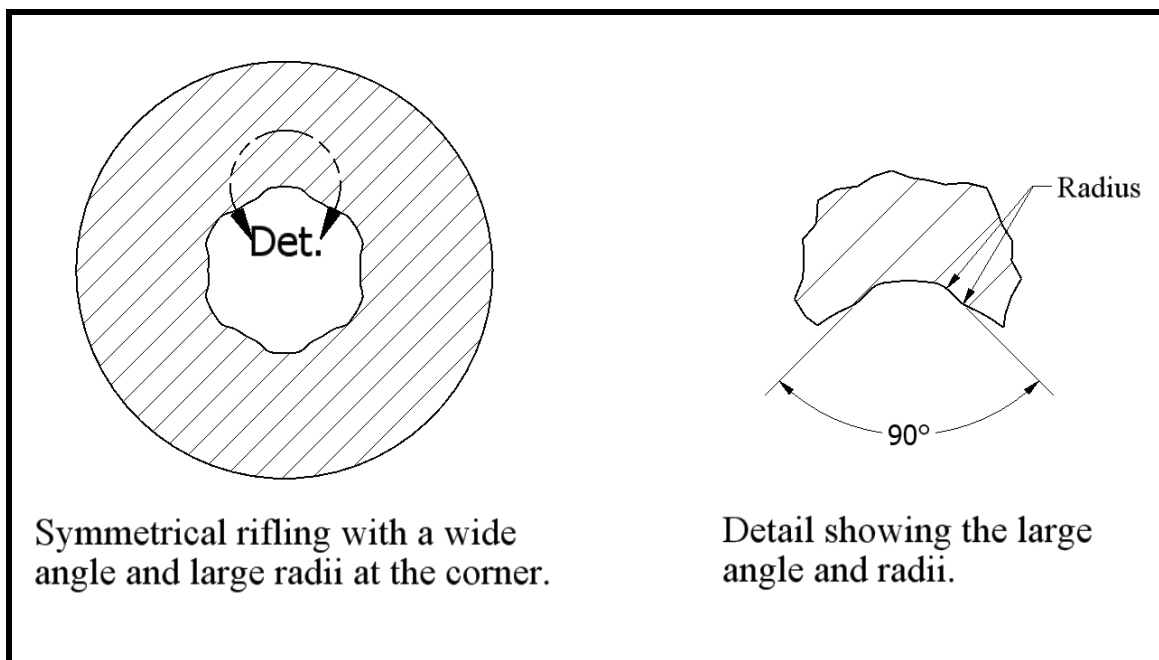


Figure 8 – Rifling similar to that used on Russian AK-74 assault rifles.

Errors in Rifling Form

Most accuracy enthusiasts understand that a smooth, uniform barrel aids accuracy and makes cleaning easier. In fact, the first thing most people do when purchasing a rifle is to look in the end of the barrel and see how smooth it appears. Serious shooters purchase a borescope to get a good look at the entire barrel. Irregularities can come from a variety of sources.

Most barrels start off as solid steel bars that are drilled using a special process called deep hole drilling or gun drilling. This produces a straight hole somewhat smaller than desired size. Reaming follows drilling to smooth and size the bore. Deep hole reaming is one of those black arts of gun making that defies complete scientific description. Each barrel maker or tool maker decides what type of reamer works best in their application. When reaming works, a smooth bore results. Otherwise, transverse tool marks perpendicular to the bore remain. These marks may then transfer into the rifling as shown in Figure 9.

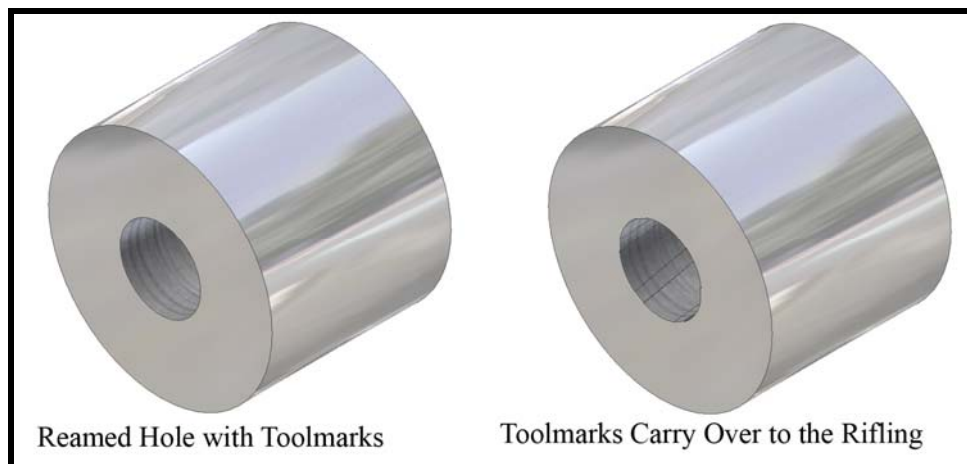


Figure 9 – Tool marks from reaming (left) may carry over to the rifling (right).

These transverse tool marks are one cause of barrel fouling. Lapping removes these marks and leaves longitudinal tool marks that collect little fouling. Hammer forging tends to smooth transverse marks out, although forging a barrel with the mandrel too far to the rear causes similar transverse marks as shown in Figure 10.

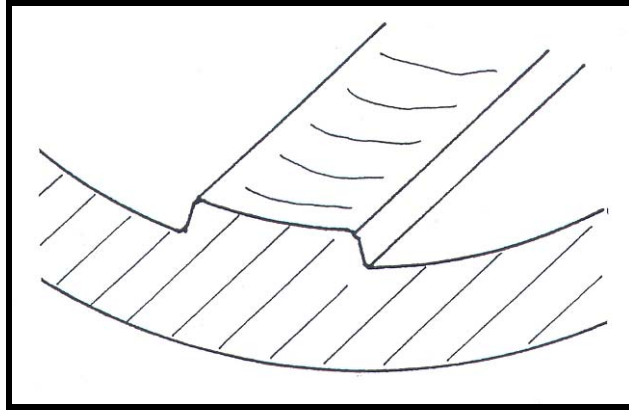


Figure 10 – Sketch of a barrel forged with the mandrel too far to the rear (from page 14 of *Cold Forging ...*).

While anyone with a borescope can detect the marks, it is much more difficult to determine how the marks were created: from reaming or from forging. Hence, only very experienced barrel makers can examine the inside of a barrel and determine how it was made. As we mentioned in our earlier articles, forged barrels manufactured with a properly controlled process come out very smooth with few tool marks of any kind detectable.

Forging Force

In our previous articles, we showed pictures of forging machines and briefly described their complexity and expense. Several readers wondered why the process has to be so expensive, and the answer lies in the force needed to forge the barrels.

Mr. Franz Hofer is currently (late 2006) the sales manager for automotive forging applications at GFM in Steyr, Austria. Prior to his current sales position, he served in several technical positions with GFM, and he has considerable barrel forging experience. Mr. Hofer was kind enough to provide the following examples that show the force required to forge barrels.¹

Caliber (with chamber)	Blank OD	Blank ID	Forged Diameter	Material Tensile Strength	Forging Force
5.56mm for Steyr AUG	27.5mm	10.3mm	22mm	140,000 psi	45 tons (metric), or 99,225 pounds
5.56mm for M-16	32 mm	10 mm	25mm	130,000 psi	55 tons (metric), or 121,275 pounds
5.56mm for Squad Automatic Weapon	37.5mm	10mm	28.5mm	130,000 psi	73 tons (metric), or 160,965 pounds

Table 1 – Approximate force required to hammer forge barrels. The values may vary depending on the specific hammer face design used.

So, typical rifle barrels require somewhere between 100,000 and 200,000 pounds of force to forge. A machine sturdy enough to reliably use such a large amount of force must be large and expensive. Furthermore, the controls needed to manage the mechanical and hydraulic functions are expensive as well.

The Sporting Arms and Ammunition Manufacturer's Institute (SAAMI)

The last topic we would like to address is the importance of SAAMI specifications on rifling design. A voluntary organization with members from 27 different firearm and ammunition manufacturers, SAAMI develops specifications covering all aspects of cartridge chambers, bore dimensions, cartridge size, and cartridge pressure. For example, .223 Remington barrels have a minimum bore and groove diameter of 0.219/0.224" with a +0.002" tolerance available. In addition, the bore must have a minimum area of 0.388 square inches. Bullet diameter is set at 0.2245" maximum with a -0.003" tolerance.

The intent of these specifications is to insure safety. In fact, there are remarkably few accidents when the proper sized factory load is fired in an appropriate factory firearm in good condition. Most accidents are from faulty handloads or attempting to fire the wrong size ammunition. Custom barrel makers don't operate under SAAMI specifications, and they can manufacture barrels with any variation of small bore size, wide lands, number of lands, etc. as they think will improve accuracy. Firearms manufacturers must adhere to the standards, although most manufacturers try to hold bore and groove size to the low end of the specifications.

Concluding Remarks

In our articles, we have attempted to remove the mystery of hammer forging barrels by presenting the processes in a clear fashion using current knowledge and historical facts when known. In our efforts to compile some of the missing history of hammer forging, we would appreciate any help in the following areas:

1. Firsthand knowledge of WWII or earlier German hammer forging techniques including slugs from MG-34 and MG-42 machine gun barrels.
2. Firsthand knowledge of Winchester's hammer forging processes.
3. Firsthand knowledge of the processes used by any current manufacturer (commercial or government) who is willing to share that knowledge with the shooting community.

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General Julian S. Hatcher was probably the best known American technical expert in the area of firearms. Starting in 1947, he collected his notes on various firearms related topics into *Hatcher's Notebook*.⁶ As we compiled the different but related topics for this article, it reminded us of the General's book, so we borrowed the "notes" concept for our title.

Bibliography

¹Email correspondence with Mr. Franz Hofer, GFM GmbH, Sales Manager, Automotive Forging Applications, A-4403 STEYR, Austria, March, 2006.

²Phone conversation with Mr. Bob Johnson, former Champion Tool & Die salesman for more than 30 years. Champion was a small tooling company near Pittsburg, PA that primarily made tooling for cold heading bolts and other fasteners. The company was started in 1947 and finally closed in 2005 after most fastener manufacturing moved out of the USA. Barrel forging dies were but a small portion of their business, although they made dies for the rotary forging process for FN Manufacturing LLC, located in Columbia, SC up until early 2005.

³Mr. Brian J. Mayer found a 1972 vintage Winchester ad on the back page of *The American Rifleman* that advertised “Winchester proof steel barrels are cold forged from chrome molybdenum steel, then lead lapped by hand” for the Model 52 and 70 target rifles. This terminology appears a few times in ads of that vintage, but not in the Winchester catalog. It seems likely that Winchester used up any available barrels and then switched to forged barrels to meet new demand.

⁴*The Modern Rifle*, Jim Carmichel, Winchester Press, 1975. Mr. Carmichel visited Winchester in 1972 and took a picture of a GFM machine being used in the Winchester plant (see page 29 of this book). Mr. Carmichel also details the process Winchester used to manufacture target rifle barrels including lapping the bore before forging.

⁵Mr. George Griffith has slugged and examined the bores of many old rifles, and he provided much of the historical information about rifling discussed in this paragraph.

⁶*Hatcher’s Notebook*, Julian S. Hatcher, Stackpole Company, 1962. This book is still available from most bookstores or online.